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GENERAL SECRETARY AND [illegible]
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TRANSACTIONS

OF THE

INTERNATIONAL ELECTRICAL CONGRESS

ST. LOUIS, 1904

IN THREE VOLUMES

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TRANSACTIONS

OF

SECTION F

Electric Transportation

Honorary Chairman, MR. G. J. VAN SWAAY
Chairman, DR. LOUIS DUNCAN
Vice President, M. MARIUS LATOUR
Secretary, MR. A. H. ARMSTRONG

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Total number of papers presented before Section F, 16.

Section F was called to order at 11 a. m., Monday, September 12th, Dr. Louis Duncan presiding.

Dr. DUNCAN: The first paper to be presented is one by Mr. Philip Dawson, entitled "Electrification of British Railways." In the absence of the author, Secretary Armstrong will please read the paper.

ELECTRIC TRACTION ON BRITISH RAILWAYS.

BY PHILIP DAWSON.

INTRODUCTORY.

The introduction of electric traction on British railways is a subject of great interest, but can only be discussed very briefly in this paper.

The position of our railways is one which is beginning to make all those connected with these interests fully alive to the necessity of improvement, both as regards increasing their freight and passenger traffic and reducing the working expenses. Owing to the stringent regulations imposed by the Government, and the very densely-populated districts which the railways traverse, the capitalization of English lines is exceedingly heavy, as the following figures clearly show:

CAPITALIZATION AND MILEAGE OF RAILWAYS IN THE UNITED KINGDOM IN 1901.

Debenture stock	£304,577,862
Preferential share capital	310,819,740
Guaranteed share capital	114,293,436
Ordinary share capital	454,379,107
Total capitalization	£1,184,070,145

Double or more lines, length of route	12,272 miles.
Single line	9,806 "
Total length of route	22,078 miles.

The ever-increasing taxation, as well as of the competition which the railway companies are beginning to feel in consequence of the rapid introduction of electric traction on tramways in and around all the large cities of Great Britain, are some of the many reasons which, notwithstanding the fact that the total number of passengers carried, as well as the total merchandise and goods conveyed, has been more or less steadily rising, has contributed, as will be seen by the following table, to reducing the percentage of net receipts to total paid-up capital:

Summary of Railway Results of the United Kingdom from 1850 to 1901.

Year.	Total number of passengers carried (exclusive of season ticket-holders.)	Weight of goods and minerals conveyed, Tons.	Percentage of net receipts to total paid-up capital.	Percentage of working expenditure to gross receipts.
1850.....	72,854,422	....	....	....
1860.....	163,435,678	89,857,719	4.19	47
1870.....	336,545,397	....	4.41	48
1880.....	603,885,025	235,305,629	4.38	51
1885.....	697,213,031	257,268,454	4.02	53
1890.....	817,744,046	303,119,427	4.10	54
1895.....	929,770,909	334,230,991	3.80	56
1899.....	1,106,691,991	413,623,025	3.61	59
1900.....	1,142,276,696	424,929,513	3.41	62
1901.....	1,172,395,900	415,593,441	3.27	63

The question, therefore, arises as to what our railways can do in order to increase the ratio of net receipts to the total paid-up capital. In my mind the answer is, that their salvation lies in the judicious adoption of electric traction.

Railways have to deal with three classes of traffic. 1). The short-distance, suburban, and interburban traffic in the neighborhood of our large towns and between the large centers which, in many parts of England, lie so close together; as for instance, such cities as Bradford, Leeds, Halifax, Blackburn, and the numerous towns on the borders of Lancashire and Yorkshire. 2). The long-distance, main-line traffic. 3.) The goods traffic.

As regards the suburban and short-distance interurban traffic, there is no doubt that electric traction will be a great benefit to the railways, and owing to the dense population of this country which makes the building of new roads expensive and difficult, and the very extensive network of railways which already exist, the steam railways in Great Britain are in exceptionally favorable conditions to benefit by electrification.

As regards long-distance, main-line traffic, there may be individual isolated cases where, after electric traction has been introduced on suburban lines it may be found advisable to extend it to the main lines.

English railway companies have progressed very considerably of late; the track construction is as good as any to be found in the world, and the locomotives, signaling apparatus, and rolling stock are, as far as steam traction is concerned, beyond criticism. At the same time, as already pointed out, the competition of electric tramways, and the demands of the public for increased facilities of locomotion, call for a development on entirely new lines. As trustee to many millions of the public for money, it is evident that no railway company can take any action or adopt any novel system involving considerable expenditure, except with the greatest care and after most thorough investigation. Necessarily, the railway companies would prefer to be perfectly certain of the results before taking any important steps, and to know what has been achieved financially by electrification of other lines. The figures of the cost of operating, and receipts on the tube lines and on the Liverpool Overhead, are very instructive, but at the same time, owing to the different conditions under which they are constructed and operated, their results do not necessarily apply to all cases. It will be some years yet before reliable information is available of the results obtained on the Lancashire and Yorkshire, and North Eastern, and under these circumstances the experience of the Mersey railway is most useful.

The conversion of the Mersey line was taken in hand and was in progress during 1902 and was completed in May of last year, and, therefore, it could hardly be said to be in full working order during the latter half of last year, for which accounts were available. Under these circumstances it is not necessary to go into these accounts in detail, but it will be interesting to note that the three minutes' service adopted has caused their train mileage to be increased from some 155,000 miles to over 401,000 miles in six months. That this result was justified is shown by the fact that the number of passengers has increased from 2,844,708 to 4,153,777, and the results show that the traffic was almost entirely made up of first and third-class passengers, the second class having to be greatly diminished, as might have been anticipated.

The results consequent on the electrification of the Milan-Varese line of the Mediterranean Railway Company are no less surprising. For six months ended June, 1903, the total number of passengers carried was 2,977,812. During the whole year 1900, when the line was entirely operated by steam, the total number of passengers carried was 2,768,541.

SUBURBAN AND SHORT-DISTANCE INTERURBAN TRAFFIC CONDITIONS.

The position of railways with respect to suburban traffic varies considerably with their location. In some cases there has been a decrease both in the number of passengers carried and in the gross receipts, due in a large measure to the competition of paralleling electric tramways. In other cases there has been little or no change, whilst in others again, particularly those serving the London suburbs, the requirements of the traveling public are so great that the steam railways have never been able to cope with them, and consequently the presence of competing tramways has not as yet been seriously felt.

The electrification of the tramways in all the big towns, as well as the construction of a large number of so-called light railways connecting the various towns, and the activity shown, both by the local authorities and private companies in promoting new lines, is rapidly bringing matters to a crisis. The speeds allowed on tramways are consequently being increased and there seems but little doubt that on a large portion of the electric lines the average speeds of from 12 to 15 miles an hour may be allowed at no very distant date. This increase in speed, as well as the frequent service given by electric tramways, will make them most serious competitors to steam railways unless their local time-tables are considerably modified and improved, both as regards frequency and average speed, and this will only be rendered possible by the introduction of electric traction.

Thus there is an urgent need for a revision of the mode of transport adopted on railways, in one case to turn the ebbing tide to traffic, and in the other to satisfy the claims of a public anxious to travel but unable to do so because of the congested state of the lines. If the railways allow competing lines to proceed unmolested, the problem will be solved in a manner extremely detrimental to the former. The congestion will steadily diminish by reason of the traffic being diverted from the railways by the opposing interests, which will give the facilities so urgently needed at the present day.

The suburban traffic of the railways has been growing rapidly with the suburbs, and as it is largely concentrated at certain stations instead of being uniformly distributed, it is naturally very congested. The state of affairs is further complicated by the intermingling of main line and suburban traffic in the termini, owing to lack of space which prevents their being kept entirely separated as they should be; and by the delay due to the impossibility at present of getting in and out of the terminal stations expeditiously.

The electric tramways, though strong and healthy, are at present a young growth, but they are extending with amazing rapidity in all directions, with the result that they are pressing hard upon the railways, even in the matter of comparatively long-distance suburban traffic; this is a branch which is essentially a province of the railways, and one in which they should easily maintain their supremacy if they are properly equipped to satisfy the requirements of the situation.

The great need of the railway companies in respect of their local traffic is both to increase their service and to improve their methods generally, and there is only one practical way of doing this, viz., electrification. Under the present conditions it is impracticable to increase the frequency of suburban trains, first, because of the cost of handling such an increase by steam locomotives, and secondly, because of the mutual interference of the main line and suburban traffic. In other words, the lines are at present being worked very near to the limit of their capacity as far as steam is concerned.

In the case of suburban trains the amount of time occupied in starting and stopping forms a very large proportion of the whole time spent on the journey, so that a very considerable saving would be effected if this waste of time could be reduced. At the same time it is essential that this should be supplemented by more efficient methods of taking up and detraining passengers, which process, under the present circumstances, entails an unnecessary waste of time at stations.

Attempts have been made in various cases to avoid the electrification of steam lines by the adoption of special locomotives giving exceptionally high rates of acceleration, but the failure of these has only served to emphasize the necessity for electric traction, for by that means alone is it possible to obtain really high rates of acceleration. Experience has conclusively shown that the only really satisfactory method of handling suburban traffic is by means of electric traction, and it is a great pity that hitherto the question has not been faced with greater boldness by those concerned.

There are such certain benefits to be derived from the electrification of steam suburban lines that the only wonder is that more progress has not been made. As already stated, the main advantage is that the use of electric power by permitting very high rates of acceleration enables the frequency and consequently the carrying capacity of the service to be largely increased, while at the same time the working expenses per train mile are decreased. Also with electric traction the delays due to signals are of less importance, owing to the quickness with which an electric train can get under way. Over and above the foregoing, the cleanliness of electricity and the consequent enhanced comfort of the passengers is a considerable factor in increasing the popularity of the line.

Not a few railway companies have expressed their opinion that they have no objection to the tramways taking their suburban traffic. According to them this branch of the service is both costly to maintain and difficult to manage, and at the same time it is not a profitable source of revenue, and they appear to be quite content to drop it altogether and fall back upon the lucrative main-line traffic. There are, however, two objections to this. In the first place, it is extremely doubtful whether any railway would be allowed by the Government to drop its suburban traffic completely. In the second place, there is too much capital tied up in this branch to render it possible to dispense with it entirely. Few companies could afford to let such a large amount of capital lie idle, and there is no reason why they should. In my opinion, there is not a single railway company that could not operate its suburban traffic in the neighborhood of most of our large manufacturing towns at a substantial profit if it were to be electrified, and in most cases the profit resulting therefrom would be more than sufficient to pay the interest on the necessary capital outlay called for by the change of motive power.

As soon as the railways electrify their suburban lines, they will hold a very strong position against the attacks of competing tramways and light railways, since in the matter of speed they will have all the good points of the tramways, without the disadvantage of having to operate in crowded thoroughfares; the greater distance between the stops will naturally permit a far higher schedule speed to be maintained, and the higher the speed the railways are able to offer to the public, the shorter will be the distance of the journeys for which the tramways will prove more convenient.

That there is room for great improvement in the railway service, and that there is a larger amount of latent traffic to be secured provided the railway companies go to work in the proper way, is clearly shown from the statistics giving the number of times the population of the large cities in Great Britain are carried annually.

The evidence given before the Royal Commission for London Traffic by Mr. Edgar Harper, the statistician of the London County Council, shows that whereas, in 1867, the population of London was carried 22.7 times, in 1901 it was carried 128.7 times. These figures only deal with the traffic in the London area, and do not include the passengers brought in by suburban trains.

It must be noted that these figures do not include all the omnibus lines.

It is interesting to note that the number of journeys per head of population in London is at present small compared to that in many other large cities, as will be seen by the following figures:

London, 1901	129	journeys.
Glasgow, 1901	174	"
Liverpool, 1901	187	"
London (Mr. Harper's estimate), 1903	200	"
Berlin	223	"
Greater New York	320	"

Facilities for traffic always create traffic, and as facilities are improved traffic will not only be actually but also relatively greater. This is shown by the following figures.

INCREASE IN NUMBER OF JOURNEYS PER HEAD OF POPULATION.

Greater London.		Greater New York.	
1867	23	1860	47
1870	27	1870	118
1880	55	1880	182
1890	92	1890	283
1900	126	1900	320
1901	129	1903 (estimated)	415
1903 (estimated)	200		

From these figures it will be seen that the population of London is carried only half the number of times that the population of New York is.

CONDITIONS TO BE FULFILLED FOR A SYSTEM OF ELECTRIC TRACTION TO BE SATISFACTORY.

There are certain conditions which require to be fulfilled before any system can be considered capable of giving satisfactory results, and these conditions are briefly set forth below.

1). Should moving machinery be found necessary in the transforming of sub-stations, these stations must be as few in number as possible. The apparatus used in sub-stations should be such as to require but little attendance and should be efficient at all loads and capable of dealing for short periods with very heavy overloads.

2). The number of conductors required to supply current to trains should be as few as possible, and should be capable of unlimited extension, and must not interfere with the tracks; hence the use of a third rail is not possible.

3). It must be possible to collect from a single conductor sufficient power to haul one or more fast trains in service on the lines between the feeding points of the conductor.

4). It is very desirable that the system should be applicable to main line as well as suburban traction, and that it should be possible to utilize at least two working pressures — a low pressure where found necessary in or near the station, and a higher pressure outside.

5). The system should be such that the trains can be operated at any speed required, and thus be capable of making up lost time.

6). All controlling apparatus must be of the simplest character, and such that no skilled labor is necessary to operate the trains; also there must be no dangerous high pressure anywhere accessible to either railway officials or passengers.

7). If alternating currents are used it is essential that the power factor be high and that the motor be capable of giving an acceleration equal to that obtained with the best series-wound direct-current motors at present in use.

8). In certain cases it might be advantageous for the motor to be constructed to return current to the line, but in any case it must be constructed to reverse and to be used for braking purposes.

OVERHEAD CONDUCTORS.

The doubts that have been expressed as to the feasibility of adopting overhead wires on the lines where steam locomotives are running, and the objections which have been urged against their use on this account, are, in my opinion, quite groundless, and there is no reason to anticipate any trouble from this cause. The engineers of the Valtelina railway informed me on the occasion of my last visit that they had never experienced the slightest difficulty in respect to the two overhead 3000-volt conductors which have been in use for over two years on that line, in spite of the fact that steam locomotives burning soft coal are continually passing over the line, and that the aerial conductors in some places have to pass through tunnels from the roof of which large quantities of water are always descending.

The conditions I have mentioned as being those with which a traction system has to comply appear to be exceedingly difficult to fulfil, and the only system which could possibly comply with the conditions is a single-phase one. As long as electric traction was applied only to tramways or lines with few or no complicated junctions, and on which only electric trains operated and there was no steam service, the continuous-current railway motor has given perfect satisfaction.

But this type of motor has its limitations, and the necessity for dispensing with third rails and using a single high-tension overhead conductor, has recently induced manufacturers and directors to investigate the question thoroughly and experiment upon the possibility of constructing a really reliable single-phase motor.

As might have been expected, as soon as there was a real demand it was not long before an article was produced to supply it. Aided by the experience obtained in the design of all types of electric machinery, consequent on the enormous extension of the applications of electricity that has taken place during the last few years, a satisfactory alternating-current single-phase motor has now been developed.

The single-phase motor at present developed may be divided into two classes, the "series" type which has been investigated and brought out in Europe by Dr. Finzi, and in America by Mr. Lamme, and the "repulsion" type, both in the original form as investigated many years ago by Prof. Elihu Thomson, and the "compensated repulsion" form as theoretically studied and discussed by Mr. Latour in France, and practically investigated by Messrs. Eichberg and Winter.

The restriction as to the pressure at which it is feasible to operate a continuous-current motor is a great drawback to its employment on electrified railways, for it means that the sub-stations must be placed close together. The use of an alternating-current motor introduces a considerable saving in the cost of distributing mains and conductors on account of the high voltage which can be utilized, and not only are the sub-stations fewer in number, but they are smaller and cheaper in first cost, maintenance, and attendance, owing to the absence of rotating machinery.

The great advantage of the single-phase motor in dispensing with the necessity for a third rail and enabling a single small high-tension overhead conductor to be used instead is further enhanced by the fact that in its operation the rheostatic losses involved in the control of continuous-current motors are avoided. An additional gain in efficiency also results from the better distributions of the sub-stations and the decreased losses at these points of distribution, whilst in some cases a line voltage can be employed which is sufficient to dispense entirely with transformer sub-stations. Also owing to the increased efficiency of the whole system the amount of plant required at the power station is less than would be the case for a similar direct-current system.

A very important point about the single-phase motor is the fact that it can easily be adapted to operate upon direct-current circuits, a simple switching device being all that is necessary to make the change.

Besides the solutions mentioned above, there have been various more or less unpractical solutions suggested, such as that proposed by the Oerlikon company and now being tried by them.

CONDITIONS TO BE FULFILLED BY CONDUCTORS BRINGING CURRENT TO TRAIN.

The conditions governing the type and position of the conductor from which the motor cars or locomotives obtain their supply of power in the case of most of the steam suburban railway systems of Great Britain are very different to those which apply to ordinary tramways, newly-built electric urban or suburban systems.

On most suburban systems the traffic is very dense and either local long-distance passenger, or goods' trains are operating over the lines for the greater portion of the 24 hours for six days a week. At many junctions the traffic is largely increased by the numerous other companies who use that station and there is but little time available for keeping in proper repair the existing track rails and points and crossings, which are very congested. As things stand at present the tracklayers have the greatest trouble in finding time to keep the permanent way in proper condition, and they are greatly hindered in their work owing to the very frequent service of trains.

Under these conditions, the introduction of a third "live" rail is practically impossible. Even if it was guarded it would constitute an additional and constant source of danger to the permanent way men who, besides having to avoid the passing trains, would also have to keep clear of the "live" third rail.

Furthermore, it is highly probable that a "fourth" or return rail, such as has been adopted on the Metropolitan district and the Lancashire and Yorkshire, would be found necessary in order to keep within the 7-volt drop in the return circuit required by the Board of Trade.

It might be possible to sectionize the third rail, and arrange so that no portion of it was alive except while a train was actually passing over it; but the necessary automatic switches would introduce most undesirable additional complications, whilst there would always be a possibility of their failing to work so that it would not do for the men to treat the rail as quite harmless.

In any case, with the complicated track work existing at many large junctions it is probable that there would be no space available to place the third and fourth rail, owing to the numerous signal wires and the rods used to operate the points.

The consequences following even a slight derailment would be most serious and the danger of fire due to short-circuits thus incurred, would be very great, not to mention the danger of electric shocks to passengers and the entire stoppage of the service for a considerable time, while the damage to the third rail was being made good.

These considerations have led a large number of railway managers and engineers in the United Kingdom, on the Continent, and in America, to the conclusion that the idea of using any "live" rail conductor installed at or near the level of the track rail must be discarded.

The only other alternative is to employ an overhead conductor. From a careful study of the conditions which have to be fulfilled, I have come to the conclusions embodied in the following:

1). The conductor must be overhead.

2). The conductor must be as far as possible at a uniform height above the track rails and have no sag.

3). The conductor must be supported in such a way that it is practically impossible for it to fall down on the track and get in the way of the train, even in the event of its breaking.

4). The current collector must be light and require little or no attention. Any wear must take place mainly on the collector and not on the overhead conductor.

5). The collector must be such that it cannot slip or slide out of contact with the conductor.

6). In the event of the collector fouling any portion of the overhead work, the collector should give way and not the overhead work.

7). The collector must be cheaply and easily replaceable.

8). The overhead conductor must be connected to safety devices that will automatically cut it out of circuit the instant any breakage occurs.

9). The insulation of the conductor and collector must permit the use of very high pressures, say, up to 10,000 volts.

I have designed a form of construction which I think will meet all requirements and which will obviate any interruption of service taking place. Furthermore, I would propose, as far as possible, not to use steel and iron except for poles or brackets and to avoid the employment of galvanized wire or hooks in any form or shape whatever. The supporting wires would be stranded wire, composed of either steel covered with an outer layer of copper rolled onto it, or else composed of phosphor or silicon bronze wire; the main conductor from which current would be collected would be of hard-drawn copper and of a diameter of at least one-half inch; the supports of this wire should not be more than four feet apart and, therefore, it would be possible to hang this wire in such a way that to all intents and purposes it would be absolutely parallel to the track rails.

CURRENT COLLECTOR.

The question of the form of current collector or trolleys to be used is one which will have to be most carefully considered. The Oerlikon company's type of trolley loses most of its special advantages when the conductor is suspended from above, over the tracks. With the wire in this position it acts almost exactly like an ordinary sliding bow, and is in no way superior to that type of collector. The chief merit of the Oerlikon trolley lies in its wide range of movement, and in the fact that it can be arranged to make contact with the conductor either on top, underneath, or at the side. But necessarily the first and last positions require a special form of construction of the overhead work, and are quite impossible where the conductor is suspended from span wires, whether longitudinal or transverse.

For main line work where there are no complicated crossings or sidings, it is quite possible that the form suggested by the Oerlikon company may be adopted with the greatest advantage.

Bow trolleys may be divided into two classes, one of which is the ordinary scraping type, as used by Messrs. Siemens & Halske, and which is the more common. With the operation and construction of this trolley I am fully acquainted. Such bows have been running for many years, the soft metal on the top of the bow which make the contact preventing wear of the trolley wire. The contact piece is easily replaceable when it wears out.

The other type of trolley is that designed and constructed by Messrs. Ganz & Company and used by them on the Valtelina line; this trolley instead of a scraping bow has a roller mounted on ball bearings. This type is considerably more expensive than the scraping trolley and I do not see any necessity for the additional complications introduced by the use of a revolving roller.

In connection with trolleys the question may arise as to whether any difficulty is likely to be encountered from the high speed at which the trolleys will run along over wire, but there is no reason to anticipate any trouble on that account. In the experiments carried out on the high-speed experimental electric railway between Berlin and Zossen, the bow was only pressed against the wire by a pressure not exceeding from 3 to 4 kgs, whereas the ordinary trolley has to be pressed against the wire with a pressure between four and five times as great; this smaller pressure is of course advantageous as it reduces the wear and tear on the trolley wire and makes it possible to have a much lighter trolley construction than would otherwise be the case.

In my opinion a trolley of the "scissors" type would present many advantages. The contact bar could be made at least as long as the whole width of the carriage and this would allow considerable latitude in the position of the overhead wire. In situations where there was not sufficient room for the conductor to be suspended over the center of tracks, it could be diverted to one side, and increased head room thus be obtained by reason of the curvature of the top of the carriage. In this way it would be quite possible to place the conductor at an altitude not greater than the highest point of the carriage roof, and thus obtain the necessary clearance. In places where it might be considered inadvisable to place a bare conductor under very low bridges, this portion might be made "dead," electrical continuity being obtained by insulated cables. With this arrangement a dummy trolley wire would be provided for the trolley to run on whilst passing under the bridge.

There is no reason to fear that a "scraping" contact would not be satisfactory, since there is ample evidence to the contrary. Many years' experience with third-rail working has demonstrated that very heavy currents can be collected in this way, and with the single-phase high-tension system the current per trolley would be very small; in fact, it would probably be considerably less than the amount which is frequently collected by small trolley wheels in ordinary practice.

ADVANTAGES OF ELECTRIC TRACTION.

There are several further advantages possessed by the modern method of traction which render it greatly superior to steam haulage, quite apart from the fact that the high acceleration demanded for the proper operation of suburban traffic can only be obtained from the use of electric power.

In the first place steam trains have to carry their own power; that is to say, a locomotive must not only be able to haul a certain weight of train, but it must carry coal, and machinery to consume that coal and convert its heat energy into tractive energy "en route," and a steam locomotive is a most uneconomical instrument for transforming heat into work for traction purposes. All this adds to the weight of the train and greatly increases the weight to be hauled per passenger. In the case of some of the trains on the suburban systems serving London, the locomotives weigh over one-third of the total useful weight of passenger coaches hauled.

In the modern electric system the heavy locomotive is replaced by a comparatively light motor car, and energy is generated under the most economical conditions at a certain power station from which it can be transmitted many miles with but slight loss.

The wear and tear of the permanent way, particularly at junctions and crossings, would be considerably less with electric traction than with steam traction, as in the former there is not that tendency to roll or pitch which exists in the case of steam locomotives and which is due to the movement of their reciprocating parts.

Electric trains with two or more motor cars on the multiple-unit system have the great advantage of distributing the weight of the train more evenly over the track and also of permitting a smaller weight on each driving axle than would be the case with a locomotive, owing to the larger number of driving axles. A steam locomotive has to be heavy enough to give sufficient weight on the driving wheels to haul the heaviest train up the steepest gradient at the highest required speed. This concentration of the weight is very detrimental to the track, and the bad effects are accentuated by the pounding action caused by the reciprocating motion of the engine.

For the same weight on the driving wheels an electric motor can exert a much greater tractive effort than a steam engine, because the electric motor exerts a constant torque upon the driving wheels, whilst the steam engine does not. In the case of steam locomotives, the ratio of the maximum tractive effort to the weight on the driving wheels is not much above 16 per cent, whereas experience has shown that with electric traction this is increased to from 25 per cent to 30 per cent.

The cost of operating electric trains will also be reduced by the fact that only one man is required, that is to say, only a driver instead of both a driver and a fireman. The Board of Trade should take no exception to this, as should the driver be incapacitated in any way, the method of control employed is such that it automatically brings the train to a standstill. The men for operating these trains need not be mechanics, and the work will be cleaner and nicer, and, therefore, sought after, as in the case of electric trains, the driving cabin is entirely inclosed and perfectly clean.

Electric traction is much more flexible than steam, and trains can either be split up into units of one or two cars or joined up into trains, the length of which is only limited by the length of platform available.

There are other advantages, but the crowning one is certainly the much higher average speed due to rapid acceleration and the economy of power and labor, as well as the reduced cost of production which is everywhere effected.

An incidental advantage in favor of the electric motor as compared to the steam engine is that the former can stand an amount of continuous service and hard usage which would be impossible with the latter, besides having far less internal friction.

A most important benefit resulting from the use of electric traction is the diminution of the present difficulties due to the lack of accommodation in termini. Mr. Aspinall, the general manager of the Lancashire & Yorkshire railway, stated to me that the recent electrification of the line from Liverpool to Southport will not only double the carrying capacity of the line but will also practically double the terminal accommodation.

How this is brought about is easily seen when we consider the time wasted at present in getting a steam train out of a station after it has once entered. First the line has to be cleared to allow another locomotive to back on to the train in readiness to take it out, which it does. Then before another train can be brought in the line has to be cleared again so that the original locomotive which brought in the first train can run out. These various manœuvers occupy a considerable amount of time, besides necessitating a considerable amount of siding accommodation, not to mention possible blocking of other lines by the steam locomotives constantly either running out or else backing on to the trains.

CONCLUSIONS.

Comparatively little has so far been done toward the introduction of electric traction on main line railways in Great Britain. This is not surprising, and as far as that is concerned, neither in the States nor on the Continent of Europe are main line railways at present operating anything like very long stretches of line by means of electric traction. The country which has the longest stretches of line is undoubtedly Italy, with its three-phase 3000-volt line working with overhead trolley between Lecco and Sondrio, and its third-rail system between Milan, Gallarate, and Varese, both of which lines have been exhaustively described in the technical press of the world. As regards this country, the Lancashire & Yorkshire railway has equipped and is operating 23 miles of route, and the North Eastern is operating 40 miles of route, both on the third-rail system. These lines have only recently been put into regular service, and no figures, either as regards increase of traffic or cost of operation, are as yet available; the only results so far obtained go to show the excessive danger of third rail. In this country a large number of accidents to third parties have taken place, some of them fatal, and in one instance a train has been set on fire and seriously damaged, fortunately with no loss of life. These results, as far as they go, amply confirm the conclusions at which I have arrived and are strong evidence that the adoption of third rails, at any rate on main line railways, is not at all desirable.

There are several lines in this country operating at high speeds with fairly heavy loads and many others are being constructed. There is, for instance, the Mersey railway, the City & South London, the Central London, the Great Northern & City, and the Liverpool Overhead, all of which have been working most satisfactorily for a considerable number of years, as well as the Metropolitan, the Metropolitan District, and other tube lines now being constructed by the Underground Electric Railway Company of London and which will commence working next year. The power station which will supply energy for the last-mentioned railways is, so far, the largest that has ever been built.

To give some idea of the large amount of railways which already exist in London, the following tabulated statement may not be without interest. I have taken them from figures published by that eminent American, the Hon. Robert P. Porter:

RAILWAYS RUNNING INTO LONDON.

North Side.

Railway.	Length of lines within county. (miles).	Number of stations within county.
Great Central	2.37	1
Great Eastern	16.79	27
Great Northern	4.31	4
Great Western	4.75	4
London & North Western	9.64	12
London, Tilbury & Southend	.62	1
Metropolitan	12.25	18
Metropolitan District	10.42	16
Metropolitan & Metropolitan District (joint)	2.12	8
Midland	7.27	6
Totten & Hampstead Junction	1.92	6
Total	72.46	103

South Side.

Railway	Length of lines within county (miles).	Number of stations within county.
London, Brighton & South Coast	31.14	29
London, Chatham & Dover	26.22	33
London & South Western	14.05	12
South Eastern	37.86	27
London & South Western and London & South Coast (joined)	.60	—
Totals	109.87	101

Wholly in London.

Railway	Length of lines within county (miles).	Number of stations within county.
City of London Electric	6.50	13
City & South London Electric	6.65	14
East London	7.22	7
Hammersmith & City	3.00	5
North London	11.19	18
Waterloo & City Electric	1.50	2
West London	2.30	2
West London Extensions	4.76	4
Whitechapel & Bow	3.00	4
Totals	46.12	69
Making a grand total of	228.45	273

In this connection it must be borne in mind that the mileage here given are miles of route and not miles of single track, and that they only represent the miles of route actually inside the county of London. In order to represent the actual mileage which is only, or to a large extent, devoted to suburban service, the total would have to be more than doubled; in the case of the London, Brighton & South Coast railway only just over 31 miles of route are given, whereas the suburban system comprises 75 miles, and on this system, the average distance between stations does not exceed one mile. A glance at a railway map of London and its environs clearly shows the enormous network of railways which converge into the center of the city, and a careful examination of such a map on which the existing electric tramways and light railways have been drawn will show how, in the next few years, the electric tramways and light railways will enable passengers to travel from any portion of London to places from 20 to 30 miles outside the center of the city. Under the existing conditions it would in many cases be advantageous for passengers to travel as far as 15 miles by tramway instead of taking the steam railway, owing both to the low average speed and, in many cases, the long interval between the trains.

What has been stated as regards London, applies quite as well to other large towns of the United Kingdom, and I am firmly convinced that there is no country in which electrification will be a greater benefit to the railways than the United Kingdom. I believe that the British railway companies are rapidly realizing that a move will become necessary, and when once the movement begins, the transformation as regards our railways will be quite as great as that which has taken place during the last few years with tramway construction.

DISCUSSION.

CHAIRMAN DUNCAN: The paper abstracted by Mr. Armstrong is now open for discussion.

MR. H. WARD LEONARD: There is one figure that drew my attention in the early part of the paper, and that is the statement of the very high capitalization of the English roads, as an average. I can only speak from memory, but I believe that the most efficient railway as regards earnings we have — the Pennsylvania railroad — has a capitalization of about $370,000 per mile,— which is about 50 per cent in excess of the figure named. So that very high capitalization, while of course it is of tremendous importance, is not necessarily an indication of poor earning capacity. The average figure in New York, Pennsylvania, and New Jersey which is the part of the United States most fairly comparable with England is about $120,000 a mile.

MR. F. J. SPRAGUE: You refer now to single or double tracks? And does the paper refer to single or double tracks?

SECRETARY ARMSTRONG: It is per mile of road. It is partly single and partly double.

MR. LEONARD: The figures I have named are all per mile of road. The figures I have stated are from the statistics of the United States Railway Commission Reports. They are per mile of road, that is, per mile of line.

I think it is quite proper to emphasize the statement the author has made in the paper as to the steam locomotive having to carry around with it continuously a very large number of tons that are entirely idle. I think it would probably be conservative to say that the net cost represented by the ton miles of a locomotive due to the non-tractive part of a heavy freight locomotive in this country would be not far from $50 per day. And that brings up another point, namely, that in discussions on this subject, a great deal of attention is usually spent on the cost of fuel, and the question of whether or not it would be possible to save the wages of the fireman. Personally, I consider all those matters as extremely trivial as compared with the really important matters. Considering $100 of earnings by railways of this country only about $7 of that amount is spent for fuel. So that it does not seem advisable to confine the discussion so much to fuel consumption.

I think that the very greatest importance should be laid upon the requirement of endeavoring to utilize to the highest degree the very large investments and fixed charges that are represented by the equipment and maintenance of a mile of road. Something like 86 per cent of the total cost of moving a ton-mile is represented in this way, and is totally independent of the coal and wages on the train. And it seems to me conspicuous that the problem narrows itself down to the question of getting from every mile of track per hour the maximum possible ton miles — which means again the maximum possible number of tons moved at the highest possible rate of speed.

If we go back, for example, in the statistics of the Pennsylvania Railway for about thirty years we find that the cost of moving a ton one mile used to be at that time about a cent and six-tenths; and in 1902 the cost of moving a ton one mile by the same railway was thirty-six hundredths of one cent. Now, this very striking reduction in the cost of moving freight has not been in any way due to any reduction in cost of wages or cost of coal. On the contrary, those have increased. And personally I am strongly of the belief that to-day the cost of moving freight is inversely proportionate to the power that is employed in moving the train, and with that thought in mind it seems to me that the electric moving of freight has possibilities that are not at all to be expected from any steam operation.

There are probably not more than 10 per cent of the locomotives that are used in this country that are capable of developing over 1000 horsepower. Those large locomotives are the most economical ones we have as regards moving freight. There are some 40,000 locomotives in the United States, and less than 4000 of them are of modern efficient size. The boiler is the principal limitation to the power of the locomotive, and it seems unlikely that there will be very much growth in the power of the boiler used on steam locomotives; whereas, theoretically speaking, there is no limit to the amount of power that could be applied to the movement of a freight train by electricity.

The draw-bar pull of the freight locomotive, in the best types, reaches sometimes as high as 50,000 pounds, but that draw-bar pull is only obtained when steam is taken at full stroke,— which means at an extremely slow rate of speed, and by the time such a rate of speed is reached as would represent the average speed desired the draw-bar pull is less than half of that figure.

The mountain sections of our principal railways are the places where the requirements for power are most keenly felt to-day. There is always a great congestion of freight at such places. If we employ electric locomotives we have, fortunately, coincident with the grades of those mountain sections, as a usual thing, power in cheap form represented by the water power of the mountain section.

It seems to me that what is wanted is a locomotive which will produce about 50,000 pounds draw-bar pull and maintain that at about thirty miles per hour — and that means 4000 horse-power at the draw-bar. We already are subjecting our draw-bars to that strain, and they are strong enough to stand it, provided that we have some form of operation which is not going to subject those draw-bars to intermittent large strains due to irregular methods of control, or to the bucking of the various units that are employed under multiple control.

It seems to me that the principal cause of the poor showing of the British railroads in the cost of handling freight, as compared with the United States, can be found in the fact that as an average the horse-power of their locomotive is very small compared with the best practice in this country.

Mr. **Sprague**: I have only a few words, Mr. Chairman, on this paper. Not having read it, I am not prepared to discuss it at length. Probably in what little I say I may disagree with Mr. Dawson, and to some extent with what Mr. Leonard has said. In one form or another I have for many years advocated electric traction. It has already naturally supplanted a method of traction which at the best was poor — that is, animal traction; and in supplanting it, it has achieved results in transportation greater than its most ardent advocates had hoped, in cheapening operating cost, increasing schedule speeds and opening up new fields.

But we must not forget that one of the chief reasons for the great success of the electric railway has been the fact that it has been what may be called a house-to-house railway, one making frequent stops convenient to the passenger. As a result we have seen here in the United States practically every horse-car disappear, almost all cables abandoned, existing lines consolidated, and new lines link together towns and cities and wipe out the divisions between urban and rural communities.

But when approaching the steam railway problem I have always done so with a good deal of deference to existing conditions. Electricity, after all, is merely a convenient method of transmitting power. We do not create anything by it, we do not establish any new laws by its use. By concentrating at central stations the power used on a railroad and distributing it in the best possible manner we hope to utilize that power more economically. But in order to do so successfully from a power standpoint there is one essential; the load factor must be high, which brings me back to an assertion which I have made again and again for the last fifteen years; namely, that leaving out for the moment the influence of competing lines, diversion of traffic and what not, there is a point on any railroad where the adoption of electricity may be justified, and that point is primarily determined by one essential, density of traffic. And I do not mean by density of traffic concentration of loads at one point, but multiplicity of units well distributed. So long as the operation of any road means the sending out of high powered units at long and irregular intervals over great distances we might as well be frank with ourselves and say that there is not the field for electric transportation.

As the traffic increases we approach a point where the number of units between terminal points warrants the consideration of a change of motive power, and I think that condition has arisen on a number of steam railroads. Beyond that point there can, I think, be very little question as to whether electricity can be economically adopted.

The problems in Great Britain, the Continent and the United States are somewhat different. Here it will be many years before we can in even the most hopeful attitude look for many of our main roads to be operated other than by steam. There are some roads and certain sections of railroads which will undoubtedly be operated by electricity — but oftentimes for reasons not determined by economy of operation.

I may, perhaps, cite the most important two instances in this country, if not in the world, at present — the operation of the Pennsylvania Railroad tunnels and terminals in Jersey City, New York and Long Island, and then those of the New York Central Railroad in New York and a part of its main line. I have the honor to be a member of the Commission on the latter road, which has to do with the electrification of the equipment. It is, perhaps, too soon to go into details in connection with it, except this: One of the requirements — a legal one — which determined the use of electricity on this road was that no steam-operated train should be used below the Harlem River. The Harlem River is well within the city limits of New York, and only a comparatively short distance from the terminal at 42nd Street. The movement of trains within that district is enormously congested. According to a report made by Mr. Arnold sometime ago, at certain periods there are over 700 daily train movements, and the trains vary anywhere from 150 to 700 tons in weight.

The law said we should abandon the use of steam. Of course, we were permitted to use anything else in the tunnel, but that was practically the same as saying that electricity should be used. But within even the district determined for electrical operation extending out some 35 miles, I do not think any calculation made, taking into account the interest on investment, shows any real economy in operation over steam, all things considered.

The determining considerations may be stated as first, the law which practically required the use, part of the way, which part was to a point where there were no terminal facilities whatever, and second, that it was advisable from a transportation standpoint to operate suburban trains electrically — certainly within a distance of perhaps an hour's run to New York. Having determined that, then it was common sense to operate all trains located within that zone by electricity, instead of having a duplicate system.

The result is that for some distance from New York city we will have what may be considered a great terminal, within which there are suburban trains operated by motors under the cars on the multiple-unit plan, and other trains dropping off their steam locomotives at the termini, and taking on electric locomotives likewise so operated.

It is, perhaps, unwise to attempt any limitation as to this particular development. Certainly I would not be rash enough to hazard it, but it is a special problem, and I do not think has yet any great bearing upon the broad question whether trunk railways will be operated by electricity. There are many other problems to be taken up when that subject is considered.

The British railways, especially those terminating in London, will mostly adopt electricity only when they are compelled to; few of them will do it of their own volition. The competition which exists in this country with electric railways will not be quite so forcibly felt on English roads, because there is not that same freedom in granting of franchises for parallel lines of railways that we have here. But there is a special reason why electric equipment should be considered. The traffic in London, for example, is enormously congested at certain times of the day. The result is that the facilities are entirely inadequate, and new construction, whether of an overhead line over existing tracks, or tunnels beneath or tracks parallel to them, is almost prohibitive in cost. So that the natural, and so far as I can see about the only way, in which they can increase their capacity is by electric equipment, and I think that the British roads in time will see that fact.

Perhaps one of the most important means by which the changes could be brought about would be in the reduction of the age limit in their directorates. You gentlemen know the English and American practice is somewhat different in this regard. When a man becomes a director on an English railway the position practically terminates only at his death or permanent disability, or when for some good practical reason he gives away to another. He rarely represents, in that conservative method which governs English railways, the progressive element of the stockholders. Being a man of mature years, and often having reached that age when most men are ultra conservative, he will hesitate to abandon an existing system and adopt another. It usually takes younger men to do that, and to believe what can be accomplished by such a change.

Here in the United States the directors have not that hold upon the administration that they have abroad. A change of ownership in the road, a change in the holdings of the stock, may result in a very prompt and radical change in its management from the president down, but such a thing is almost impossible in the British Isles.

I do not know that there is anything further, Mr. Chairman, that I want to add. In fact, I did not intend to say anything. I am as hopeful, perhaps, as any one can be that electricity will be used on steam railroads, but I do not want to shut my eyes to the fact that there are a good many difficulties inherent to trunk-line railway service for which electricity is no cure-all.

Mr. Leonard: Mr. Chairman, if I may be allowed to add a word, I should like to speak of one point I have heard frequently raised and it seems a fitting opportunity to mention it. In comparing the cost of operation of English railways with American railways, I find that the Englishmen are very apt to retreat behind the argument that in England the mail and express business is classified in the freight figures, whereas we in this country have those classified in the passenger business, and receive compensation for those, which make so important a factor as to distort the figures materially; and that, therefore, deductions cannot be fairly drawn by comparison in the cost per ton-mile of the English railways and the American railways.

The express is 2 per cent of the receipts in this country, and the mail also about 2 per cent of the total receipts, so that those figures are not sufficiently influential to in any way influence the very striking difference in the costs. About nine-tenths of our present steam locomotives in our country seem to me a liability, rather than an asset, to the railways that operate them; and since there seems to me to be a necessity for "scrapping" about nine-tenths of the inefficient small locomotives and the replacement of them by the larger efficient ones, we are not confronted with the same condition of affairs as we would be if the steam railways had already made a comprehensive equipment of the highest class of steam locomotives.

Chairman Duncan: Any further discussion, gentlemen? If not, we will proceed to the paper on "The Storage Battery in Electric Railway Service," by Mr. J. B. Entz. We will now read the paper:

STORAGE BATTERIES IN ELECTRIC RAILWAY SERVICE.

BY JUSTUS B. ENTZ.

The principal applications of batteries to electric railway systems are made at the generating stations, at distributing sub-stations, and directly connected to points on a direct-current distributing line. The objects of such installations are to store electrical energy at efficient and convenient periods and to return it when most useful, generally at periods of increasing or heavy load. A storage battery, which is a reservoir of electrical energy, when connected to the circuit, makes the conditions of generation and transmission up to the point where the battery is connected independent of the load demand of the circuit beyond that point. The storage battery also permits the rate of production of energy to be independent of the rate of demand. The demand for electric current may occur at a time when its production will be inconvenient or inefficient, or both, The demand may call for a very high rate of output for a short time, as in electric railway systems, where the maximum demand lasts only for a period of a few seconds. By the use of a battery the rate of producing energy may be adjusted with reference to other considerations, such as efficiency of generating apparatus. This energy may be produced at low and constant rates and stored in a battery and given out to meet the demands of variable and very high rates. The results thus obtained are improved efficiency of operation and greater reliability of service.

In comparing a battery with the generating and transmission apparatus, it will be noted that the battery handles most economically those portions of the load which are least economical for generating or transmission apparatus, namely, those which are of extremely short duration and excessive in amount, as well as those which are of considerable duration, but of very small amount. The maximum economy of usefulness is secured by such division of load between the battery and other apparatus that each handles that portion to which it is best adapted.

The reasons for installing storage batteries in railway work are as follows:

1). Reasons affecting investment.

2). Reasons affecting economy of operation.

3). Reasons affecting reliability and public convenience and safety.

It is impossible to draw a sharp line between the three classes of reasons. A part of the total investment for railway equipment is made for economy or for reliability. The consideration of a battery in this class of work usually involves the comparison of battery with generating machinery, or in some cases the transmission copper and sub-station equipment, or with all of them on the three headings enumerated above. In such a comparison the following points must be considered:

1). The results of the comparison of investment will depend upon the shape of the load diagram and upon the methods and distances of transmission and upon what portion of the load is assigned to the battery. In general, however, it may be stated that there is almost invariably some portion of the maximum load which may be carried by a battery at an investment cost not exceeding that for the apparatus it actually displaces to do the same work. It is often sound engineering to increase the proportion of the battery considerably beyond that point to secure more fully the advantages in headings 2 and 3; and it must be borne in mind that many of the functions of a battery can be performed by no other class of apparatus, and where these functions are vital, the investment comparison is of minor importance.

2). Under the head of economy of operation must be included both generation and transmission of energy and both labor and fuel economy, as well as cost of maintenance and depreciation. As loads of certain nature are handled more economically by the battery than by generating machinery, the maximum fuel economy is secured by such division of load between the battery and machinery that each handles that portion for which it is best adapted.

The question of the size of a power equipment is, of course, confined to a determination of the requirements necessary to meet the maximum load conditions, whereas, considering economy of operation, the average load conditions must be considered. In the sub-station there is an increased efficiency of rotaries and transformers due to the operation of batteries which must be compared with the losses in the battery. With the batteries used very considerably on peak work, their output will amount to from 15 to 20 per cent of the total output of the station. As the battery under average conditions will not be fully used, but a certain portion of it held in reserve to meet abnormal conditions, the efficiency of the battery will be high. Taking this at 85 per cent as a minimum, we find that the losses in the batteries, where their output is 20 per cent of the total, is 3 per cent of the total output of the system.

It is safe to say that on account of the improved efficiency in transmission and the improved load factors on the rotaries, the efficiency of the sub-station should be increased by considerably more than this amount, and that any improved economy in the generation of power at the main power-house will be net gain.

The economies at the power-house from the operation of batteries will be such as to produce ideal economy in both boiler and engine-room. The load on the engines and boilers can be adjusted to practically the 24-hour average, and need be varied only when this average is changed. With peaks in the morning and evening to double the height of the average load, this will mean operating through the day at practically one-half the capacity that will be needed at the peaks without the battery. To handle these peaks without the battery, it would be necessary to keep one-half of the total boiler capacity with fires banked from 18 to 20 hours a day for operation during the hours of peaks. The constant loss in these boilers through radiation and the escape of heated gases would probably not be less than 20 per cent of their capacity; and one-half of these losses, or 10 per cent of the boiler capacity required with the battery in service, would be saved. This would mean a saving of 10 per cent of the total fuel.

The improved load factor on the engines and generators and the reduction in the number of engine hours of operation would effect an additional economy. There is a considerable loss of steam when every unit is started up, this being the steam consumed from the time the throttle is opened to the time the load is thrown on the generator. As the operation of batteries would reduce the number of times the unit is started up and shut down, there would be a saving on this point. I believe that it would be conservative to expect a saving on this point of from 5 per cent to 10 per cent, making a total saving of fuel in the operation of a power plant with batteries of from 15 to 20 per cent.

It has been stated that a storage battery is a good thing to patch up bad engineering. This is true, and there is a considerable field for its application in this way. It is, however, not limited to such cases, and is often the only means of preventing engineering proving to be bad owing to the impossibility of foretelling what conditions are to be met exactly. The extreme flexibility of a battery in meeting conditions varying over a very wide range renders it peculiarly applicable to such cases.

Under the question of maintenance and depreciation it may be noted that with a storage battery these two items are combined in one. The renewals of plates which are made from time to time keep the battery up to date, so that at the end of a period of years it is not an obsolete piece of apparatus, but it is up to date in every respect and equal to the batteries then in the market, including all the improvements in plate construction which have been introduced since it was installed. The flexibility of the battery to meet changes in conditions, such as desirability of increased voltage or larger capacity, is also to be noted, such changes in conditions often involving the discarding of generating apparatus; whereas in a battery, the simple modification in the number of cells, or the number of plates in each cell, will suffice.

3). The reliability of the storage battery and its absolute freedom from break-down without warning is due in part to the fact that it is composed of a multitude of small units, each unit being a battery plate, any one of which can be put out of service without noticeably affecting the operation of the entire installation; whereas, in a generating plant, the various parts, such as boilers, engines, generators, switchboard apparatus, transmission lines, transformers, and converters, are all connected in series and the derangement of any one class of these parts instantly interrupts completely the operation of the whole. The deterioration of a battery is in all cases very gradual, and repairs can be made without taking the battery out of service.

As an emergency reserve, the battery can be found of immense value in any one of the following ways:

a). In case of a total shut-down of the power-house or high-tension lines, the amount of battery which would usually be installed from other considerations would be sufficient to maintain the entire service of the road at the time of the peak for three-quarters to one and one-half hours, or for twice as long during the middle of the day, thus permitting temporary repairs to be made. In case of an interruption of longer duration, the battery would at least enable the trains to be run into the station and the passengers discharged, instead of leaving them stalled between stations.

b). At a sub-station the rotaries could be shut down for an indefinite period of time, the battery being floated on the line at a somewhat reduced voltage.

c). The batteries are available instantly to take care of sudden excessive load of short duration, due to any unusual congestion of traffic.

d). They will take care of and prevent interruptions from short-circuits on the line which would otherwise fall on the machines, saving overloading them and then throwing out the breakers and interrupting the traffic.

e). The batteries would permit the entire machinery of the power-house and sub-station to be shut down at night and the current cut off the alternating-current lines for a period of several hours for repairs and inspection.

f). The batteries would often make it possible to purchase either alternating or direct current from other systems at times when they were not overloaded, and at a constant and controllable rate which would cause no disturbance. This power could be utilized on the system at times of peak load, when it probably could not be purchased.

The fact that the batteries are available in case of emergency would permit the shutting down of machinery when signs of trouble first appear, thus reducing the extent of the damage which might be caused by continuing to run partially disabled machinery until a substitute could be put in service.

The points enumerated above apply to batteries installed at the power-house and those installed on the line. Certain additional advantages arise in many cases from installing a battery at some distance from the source of power, due to the improved conditions of transmission. With such a battery, it becomes necessary to transmit only the average power required instead of the maximum. The result will be a saving in the amount of copper required for a given drop in voltage, or an improvement in the voltage with a given amount of copper, or the advantages may be divided between the two methods. An increase in economy will also be secured, since it is a well-known fact that to transmit a given amount of energy over a certain conductor in a given time, with a minimum loss, the rate of transmission should be constant.

The installation of a storage battery at a generating station is to take the peak of the load for its maximum two or three hours, and to regulate or control the rapid fluctuations of load occurring all day. Where the station voltage has not a drooping characteristic it is necessary to add to the voltage of the battery the voltage of an auxiliary generator, in order to cause it to discharge at the time and by the amount necessary. This auxiliary generator, commonly called a booster, also serves for charging the battery without varying the bus-pressure of the station by adding its voltage to that of the bus, the armature of the booster being in series with the battery and its field strength being automatically controlled where the changes of load are at all rapid. When located at some distance from the power-house, the booster may be dispensed with, as the variation in the line voltage will be sufficient to cause the battery to do its work. Located in this way the battery will maintain the voltage on the line at approximately its average point. If the number of cells in the battery are properly adjusted to float this average voltage, the battery will remain in the same average state of charge. If the average voltage at the point where a line battery is located is found too low for satisfactory results, a booster may be installed at the power-house and sufficient current transmitted over a feeder direct to the battery at a voltage higher than the bus to maintain the battery voltage at the desired point, this latter arrangement affording means for adjusting the voltage at the battery to meet changes in local conditions — which is usually very desirable.

Such installations are very satisfactory and economical, showing a saving in investment over copper and generating machinery, as well as a considerable saving in energy, as not only is the energy transmitted at its average current value to such a point on the line, but the average current consumption is lessened by the increase of voltage at the point of consumption; and this increase and maintenance of voltage very often brings about an actual reduction in wattage at the point of consumption, because of the higher acceleration rates permitted by the cars themselves, resulting, as is well known, in a considerable reduction in energy consumed where stopping and starting is at all frequent. A booster for such a purpose is usually an independently excited booster located at the power-house and hand-controlled, so as to have control over the average output over the battery feeder.

The automatic control of a battery by its booster when the battery is connected in parallel with generating machinery of a constant or rising characteristic is accomplished in one of the following ways:

A regulating battery is generally discharged at a rate at least as high as its one-hour rate; that is to say, the rate at which it would discharge continuously without its voltage drop becoming too great. This does not mean that a battery is totally discharged at this rate in one hour's time, as a reduction in the rate would permit considerably greater capacity to still be taken out of the battery without its voltage falling too low. Within the full range of the one-hour capacity of a battery the voltage change for a change of the one-hour rate of current is from 5 to 7 per cent, due to the internal ohmic resistance of the battery, and this change of voltage is simultaneous with the change of current. If the full rate of current be maintained for 30 seconds, an increased change of voltage of from 4 to 5 per cent will take place in about 30 seconds' time, due to polarization. After 30 seconds the increased change of voltage due to polarization is comparatively slight, except at the very end of discharge or of a full charge. The booster must, therefore, be provided so as to give a voltage of about 12 per cent of the battery voltage at the time that the battery is charging or discharging at its maximum rate; and we must further insure that it will give a voltage of 20 per cent of that of the battery at a rate of current of from one-third to one-fifth that of the maximum rate, in order to bring the battery up to a point of full charge. The characteristic of most boosters allows them to give this additional voltage at reduced current with but comparatively little increase in the size of their field magnets.

The automatic excitation of the booster field is accomplished either by including an exciting coil in the working circuit by means of which the full output of the station to be regulated passes through this coil, so that an increased load demand strengthens the booster field and gives added voltage to the battery circuit sufficient to cause it to discharge by an amount equal to the increase, thus keeping the load on the generator constant, or to take any proportion of the increased load that is desirable. Such a main exciting coil in the working circuit must be neutralized by a separate exciting coil, so that with any predetermined average output of the station the booster shall neither add nor oppose its voltage to that of the battery. For currents below this established load, this opposing coil becomes stronger and reverses the polarity of the booster, causing the battery to charge by the proper amount to maintain the regulation desired. In order to make such a combination as stable as possible, another main-current coil has been included in the generator circuit, so that an increase of current falling upon the generator following an increase of outside load would further affect the battery and cause it to discharge. Where the outside main-current coil has been adjusted to exactly meet the state of the battery and so effect absolutely constant current delivered from the generator, this inside coil in the generator circuit, of course, accomplishes no purpose; but it prevents any lack of exact adjustment affecting the regulation to any great degree, and where very perfect regulation is required, this form of booster is very extensively used and is generally known as a differential booster.

Regulating altogether by variations in the generator load while trying to keep that variation within small limits, calls for some means of magnifying the effect of such variations upon the booster excitation. There are two methods of this kind in general use, in one of which a small generator with a voltage normally equal to that of the station bus has included in its circuit the exciting coil of the battery booster. When the voltage of the small generator and that of the bus are equal, no current flows through this booster exciting coil. This small generator is known as a counter e.m.f. generator, and derives its field excitation, and, consequently, its voltage, from a coil placed in the generator circuit, the said coil being so adjusted that the average load that is to be kept upon the generator produces a voltage of the counter e.m.f. generator equal to and opposed to that of the station voltage, so that under such conditions the battery is neither charging nor discharging. If, now, the generator output increased 10 per cent, the voltage of the counter e.m.f. generator, if it has a perfectly straight characteristic, will increase 10 per cent above the station voltage, and this excess of voltage should be sufficient to excite the booster to an extent necessary to cause the battery to discharge the balance of the load increase which caused the increase upon the generator, part having fallen upon the generator for the purpose of effecting the regulation. The lowering of the generator output following the lowering of the station output acts in the same manner, sends a reverse current through the booster field and causes the battery to charge.

If, as cited above, regulation of the generator load within 10 per cent were to be maintained, the output of the counter e.m.f. generator would have to be 10 times that of the energy required for the field excitation of the booster, as but 10 per cent of its voltage is applied for that purpose. If the regulation were to be 5 per cent in either direction, the output of the counter e.m.f. generator would have to be 20 times that of the energy required for the booster field excitation. The excess output is, of course, not lost, but passes to the line. The maintenance of any fixed load upon the generators in this system is controlled by means of variable shunts around the exciting coil of the counter e.m.f. generator, which carries all the generator output.

The other method of regulating by variations in the generator load is by means of an electromechanical regulator. This regulator consists of two or more groups of carbon discs, connected in the manner of the Wheatstone bridge, with the exciting field coil of the booster connected in the position of the galvanometer. A pivoted lever is so mounted that its movement brings pressure to bear upon one set of the groups and releases it upon the other, so as to change their respective resistance and to vary and reverse current through the field of the exciting coil. To one end of the lever an adjustable spring is attached and to the other end a magnet core influenced by the current in the generator circuit. At the average generator load which is to be maintained, the pull of the magnet is balanced by the pull of the spring at the other end of the lever. Under these conditions the pressure upon the two groups of carbons is the same, and no current flows through the booster field coil. A slight increase of current in the generator circuit is sufficient to cause additional pressure upon one of the groups of carbons compared with the other, and send current to the field regulating coil of the booster in a direction to cause the battery to discharge, which it does to an amount practically equal to the increase of load in the outside circuit, letting only a small portion of the additional load fall upon the generator to effect the regulation. If the generator load is decreased following the decrease in the outside load, the spring becomes stronger than the magnet, and a pressure is put upon the opposite group of carbons, reversing the current through the booster field coils and causing the battery to charge.

It has been found that very close regulation can be maintained in this way, even with a load varying almost instantaneously. Regulation of less than 2 per cent in either direction has been frequently obtained. Complete control of the output of the generators is secured by this system, and the generators can be set to run at any average load desired, by simply varying the strength of the spring opposing the magnet. If the pull of the spring is increased, the generator current is immediately increased to a corresponding degree, as otherwise the battery would charge till the increase of the generator load would balance the spring pull. The end of the spring carries a pointer, and there is a calibrated scale in amperes by which the generator output can be instantly set at its desired value.

This form of regulator is mounted on a switchboard, and occupies not much more space than the ordinary recording wattmeter. The spring and its indicator, as well as the carbons, are on the front of the board, and the lever extends through the board, and in stations of any considerable size carries a simple horseshoe of soft iron which is hung over the bus-bar carrying the total load of the generators. The usual connection for such a regulator is to have, electrically considered, two groups of carbons. These are connected all in series, and by means of a connection made to the storage battery a small current is maintained through them. At the middle point of the carbons, which is the point where pressure is divided, a lead is taken through the field coil of the booster to the middle point of the battery, to which the two ends of the carbons are connected. In this way, when the pressure on the two groups of carbons is equal and the resistance is, therefore, equal, there is no difference of potential between the midway point of the carbons and the midway point of the battery.

In plants where very large boosters are used it is desirable to magnify the effect of the regulator by means of an exciter connected between the regulator and the booster, rather than to increase the size of the regulator. This regulator has some advantages over any other method of battery regulation, in that it is possible to adjust the sensitiveness of regulation on the charge side of the battery as compared with the discharge, and *vice versa*. For instance, in a generating station or a sub-station with a fluctuating load, it is not necessary or always desirable to maintain the load on the generating machinery absolutely at its ratings but to allow it to share the increased loads to some considerable extent, in order to reduce the discharge rate of the battery. If this is done by any direct means of field-coil regulation it will follow that if the generating apparatus shares a portion of the overload it will also have to share the underloads, or loads below the average, in the same proportion.

With the carbon regulator, on the other hand, by the introduction of a resistance in one of the groups of carbons, the regulation on discharge, for instance, may be made of any degree of sensitiveness, so as to allow the generator machinery to share any portion of the overloads, while on the underloads full sensitiveness of regulation may be maintained and the load on the generators not allowed to drop off below the average. In this way the battery may be accumulating charge; as it receives more charge than discharge, the actual variation of load on the station is considerably lessened and the maximum output of the generating machinery and the battery is not increased. In this manner the overload capacities of engines, generators, rotary converters, etc., may be utilized to the fullest advantage, and the battery may be discharging at very high rates; but by taking full advantage of every dropping off of the load below a predetermined point sacrifice as little of its capacity as possible, and may assist the generator on the peak of the load, while losing but a minimum of its capacity. Also with this form of regulator, a zone of non-regulation may be created extending say from 10 per cent above and below the average load, whereas for loads above and below this the regulation may be as perfect as possible. This permits of reducing the total amount of charge and discharge in ampere-hours that a battery may receive by a very great amount, while keeping the variation of the load on any system within non-objectionable limits, and the life of the battery may be materially increased, often without reducing any of its benefits.

As to the construction of a battery for railway service, it is pretty well established that the positive plates should be of the "Planté" type and not of the "pasted" type; while the negative plates are preferably of the "pasted" type.

The characteristic trouble of negative plates has been loss of capacity due to shrinkage of the spongy, finely divided, active material into a denser and less porous material. This has particularly been true of "Planté" negative plates, where the active material is relatively small in quantity and has been reduced from the peroxide previously formed from the plate itself. A process has been discovered of manufacturing a negative active material which always retains its loose, spongy, porous condition; but, as this has but little mechanical strength, means have to be provided in the plate for retaining it in position. Such plates have proven eminently satisfactory in service and extended tests show a very greatly increased life and the maintenance of low resistance and low polarization factors.

In considering the life of a positive "Planté" plate, it should be taken into account that the life in ampere-hours of a pound of lead entering into the construction of a positive plate is not governed by the surface development of the lead, but by the means which have been provided for retaining the active material formed from the plate itself in proper contact with it, and the prevention of the loss of such active material from being washed away or carried away by the gases which rise from the surface of the plate. The extended development of a pound of lead increases the capacity which it would yield on any one discharge, but lessens the total number of discharges available by more than a proportionate amount, a very highly-developed plate yielding less total life in ampere-hours mainly because its mechanical structure and its conductivity are affected to a greater extent by the removal or loss of a portion of the substance of the plate. For this reason the development of the active lead should be made in such a manner that it will provide secure receptacles for the retaining of the active material; and the necessary further corrosion of the active lead for the purpose of replacing active material carried away should not interfere with the mechanical strength or with the conductivity of the plate.

No modern battery installed for railway service should be in danger of a break-down at any rate of discharge that could possibly be imposed upon it, and in well-designed batteries there is absolutely no danger of break-down due to any rate of overload.

Some years ago the electrical engineer was disposed to look upon a storage battery with more or less misgiving. Even at the present time there may be found occasionally an engineer who, not realizing the progress that has been made in this art and the place that the storage battery has established for itself, is disposed to take this skeptical attitude. If, however, the history of the storage battery business for the past 10 years, which period practically covers its entire commercial history, should be compared with the first 10 years of any other electrical apparatus, we believe that the comparison will show a series of complete successes and the absence of anything approaching a failure or setback, that will compare favorably with the history of any other electrical apparatus.

DISCUSSION.

CHAIRMAN DUNCAN: The paper is now open for discussion. I would like to ask Mr. Sprague if the New York Central is going to put in batteries, or if he can say whether they are or not?

MR. F. J. SPRAGUE: That is a question I cannot answer at present. My experience with storage batteries has been such as to lead me to regard them with favor in some classes of work. On the South Side Elevated road in Chicago, storage batteries were introduced for two reasons, one to help take the sharp fluctuations in load, and the other to provide additional facilities when the demands of the road were growing so rapidly as to run ahead of possible direct equipment. No boosters were used, the batteries responding fairly well automatically to the rise and fall of potential where connected to the line, but varied somewhat in action by cutting in or out an extra feeder.

The New York Central presents a problem which is materially different from that of elevated and suburban roads. Usually on those classes of service there are a large number of units, and the load is fairly distributed. The New York Central has about nine sub-stations, the units weigh from 150 to 700 tons, and the sub-stations are a considerable distance apart. It is impossible to avoid a condition which is emphasized on heavy steam railway work, extreme local variations of load. There will probably be at times as many as four trains supplied almost entirely by one sub-station, while at other times there will not be any load whatever on it. Of course that means a pretty large variation, and sometimes a very rapid one.

Personally, I am strongly in favor of the use of storage batteries in this instance, not only partly to relieve the sub-station machinery and to reduce its capacity; but also to provide a reserve, in case of any accident to the central power plants or transmission system.

The equipment is being laid out with the idea of maintaining train movements from two stations, either of which in emergency can operate the entire service for a reasonable time. I do not think that in the matter of cost, all things considered, there would be much difference between the installation of a plant with or without storage batteries, that is, the saving of central station and sub-stations would be about offset by the cost of batteries and boosters.

Mr. J. Sigfrid Edström: It is very interesting to hear of these American plans of railways and the questions arising in their operation. Why do we in Europe not have the same difficulties, and why is the opposite the case in America? I find the question very easily answered. We have in Europe comparatively small installations, while you here in America generally have large plants, for instance, the one Mr. Sprague was speaking about, the New York Central. We find in our plants storage batteries to be of great advantage. Take for instance a railway with three or four cars running and without the battery, it would be very difficult to get a steady and economical load. If we did not have the storage battery, we should at night have our power station working at full capacity, while now with storage battery we can run a few cars on the line all night. The lighting of the car barns is also attended to by the battery. The principal advantage of the storage battery is, however, that it evens up the load of the machinery. Take, for instance, the city of Gothenburg, for which I built the street car system, and where some forty cars are running. We have been running this plant at times with a battery and at times without one, and we find the battery system very favorable, very economical and less trying for the machinery. Of course, when you get to the big power plants like the ones in Berlin, Copenhagen and other large cities, the size of the plant makes it less necessary to have storage batteries, but for smaller plants the European practice is always to use them.

I do not know anything about American practice with respect to batteries, but I think it worth while to mention that in Europe there are several manufacturers who give a guaranty that the battery shall give the same capacity at the end of ten years as when the battery is installed. If there is any other question I can answer regarding the European methods, I shall be glad to do so. I am sorry I was unable to be here and hear the paper read and beg you to excuse me if my remarks have sidetracked the question.

Mr. SPRAGUE: I think the reasons given by the gentleman are quite satisfactory for the installation of storage batteries in European plants. A great many of the installations are small, and subject to wide load variation. On the New York Central, for example, if it were a question of installing batteries at the central station — then their introduction would present an entirely different question. But when we have substations on which the loads vary rapidly and greatly, we get right back to the conditions mentioned — a local station having a few units, and subject to very wide fluctuations.

CHAIRMAN DUNCAN: I think there is considerable difference in the cost of the batteries, too.

Mr. SPRAGUE: Possibly. In Europe there is a great deal of competition in the manufacture of batteries — probably both in price and guarantee. There are not the same differences here.

CHAIRMAN DUNCAN: If there is no further discussion, gentlemen, we will adjourn until to-morrow when there will be a joint meeting with Section B on alternating-current motors.

The meeting then adjourned.

TUESDAY MORNING SESSION, SEPTEMBER 13.

Joint session of Sections B and F. Prof. Steinmetz, Chairman of Section B, and Louis Duncan, Chairman of Section F, presiding.

CHAIRMAN STEINMETZ: Gentlemen, the joint session of Sections B and F, arranged to discuss papers relating to alternating-current railway problems and allied subjects, is called to order. I will call upon Mr. Bion J. Arnold to report on "Some Early Work in Polyphase and Single-phase Electric Traction."

SOME EARLY WORK IN POLYPHASE AND SINGLE-PHASE ELECTRIC TRACTION.

BY BION J. ARNOLD.

In 1896 I became interested in a proposed road projected to run west and north from Chicago into the lake regions of Wisconsin, and to be known as the Wisconsin Inland Lakes & Chicago Electric Railway.

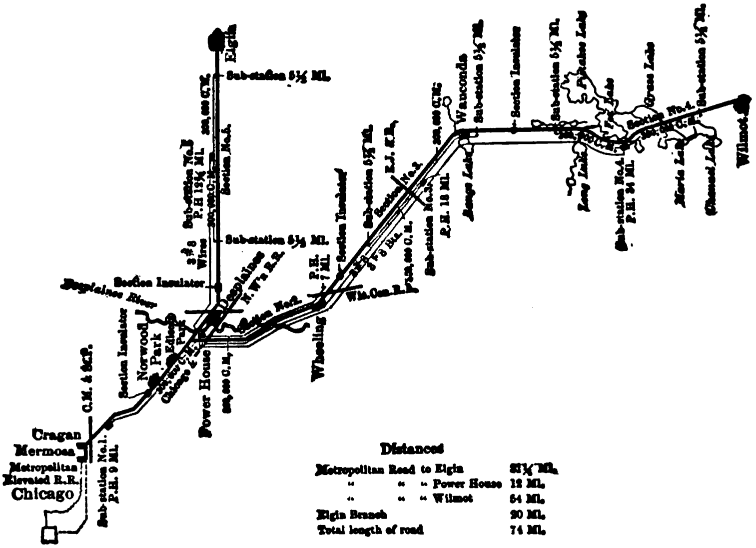
The rotary converter was then just beginning to be commercially exploited, and had, I believe, been used in some instances for power transmission, but so far as I know it had not been used for railway work. Desiring to construct the road, some 75 miles in length, as economically as practicable, and seeing no reason why rotary converters would not operate on railway work, I decided to adopt a three-phase high-tension transmission system with sub-stations, using rotary converters and storage batteries — a radical departure from the then standard 500-volt direct-current system.

Complete detailed specifications for the road and its equipment were prepared, calling for three-phase generators capable of supplying current at 1040 volts, the necessary step-up and step-down transformers, switchboard apparatus, rotary converters, etc., required to generate alternating-current energy at 1040 volts, transmit it at 5000 volts, and convert it into direct current at 700 volts to supply the overhead conductor, from which standard direct-current railway motors were to be operated, using storage batteries as equalizers in sub-stations distributed along the line.

Fig. 1, which shows the arrangement proposed, is a reproduction of one of the original drawings attached to the specifications submitted to the railway company at the time the final specifications were delivered.

It happened, unfortunately, that the promoters of the road were unable to secure the necessary franchises for its construction, and it remains unbuilt today, while the specifications and plans repose among the archives of my office as evidence that an engineer, eager to see his ideas executed, is apt sometimes to do much work for no pay and stand the preliminary expenses himself. The territory has since been partially occupied by the Aurora, Elgin & Chicago Electric Railway, and the Chicago & Milwaukee Electric Railroad.

However, while this experience was somewhat disappointing financially, the time and study put upon it were not lost. A few months later the promoters of another road, now a part of the Chicago & Milwaukee Electric Railroad, came and stated that they must build 15 miles of new road in order to connect two small roads, each about a mile long, and that out of the total money available to build this road they had provided but $10,000 to put into copper. After carefully calculating the cost of the road and finding it prohibitive, if built under the then standard 500-volt direct-current system of distribution, the plans of the Inland Lakes Road were resurrected. To have built the new road under the 500-volt direct-current system would have necessitated investing almost as much money for copper alone as the parties had at their disposal for building the complete electrical and mechanical equipment.



Distances

Metropolitan Road to Elgin	31¼ Mi.
" " " Power House	12 Mi.
" " " Wilmot	64 Mi.
Elgin Branch	20 Mi.
Total length of road	74 Mi.

FIG. 1.—MAP SHOWING LOCATION OF POWER-HOUSE, SUBSTATION AND DISTRIBUTION SYSTEM OF THE WISCONSIN INLAND LAKES & CHICAGO ELECTRIC RAILWAY AS PLANNED IN 1896.

FIG. 6.— FIRST SINGLE-PHASE ELECTRO-PNEUMATIC LOCOMOTIVE, KNOWN AS NO. 1.

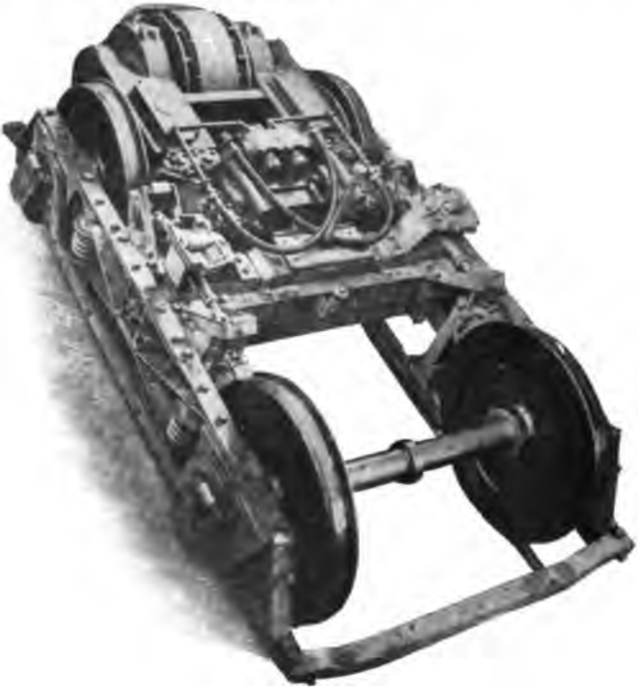


FIG. 7.— TRUCK AND MOTOR OF LOCOMOTIVE NO. 1.

After explaining the alternating-current plan and showing its adaptability to the case, and the impossibility of constructing under the standard 500-volt system, a remark was made by one of the owners to the effect that: "If the engineer was willing to take the professional risk the owner would take the financial risk." Authority was secured to build in accordance with the rotary-converter plan I had submitted, on condition that the road must be in operation within 90 days, in order to save the franchises under which it was authorized.

One of the leading manufacturing companies had on hand at this time (March, 1898) three 120-kw rotary converters, which had been built for experimental purposes mainly, and by contracting with this company for the new electrical machinery required for the road, the use of these rotaries, provided with temporary transformers and switchboard apparatus, was secured.

A new power-house was built, a transmission line eight miles long, consisting of three No. 8 bare copper wires carried upon ordinary Western Union single-petticoat glass insulators, was constructed, and the temporary apparatus installed.

It was necessary to belt two of the rotaries in tandem from the fly-wheel of the engine, and use them as generators, one supplying direct current to the section of the line nearest the power-house, while the other supplied three-phase current to the third rotary placed in the sub-station eight miles away. The alternating current was stepped up at the power-house and transmitted at 5000 volts.

The road was opened for traffic July 1, 1898, and ran with fair success with the temporary apparatus until the following spring.

In the meantime the ownership had changed hands, and the new owners, owing to their unfamiliarity with electric railways and the trouble due to the temporary character of the plant (the new machinery not yet having been received from the manufacturers), desired to change the road into a standard direct-current system, and in this position they were supported by several engineers whom they consulted, and who reported adversely to the new system. It was also intended to extend the road southward 10 miles to Evanston, the road previous to this time having extended only from Waukegan to Highland Park, a distance of about 15 miles. In order to prevent the abandonment of my plans and of the alternating system it became necessary for me to assume the entire risk, and a contract was entered into whereby

I undertook to complete and extend the road in accordance with the original designs and guarantee, under a bonus and forfeiture contract, a certain efficiency between the steam-engine cylinders and the car motors under working conditions, and the successful operation of the system as a whole.

The contract was dated March 21, 1899, and as an example of how rapidly engineering and construction work can be done when necessary, I will state that the conditions of the contract were successfully met on time, and when the work called for by it was completed the road stood, on June 20, 1899, equipped with a central power station, and two sub-stations, each eight miles from the power-house, all equipped with new machinery, regulating batteries, together with all necessary high-tension transmission lines and direct-current feeders for operating 16 40-ton trains between Evanston and Waukegan, a distance of 27 miles, at an average speed of 20 miles per hour, with stops averaging one per mile.

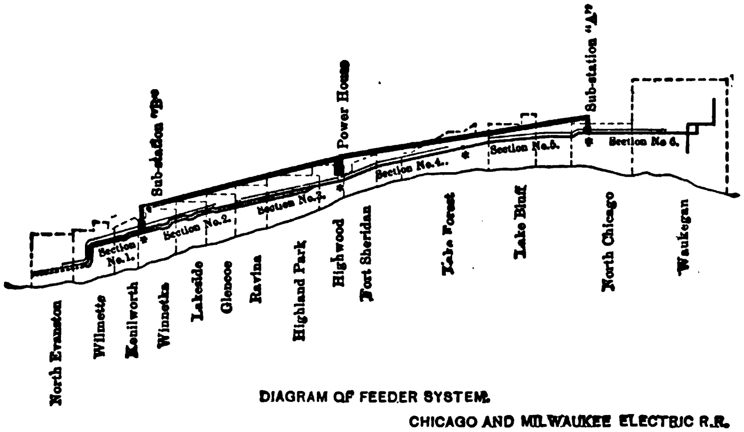


FIG. 2.—MAP SHOWING LOCATION OF POWER-HOUSE, SUB-STATION AND DISTRIBUTION SYSTEM OF THE CHICAGO & MILWAUKEE ELECTRIC RAILWAY COMPANY, AS PLANNED IN 1898 AND COMPLETED IN 1899. FIRST ROTARY CONVERTER SUB-STATION ROAD.

The energy was generated and transmitted at 5500 volts, as this was the highest pressure that the manufacturers, whom the conditions made it desirable to contract with for the electrical machinery on account of their experience and ability to make prompt deliveries, were prepared to furnish machinery for at that time.

FIG. 9.—OUTSIDE VIEW OF CAR SHOWN IN FIG. 8.

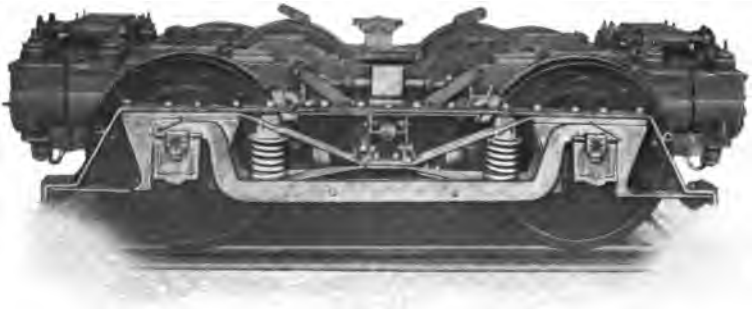


FIG. 23.—SIDE VIEW OF TRUCK AND MOTORS OF LOCOMOTIVES NOS. 2 AND 3.

The success of the road was immediate, and its traffic has grown so rapidly that its capacity has been increased to three times its original capacity, during the past year, under the direction of my office.

While there was an instance of a one-car road at Concord, N. H., taking its power through a rotary converter, located about four miles from a water-power generating station, the road I describe, I believe, was the first road to be put in operation designed to run from a central alternating-current power station, using high-tension transmission lines, rotary converters and sub-stations.

Fig. 3.—Map showing geographical location of the Chicago & Milwaukee Electric Railway.

It was thus probably the prototype of the system that rapidly became standard, and upon which almost all suburban lines have been built since.

Fig. 2 is a map of the road, drawn to scale, giving the relative locations of the power-house and sub-stations, and is a reproduction of one of the original sketches attached to the contract entered into on March 21, 1899. The portion of the line, north of the power-house at Highwood, was installed during the previous year and equipped with the temporary machines.

Fig. 3 shows the relative location of the road to the surrounding territory.

While this system was a marked step in advance in electric railroading, effecting as it did a great reduction in first cost and operation, it did not seem to me to be the final solution of the electric railway problem on account of the losses due to the many conversions of the current and the excessive investment in sub-station machinery, with the attendant operating expenses.

In 1899, while still engaged upon this work, I, therefore, commenced to develop a system which should utilize the alternating current directly in the motor and employ but one overhead conductor, and thus eliminate the sub-station completely, together with the disadvantages of the complicated overhead work made necessary by the use of three-phase motors as then applied to alternating-current railway work in Europe. Realizing the advantages that storage batteries offered for equalizing the load in direct-current work I planned to retain a similar advantage for the alternating-current system by utilizing some form of a storage system to be carried upon the car. As the single-phase motor was not at that time capable of self-starting under load, some supplemental means must be provided for starting it. Air was the medium chosen, for by its use in combination with a high-tension single-phase motor I saw a possibility of requiring not only a single overhead working conductor, but of maintaining a constant load upon the power-house, thus enabling the investment in machinery and transmission lines for any given case to be much less than would be possible with the heavy fluctuating loads common to all electric-railway systems. The essentials decided upon were:

(1) A motor which would use single-phase alternating current without conversion.

(2) Single overhead working conductor.

(3) Steady load upon the power-house.

(4) Independent unit for switching purposes.

The principles underlying the system which I developed to accomplish these results were:

(*a*) A single-phase motor mounted directly upon the car axles, designed for the average power required by the car, running at a constant speed and a constant load, and, therefore, at maximum efficiency.

FIG. 12.— VIEW OF CARHOUSE SITE AFTER FIRE WHICH DESTROYED LOCOMOTIVE NO. 1.

FIG. 13.— VIEW OF STEAM LOCOMOTIVE USED ON LANSING, ST. JOHNS & ST. LOUIS LINE AFTER TRIP OVER ROAD AT TIME OF FIRE.

(*b*) Instead of stopping and starting this motor and dissipating the energy through resistance, as was then common to all railway systems, the speed of the car was controlled by accelerating or retarding the parts usually known as the rotor and the stator, by means of compressed air in such a manner as not only to regulate the speed of the car but also to store the kinetic energy of the car when stopping and utilize it in starting.

Draughtsmen were put at work preparing the Patent Office drawings for different methods of applying the above principles, and late in 1899 an opportunity for trying the system was offered in the case of a road designed to extend about 60 miles northward from Lansing, Mich., and to be known as the Lansing, St. Johns & St. Louis Electric Railway. In January, 1900, I rode over the proposed right of way with a party of gentlemen interested in the road, and as a result of the negotiations that ensued a contract for its construction was entered into on April 23, 1900, wherein I undertook to build the road, assuming part of the financial risk.

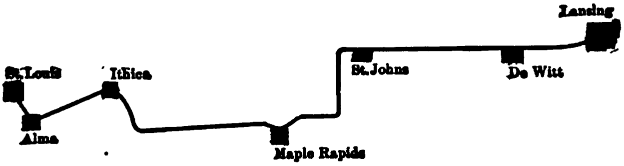


FIG. 4.—MAP SHOWING LOCATION OF THE LANSING, ST. JOHNS & ST. LOUIS ELECTRIC RAILWAY. FIRST SINGLE-PHASE ROAD.

Fig. 4 is a reproduction of one of the original sketches attached to the contract, and Fig. 5 is a map showing the relative location of this road to the other roads in the State of Michigan.

Locating engineers were at once placed in the field, and the construction proceeded systematically until 20 miles of the road (extending from Lansing to St. Johns) were completed to such an extent that it was opened for operation with steam locomotives about Nov. 15, 1901.

For financial reasons the construction work was delayed but in the meantime the development of the electrical system was going on in different offices and shops.

The overhead work of the 20-mile section of the road was completed and ready for operation about Dec. 15, 1902, and the power installed, so that experiments with the electropneumatic system began in March, 1903. During these and all subsequent experiments the power was supplied from a 300-kw rotary converter, generating at 25 cycles and located in a combined water and steam-

FIG. 5.— MAP SHOWING RELATIVE GEOGRAPHICAL LOCATION OF THE LANSING, ST. JOHNS & ST. LOUIS ROAD.

power plant about two miles from the Lansing end of the line. The energy was carried to the motor over two No. 3 bare copper

FIG. 14.— END VIEW OF LOCOMOTIVE "PHŒNIX" OR "NO. 3."

FIG. 15.— SIDE VIEW OF "NO. 3."

wires, one of which was attached to the rails of the track and the other to the No. .00 trolley wire. Much experimental work had been done at the shops where the machine was constructed during the preceding year.

On June 15, 1903, two trips were made, each about three miles long, with the first experimental machine, which is illustrated in Fig. 6.

On the first trip eight persons[1] were carried and on the second trip 13[2] persons were aboard, and I give the names, as I believe this was the first public demonstration of a single-phase railway built for commercial use. At this time the voltage on the overhead conductor was carried at 2400 volts.

The locomotive was a crude affair made hastily from a truck of one of the cars (Fig. 7) upon which was placed the motor, some rough timber for supporting the transformers, and the air tanks and controlling devices originally planned to be placed on a large car as shown in Figs. 8 and 9, but which a single motor was unable to drive, thus necessitating the temporary construction shown in Fig. 6.

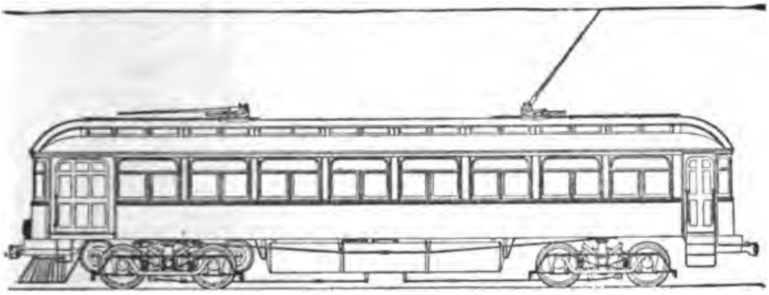


FIG. 8.—DRAWING OF CAR OF LANSING, ST. JOHNS & ST. LOUIS ELECTRIC RAILWAY.

The above tests demonstrated that the motor would work, and as the first machine was necessarily a makeshift and had been considerably damaged during its preliminary trials, it was thought best not to attempt further tests until a complete equipment could be built.

[1] A. S. Courtright, G. A. Damon, W. A. Blanck, J. F. Scott, T. M. Keeley, Fred Rider, M. P. Otis and B. J. Arnold.

[2] Mr. and Mrs. A. S. Courtright, Paul Courtright, Mr. and Mrs. T. M. Keeley, Leroy Keeley, Mr. and Mrs. Fred Rider, Mrs. T. E. Hamilton, Mrs. A. N. Hamilton, Miss Isabel Hamilton, H. B. Quick and M. P. Otis.

A new double-motor equipment in the form of a locomotive, illustrated in Figs. 10 and 11, was completed and made ready

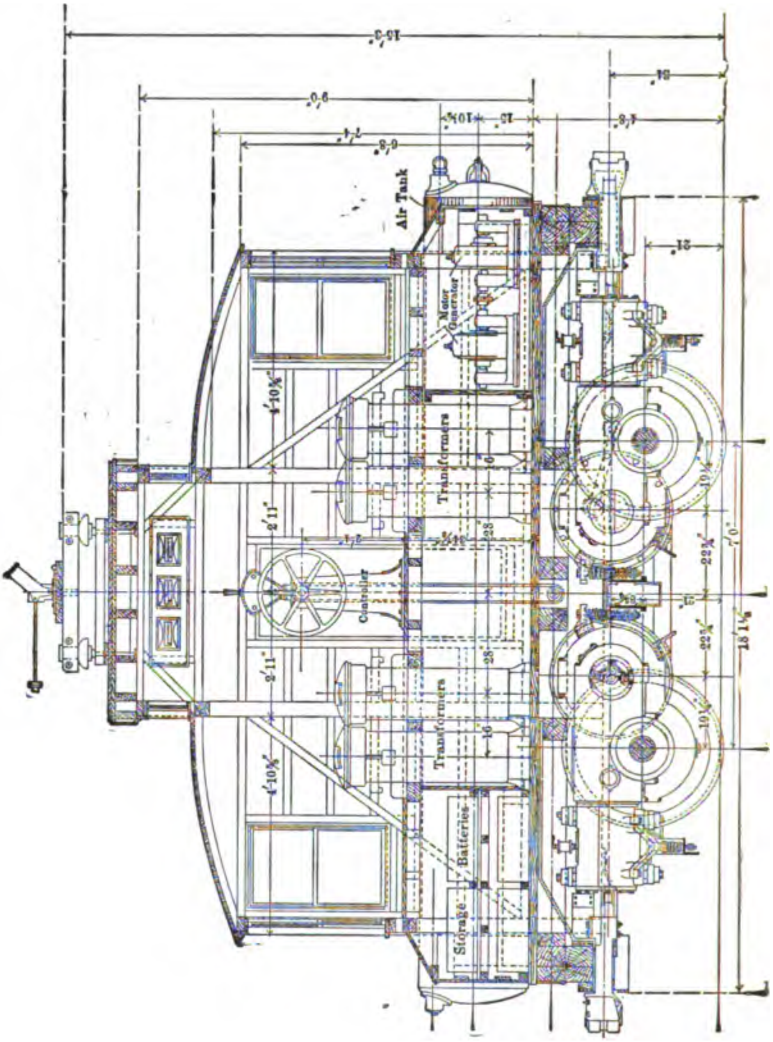


Fig. 10.—Longitudinal section of locomotive no. 2.

for operation early in December, 1903, but on the morning of Dec. 18, a few days prior to the date set for public tests, the carhouse in which it was stored was completely destroyed by fire

FIG. 18.— OUTSIDE VIEW OF ELECTRIC MOTOR.

FIG. 19.— INTERIOR VIEW OF ELECTRIC MOTOR.

and with it went the locomotive, two new cars built for the system, and a steam locomotive used on the line.

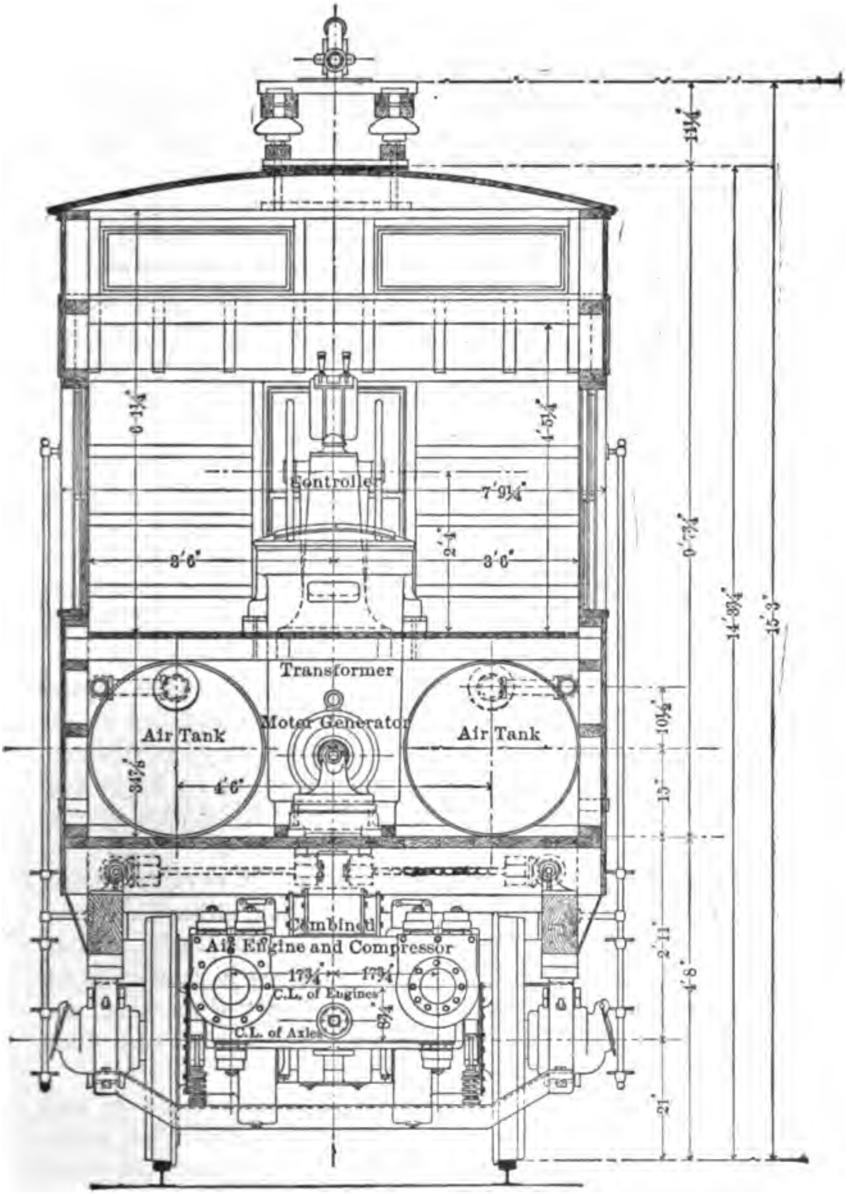


FIG. 11.—TRANSVERSE SECTION OF LOCOMOTIVE NO. 2.

Unfortunately no photographs were secured of the complete machine before it was destroyed, but Fig. 12 shows the wreck the morning after the fire, and Fig. 13 shows the character of the weather and the conditions of the road at the time.

No insurance was carried upon the machine, but the work of rebuilding was at once commenced. All of the electrical machinery and other electrical parts were returned to the manufacturers to be rewound or rebuilt, and all parts of the air machinery that could not be repaired on the ground were ordered new, except the main cylinder castings, which though cracked were in such a condition as to warrant attempting their repair by pumping a strong solution of sal ammoniac and water into them under pressure and thus attempting to close the cracks by oxidization. This was partially successful, and a new locomotive, Figs. 14 and 15, christened "Phœnix" was completely and recently made ready for trial.

In the meantime, as it became necessary to place the road in operation electrically in order to operate in conjunction with the local street railway system in the city of Lansing, which had been acquired by the owners of the Lansing, St. Johns & St. Louis line, provision for operating the direct-current motor cars of the city line was made, under my direction, by adding additional copper and the installation of a rotary sub-station.

It is interesting to know that the rotaries and sub-station apparatus now operating this road are the same ones installed on the Chicago & Milwaukee Electric Railway in 1899, they having served their purpose well and been removed to make room for larger ones recently installed to take care of the increased demands of that road.

The Lansing, St. Johns & St. Louis road is now so equipped that by throwing suitable switches in the sub-station, either direct current at 600 volts, or alternating current at 6000 volts, can be turned on the trolley-wire at will, thus making it practicable for the road to run direct-current cars a large part of the time, and allow the operation of my experimental locomotive at such times as may be desired.

On the evening of Aug. 3, 1904, the Phœnix made its trial run from Lansing to Dewitt, a distance of eight miles, carrying the superintendent of the road, two newspaper men, the writer and three assistants.

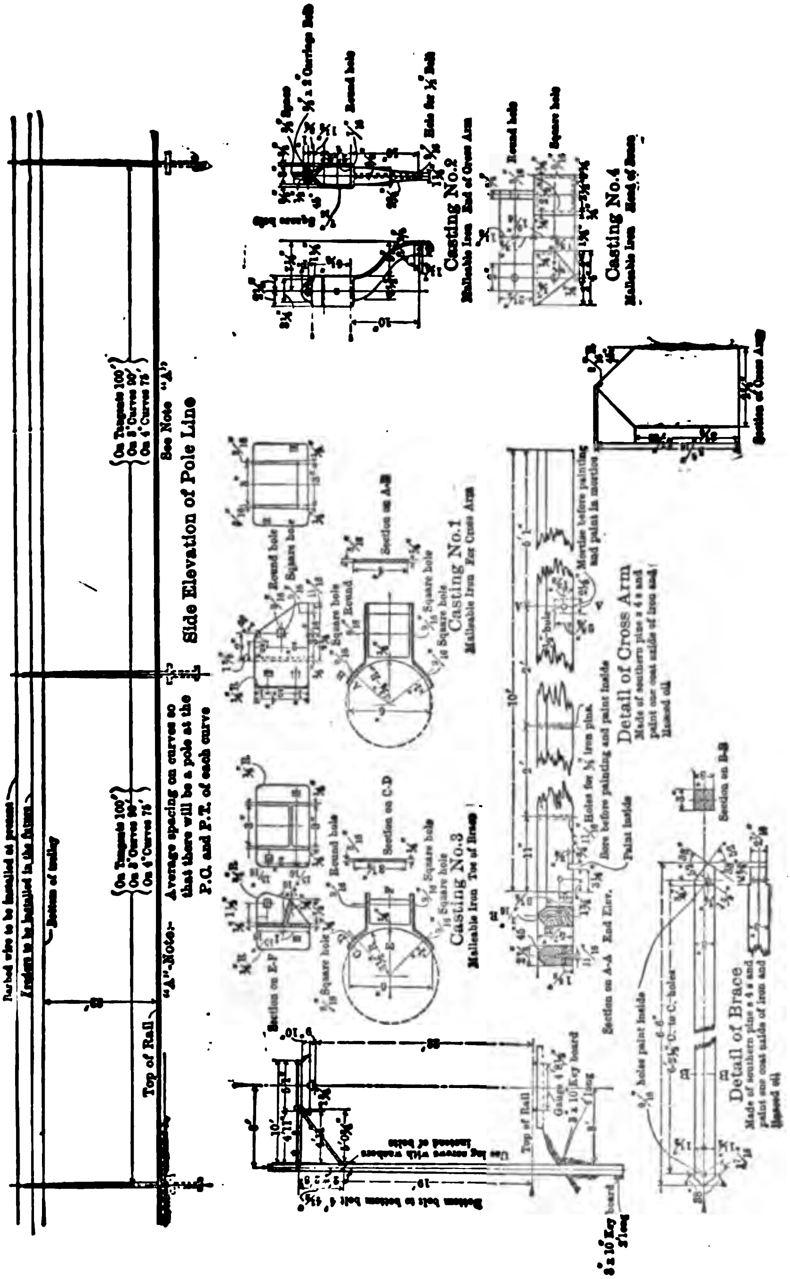


FIG. 16.— DETAILS OF OVERHEAD WORK, USED ON LANSING, ST. JOHNS & ST. LOUIS RAILWAY.

Trouble in the power-house, due to the breaking of an engine prior to the trial, made it impossible to maintain the current on the line continually, on account of the blowing of the circuit breaker; otherwise the run would have been made over the entire 20 miles to St. Johns. The run was made with 6000 volts on the trolley-wire, and on the whole was satisfactory, as it demonstrated the ability of the machine to run smoothly at all speeds from zero to synchronous speed, and maintain a constant load on the power-house. The control of the speed of the car seemed perfect.

Owing to the cracks in the cylinder castings not having been fully stopped, and loss of current from the absence of several insulators on the line, no attempt to determine efficiency of operation was made, but as these defects can be remedied additional runs will be made to determine the efficiency of the system. This is, I believe, the longest run yet made upon a road built for single-phase operation.

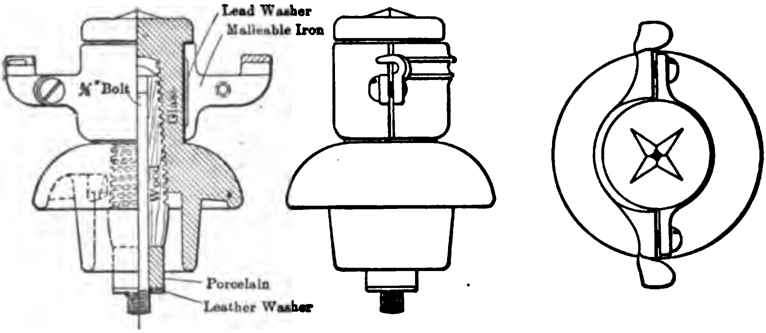


FIG. 17.—VIEWS OF SPECIAL INSULATOR USED FOR SUPPORTING THE WORKING CONDUCTOR.

Having thus described the conditions surrounding the development and application of the system, a more detailed description of it may be of interest.

The track of the road does not differ from standard steam or electric railroad construction, except that but one line of rails was bonded, as it was thought that at the high-working voltage the amount of current would be so small that the bonding of the other rail would be unnecessary.

Wood was used for both pole and bracket, as illustrated in Fig. 16, which also shows the details of construction of the overhead work. A special trolley insulator was designed, Fig. 17, as

FIG. 20.— BOTTOM VIEW OF ELECTRO-PNEUMATIC MOTOR.

FIG. 21.— TOP VIEW OF ELECTRO-PNEUMATIC MOTOR.

FIG. 22.— END VIEW OF TRUCK AND MOTORS OF LOCOMOTIVES NOS. 2 AND 3.

it was intended to experiment with pressures as high as 15,000 volts on the working conductor. The insulators were made of annealed glass and tested up to 30,000 volts.

Had a bow or some form of sliding contact been used as originally intended, these insulators would probably have proven satisfactory; but with the running of short four-wheeled direct-current cars over the line came the frequent jumping off of the trolley wheels, resulting in the breaking of many of the insulators. Such construction should, therefore, not be used with anything but a sliding contact or bow trolley.

One of the most difficult problems in the development of the electropneumatic system was to design an air compressor which would not only work efficiently as a compressor but could also be made to work efficiently as an engine. Much time was spent upon the development of various valve mechanisms and many types of engines were designed. The objects to attain were first, quick-opening and quick-closing valves; and second, valves so driven that when the machine was not running as an engine they would not be mechanically moved. They should also be capable of operating automatically when the machine is running as a compressor. By the development of electropneumatically operated valves. described later, these objects were accomplished, and the inequality of the point of cut-off, due to what is technically known as "the angularity of the connecting rod" was eliminated, thus making it possible for each compressor when running as an engine to open its inlet and outlet valves at exactly the right point of cut-off for each end of the cylinder under all conditions of operation, regardless of the direction in which the engine runs. This was accomplished by the use of valves which operate pneumatically without loss of air, the time of opening and closing being electrically piloted by means of collector rings mounted upon or driven by the main shaft of the engine. These collector rings consist of several insulated segments so placed with reference to the crank that they operate the valves instantaneously at such times as an eccentric would if it were placed directly in line with or directly opposite the crank pin.

Primarily a car-motor equipment consists of a single-phase motor having both its rotor and its stator free to revolve (Figs. 18 and 19), each of which is attached to an air compressor in such a manner that when it revolves its compressor will be driven or either air compressors may at times become an air engine and drive the part of the electric motor to which it is attached. Fig. 20 shows the bottom view and Fig. 21 the top view of the combined electro-pneumatic motor standing on end in the shop prior to being placed upon the truck, and Figs. 22 and 23 show the two motors complete mounted upon a truck. The following description will make clear the application of the principles and the operation of the different parts of the system. Perhaps I cannot describe the theory and working of the machine better than by employing language which I have previously used, so amplified as to conform to the additional figures given in this paper showing more clearly the interior mechanism of the machine.

Fig. 24 represents diagrammatically the working parts of the system when a reciprocating type of air compressor is used. Fig. 25 shows a transverse section through the air cylinders, the regulating valves and the individual cylinder valves of the machine shown in Figs. 22 and 23.

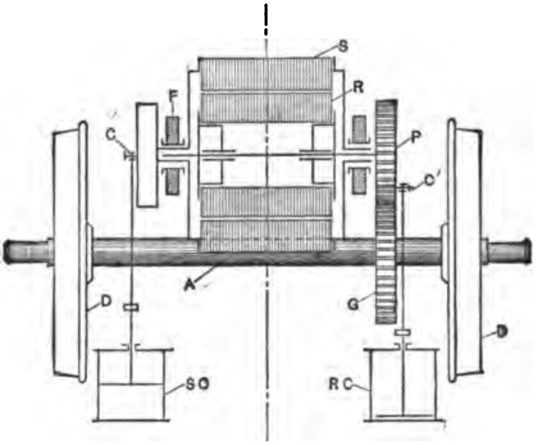


FIG. 24.—DIAGRAMMATIC ARRANGEMENT OF ELECTRO-PNEUMATIC MOTOR.

The rotor *R*, Fig. 24, is geared to the axle of the car, and by means of crank pin *C′*, secured in pinion *P*, also drives the compressor cylinder *R C*, while the stator *S* is free to revolve around the rotor and drive by means of crank-pin *C* the compressor cylinder *S C*. Both cylinders are piped to air reservoirs located under the car, and are also provided with suitable valves, *A*, *B*, *C* and *C′*, shown in Fig. 25, which in connection with the pneumatically operated cylinder valves previously mentioned, are manipulated

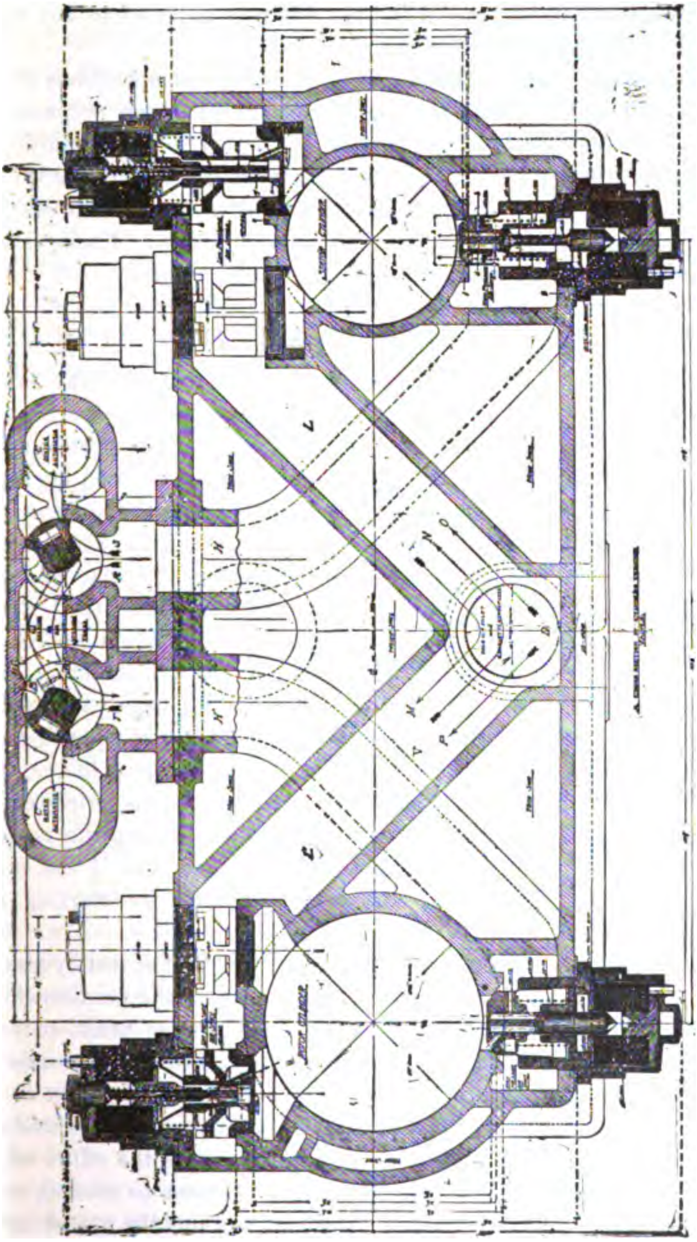


FIG. 25.—TRANSVERSE SECTION THROUGH CYLINDERS AND VALVES OF LOCOMOTIVES 2 AND 3.

from the controller in such a manner as to make them perform their various functions. Thus the entire regulation of the speed of the car is controlled by the air cylinders.

For the purpose of making clear the different operations of the system, Fig. 26, showing a speed diagram, has been prepared, in which on the axis of abscissæ *O D L* are represented the different car speeds in per cent of the synchronous motor speed, and the co-ordinate axis *A O B* represents the rotor and stator speeds corresponding to the car speeds shown on axis *O D L*. The operation of the car may be divided into the following periods:

1. *Standing in the Station.*

In Fig. 24, the rotor *R* being rigidly geared to the car axle is now standing still, while the stator *S* runs with full synchronous speed, and is thus transferring the full energy of the electric motor through crank *C* to the compresser cylinder *S C*, which energy is being delivered in the form of compressed air into the air reservoir. Since the relative velocity between the stator and the rotor is constant under all conditions of operation, the speed curves of stator and rotor may be represented by two parallel lines, *O C R* and *A D S*, shown in Fig. 26. The origin *O* of the given co-ordinate system represents the period of rest of the car, and, therefore, indicates zero rotor speed and full stator speed in a negative or downward direction, as the stator is now revolving in an opposite direction from that which the rotor must revolve to drive the car forward. If it is assumed that *O A* equals the active torque of the stator, then *O B*, which equals *O A*, will represent the reactive torque of the rotor exerted on the car axle, so that if the car is free to move the reactive torque can be used for starting and accelerating the car.

When the car is standing in the station it is held at rest by placing valve *B* (Fig. 25) by means of the controller, in the position shown in full lines, thus allowing air from the storage tanks to enter through opening *Q* in the direction of the arrow *R* to passage *H'*, which is in communication with the high-pressure valves of the rotor cylinder. The pressure may be thus increased behind the rotor piston to such an extent that it overcomes the effort of the rotor to revolve, thus tending to cause the stator to revolve, while at the same time it holds the car at rest without the use of wheel-brakes. When the car is standing, the stator is running at full synchronous speed and the stator cylinder is drawing in cold air through opening *D* in the direction of arrow *O,* which enters the stator cylinder through the inlet valves shown at the top of the cylinder. The air is delivered from the stator cylinder through the outlet valves into passage *H,* and may be delivered in the direction of arrow *R* into opening *Q* and thence to the storage tanks or into the passage *H′* for the purpose of holding the rotor cylinder still or supplying it with air in starting.

2 *Starting and Accelerating.*

To start the car the air cushion behind the piston of rotor cylinder *R C,* Fig. 24, is removed by so manipulating the controller that the exhaust valves shown at the top of Fig. 25 are opened; the air which is being compressed by the stator cylinder is then delivered from passage *H* into *H′,* as indicated by the arrow *R,* supplemented by the stored air from the tanks. The controller is now set at the position of maximum cut-off for the inlet valves of the rotor cylinder, shown at the bottom of Fig. 25.

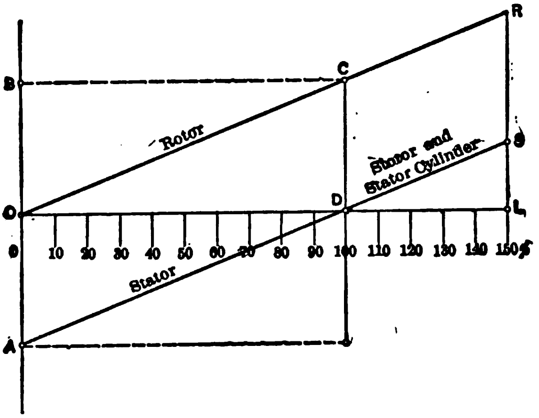


FIG. 26.—DIAGRAMMATIC REPRESENTATION OF OPERATION OI ELECTRO-PNEUMATIC MOTOR.

The rotor then begins to revolve and as it accelerates the stator slows down by exactly the same amount that the rotor has increased its speed; as the rotor and car speed increase the controller is gradually moved so that the inlet valves of the rotor cylinder give a smaller percentage of cut-off until the car speed corresponds to the full synchronous speed of the motor, at which time the stator comes to rest. During this period of acceleration the air compressed by the stator cylinder, instead of being delivered to the tanks to lose its heat, is delivered, hot, directly to the rotor cylinder through the passages *H* and *H'*, either directly, as indicated by arrow *R*, in case the valve *A* is placed as shown in full lines, or through the automatic valve *C*, as indicated by arrow *S*, thence through a passage (not shown) communicating with opening *Q*. In the latter case the valve *A* is placed in position *A'*. The valve *C*, known as the stator automatic valve, is provided with a spring so set that it maintains a constant pressure in passage *H* and hence a constant load upon the electric motor.

After the air thus delivered from the stator cylinder has done its work behind the rotor piston, it is exhausted cold, owing to the rapid expansion, into the passage *L'*, and thence in the direction of the arrow *N* into the passage *L* leading to the inlet valves of the stator cylinder. Thus a complete cycle is established and the same air may be used repeatedly if the rate of acceleration is such that the rotor cylinder uses all of the air supplied by the stator cylinder and under these conditions no exhaust to the atmosphere from the rotor cylinder will take place. Since all of the air passages and both cylinders are enclosed in a water-jacket, the heat generated while compressing is delivered to the water and extracted by the rotor cylinder when working as an engine, the water performing the double function of cooling the air during compression and reheating it during the process of expansion, thus increasing the efficiency of the combination. Tests already made indicate that this jacketing water will remain at a fairly constant and comparatively low temperature.

Opening *D* is known as the cold-air inlet and the exhaust outlet. It is provided with a valve acting against a spring which normally keeps opening *D* closed to the outside air. In case the volume of air required by the stator cylinder is greater than the amount exhausted from the rotor cylinder, this valve automatically opens and permits the outside air to enter the passage *L* through the opening *D*, as indicated by the arrow *O*. This valve also opens automatically to admit air to the rotor cylinder in the direction of the arrow *P* at such times, hereinafter described, as it may be compressing air. The valve is also electrically controlled in such a manner that it can be opened by the motorman when it is desired to operate the car as an independent unit with air alone by means of the rotor cylinders acting as engines.

Referring to Fig. 26, which graphically represents the period of acceleration, since the electric motor always runs at a constant speed and constant load, it has a constant torque, and, therefore, the vertical distance *O A* between *A D S* and *O C R* may be considered as representing the energy delivered by the electric motor. The length of any ordinate extending from *O D* to *O C* represents the proportionate amount of energy derived from the electric motor which is applied directly through pinion *P* and gear *G*, Fig. 24, to the propulsion of the car wheel. The corresponding ordinate extending below *O D* to *S D* represents the proportionate amount of the energy of the electric motor which is absorbed in compressing air through the cylinder *S C*, which energy, in the form of air, is immediately transferred to cylinder, the *R C*, and is utilized in accelerating the car. In practice, however, since there will be some loss in transferring the energy from electrical energy to energy in the form of compressed air and back again into mechanical energy, the energy thus lost, whatever it may be, must be drawn from the storage tanks and the requisite amount of air from these tanks supplied to the rotor cylinder *R C* in order to maintain the full power of the electric motor upon the car axle during the period of acceleration.

Should it be desired to accelerate at a greater rate than the full power the electric motor is capable of giving to the car, the additional energy may be supplied in the form of air from the storage tanks through the rotor cylinder, thus increasing the total energy given to the car during acceleration, in which case this total power would be represented for any given instant by a point above line *B C*.

The air thus drawn from the tanks enters through the opening *Q* and flows in the direction of arrow *R* into the passage *H′*, and thence to the rotor cylinder.

3 *Running Speeds.*

Assuming that during the accelerating period valve *A* has been in position *A′*, the air from the stator cylinder has been delivered through the stator automatic *O*, and a constant load has been maintained upon the motor. As soon as the car by the previous processes reached a speed corresponding to the synchronous speed of the motor, the exhaust valves of rotor cylinder *R C* are held open by setting the controller at a suitable position and the piston of the rotor cylinder now runs free. The electric motor now gives its full power to the car axle and the stator and its air mechanism remain at rest as long as the car runs at the speed corresponding to the synchronous speed of the motor. Since the pressure behind the piston of the stator cylinder is maintained constant by the valve *C*, the stator will remain at rest only so long as the resistance offered by the car is exactly equal to the power of the electric motor. In case this resistance is less than the capacity of the electric motor, the stator cylinder will automatically reverse and begin to rotate in the same direction as the rotor is running, and slowly compress air and deliver it to the storage reservoir. In case the resistance of the car is greater than the capacity of the motor, the speed will decrease and the stator automatically reverse and run in an opposite direction from that of the rotor, and will then be operating in the same manner as during the accelerating period. It will thus be seen that no attention need be paid to the stator during the running period, for it automatically takes care of itself.

When the resistance of the car is greater than the capacity of the electric motor, speeds above synchronism can be maintained only by supplying the rotor cylinders with stored air from the tanks, and can only be maintained for short distances, or until the storage capacity of the air reservoirs is exhausted.

The distance from the line *O D L* to that portion of the line *A D S* above *O D L* in Fig. 26 represents, at any given speed, the proportionate amount of energy which must come from the tanks and be supplied through cylinder *S C*. The distance from *D L* to *C R* represents the total energy given to the car by the combined action of the electric motor and stator cylinder.

4. *Retardation.*

To bring the car to rest, instead of applying mechanical brakes to the wheels in the ordinary manner, thereby dissipating the entire stored energy of the car in the form of heat, this energy is saved in the form of compressed air to assist in starting the car, by setting the controller in such a position that the rotor cylinder compresses air and delivers it into the storage tanks. Any desired rate of retardation can be secured by throttling the delivery passages from the rotor cylinder by means of valve *B*, Fig. 25, by moving it toward the direction indicated at *B′*. When the valve is in the position *B′*, the passage *H′* is brought into communication with the automatic valve *C′*, so set that it will release just before the slipping point of the wheels is reached. The kinetic energy of the car can thus be all absorbed by means of the rotor cylinder and the car brought to rest without wheel brakes, although such brakes are supplied for emergency, but need not be often used.

5. *Reversing.*

When it is desired to run the car backward for short distances the electric motor is not disturbed, and the power is furnished from the rotor cylinders acting as engines; but if it is desired to run backward for any great distance, the current is thrown off the motor, the stator engine is reversed and the stator is brought to speed with the air, when the current is again thrown on to the motor, and the cycle of operation is the same as when running forward.

A detailed description of the valves may now be of interest:

DESCRIPTION OF VALVES.

Referring to Fig. 25, the lower valves are termed the high-pressure valves and act as inlet valves when the machine is running as an engine and as outlet valves when the machine is running as a compressor.

The upper valves are the outlet or exhaust valves when the machine is running as an engine and the inlet or admission valves when the machine is running as a compressor. Both valves are shown in detail drawn to a larger scale in Fig. 27.

In Fig. 27 (bottom valve) part 15–79 is the valve proper and is of steel; it is carried in a brass guiding case, 15–464, screwed solidly in the retaining walls of the cylinder. Into this seat 15–464, is screwed a brass guiding piece, 15–463, which serves the double purpose of guiding the solenoid plunger, 15–78, and as a chamber for the solenoid coil *X*. In the center of the valve 15–479 is bored a round, true socket or port chamber, into which fits a round plunger or piston, this being an integral part of the solenoid core, 15–78. This core carries a flange, also integral with it, against which the spring 15–80 rests, the other end of the spring resting against 15–463. Surrounding the solenoid core 15–78, is placed a solenoid coil *X* which, when energized, draws 15–78 downward and with it the piston which fits into the port chamber, 15–79.

Valve 15–79 is provided with one or more ports, *a*, drilled into its face and terminating in the central port chamber. It is also provided with radial ports, *b*, terminating in the port chamber. The portion of the solenoid core, 15–78, which enters the port chamber is also provided with channels, *c*, drilled longitudinally,

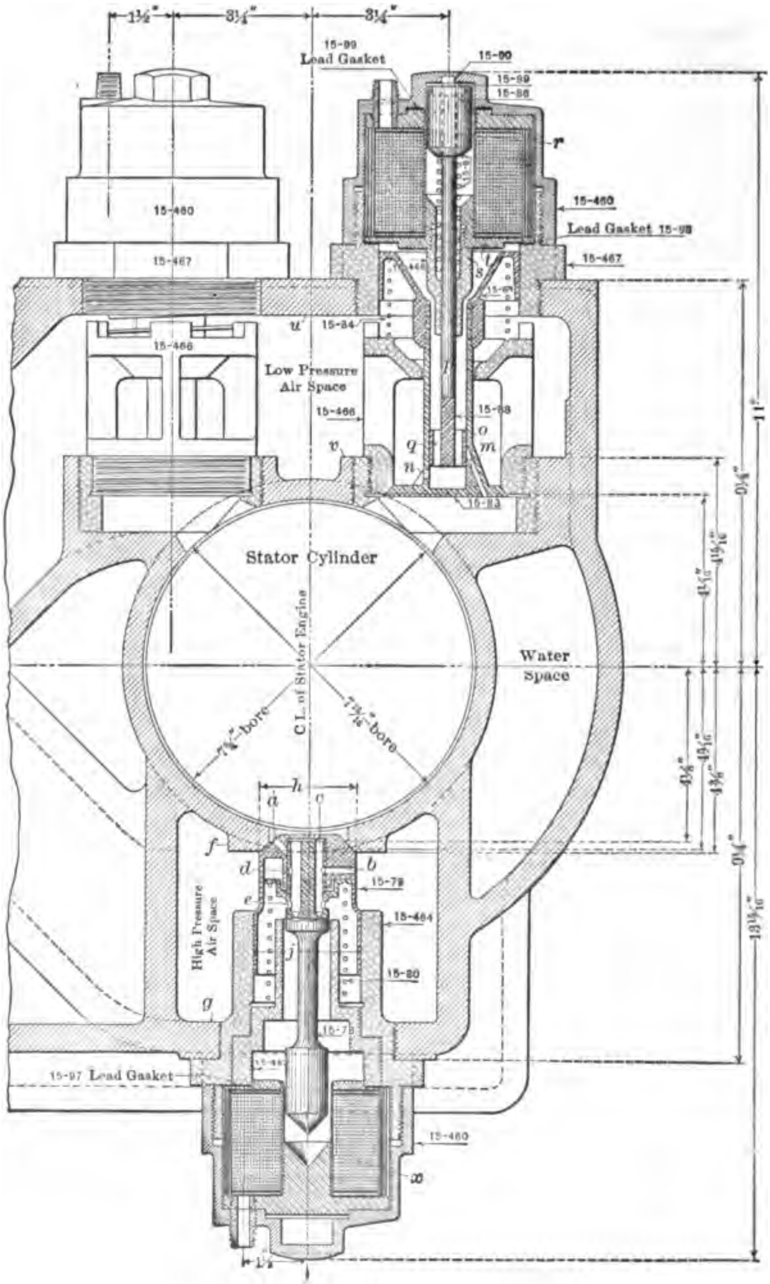


FIG. 27.—SECTION OF CYLINDER THROUGH VALVES.

which are connected with radial openings *d* and *e*. Under normal conditions of operation the space between walls *f* and *g* is filled with air.

Valve 15–78 is round, and the portion *h* is slightly less in diameter than portion *j*, the latter sliding air tight in 15–464, so that if pressure is admitted through ports *b*, *d*, *c* and *e*, into the chamber behind 15–79, the pressure will act upon the portion *j* of the piston or that portion which has the largest diameter and consequently the greatest area, and the valve will be held tight against its seat. The operation of the valve is then as follows:

When working as an admission valve for the engine, current is sent through the solenoid coil *X*, which causes the solenoid core 15–78 to be pulled downward, thus withdrawing its upper portion which fits into the port chamber, causing port *a*, normally closed by 15–78, to be opened, thus allowing the air to flow from the interior of portion *j* out through ports *e*, *c* and *a* into the cylinder. While this air is thus permitted to escape into a larger opening, it is not lost for it must act upon the piston before escaping to the atmosphere. Since portion *h* is smaller in diameter, and, therefore, of less area than *j*, the high-pressure air surrounding the valve will force 15–79 downward, thus opening the main port previously closed by 15–79, allowing the high-pressure air to flow from the high-pressure air chamber into the cylinder. Port 15–79 will remain open as long as current is held upon the solenoid coil *X*; but as soon as current is turned off from the solenoid coil, spring 15–80 forces 15–78 upward, thus closing port *a*, and allowing air to again enter through ports, *b*. *d*, *c* and *e* into the chamber behind 15–79, which forces it upward to its seat on account of the larger diameter and consequently larger area of portion *j*. By sending current through the solenoid coil at suitable intervals by means of the collector rings previously referred to, the valve can be made to open and close and act as an admission valve when the machine is operating as an engine, using air for its driving power and utilizing the air to be used in the cylinder of the engine afterward. The solenoid feature of the valve, therefore, acts only as a pilot and requires but little energy, which can be supplied from the line or from any secondary source, such as a small motor-generator or a storage battery.

When acting as an outlet valve for the compressor, no current is sent through the solenoid coil, and 15–78 is held in its upward position by the spring 15–80, thus, as before, admitting high-pressure air through ports *b, d, c* and *e,* behind portion *j* of 15–79, the air thus supplementing spring 15–80 to hold 15–79 against its seat. The valve will thus operate automatically like the outlet valve of an ordinary air compressor whenever the pressure in the cylinder is sufficiently great to overcome the combined action of spring 15–80 and the air pressure behind 15-79.

Referring now to the upper or low pressure valve, Fig. 27, part 15–466 is a brass seat normally screwed into the casting of the cylinder. In the drawing these valves on the stator cylinder are shown screwed at their bases into brass bushes which have nothing to do with the valves, but were used on the stator side on account of a mechanical defect in the stator cylinder casting.

As in the case of the high-pressure valves, part 15–467 is a brass seat screwed into the cylinder casting, and screwed on it for mechanical protection of the solenoid coil is a cast-iron part 15–460. On the interior of 15–467 fits piston 15–81, which is screwed on to valve seat 15–83, thus making parts 15–81 and 15–83 practically integral so far as operation is concerned, they having been made in different parts only for convenience in assembling.

Part 15–83 is provided with a round port chamber into which ports *m* and *n* enter in such a manner that they can be closed or opened by plunger *o*. Plunger *o* is made of steel and is firmly secured to plunger rod *p* and provided with ports *q* extending completely through it. To the upper portion of rod *p* is attached the solenoid core *r*. Solenoid *r* and with it rod *p* and plunger *o* are normally held in their upward position by means of spring 15–87 resting against part *s* which is screwed into part *t*, the latter forming the path for the lower part of the magnetic circuit created by the solenoid coil. The chamber between walls *u* and *v* is the exhaust or low-pressure chamber. The action of the valve when in operation as an exhaust valve when the stator cylinder is operating as an engine is as follows:

Spring 15–87 normally holds plunger *r* and with it rod *p* and plunger *o* in their upward position, thus causing plunger *o* to close the ports *m*. When it is desired to operate the valve, and thus exhaust air from the cylinder, current is sent through the solenoid coil, which causes plunger *r* to be drawn into the solenoid coil and downward against the resistance of the spring 15–87, thus carrying the stem *p* and plunger *o* to the downward position and opening the ports *m* so that the air behind the piston of the stator cylinder can flow freely through ports *m* up through the interior of the port chamber inside of 15–83 and enter the space above piston 15–81. As the piston 15–81 is larger in area than the valve

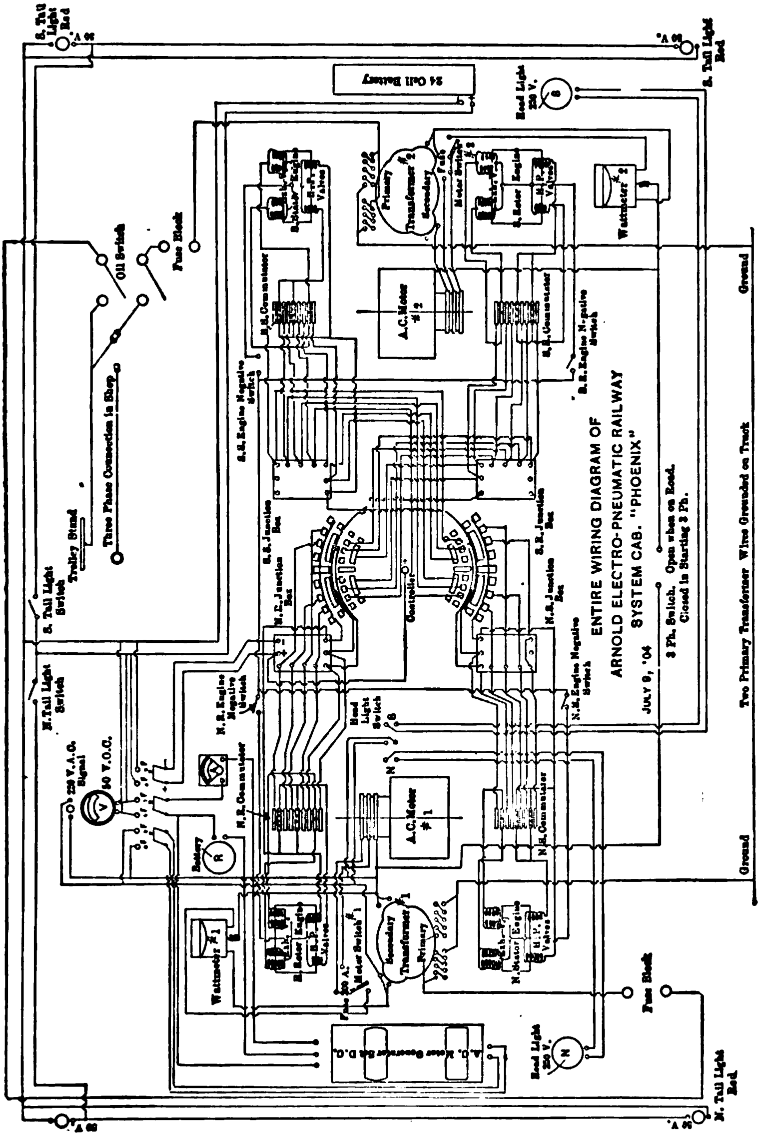


FIG. 28.—WIRING DIAGRAM OF LOCOMOTIVE "PHŒNIX."

15–83, the air thus admitted above the piston causes it to press downward, thus carrying with it and opening valve 15–83, which will remain open and allow the air to exhaust from the cylinder into the exhaust or low-pressure space so long as current remains upon the solenoid coil. When the valve is used as an inlet valve for the compressor, no current is sent through the solenoid coil and the valve works mechanically, due to the suction of the piston in the cylinder, which draws valve 15–83 and piston 15–81 downward against spring 15–84, the latter being only of sufficient strength to normally hold valve 15–83 against its seat. The valves when used

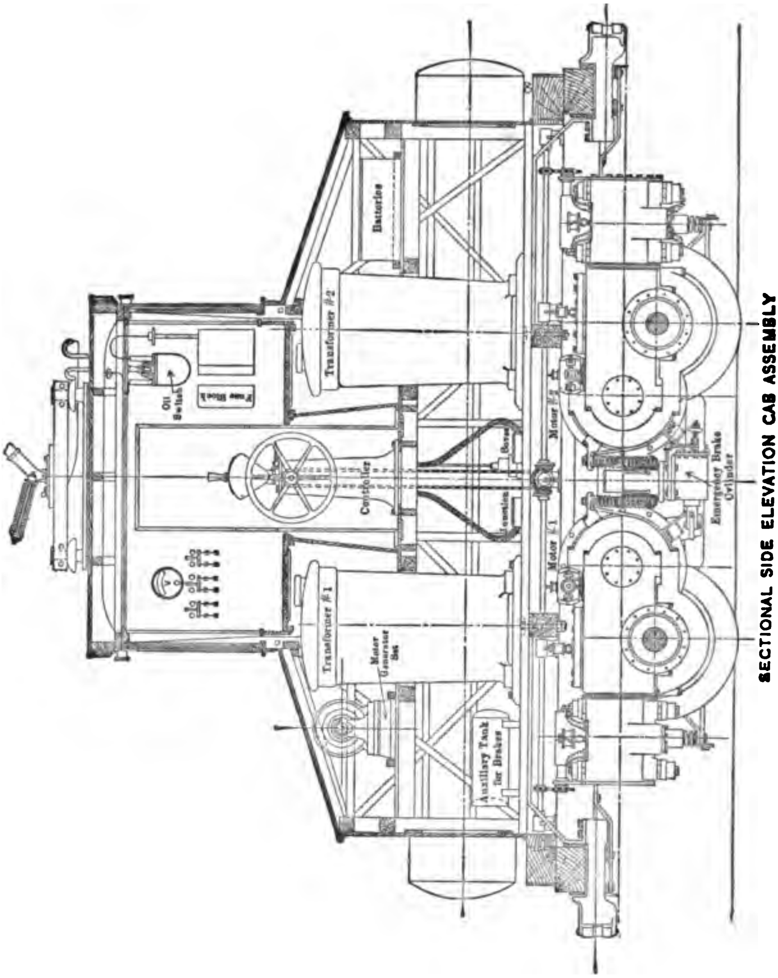


FIG. 29.—LONGITUDINAL SECTION OF LOCOMOTIVE "PHŒNIX."

for the purpose of operating the air cylinders as engines are controlled by means of revolving commutators and suitable circuits in combination with the controller, all as shown diagrammatically in Fig. 28.

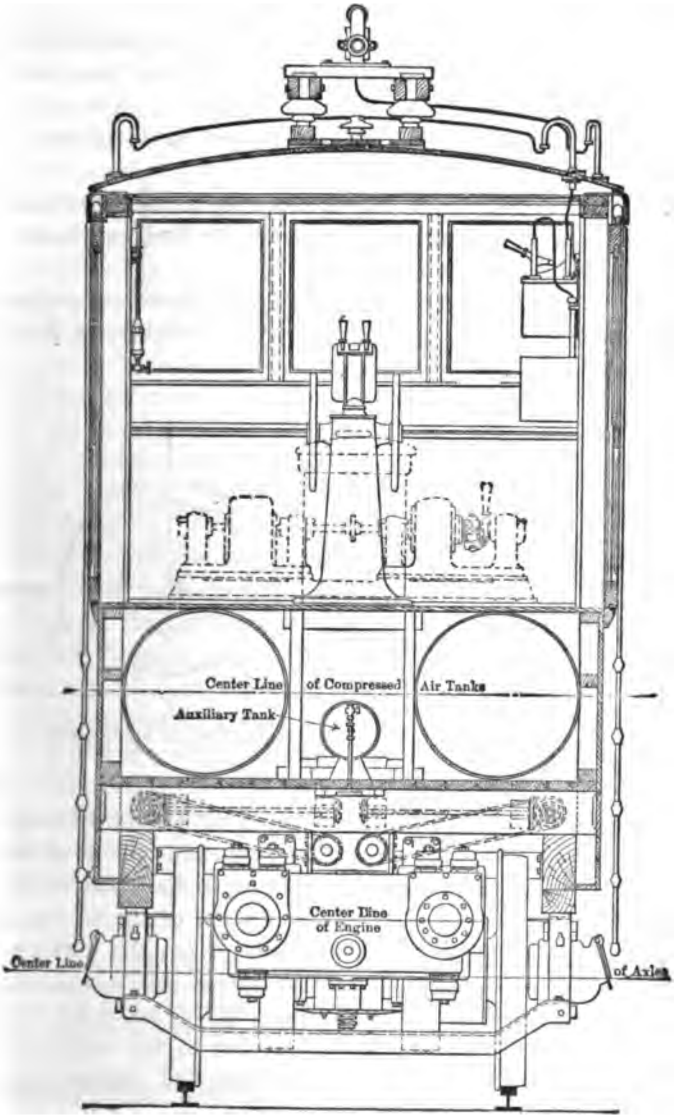


Fig. 30.— Transverse section of locomotive "Phœnix."

Since it was impracticable for me to get the manufacturer to build a single-phase motor for my first machine at the time the order was placed (January, 1901), I was compelled to utilize the parts of a three-phase motor and have it built as such in order to get it at all. For this reason the machines were built as three-phase machines, and provision was made in the locomotive for running them three-phase when it was desired to do so during the preliminary tests in the carhouse.

The diagram, Fig. 28, therefore, shows the connections necessary for running three-phase, but all tests on the line were made running single-phase.

Figs. 29 and 30 show longitudinal and transverse sections of the locomotive "Phœnix," outside views of which are shown in Figs. 14 and 15.

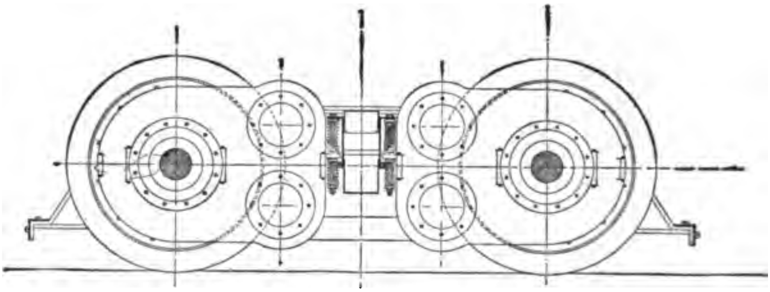


FIG. 31.— ELEVATION OF ELECTRO-PNEUMATIC TRUCK WHERE ROTARY AIR MOTORS ARE USED.

This machine was similar to "Number 2," the one destroyed by fire, both being equipped with the truck and motors shown in Figs. 22 and 23, the only difference being in the form of the cab, the type of the transformer and the location of the auxiliaries in the cab. In both cases the current came from the working conductor directly into the terminal on one side of the stationary transformers while the terminal of the other side was grounded.

The secondaries of the transformers led to the collector rings of the stator parts of the motor and supplied current at about 250 volts.

In order to permit the machines to operate as independent units by using air, each was supplied with a motor generator and a storage battery to supply energy for operating the valves of the engines.

While the development of this system has proven to be a most interesting and fascinating field of work, I regard the machine in its present form as somewhat complicated for commercial application, for like most all new mechanical problems the first designs are much more complicated than subsequent experience finds necessary.

By the development of suitable rotating air machinery the system is capable of great simplification, as by this means all of the above mentioned reciprocating parts, valves with their revolving collector rings and connections, together with the motor generator and battery disappear. The machine would then take the form shown in Fig. 31 and be controlled entirely by two valves similar to those shown at the top of Fig. 25.

If the motors then be designed for the working pressure of the line, the transformer will also disappear from the car; and as the current is not manipulated in controlling the speed of the car, the use of high-pressure motors becomes practicable.

What the commercial value of the system is will depend upon the results shown by future tests, and on the relative merits of the various single-phase systems that have been developed since the announcement of the principles of this system were made public at the Great Barrington Convention of the American Institute of Electrical Engineers in June, 1902.

Whatever its value may be commercially, I believe its influence in stimulating others to greater effort along new lines cannot be denied, and that the art of electric railroading is one step nearer its final solution than it would be today had my efforts not been exerted in this attractive field of achievement in which I have publicly,[3] and often unsupported, proclaimed my faith in the ultimate supremacy of the alternating-current motor for railway work.

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[3] See *Transactions* American Institute of Electrical Engineers as follows: Joint meeting with the British Institution of Electrical Engineers, Paris, August 16, 1900; Niagara Falls Convention, August 24, 1901; Great Barrington Convention, June 19, 1902; New York Meeting, Sept. 26, 1902.

CHAIRMAN DUNCAN: Gentlemen, the next paper is by Mr. Steinmetz, on "Alternating-Current Motors."

ALTERNATING-CURRENT MOTORS.

BY CHARLES PROTEUS STEINMETZ.

I.

In recent years a number of types of alternating-current motors have become of interest, which, while not new in their general principles, but antedating even the polyphase induction motor, have been for some time overshadowed by the latter, due to its greater simplicity, resulting from the absence of the commutator, and its constancy of speed.

With the rapid extension of the applications of electricity, alternating-current motors were demanded for railway and similar classes of work, which give high-starting torque efficiency and high efficiency over a wide range of speed; that is a speed-torque characteristic similar to that of the direct-current series motor. The characteristic of the alternating-current induction motor, however, is that of a constant-speed motor, and indeed the polyphase induction motor can theoretically be considered as an adaptation of the direct-current shunt motor to alternating current, as I have shown elsewhere. By the introduction of the commutator almost any speed-torque characteristic can be produced. A number of types of such commutator motors have been produced and more or less developed, but thus far practical experience has not yet advanced so far as to weed out the less desirable types. To enable a critical judgment of their relative advantages and disadvantages, I shall endeavor in the following to give a general theory of the alternating-current motor, applicable alike to the induction and commutator motors.

The starting point of the theory of the polyphase and single-phase induction motor usually is the general alternating-current transformer, and from the equations of the general alternating-current transformer the induction motor equations can be developed.[1] Coming, however, to the commutator motors, this method becomes less suitable.

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[1] *Transactions* A. I. E. E., 1895.

In its general form the alternating-current motor consists of one or more stationary electric circuits magnetically related to one or more rotating electric circuits. These circuits can be excited by alternating currents, or some by alternating, others by direct current, or closed upon themselves, etc., and connection can be made to the rotating member either by collector rings — that is, to fixed points of the windings — or by commutator — that is to fixed points in space.

The alternating-current motors can be subdivided into two classes — those in which the electric and magnetic relations between stationary and moving members do not vary with their relative positions, and those in which they vary with the relative positions of stator and rotor. In the latter a cycle of rotation exists, and therefrom the tendency of the motor results to lock at a speed giving a definite ratio between the frequency of rotation and the frequency of impressed e.m.f. Such motors, therefore, are synchronous motors.

The main types of synchronous motors are as follows:

(1) One member supplied with alternating and the other with direct current — polyphase or single-phase synchronous motors.

(2) One member excited by alternating current, the other containing a single circuit closed upon itself — synchronous induction motors.

(3) One member excited by alternating current, the other of different magnetic reluctance in different directions (as polar construction) — reaction motors.

(4) One member excited by alternating current, the other by alternating current of different frequency or different direction of rotation — general alternating-current transformer or frequency converter.

No. 1 is the synchronous motor of the electrical industry. Nos. 2 and 3 are used occasionally to produce synchronous rotation without direct-current excitation, and of very great steadiness of the rate of rotation, where weight — efficiency and power factor are of secondary importance. No. 4 is used to some extent as frequency converter.

In the following I shall discuss only that type of motor in which the electric and magnetic relations between the stator and rotor do not vary with their relative positions, and the torque is, therefore, not limited to a definite synchronous speed. This requires that the rotor when connected to the outside circuit is connected through a commutator, and when closed upon itself several closed circuits exist, displaced in position from each other so as to offer a resultant closed circuit in any direction. In the theoretical investigation I shall use the method of complex quantities, the application of which to alternating-current phenomena I outlined in a paper before a previous congress.[2] The extension of this method to vector products as torque and power is given in the appendix.[3]

II.

An alternating current I flowing through an electric circuit produces a magnetic flux Φ interlinked with this circuit. Considering equivalent sine waves of I and Φ, Φ lags behind I by the angle of hysteretic lag α. This magnetic flux ϕ induces an e.m.f. $E = 2\pi Nn\Phi$, where $N =$ frequency, $n =$ number of turns of electric circuit. This induced e.m.f. E lags 90 deg. behind the magnetic flux Φ, hence consumes an e.m.f. 90 deg. ahead of Φ, or $90 - \alpha$ deg. ahead of I. This may be resolved in a wattless component: $E = 2\pi Nn\,\Phi\cos\alpha = 2\pi N\,L\,I = x\,I$, the e.m.f. consumed by self-induction, and an energy component: $E'' = 2\pi Nn\,\Phi\sin\alpha = 2\pi N\,H\,I = r''\,I =$ e.m.f. consumed by hysteresis (eddy currents, etc.), and is, therefore, in vector representation denoted by

$E' = -j\,x\,I$ and $E'' = r''\,I$

where $x = 2\pi N\,L =$ reactance, $L =$ inductance,

$r'' =$ effective hysteretic resistance.

The ohmic resistance of the circuit, r', consumes an e.m.f. $r'I$ in phase with the current, and the total or effective resistance of the circuit is, therefore, $r = r' + r''$, and the total e.m.f. consumed by the circuit, or the impressed e.m.f. is

$$E = (r - j\,x)\,I = Z\,I$$

where

$Z = r - jx =$ impedance, in vector notation,

$z = \sqrt{r^2 + x^2} =$ impedance, in absolute terms.

If an electric circuit is in inductive relation to another electric circuit, it is advisable to separate the inductance L of the circuit into two parts—the self-inductance S, which refers to that part of

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[2] Chicago, 1903, *Proceedings* Int. Elec. Cong., 1894.
[3] See also *Transactions* A. I. E. E., 1899.

the magnetic flux produced by the current in one circuit which is interlinked only with this circuit but not with the other circuit, and the mutual inductance, *M*, which refers to that part of the magnetic flux interlinked also with the second circuit. The desirability of this separation results from the different character of the two components: The self-inductance induces a wattless e.m.f. and thereby causes a lag of the current, while the mutual inductance transfers power into the second circuit, hence generally does the useful work of the apparatus. This leads to the distinction between the self-inductive impedance $Z_0 = r_0 - j\, x_0$ and the mutual inductive impedance $Z = r - j\, x$.

r_0 is the coefficient of power consumption by ohmic resistance, hysteresis and eddy currents of the self-inductive flux — effective resistance.

x_0 is the coefficient of e.m.f. consumed by the self-inductive flux — self-inductive reactance.

r is the coefficient of power consumption by hysteresis and eddy currents due to the mutual magnetic flux (hence contains no ohmic resistance component).

x is the coefficient of e.m.f. consumed by the mutual magnetic flux.

The e.m.f. consumed by the circuit is then

$$E = Z_0\, I + Z\, I$$

If one of the circuits rotates relatively to the other, then in addition to the e.m.f. of self-inductive impedance: $Z_0\, I$ and the e.m.f. of mutual-inductive impedance or e.m.f. of alternation: $Z\, I$, an e.m.f. is consumed by rotation. This e.m.f. is in phase with the flux through which the coil rotates — that is the flux parallel to the plane of the coil — and proportional to the speed — that is the frequency of rotation — while the e.m.f. of alternation is 90 deg. ahead of the flux alternating through the coil — that is the flux parallel to the axis of the coil — and proportional to the frequency. If, therefore, Z' is the impedance corresponding to the former flux, the e.m.f. of rotation is $j\, a\, Z'\, I$, where a is the ratio of frequency of rotation to frequency of alternation, or the speed expressed as a fraction of synchronous speed. The total e.m.f. consumed in the circuit is thus: $E = Z_0\, I + Z\, I + j\, a\, Z'\, I$.

Applying now these considerations to the alternating-current motor, we assume all circuits reduced to the same number of turns — that is, selecting one circuit, of n effective turns, as starting point, if n_1 = number of effective turns of any other circuit, all the e.m.f's. of the latter circuit are divided, the currents multiplied with the ratio n_1/n, the impedances divided, the admittances multiplied with $(n_1/n)^2$ This reduction of the constants of all circuits to the same number of effective turns is convenient by eliminating constant factors from the equations, and so permitting a direct comparison. When speaking, therefore, in the following of the impedance, etc., of the different circuits, we always refer to their reduced values (as it is customary in induction motor designing practice).

Let then, in Fig. 1, E_0, I_0, Z_0 = impressed e.m.f., current and self-inductive impedance resp. of a stationary circuit, E_1, I_1, Z_1 =

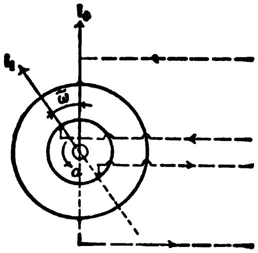

FIG. 1.

impressed e.m.f., current and inductive impedance respectively of a rotating circuit, ω = angle between the axis of the two circuits, Z = mutual-inductive or "exciting" impedance in the direction of the axis of the stationary coil, Z' = exciting impedance in the direction of the axis of the rotating coil, Z'' = exciting impedance at right angles to the latter axis, and a = speed, as fraction of synchronism. It is then:

In the stationary coil:

E.m.f. consumed by self-inductive impedance: $Z_0\, I_0$

E.m.f. consumed by mutual-inductive impedance: $Z\ (I_0 + I_1 \cos \omega)$ since the m.m.f. acting in the direction of the axis of the stationary coil is the resultant of both currents. Hence:

$$E_0 = Z_0\, I_0 + Z\ (I_0 + I_1 \cos \omega)$$

In the rotating circuit, it is:

E.m.f. consumed by self-inductive impedance: $Z_1\, I_1$

E.m.f. consumed by mutual-inductive impedance or "e.m.f. of alteration:" $Z'\ (I_1 + I_0 \cos \omega)$

E.m.f. of rotation: $j a Z'' I_0 \sin \omega$

Hence the impressed e.m.f.:

$$E_1 = Z_1 I_1 + Z' (I_1 + I_0 \cos \omega) + j a Z'' I_0 \sin \omega$$

In a structure with uniformly distributed winding, as used in induction motors, repulsion motors, etc., $Z' = Z'' = Z$, that is, the exciting impedance is the same in all directions.

Z is the reciprocal of the "exciting admittance," Y of the induction motor theory.

In the most general case, of a motor containing n circuits, of which some are revolving, some stationary, if:

E_k, I_k, Z_k = impressed e.m.f., current and self-inductive impedance respectively of any circuit k

Z^i, and Z^{ii} = exciting impedance parallel and at right angles respectively to the axis of a circuit i,

ω_k^i = angle between the axes of coils k and i, and

a = speed, as fraction of synchronism, or "frequency of rotation."

It is then, in a coil i:

$$E_i = Z_i I_i + Z^i \sum_{\frac{k}{1}}^{n} I_k \cos \omega_k^i + j a Z^{ii} \sum_{\frac{k}{1}}^{n} I_k \sin \omega_k^i$$

where:

$Z_i I_i$ = e.m.f. of self-inductive impedance.

$Z^i \sum_{\frac{k}{1}}^{n} I_k \cos \omega_k^i$ = e.m.f. of alternation

$E_i' = j a Z^{ii} \sum_{\frac{k}{1}}^{n} I_k \sin \omega_k^i$ = e.m.f. of rotation

which latter $= o$ in a stationary coil, in which $a = o$.

The power output of the motor is the sum of the powers of all the e.m.fs. of rotation, hence, in vector denotation[4]:

$$P = \sum_{\frac{i}{1}}^{n} / E_i' I_i /^1$$

$$= a \sum_{\frac{i}{1}}^{n} / j Z^{ii} \sum_{\frac{k}{1}}^{n} I_k \sin \omega_k^i , I_i /^1$$

and, therefore, the torque, in synchronous watts[5]:

$$T = \frac{P}{a} = \sum_{\frac{i}{1}}^{n} / j Z^{ii} \sum_{\frac{k}{1}}^{n} I_k \sin \omega_k^i , I_i /^1$$

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[4] See appendix. Also *Transactions* A. I. E. E., 1899.

[5] See *Transactions* A. I. E. E., 1897, 1898, 1900.

The power input, in vector denotation, is:

$$
\begin{aligned}
P_0 &= \sum_{1}^{n}{}_{i} E_i, I_i / \\
&= \sum_{1}^{n}{}_{i} / E_i, I_i /^1 + \sum_{1}^{n}{}_{i} / E_i, I_i /^j \\
&= P_0^1 + j\, P_0^j
\end{aligned}
$$

and therefore:

P_0^1 = true power input

P_0^j = wattless voltampere input

$Q_0 = \sqrt{(P_0^1)^2 + (P_0^j)^2}$ = apparent or voltampere input

$\frac{P}{P_0^1}$ = efficiency; $\frac{T}{P_0^1}$ torque efficiency;

$\frac{P}{Q_0}$ = apparent efficiency; $\frac{T}{Q_0}$ = apparent torque efficiency

$\frac{P_0^1}{Q_0}$ = power factor

From the n circuits: $i = 1, 2, \ldots$ thus result n linear equations, with $2n$ complex variables: I_i and E_i.

Hence n further conditions must be given to determine the variables. These obviously are the conditions of operation of the n circuits.

Impressed e.m.f's. E_i may be given.

Or circuits closed upon themselves: $E_i = 0$.

Or circuits connected in parallel: $c_i E_i = c_k E_k$, where c_i and c_k are the reduction factors of the circuits to equal number of effective turns, as discussed before.

Or circuits connected in series: $c_i I_i = c_k I_k$, etc.

When a rotating circuit is connected through a commutator, the frequency of the current in this circuit obviously is the same as the impressed frequency. Where, however, a rotating circuit is permanently closed upon itself, its frequency may differ from the impressed frequency, as, for instance, in the polyphase induction motor it is the frequency of slip $s = 1 - a$, and the self-inductive reactance of the circuit, therefore, is: $s\,x$, though in its reaction upon the stationary system the rotating system necessarily is always of full frequency.

After this introduction we come now to the discussion of a few motor types. We shall, however, consider only such types as have been more or less developed commercially or at least seriously considered.

III.

(1) *Polyphase Induction Motor.*

In the polyphase induction motor a number of primary circuits, displaced in position from each other, are excited by polyphase e.m.f's. displaced in phase from each other by a phase angle equal to the position angle of the coils. A number of secondary circuits are closed upon themselves. The primary usually is the stator, the secondary the rotor.

In this case the secondary system always offers a resultant closed circuit in the direction of the axis of each primary coil, irrespective of its position.

Let us assume two primary circuits in quadrature as simplest form, and the secondary system reduced to the same number of phases and the same number of turns per phase as the primary system. With three or more primary phases the method of procedure and the resultant equations are essentially the same.

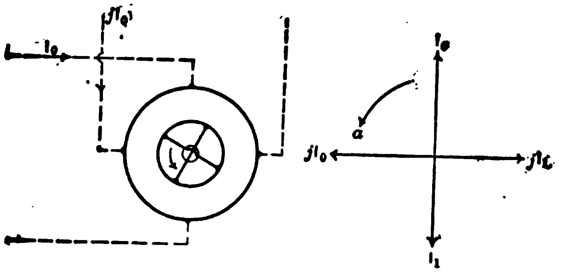

FIG. 2.—POLYPHASE INDUCTION MOTOR.

Let in the motor shown diagrammatically in Fig. 2:

E_0 and jE_0, I_0 and jI_0, Z_0 = impressed e.m.f's., currents and self-inductive impedance respectively of the primary system.

0, I_1 and jI_1, Z_1 = impressed e.m.f., currents and self-inductive impedance respectively of secondary system, reduced to primary.

Z = mutual-inductive impedance between primary and secondary.

a = speed; $s = 1 - a$ = slip, as fraction of synchronism.

The equation of the primary circuit is then:

$$E_0 = Z_0 I_0 + Z (I_0 - I_1) \qquad (1)$$

The equation of the secondary circuit:

$$o = Z_1 I_1 + Z\ (I_1 - I_0) + jaZ\ (jI_1 - jI_0) \qquad (2)$$

from (2) follows:

$$I_1 = I_0 \frac{Z_0\,(1-a)}{Z\,(1-a)+Z_1} = I_0 \frac{Zs}{Zs+Z_1} \qquad (3)$$

and, substituted in (1):

Primary current:

$$I_0 = E_0 \frac{Zs+Z_1}{ZZ_0 s + ZZ_1 + Z_0 Z_1} \qquad (4)$$

Secondary current:

$$I_1 = E_0 \frac{Zs}{ZZ_0 s + ZZ_1 + Z_0 Z_1} \qquad (5)$$

Exciting current:

$$I_{00} = I_0 - I_1 = E_0 \frac{Z_1}{ZZ_0 s + ZZ_1 + Z_0 Z_1} \qquad (6)$$

E.m.f. of rotation:

$$E^1 = jaZ\ (jI_1 - jI_0) = aZ\ (I_0 - I_1)$$

$$= aE_0 \frac{ZZ_1}{ZZ_0 s + ZZ_1 + Z_0 Z_1}$$

$$= (1 - s)\ E_0 \frac{ZZ_1}{ZZ_0 s + ZZ_1 + Z_0 Z_1} \qquad (7)$$

It is, at synchronism: $s = o$:

$$I_0 = \frac{E_0}{Z+Z_0};\quad I_1 = o;\ I_{00} = I_0;\ E^1 = \frac{E_0 Z}{Z+Z_0} = \frac{E_0}{1+Z_0/Z}$$

At standstill: $s = 1$:

$$I_0 = \frac{E_0(Z+Z_1)}{ZZ_0 + ZZ_1 + Z_0 Z_1};\quad I_1 = \frac{E_0 Z}{ZZ_0 + ZZ_1 + Z_0 Z_1};$$

$$I_{00} = \frac{E_0 Z_1}{ZZ_0 + ZZ_1 + Z_0 Z_1};\quad E^1 = o$$

Introducing as parameter the counter e.m.f., or e.m.f. of mutual induction:

$$E = E_0 - Z_0 I_0$$

or:

$$E_0 = E + Z_0 I_0$$

it is, substituted:

Counter e.m.f.:

$$E = E_0 \frac{ZZ_1}{ZZ_0 s + ZZ_1 + Z_0 Z_1} \qquad (8)$$

hence:

Primary impressed e.m.f.:

$$E_0 = E \frac{ZZ_0 s + ZZ_1 + Z_0 Z_1}{ZZ_1} \qquad (9)$$

E.m.f. of rotation:

$$E^1 = Ea = E\ (1 - s). \tag{10}$$

Secondary current:

$$I_1 = \frac{Es}{Z_1} \tag{11}$$

Primary current:

$$I_0 = E\frac{Zs + Z_1}{ZZ_1} = \frac{Es}{Z_1} + \frac{E}{Z} \tag{12}$$

Exciting current:

$$I_{00} = \frac{E}{Z} \tag{13}$$

These are the equations from which the transformer theory of the polyphase induction motor starts.

Since the frequency of the secondary induced currents is the frequency of slip, hence varies with the speed $a = 1 - s$. the secondary self-inductive reactance also varies with the speed, and so the impedance:

$$Z_1 = r_1 - jsx_1 \tag{14}$$

The power output of the motor, per circuit, is:

$$P = /E^1, I_1/$$

$$= \frac{e_0{}^2 z^2 s\ (1-s)}{[ZZ_0 s + ZZ_1 + Z_0 Z_1]^2}\ (r_1 + jsx_1) \tag{15}$$

where the brackets [] denote the absolute value of the term included by it, and the small letters e_0, z, etc., the absolute values of the vectors E_0, Z, etc.

Since the imaginary term of power seems to have no physical meaning, it is:

Mechanical power output:

$$P = \frac{e_0{}^2 z^2 s\ (1-s)\ r_1}{[ZZ_0 s + ZZ_1 + Z_0 Z_1]^2} \tag{16}$$

This is the power output at the armature conductors, hence includes friction and windage.

The torque of the motor is:

$$T = \frac{P}{1-s} = \frac{e_0{}^2\ z^2 r_1 s}{[ZZ_0 s + ZZ_1 + Z_0 Z_1]^2} + j\frac{e_0{}^2\ z^2 x_1 s}{[ZZ_0 s + ZZ_1 + Z_0 Z^1]^2} \tag{17}$$

The imaginary component of torque seems to represent the radial force or trust acting between stator and motor. Omitting it, it is:

$$T = \frac{e_0{}^2\ z^2 r_1 s}{[ZZ_0 s + ZZ_1 + Z_0 Z^1]^2} \tag{18}$$

The power input of the motor per circuit is:

$$P_0 = /E_0, I_0/$$

$$= e_0^2/1, \frac{Zs + Z_1}{ZZ_0s + ZZ_1 + Z_0Z_1}/ \qquad (19)$$

$$= P_0^1 + j P_0^j$$

where: P^1_0 = true power, P^j_0 = reactive or "wattless power,"

$Q_0 = \sqrt{P^{1^2}_0 + P^{j^2}_0}$ = apparent power, or voltampere input.

Herefrom follows power factor, efficiency, etc.

Introducing the parameter: E, or absolute: e, it is:

Power output:

$$P = /E^1, I_1/$$

$$= /ea, \frac{es}{Z_1}/$$

$$= e^2sa/1, \frac{1}{Z_1}/$$

$$= \frac{e^2sar_1}{z_1^2} + j\frac{e^2s^2ax_1}{z_1^2}$$

$$= \frac{i_1^2ar_1}{s} + j\, i_1^2ax_1 \qquad (20)$$

Power input:

$$P_0 = /E_0, I_0/$$

$$= e^2/\frac{ZZ_0s + ZZ_1 + Z_0Z_1}{ZZ_1}, \frac{Zs + Z_1}{ZZ_1}/$$

$$= e^2/\frac{Z_0(Zs + Z_1)}{ZZ_1} + 1, \frac{Zs + Z_1}{ZZ_1}/$$

$$= e^2\left[\frac{Zs + Z_1}{ZZ_1}\right]^2 \left\{ /Z_0 1/ + e^2/1, \frac{s}{Z_1} + \frac{1}{Z} \right\}$$

$$= e^2\left[\frac{Zs + Z_1}{ZZ_1}\right]^2 \left\{ /Z_0, 1/ + \frac{e^2s}{z_1^2}/Z_1, 1/ + \frac{e^2}{z^2}/ Z, 1/ \right\}$$

$$= e^2\left[\frac{Zs + Z_1}{ZZ_1}\right]^2 \left\{ (r_0 + jx_0) + \frac{e^2s}{z_1^2}(r_1 + jsx_1) + \frac{e^2}{z^2}(r + j^1x) \right\}$$

$$= i_0^2(r_0 + jx_0) + i_1^2\left(\frac{r_1}{s} + jx_1\right) + i_{00}^2(r + jx)$$

And since: $\frac{r_1}{s} = \frac{a + s}{s} r_1 = \frac{ar_1}{s} + r_1$, and $\frac{i_1^2ar_1}{s} = P$, it is:

$$P_0 = (i_0 r_0 + i_1^2r_1 + i_{00}^2 r + P) + j(i_0^2x_0 + i_1^2x_1 + i_{00}^2x) \qquad (21)$$

Where:

$i_0^2 r_0$ = primary resistance loss,
$i_1^2r_1$ = secondary resistance loss,
i_{00}^2r = core loss (and eddy current loss),
P = output,
$i_0^2x_0$ = primary reactive voltamperes,

$i_1^2 x^1$ = secondary reactive voltamperes,

$i_{00}^2 x$ = magnetizing voltamperes.

Introducing into the equations (3) (4) (5) (6) (8) the terms:

$$\left.\begin{aligned} Z_0 / Z &= \lambda_0 \\ Z_1 / Z &= \lambda_1 \end{aligned}\right\} \qquad (22)$$

Where λ_0 and λ_1 are small quantities, and: $\vartheta = \lambda_0 + \lambda_1$ is the "characteristic constant" of the induction motor theory, it is:

Primary current:

$$I_0 = \frac{E_0}{Z} \, \frac{s + \lambda_1}{s\lambda_0 + \lambda_1 + \lambda_0\lambda_1} = \frac{E_0}{Z} \, \frac{s + \lambda_1}{s\lambda_0 + \lambda_1} \qquad (23)$$

Secondary current:

$$I_1 = \frac{E_0}{Z} \, \frac{s}{s\lambda_0 + \lambda_1 + \lambda_0\lambda_1} = \frac{E_0}{Z} \, \frac{s}{s\lambda_0 + \lambda_1} \qquad (24)$$

Exciting current:

$$I_{00} = \frac{E_0}{Z} \, \frac{\lambda_1}{s\lambda_0 + \lambda_1 + \lambda_0\lambda_1} = \frac{E_0}{Z} \, \frac{\lambda_1}{s\lambda_0 + \lambda_1} \qquad (25)$$

E.m.f. of rotation:

$$E^1 = E_0 \, a \frac{\lambda_1}{s\lambda_0 + \lambda_1 + \lambda_0\lambda_1} = E_0 \, a \frac{\lambda_1}{s\lambda_0 + \lambda_1} \qquad (26)$$

Counter e.m.f.:

$$E = E_0 \frac{\lambda_1}{s\lambda_0 + \lambda_1 + \lambda_0\lambda_1} = E_0 \frac{\lambda_1}{s\lambda_0 + \lambda_1} \qquad (27)$$

As instance are shown, in Fig. 3, with the speed as abscissæ, the curves of a polyphase induction motor of the constants:

$e_0 = 320$ volts,

$Z = 1 - 10j$ ohms,

$Z_0 = Z_1 = .1 - .3j$ ohms

hence: $\lambda_0 = \lambda_1 = .0307 + .0069j.$

It is:

$$I_0 = \frac{320\{10.30s + (s + .1)j\}}{(1.03 + 1.63s) + j(.11 - 5.99s)} \text{ amps.}$$

$$T = \frac{2048\,(1 - s)}{(1.03 + 1.63s)^2 + (.11 - 5.99s)^2} \text{ synchr. k.w.}$$

$$P = (1 - s)T$$

$$\tan \omega' = \frac{s + .1}{10.3s}; \; \tan \omega'' = \frac{.11 - 5.99s}{1.03 + 1.63s}$$

$\cos(\omega' - \omega'')$ = power factor.

The curves show the well-known characteristics of the polyphase induction motor: approximate constancy of speed at all loads, and good efficiency and power factor within this narrow speed range, but poor constants at all other speeds.

(2) *Single-Phase Induction Motor.*

In the single-phase induction motor one primary circuit acts upon a system of closed secondary circuits which are displaced from each other in position on the secondary member.

Let the secondary be assumed as two-phase, that is containing or reduced to two circuits closed upon themselves at right angles to each other. While it then offers a resultant closed secondary circuit to the primary circuit in any position, the electrical disposition of the secondary is not symmetrical, but the directions parallel with the primary circuit and at right angles thereto are to be distinguished. The former may be called the secondary energy circuit, the latter the secondary magnetizing circuit, since in the former direction power is transferred from the primary to the secondary circuit, while in the latter direction the secondary circuit can act magnetizing only.

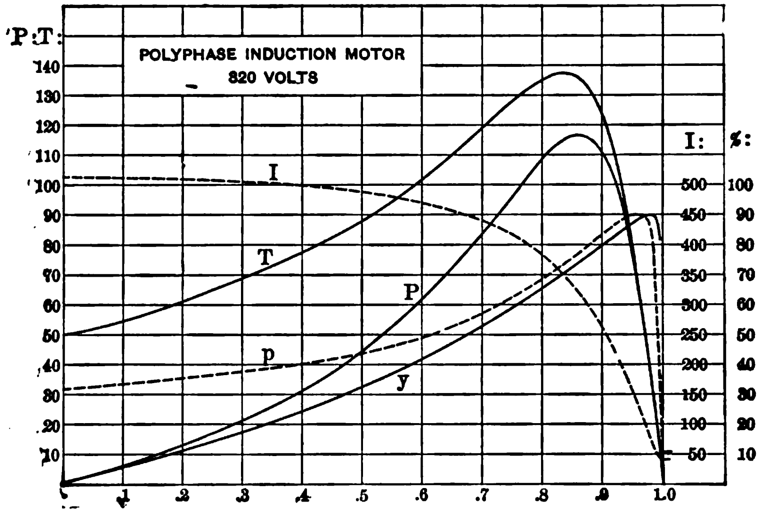

FIG. 3.

Let, in the diagram Fig. 4:

E_0, I_0, Z_0 = impressed e.m.f., current and self-inductive impedance respectively of the primary circuit

I_1, Z_1 = current and self-inductive impedance respectively of the secondary energy circuit

I_2, Z_1 = current and self-inductive impedance respectively of the secondary magnetizing circuit

Z = mutual-inductive impedance

a = speed

and let: $s_0 = 1 - a^2$ (where s_0 is not the slip)

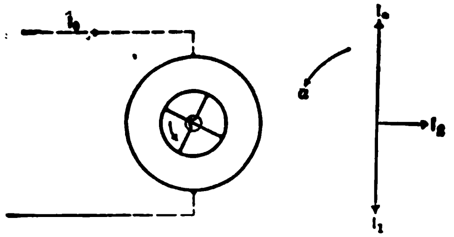

FIG. 4.—SINGLE-PHASE INDUCTION MOTOR.

It is then:

Primary circuit:

$$E_0 = Z_0 I_0 + Z\,(I_0 - I_1) \qquad (1)$$

Secondary energy circuit:

$$o = Z_1 I_1 + Z\,(I_1 - I_0) + j\,a\,Z\,I_2 \qquad (2)$$

Secondary magnetizing circuit:

$$o = Z_1 I_2 + Z\,I_2 + j\,a\,Z\,(I_0 - I_1) \qquad (3)$$

hence:

$$I_1 = I_0 \frac{Z\,(Z s_0 + Z_1)}{Z^2 s_0 + 2 Z Z_1 + Z_1^2} \qquad (4)$$

$$I_2 = -j\,a\,I_0 \frac{Z Z_1}{Z^2 s_0 + 2 Z Z_1 + Z_1^2} \qquad (5)$$

and, substituted:

Primary current:

$$I_0 = E_0 \frac{Z^2 s_0 + 2\,Z Z_1 + Z_1^2}{D} \qquad (6)$$

Secondary energy current:

$$I_1 = E_0 \frac{Z\,(Z s_0 + Z_1)}{D} \qquad (7)$$

Secondary magnetizing current:

$$I_2 = -j\,a\,E_0 \frac{Z Z_1}{D} \qquad (8)$$

E.m.f. of rotation of secondary energy circuit:

$$E_1^1 = j\,a\,Z\,I_2 = a^2 E_0 \frac{Z^2 Z_1}{D} \qquad (9)$$

E.mf. of rotation of secondary magnetizing circuit:

$$E_2^1 = j\,a\,Z\,(I_0 - I_1) = j\,a\,E_0 \frac{Z Z_1 (Z + Z_1)}{D} \qquad (10)$$

where:

$$D = Z_0 (Z^2 s_0 + 2\,Z Z_1 + Z_1^2) + Z Z_1 (Z + Z_1) \qquad (11)$$

It is, at synchronism: $a = 1$, $s_0 = o$

$$I_0 = E_0 \frac{2Z + Z_1}{Z_0(2Z + Z_1) + Z(Z + Z_1)}.$$

$$I_1 = E_0 \frac{Z}{Z_0(2Z + Z_1) + Z(Z + Z_1)}$$

$$I_2 = -j\, E_0 \frac{Z}{Z_0(2Z + Z_1) + Z(Z + Z_1)}$$

$$E_1^1 = E_0 \frac{Z^2}{Z_0(2Z + Z_1) + Z(Z + Z_1)}$$

$$E_2^1 = jE_0 \frac{Z(Z + Z_1)}{Z_0(2Z + Z_1) + Z(Z + Z_1)}$$

Hence, at synchronism, the secondary current of the single-phase induction motor does not become zero, as in the polyphase motor, but both components of secondary current become equal.

At standstill: $a = o$, $s_0 = 1$ it is:

$$I_0 = E_0 \frac{Z + Z_1}{ZZ_0 + ZZ_1 + Z_0 Z_1}$$

$$I_1 = E_0 \frac{Z}{ZZ_0 + ZZ_1 + Z_0 Z_1}$$

$$I_2 = o; \; E_1^1 = o; \; E_2^1 = o$$

That is, primary and secondary current corresponding thereto have the same values as in the polyphase induction motor, page 8. This was to be expected.

Introducing as parameter the counter e.m.f. or e.m.f. of mutual induction:

$$E = E_0 - Z_0 I_0$$

and substituting for I_0 from (6), it is:

Primary impressed e.m.f.:

$$E_0 = E \frac{Z_0(Z^2 s_0 + 2\, ZZ_1 + Z_1^2) + ZZ_1(Z + Z_1)}{ZZ_1(Z + Z_1)} \tag{12}$$

Primary current:

$$I_0 = E \frac{Z^2 s_0 + 2\, ZZ_1 + Z_1^2}{ZZ_1(Z + Z_1)} \tag{13}$$

Secondary energy circuit:

$$I_1 = E \frac{Z s_0 + Z_1}{Z_1(Z + Z_1)} = \frac{s_0 E}{Z_1} + \frac{a^2 E}{Z + Z_1} \tag{14}$$

$$E_1{}^1 = a^2 E \frac{Z}{Z + Z_1} \tag{15}$$

Secondary magnetizing circuit:

$$I_2 = -j \frac{a\, E}{Z + Z_1} \tag{16}$$

$$E_2^1 = j\,a\,E \qquad (17)$$

And:

$$I_0 - I_1 = \frac{E}{Z} \qquad (18)$$

These equations differ from the equations of the polyphase induction motor by containing the term: $s_0 = (1 - a^2)$ instead of: $s = (1 - a)$, and by the appearance of the terms: $\frac{a\,E}{Z + Z_1}$ and: $\frac{a^2\,E}{Z + Z_1}$, of frequency $(1 + a)$, in the secondary circuit.

The power output of the motor is:

$$\begin{aligned} P &= / E_1^1, I_1 /^1 + / E_2^1, I_2 /^1 \\ &= \frac{a^2\, e_0^2\, z^2}{[D]^2} \left\{ / Z Z_1, Z s_0 + Z_1 /^1 - / Z_1 (Z + Z_1), Z_1 /^1 \right\} \\ &= \frac{a^2\, e_0^2\, z^2\, r_1\, (s_0\, z^2 - z_1^2)}{[D]^2} \end{aligned} \qquad (19)$$

and the torque, in synchronous watts:

$$T = \frac{P}{a} = \frac{a\, e_0\, z^2\, r_1\, (s_0\, z^2 - z_1^2)}{[D]} \qquad (20)$$

From these equations it follows that at synchronism torque and power of the single-phase induction motor are already negative.

Torque and power become zero for:

$$s_0 z^2 - z_1^2 = o$$

hence:

$$a = \sqrt{1 - \left(\frac{z_1}{z}\right)^2} \qquad (21)$$

that is, very slightly below synchronism: Let $z = 10$, $z_1 = .316$, it is: $a = .9995$.

In the single-phase induction motor, the torque contains the speed a as factor, and thus becomes zero at standstill.

Neglecting quantities of secondary order, it is, approximately:

$$I_0 = E_0 \frac{Z s_0 + 2 Z_1}{Z (Z_0 s_0 + Z_1) + 2 Z_0 Z_1} \qquad (22)$$

$$I_1 = E_0 \frac{Z s_0 + Z_1}{Z (Z_0 s_0 + Z_1) + 2 Z_0 Z_1} \qquad (23)$$

$$I_2 = -j a E_0 \frac{Z_1}{Z (Z_0 s_0 + Z_1) + 2 Z_0 Z_1} \qquad (24)$$

$$E_1^1 = a^2 E_0 \frac{Z Z_1}{Z (Z_0 s_0 + Z_1) + 2 Z_0 Z_1} \qquad (25)$$

$$E_2^1 = j a E_0 \frac{Z Z_1}{Z (Z_0 s_0 + Z_1) + 2 Z_0 Z_1} \qquad (26)$$

$$P + \frac{a^2 e_0^2 \, z^2 r_1 s_0}{[Z(Z_0 s_0 + Z_1) + 2 Z_0 Z_1]^2} \qquad (27)$$

$$T = \frac{a e_0^2 z^2 r_1 s_0}{[Z(Z_0 s_0 + Z_1) + 2 Z_0 Z_1]^2} \qquad (28)$$

This theory of the single-phase induction motor differs from that previously communicated (see note 1, ante), in that it represents more exactly the phenomena at intermediate speeds, which are only approximated in the transformer theory of the single-phase induction motor.

As instance are shown, in Fig. 5, with the speed as abscissæ, the curves of a single-phase induction motor, of the constants:

$e_0 = 400$ volts

$Z = 1 - 10j$ ohms

$Z_0 = Z_1 = .1 - .3j$ ohms

hence:

$I_0 = 400 \dfrac{N}{D}$ amps.

$N = (s + .2) - j(10s + .6 - .6a)$

$D = (.1 - .3j)N + (1 - 10j)(.1 - j(.3 - .3a))$

$T = \dfrac{1616\, as}{[D]^2}$ synchr. kw.

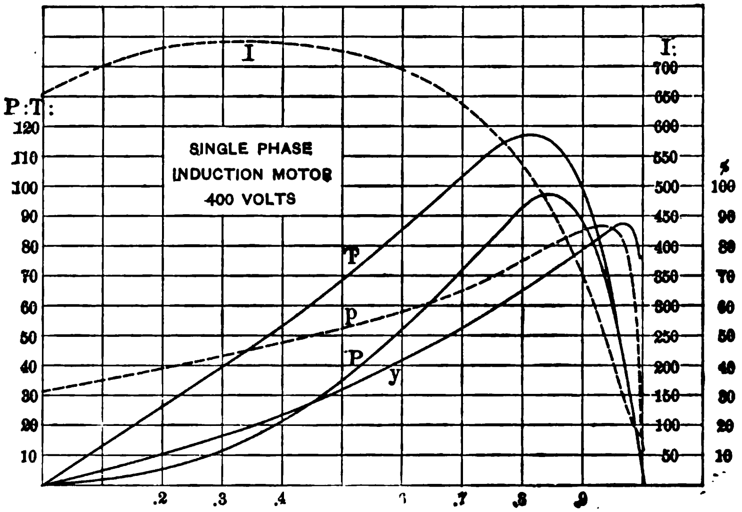

FIG. 5.

(3) *Single-phase Condenser Motor.*

The single-phase induction motor is not self-starting, as seen from the equations and diagram, Fig. 5. To secure starting torque, either a commutator has to be used — that is, the motor started as repulsion motor or series motor, etc. — or a quadrature magnetic flux impressed upon the motor, that is the motor converted into a more or less unsymmetrical, polyphase motor. To a considerable extent used in practice are only the starting as repulsion motor, which will be discussed later, and the starting by a condenser in the tertiary circuit, both methods giving good starting efficiencies. The use of a condenser also permits to greatly increase the power factor in running, by retaining the condenser in circuit. This is usually carried out by employing a three-phase winding on the motor primary, of which two terminals are connected to the single-phase supply, two terminals permanently connected to a condenser, either directly or by step-up transformer. This condenser so closes a circuit displaced by 60 deg. in position from the primary circuit, as shown diagrammatically in Fig. 6.

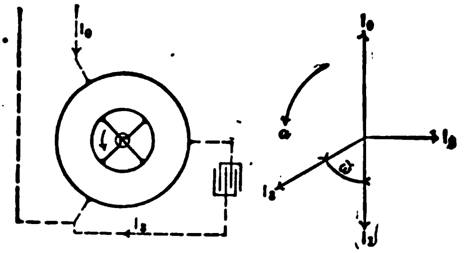

FIG. 6.— INDUCTION SINGLE-PHASE CONDENSER MOTOR.

Let, in the diagram Fig. 6, of such a single-phase condenser motor:

E_0, I_0, Z_0 = impressed e.m.f., current and self-inductive impedance respectively of the primary circuit,

I_1, Z_1 = current and self-inductive impedance of the secondary energy circuit,

I_2, Z_1 = current and self-inductive impedance of the secondary magnetizing circuit,

I_3 = current in the condenser circuit, or tertiary circuit,

$Z_3 = r_3 + j x_3$ = total effective impedance (leading) of the condenser circuit,

Z = mutual-inductive impedance,

ω = position angle between the axes of primary and tertiary circuit,

$a =$ speed.

The equations of the motor then are:

Primary circuit:

$$E_0 = Z_0 I_0 + Z (I_0 - I_1 - I_3 \cos \omega) \qquad (1)$$

Secondary energy circuit:

$$o = Z_1 I_1 + Z (I_1 - I_0 + I_3 \cos \omega) + j a Z (I_2 - I_3 \sin \omega) \quad (2)$$

Secondary magnetizing circuit:

$$o = Z_1 I_2 + Z (I_2 - I_3 \sin \omega) + j a Z (I_1 - I_0 + I_3 \cos \omega) \quad (3)$$

Tertiary or condenser circuit:

$$o = Z_3 I_3 + Z (I_3 - I_0 \cos \omega + I_1 \cos \omega - I_2 \sin \omega) \qquad (4)$$

These four linear equations give the four currents:

$$I_0, I_1, I_2, I_3$$

and thereby the e.m.f's. of rotation:

$$E_1 = j a Z (I_2 - I_3 \sin \omega) \qquad (5)$$

$$E_2 = j a Z (I_1 - I_0 + I_3 \cos \omega) \qquad (6)$$

and therefrom the torque, power output, input, etc.

Usually ω is made 60 deg. in this type of motor.

(4) *Polyphase Shunt Motor.*

Since the characteristics of the polyphase motor do not depend upon the number of phases, here, as in the preceding, a two-phase system may be assumed: that is, a two-phase stator winding acting upon a two-phase rotor winding, that is a closed coil rotor winding connected to the commutator in the same manner as in direct-current machines, but with two sets of brushes in quadrature position excited by a two-phase system of the same frequency. Mechanically the three-phase system here has the advantage to require three sets of brushes only instead of four with the two-phase system, but otherwise the general form of the equations and conclusions are not different.

Let E_0 and $j E_0 =$ e.m.f's. impressed upon the stator, E_1 and $j E_1 =$ e.m.f's. impressed upon the rotor, $\omega_0 =$ phase angle between e.m.f. E_0 and E_1 and $\omega_1 =$ position angle between the stator and rotor circuits. The e.m.f's. E_0 and $j E_0$ produce the same rotating m.m.f. as two e.m.f's. of equal intensity, but displaced in phase and in position by angle ω_0 from E_0 and $j E_0$, and instead of considering a displacement of phase ω_0 and a displacement of position ω_1 between stator and rotor circuits, we can, therefore, assume zero-phase displacement and displacement in position by angle $\omega_0 + \omega_1 = \omega$. Phase displacement between stator and rotor e.m.f's. is, therefore, equivalent to a shift of brushes.

Without losing in generality of the problem, we can, therefore, assume the stator e.m.f's. in phase with the rotor e.m.f's., and the polyphase shunt motor can thus be represented diagrammatically by Fig. 7.

Let, in the polyphase shunt motor, shown two-phase in diagram Fig. 7:

E_0 and jE_0, I_0 and jI_0, $Z_0 =$ impressed e.m.f's., currents and self-inductive impedance respectively of the stator circuits,

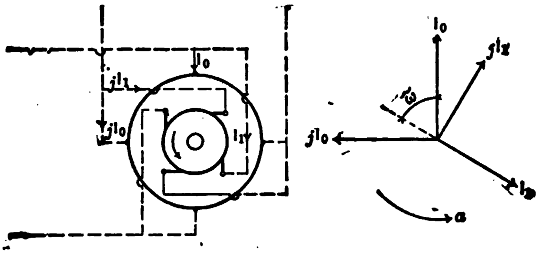

FIG. 7.—POLYPHASE SHUNT MOTOR.

cE_0 and jcE_0, I_1 and jI_1, $Z_1 =$ impressed e.m.f's., currents and self-inductive impedance resp. of the rotor circuits, reduced to the stator circuits by the ratio of effective turns c,

$Z =$ mutual-inductive impedance,

$a =$ speed, hence: $s = 1 - a =$ slip,

$\omega =$ position angle between stator and rotor circuits, or "brush angle."

It is then:

Stator:

$$E_0 = Z_0\, I_0 + Z\ (I_0 - I_1 \cos\omega + jI_1 \sin\omega) \qquad (1)$$

Rotor:

$$\begin{aligned} cE_0 = Z_1 I_1 + Z\ (I_1 - I_0\ \cos\omega - jI_0\ \sin\omega) + jaZ\ (jI_1 + \\ I_0 \sin\omega - jI_0 \cos\omega) \end{aligned} \qquad (2)$$

Substituting:

$$\left.\begin{aligned} \sigma &= \cos\omega + j\sin\omega \\ \delta &= \cos\omega - j\sin\omega \end{aligned}\right\} \qquad (3)$$

it is:

$$\sigma\delta = 1$$

and:

$$E_0 = Z_0 I_0 + Z\ (I_0 - \delta\ I_1) \qquad (4)$$

$$\begin{aligned} cE_0 &= Z_1 I_1 + Z(I_1 - \sigma I_0) + jaZ(jI_1 - j\ \ I_0) \\ &= Z_1 I_1 + sZ\ (I_1 - \sigma I_0) \end{aligned} \qquad (5)$$

Herefrom follows:

$$I_0 = E_0 \frac{(s+\delta c)Z+Z_1}{sZZ_0+ZZ_1+Z_0Z_1} \qquad (6)$$

$$I_1 = E_0 \frac{(\sigma s+c)Z+cZ_1}{sZZ_0+ZZ_1+Z_0Z_1} \qquad (7)$$

for: $c = o$, this gives:

$$I_0 = E_0 \frac{sZ+Z_1}{sZZ_0+ZZ_1+Z_0Z_1}$$

$$\dot{I}_1 = \sigma E_0 \frac{sZ}{sZZ_0+ZZ_1+Z_0Z_1}$$

that is, the polyphase induction motor equations of page 83 et seq., $\sigma = \cos\omega + j\sin\omega = 1^{\frac{\omega}{2\pi}}$ representing the displacement of position between stator and rotor currents.

This shows the polyphase induction motor as a special case of the polyphase shunt motor, for: $c = o$.

The e.m.f's. of rotation are:

$$E_1^1 = jaZ\ (jI_1 + I_0 \sin\omega - jI_0\cos\omega)$$
$$= aZ\ (\sigma I_0 - I_1)$$

hence:

$$E_1^1 = aE_0 \frac{Z(\sigma Z_1 - cZ_0)}{sZZ_0+ZZ_1+Z_0Z_1} \qquad (8)$$

The power output of the motor is:

$$P = /E_1^1, I_1/^1$$
$$= \frac{ae_0^2}{[sZZ_0+ZZ_1+Z_0Z_1]^2}/(\sigma Z_1 - cZ_0)Z, (\sigma s+c)Z + cZ_0/^1$$

which, suppressing terms of secondary order, gives:

$$P = \frac{ae_0^2\ z^2 \}s(r_1 + c(x_0\sin\omega - r_0\cos\omega)) + c(r_1\cos\omega + x_1\sin\omega - cr_0)\}}{[sZZ_0+ZZ_1+Z_0Z_1]^2} \qquad (9)$$

for: $c = o$, this gives:

$$P = \frac{a\ e_0^2\ z^2 sr_1}{[sZZ_0+ZZ_1+Z_0Z_1]^2}$$

the same value as for the polyphase induction motor.

The power output becomes zero: $P = o$, for the slip:

$$s_0 = -c \frac{r_1\cos\omega + x_1\sin\omega - cr_0}{r_1 + c(x_0\sin\omega - r_0\cos\omega)} \qquad (10)$$

This slip $s_0 = o$, or the motor output becomes zero at synchronism, if:

$$r_1\cos\omega + x_1\sin\omega - cr_0 = o$$

hence:

$$c = \frac{r_1\cos\omega + x_1\sin\omega}{r_0} \qquad (11)$$

or, substituting:

$$\frac{x_1}{r_1} = \tan \alpha_1 , \qquad (12)$$

where α_1 is the phase angle of the rotor impedance, it is:

$$c = \frac{z_1}{r_0} \cos (\alpha_1 - \omega) \qquad (13)$$

or:

$$\cos (\alpha_1 - \omega) = \frac{r_0}{z_1} c. \qquad (14)$$

That is:

At given brush angle ω, a value of secondary impressed e.m.f; cE_0, exists, which makes the motor tend to synchronize at no load, and:

At given rotor impressed e.m.f.; cE_0, a brush angle ω exists, which makes the motor synchronize at no load.

Since r_0 is usually very much smaller than z_1, if c is not very large, it is:

$\cos (\alpha - \omega) = 0$,

hence:

$$\omega = 90° - \alpha_1 \qquad (15)$$

That is, if the brush angle ω is complimentary to the phase angle of the self-inductive rotor impedance α_1 the motor tends toward approximate synchronism at no load.

The rotor current:

$$I_1 = E_0 \frac{\sigma s Z + c(Z + Z_0)}{s Z Z_0 + Z Z_1 + Z_0 Z_1}$$

becomes zero, if:

$$c = - \sigma s \frac{Z}{Z + Z_0}$$

or, since Z_0 is small compared with Z, approximately:

$c = - \sigma s = - s \, (\cos \omega + j \sin \omega)$

hence, resolved:

$c = - s \cos \omega$

$0 = s \sin \omega$

hence:

$$\left. \begin{aligned} \omega &= \sigma \\ c &= - s \end{aligned} \right\} \quad (16)$$

That is, the rotor current can become zero only if the brushes are set in line with the stator circuit or without shift, and in this case the rotor current, and therewith the output of the motor, becomes zero at the slip $s = - c$.

Hence such a motor gives a characteristic curve very similar to that of the polyphase induction motor, except that the stator tends not toward synchronism but toward a definite speed equal to $(1 + c)$ times synchronism.

The speed of such a polyphase motor with commutator can, therefore, be varied from synchronism by the insertion of an e.m.f. in the rotor circuit, and the percentage of variation is the same as the ratio of the impressed motor e.m.f. to the impressed stator e.m.f. A rotor e.m.f. in opposition to the stator e.m.f. reduces, in phase with the stator e.m.f. increases the free running speed of the motor. In the former case the rotor impressed e.m.f. is in opposition to the rotor current, that is the rotor returns power into the system in the proportion in which the speed is reduced, and the speed variation, therefore, occurs without loss of efficiency, and is similar in its character to the speed control of a direct-current shunt motor by varying the ratio between the e.m.f. impressed upon the armature and that impressed upon the field.

Substituting in the equations:

$$\left.\begin{array}{l} w = o \\ s + c = s_1 \end{array}\right\} \qquad (17)$$

it is:

$$I_0 = E_0 \frac{{}_1Z + Z_1}{s\,ZZ_0 + ZZ_1 + Z_0Z_1} \qquad (18)$$

$$I_1 = E_0 \frac{s_1\,Z}{s\,ZZ_0 + ZZ_1 + Z_0Z_1} \qquad (19)$$

$$P = \frac{a\,e_0^2\,z^2\,s_1\,(r_1 - cr_0)}{[s\,ZZ_0 + ZZ_1 + Z_0Z_1]^2} \qquad (20)$$

These equations are very similar to the polyphase induction motor equations.

The stator current:

$$I_0 = E_0 \frac{s\,Z + Z_1 + \delta\,c\,Z}{s\,ZZ_0 + ZZ_1 + Z_0Z_1}$$

can be resolved into a component:

$$I_0^1 = E_0 \frac{s\,Z + Z_1}{s\,ZZ_0 + ZZ_1 + Z_0\,Z_1} \qquad (21)$$

which does not contain c, and is the same value as the primary current of the polyphase induction motor, and a component:

$$I_0^{11} = E_0 \frac{\delta\,c\,Z}{s\,ZZ_0 + ZZ_1 + Z_0Z_1} \qquad (22)$$

Resolving I_0^{11}, it assumes the form:

$$I_0^{11} = E_0 \delta c(A_1 + jA_2)$$
$$= c\{A_1 \cos \omega + A_2 \sin \omega) - j\,(A_1 \sin \omega - A_2 \cos \omega)\}$$

Hence, by choosing:

$$A_1 \cos \omega + A_2 \sin \omega = o$$

or:

$$\tan \omega = -\frac{A_1}{A_2} \qquad (23)$$

it is:

$$I_0^{11} = j\,c\,\sqrt{A_1^2 + A_2^2} = \frac{j\,c\;zE_0}{[s\,ZZ_0 + ZZ_1 + Z_0 Z_1]} \qquad (24)$$

Hence this component can, by choosing ω, be made wattless, and by choosing c, any desired positive or negative, that is lagging or leading value, can be given to it. The wattless lagging component of I_0 can, therefore, be compensated by a leading value of I_0^{11}, that is unity power factor produced, or overcompensated, that is the main current made leading.

If:

$$I^1_0 = i_0^1 + j i_0^{11},$$
$$c = -\frac{i_0^{11}}{z}[s\,ZZ_0 + ZZ_1 + Z_0 Z_1] \qquad (25)$$

gives unity power factor, higher values of c give leading, lower lagging current, and by varying c, a phase characteristic of the polyphase shunt motor can be produced, closely resembling the V-shaped phase characteristic of the synchronous motor produced by varying its field excitation.

Such phase characteristics of polyphase shunt motors have been observed.

In the exact predetermination of the characteristics of such a motor, the effect of the short-circuit current under the brushes has to be taken into consideration, however. When a commutator is used, by the passage of the brushes from segment to segment coils are short-circuited. Therefore, in addition to the circuits considered above, a closed circuit on the rotor has to be introduced in the equations for every set of brushes. Reduced to the stator circuit by the ratio of turns, the self-inductive impedance of the short-circuit under the brushes is very high, the current, therefore, small, but still sufficient to noticeably affect the motor characteristics, at least at certain speeds. Since, however, this phenomenon will be considered in the chapters on the single-phase series and repulsion motors, it may be omitted here.

(5) *Polyphase Series Motor.*

If in a polyphase commutator motor the rotor circuits are connected in series to the stator circuits, entirely different characteristics result, and the motor no more tends to synchronise, as the induction motor with short-circuited secondary, nor approaches a definite speed at no load, as a shunt motor, but with decreasing load the speed increases indefinitely. In short, the motor has similar characteristics as the direct-current series motor. In this case, as in the following investigations of single-phase alternating-current motors, we may assume the stator reduced to the rotor by the ratio of effective turns.

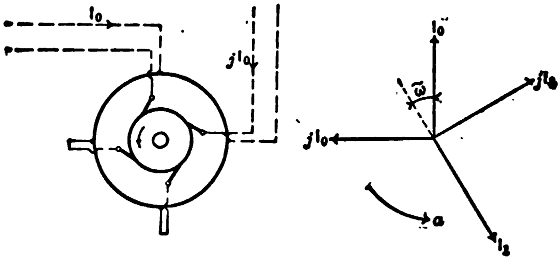

Fig. 8.— Polyphase series motor.

Let then, in the motor shown diagrammatically in Fig. 8:

E_0 and jE_0, I_0 and jI_0, Z_0 = impressed e.m.f's., currents and self-inductive impedance of stator circuits, assumed as two-phase, and reduced to the rotor circuits by the ratio of effective turns, c,

E_1 and jE_1, I_1 and jI_1, Z_1 = impressed e.m.f's. currents and self-inductive impedance of rotor circuits,

Z = mutual-inductance impedance,

a = speed and: $s = 1 - a$ = slip,

ω = brush angle,

c = ratio of effective stator turns to rotor turns.

If then:

E and jE = impressed e.m.f's., I and jI = currents of motor, it is:

$$I_1 = I \qquad (1)$$

$$I_0 = cI \qquad (2)$$

$$cE_0 + E_1 = E \tag{3}$$

and, stator:

$$E_0 = Z_0 I_0 + Z (I_0 - I_1 \cos\omega + jI_1 \sin\omega) \tag{4}$$

rotor:

$$E_1 = Z_1 I_1 + Z (I_1 - I_0 \cos\omega - jI_0 \sin\omega) + jaZ (jI_1 + I_0 \sin\omega - jI_0 \cos\omega) \tag{5}$$

and, e.m.f. of rotation:

$$E_1^1 = jaZ (jI_1 + I_0 \sin\omega - jI_1 \cos\omega) \tag{6}$$

Substituting (1), (2) in (4), (5), (6), and (4), (5) in (3), gives:

$$I = \frac{E}{(c^2 Z_0 + Z_1) + Z(1 + c^2 - 2c\cos\omega) + aZ(c\sigma - 1)} \tag{7}$$

where:

$$\sigma = \cos\omega + j\sin\omega \tag{8}$$

and:

$$E_1^1 = \frac{aZE(c\sigma - 1)}{(c^2 Z_0 + Z_1) = Z(1 + c^2 - 2c\cos\omega) + aZ(c\sigma - 1)} \tag{9}$$

and the power output:

$$P = /E_1^1, I_1/^1$$

$$= \frac{ae^2\{c(r\cos\omega + x\sin\omega) - r\}}{[(c^2 Z_0 + Z_1) + Z(1 + c^2 - 2c\cos\omega) + aZ(c\sigma - 1)]^2} \tag{10}$$

For: $c = 1$, or equal number of effective turns in stator and rotor, it is:

$$I = \frac{E}{Z_0 + Z_1 + 2Z(1 - \cos\omega) + aZ(\sigma - 1)} \tag{11}$$

$$P = \frac{ae_2(r\cos\omega + x\sin\omega - r)}{[Z_0 + Z_1 + 2Z(1 - \cos\omega) + aZ(\sigma - 1)]^2} \tag{12}$$

The characteristics of this motor entirely vary with a change of the brush angle ω. It is, for: $\omega = \sigma : P = \frac{ae^2r(c - 1)}{[D]^2}$, hence very small, while for $\omega = 90°$: $P = \frac{ae^2(xc - r)}{[D]^2}$, hence considerable. Some brush angles give positive P: motor, others negative P: generator.

Substituting in (7) for Z, etc., it is:

$$I = \frac{E}{\{c^2 r_0 + r_1 + r(1 + c^2 - 2c\cos\omega) + a(c(r\cos\omega + x\sin\omega) - r)\} - j\{c^2 x_0 + x_1 + x(1 + c^2 - 2c\cos\omega) + a(c(x\cos\omega - r\sin\omega) - x)\}} \tag{13}$$

hence the angle of lag of the current input behind the impressed e.m.f. is given by:

$$\tan\varphi = \frac{c^2 x_0 + x_1 + x\,(1 + c^2 - 2\,c\cos\omega) + a\,(c\,x\cos\omega - r\sin\omega) - x)}{c^2 r_0 + r_1 + r\,(1 + c^2 - 2\,c\cos\omega) + a\,(c(r\cos\omega + x\sin\omega) - r)}. \qquad (14)$$

In such a motor, by choosing ω and c, appropriately unity power factor or leading current as well as lagging current can be produced. The limits of this paper, however, do not permit a further discussion of the very interesting characteristics derived by choosing different values of c and ω in polyphase as well as single-phase shunt and series motors, and an investigation of the effect of the short-circuit current under the commutator brushes.

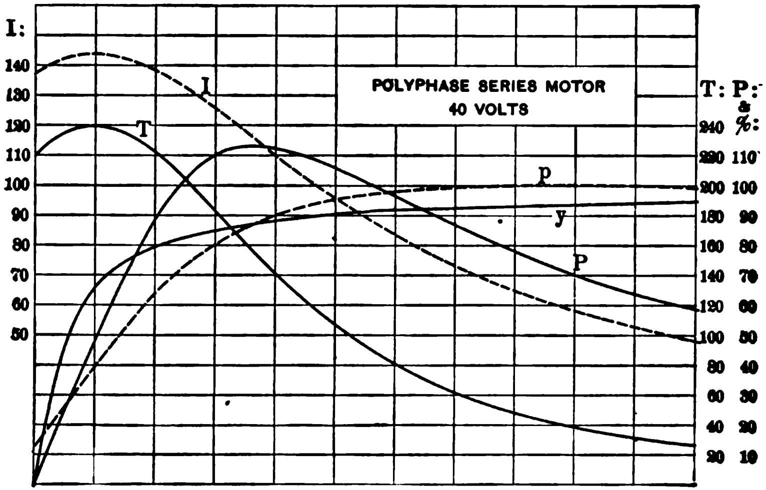

FIG. 9.

As instance as shown in Fig. 9, with the speed as abscissæ, and values from standstill to over double synchronous speed, the characteristic curves of a polyphase series motor of the constants:

$e = 640$ volts

$Z = 1 - 10\,j$ ohms

$Z_0 = Z_1 = .1 - .3\,j$ ohms

$c = 1$

$\omega = 37^\circ$ ($\sin\omega = .6$; $\cos\omega = .8$)

hence:

$$I = \frac{640}{(.6 + 5.8a) - j(4.6 - 2.6a)} \text{ amps.}$$

$$P = \frac{4673a}{(.6 + 5.8a)^2 + (4.6 - 2.6a)^2} \text{ kw.}$$

As seen, the motor characteristics are similar to those of the direct-current series motor: very high torque in starting and at low speed, and a speed, which increases indefinitely with the decrease of load. That is the curves are entirely different from those of the induction motors shown in the preceding. The power factor is very high, much higher than in induction motors, and becomes unity at the speed: $a = 1.77$, or about one three-quarter synchronous speed.

IV.

Single-Phase Commutator Motors.

In polyphase motors and motors of similar type a distributed rotor and stator winding is used, that is a structure having uniform magnetic reluctance and thus exciting impedance in all directions, and a polar construction of the stator winding results in lower power factor, and thus is permissible only in very small motors — as fan motors, etc. In direct-current motors a polar construction of the stator is almost exclusively used, that is a construction in which the reluctance in the direction of the magnetic field, which produces the e.m.f. of rotation, is very much smaller than in the direction at right angles thereto. In single-phase alternating commutator motors (as series motors, repulsion motors, etc.) both stator constructions may be used, and in the most general case we must, therefore, assume the magnetic reluctance and so the exciting impedance in the direction of the axis of the rotor circuits Z' as different from the exciting impedance Z at right angles to this axis. When different, the latter Z is usually far larger than the former Z', since Z is in the direction of the magnetic flux which produces the e.m.f. of rotation, that is corresponds to the field excitation, while in the direction of Z' energy transfer between stator and rotor, or compensation of rotor reaction takes place, but magnetic flux in the direction Z' does not produce e.m.f. and thereby power by the rotation of the motor.

The stator winding can, therefore, be considered as consisting of two components, or may be constructed of two separate circuits, in the directions in line and at right angles to the rotor winding, which circuits may be connected in series or energized in any other manner, as, for instance, by exciting one by the impressed e.m.f., short-circuiting the other upon itself, etc. With a completely distributed winding and an angle ω between the axes of the stator and the rotor circuits (the angle of brush position), the exciting or magnetizing component of the stator winding is $I_0 \sin \omega$, the compensating or power transferring component $I_0 \cos \omega$ if $I_0 =$ stator current, as shown in diagram Fig. 10. When using separate circuits for the two stator components, they can even magnetically be arranged differently, as, for instance, a unitooth or polar arrangement chosen for the field exciting circuit, a distributed winding for the compensating circuit. In this case obviously, when reducing all circuits to each other by the ratio of effective turns, the resultant vector of the distributed winding has to be used.

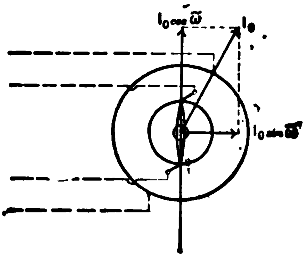

FIG. 10.

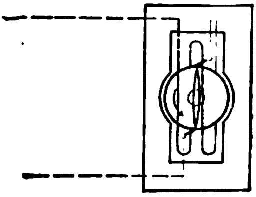

FIG. 11.— SINGLE-PHASE SERIES MOTOR.

As limit case, with zero compensating winding, appears the plain uncompensated series motor, consisting of a polar field exciting circuit and an armature with brushes at the neutral or at right angles to the field, as shown in Fig. 11; as a further limit case, a motor with zero field exciting winding on the stator and excitation of the rotor by a second system of brushes at right angles to the main or power brushes, as shown diagrammatically in Fig. 12.

In alternating-current commutator motors, especially of the single-phase type, the short-circuit current in the coils under the brushes during commutation has to be taken into consideration. While with numerous commutator segments, carbon brushes and possibly an additional resistance in the commutator leads, as occasionally used in such motors, these short-circuit currents may be moderate, they still are sufficient to noticeably affect the constants of the motor, especially at high speeds, where the main current is small, and at standstill, where the main magnetic flux is very large. Furthermore, the character of the commutation of the motor, and, therefore, its operativeness, depends upon these currents. An excessive short-circuit current gives destructive sparking, while zero short-circuit current would be conducive to perfect commutation. In comparing different types of such motors, the investigation of the short-circuit current under the brushes is, therefore, of fundamental practical importance.

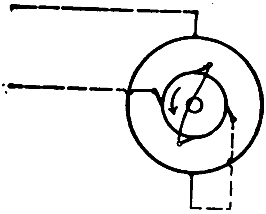

FIG. 12.—WINTER-EICHBERG-LATOUR MOTOR.

In its most general form, the single-phase commutator motor can thus be represented diagrammatically by Fig. 13.

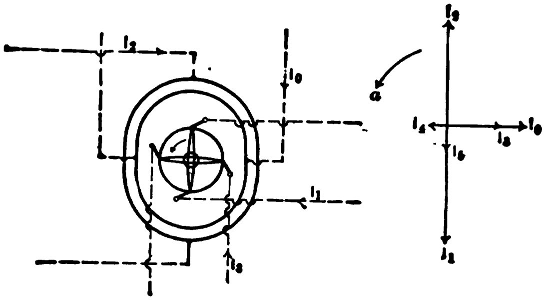

FIG. 13.

Let: E_0, I_0, Z_0 = impressed e.m.f. current and self-inductive impedance of magnetizing or exciter circuit of stator (field coils), reduced to the rotor energy circuit by the ratio of effective turns c,

E_1, I_1, Z_1 = impressed e.m.f., current and self-inductive impedance of rotor energy circuit (or circuit at right angles to I_0),

E_2, I_2, Z_2 = impressed e.m.f., current and self-inductive impedance of stator compensating circuit (or circuit parallel to I_1; the "cross-coil" of the Eickemeyer motor), reduced to the rotor circuit by the ratio of effective turns b,

E_3, I_3, Z_1 = impressed e.m.f., current and self-inductive impedance of the exciting circuit of the rotor, or circuit parallel to I_0,

I_4, Z_4 = current and self-inductive impedance of the short-circuit under the brushes I_1, reduced to the rotor circuit,

I_5, Z_5 = current and self-inductive impedance of the short-circuit under the brushes I_2, reduced to the rotor circuit,

Z = mutual impedance of field excitation, that is in the direction of I_0, I_3, I_4,

Z^1 = mutual impedance of armature reaction, that is, in the direction of I_1, I_2, I_5.

Z^1 usually either equals Z, or is much smaller than Z,

I_4 and I_5 are very small, Z_4 and Z_5 very large quantities.

Let: a = speed, as fraction of synchronism.

The equations of the six circuits now are:

$$E_0 = Z_0 I_0 + Z\ (I_0 + I_3 - I_4). \qquad (1)$$

$$E_1 = Z_1 I_1 + Z^1\ (I_1 + I_5 - I_2) + j\,a\,Z\ (I_0 + I_3 - I_4) \qquad (2)$$

$$E_2 = Z_2 I_2 + Z^1\ (I_2 - I_1 - I_5). \qquad (3)$$

$$E_3 = Z_1 I_3 + Z\ (I_3 + I_0 - I_4) + j\,a\,Z^1\ (I_2 - I_1 - I_5). \qquad (4)$$

$$o = Z_4 I_4 + Z\ (I_4 - I_0 - I_3) + j\,a\,Z^1\ (I_1 + I_5 - I_2). \qquad (5)$$

$$o = Z_5 I_5 + Z^1\ (I_5 + I_1 - I_2) + j\,a\,Z\ (I_0 + I_3 - I_4). \qquad (6)$$

Substituting:

$Z^1/Z = A$, where $A = 1$ with a motor of uniform reluctance, (7)

$$\left.\begin{aligned} Z/Z_4 &= \lambda_4 \\ Z/Z_5 &= \lambda_5 \end{aligned}\right\} \quad (8)$$

where λ_4 and λ_5 are small quantities, and suppressing terms of secondary order, equations (5) and (6) give:

$$I_4 = \lambda_4 \} (I_0 + I_3) + j\,a\,A\,(I_2 - I_1) \{ \qquad (9)$$

$$I_5 = \lambda_5 \{ (I_2 - I_1) - j\,a\,A\,(I_0 + I_3) \{ \qquad (10)$$

Substituting (9) and (10) into (1), (2), (3), (4), gives four equations containing the eight quantities: E_0, E_1, E_2, E_3, I_0, I_1, I_2, I_3, requiring four further conditions to be given, which are the conditions of operation of the four circuits, and distinguish the different types or modifications of such single-phase alternating-current motors.

Some of the types under practical considerations at present are:

(1.) Series Motor:

$$E = cE_0 + E_1;\ I_0 = cI_1;\ I_2 = o;\ I_3 = o.$$

(2.) Compensated Series Motor (Eickemeyer Motor).

(a.) direct compensation:

$$E = cE_0 + E_1 + bE_2;\ I_0 = cI_1;\ I_2 = bI_1;\ I_3 = o.$$

(b.) inductive compensation:

$$E = cE_0 + E_1;\ E_2 = o;\ I_0 = cI_1;\ I_3 = o.$$

(3.) Repulsion Motor (Thomson Motor):

$$E = cE_0 + bE_2;\ E_1 = o;\ cI_0 = bI_2;\ I_3 = o.$$

(4.) Compensated Repulsion Motor (Winter-Eichberg-Latour Motor):

$$E = bE_2 + fE_3;\ E_1 = o;\ I_0 = o;\ bI_2 = fI_3.$$

(5.) Inverted Series Motor:

$$E = E_1 + bE_2 + fE_3;\ I_0 = o;\ I_2 = bI_1;\ I_3 = fI_1.$$

(6.) Inverted Repulsion Motor:

$$E = E_1;\ cE_0 + bE_2 = o;\ cI_0 = bI_2;\ I_3 = o.$$

(7.) Induced Series Motor:

$$E = E_2;\ E_1 + cE_0 = o;\ cI_0 = I_1;\ I_3 = o.$$

Types (4.) and (5.) have two sets of brushes on the rotor.

In types (3.) and (7.), the rotor is not connected to the external or supply circuit, and its voltage can, therefore, be chosen independent of the supply voltage; in type (4.), by feeding circuit E_3 through transformer, the same may be secured.

Frequently in motors of uniform reluctance: $Z^1 = Z$, as the two stator circuits I_0 and I_2 the two parts of the same uniformly distributed circuit are used, and then $c/b = \tan \omega$, where ω = angle of brush shift.

Only a few of the more important types can be discussed in the following:

(1.) *Single-phase Series Motor.*

The plain or uncompensated single-phase series motor is usually designed with definite field poles, similar to the direct-current series motor (only that the field is laminated also). The object of the polar construction is to secure as low a value of Z^1 and as high a value of Z as possible, so as to reduce the armature self-induction which is not compensated, and secure a fair power factor.

Let then, in the motor shown diagrammatically in Fig. 14:

E = impressed e.m.f., I = current, c = ratio of effective field turns to effective armature turns;

E_0, I_0, Z_0, Z = impressed e.m.f., current, self-inductive and mutual-inductive impedance of field circuit, reduced to armature circuit;

E_1, I_1, Z_1, Z^1 = impressed e.m.f., current, self-inductive and mutual-inductive impedance of armature circuit;

I_4, Z_4 = current and self-inductive impedance of the short-circuit under the brush, reduced to the armature circuit.

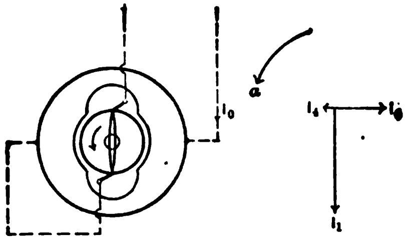

FIG. 14.— SINGLE-PHASE SERIES MOTOR.

a = speed.

$Z/Z_4 = \lambda = \lambda_1 - j\lambda_2 \quad Z^1/Z_4 = \lambda^1 = \lambda_1^1 - j\lambda_2^1$

It is then:

$$E = cE_0 + E_1 \tag{1}$$

$$I_0 = cI \tag{2}$$

$$I_1 = I \tag{3}$$

$$E_0 = Z_0\, I_0 + Z\,(I_0 - I_4) \tag{4}$$

$$E_1 = Z_1\, I_1 + Z^1 I_1 + jaZ\,(I_0 - I_4) \tag{5}$$

$$0 = Z_4\, I_4 + Z\,(I_4 - I_0) + jaZ^1\, I_1 \tag{6}$$

Hence:

$$I_4 = I\,(\lambda c - ja\lambda^1) \tag{7}$$

And:

$$I = \frac{E}{c^2(Z + Z_0) + (Z^1 + Z_1) + jacZ - Z\,(c + ja)\,(c\lambda - ja\lambda^1)}$$

$$= \frac{E}{c^2 Z_0 + Z_1 + Z^1 + Z\,(c + ja)\,(c\,(1 - \lambda) + ja\lambda^1)} \tag{8}$$

Or, denoting:

$$D = c^2 Z_0 + Z_1 + Z^1 + Z\quad (c + ja)(c(1 - \lambda) + ja\lambda^1) \tag{9}$$

$$I = \frac{E}{D} \tag{10}$$

$$I_4 = \frac{E\,(\lambda c - ja\lambda^1)}{D} \tag{11}$$

The e.m.f. of rotation of the main circuit is:

$$E_1^1 = jaZ\,(I_0 - I_4)$$

$$= \frac{jacZE\,(1 - \lambda + j\frac{a}{c}\lambda^1)}{D} \tag{12}$$

of the short-circuit under the brush:

$$E_4^1 = jaZ^1 \, I_1$$

$$= \frac{j a Z^1 E}{D} \qquad (13)$$

The power output of the motor is the algebraic sum of the power of the main rotor circuit, and that of the short-circuit under the brush, hence is:

$$P = /E_1^1, I/^1 + E_4^1, I_4/^1$$

$$= \frac{ace^2}{[D]^2} \left\{ /jZ(1 - \lambda + j\frac{a}{c}\lambda^1), 1/^1 + /jZ_1^1, \lambda - j\frac{a}{c}\lambda^1 /^1 \right\}$$

$$= \frac{ace^2}{[D]^2} \left\{ /jZ, 1/^1 - /jZ \, \lambda, 1/^1 - \frac{a}{c}/Z\lambda^1, 1/^1 + /jZ^1, \lambda/^1 - \right.$$

$$\left. \frac{a}{c}/Z^1, \lambda^1/^1 \right\}$$

and since:

$$/jZ, \, 1/^1 = x$$

$$/jZ\lambda, \, 1/^1 = x\lambda_1 + r\lambda_2$$

$$/Z\lambda^1, \, 1/^1 = r\lambda_1^1 - x\lambda_2^1$$

$$/jZ^1, \, \lambda/^1 = x^1\lambda_1 - r^1\lambda_2$$

$$/Z^1, \, \lambda^1/^1 = r^1\lambda_1^1 + x^1\lambda_2^1$$

it is:

$$P = \frac{acxe^2}{[D]_2} \left\{ 1 - \frac{1}{x} \left((x - x^1)\lambda_1 1 + (r + r^1)\lambda_2 + \frac{a}{c} \right. \right.$$

$$\left. \left. (r + r^1)\lambda_1^1 - \frac{a}{c}(x - x^1)\lambda_2^1 \right) \right\} \qquad (14)$$

and the torque:

$$T = \frac{P}{a} = \frac{cxe^2}{[D]^2} \left\{ 1 - \frac{1}{x} \left((x - x^1)\lambda_1 + (r + r^1)\lambda_2 + \frac{a}{c} \right. \right.$$

$$\left. \left. (r + r^1)\lambda_1^1 - \frac{a}{c}(x - x^1)\lambda_2^1 \right\} \right) \qquad (15)$$

In the equation of the current (8),
$c^2 \, (Z_0 + Z)$ is the total impedance of the field,
$Z_1 + Z^1$ is the total impedance of the armature, hence:
$c^2 \, (Z_0 + Z) + (Z_1 + Z^1)$ is the total impedance of the motor, corresponding to the e.m.f. consumed by the effective resistance and the self-induction of field and armature,
$jacZ$ corresponds to the e.m.f. of rotation, or the mechanical work done by the motor, and
$Z \; (c + ja) \; (c\lambda - ja\lambda^1)$ is the effect of the short-circuit current under the commutator brush.

Neglecting the short-circuit current of commutation, as of secondary order, it is:

$$\left.\begin{aligned} I &= \frac{E}{c^2(Z+Z_0)+(Z^1+Z_1)+jaZ} \\ &= \frac{E}{\{c^2(r+r_0)+(r^1+r_1)+acx\}-j\{c^2(x+x_0)+(x^1+x_1)-acr\}} \end{aligned}\right\} \tag{16}$$

hence, the angle of lag of the current I behind the impressed e.m.f. E is given by:

$$\tan\varphi = \frac{c_2(x+x_0)+(x^1+x_1)-acr}{c^2(r+r_0)+(r^1+r_1)+acx} \tag{17}$$

With increasing speed a, the numerator decreases, the denominator increases, hence the angle of lag ϕ decreases and the power factor cos ϕ increases.

The power factor of the motor becomes unity, or $\phi = o$, at the speed:

$$a = \frac{c^2(x+x_0)+(x^1+x_1)}{cr} \tag{18}$$

That is at some very high speed the power factor of the single-phase alternating-current series motor, even if not compensated, would become unity, if there were no commutation losses.

On first sight this is unexpected, since even assuming the armature as entirely non-inductive, in addition to the e.m.f. induced in the armature by the rotation through the alternating magnetic field, and in phase thereto, in the field coils a quadrature e.m.f. must be induced by the same magnetic flux, and while the former increases relatively to the latter with the speed, the quadrature e.m.f. obviously never can become zero.

The explanation is found in the following: In equation (17) the denominator contains the effective exciting resistances r as factor, which represents the hysteretic loss in the motor, and if $r = o$, or no hysteresis loss, unity power factor would be reached only at infinite speed. Due to the hysteresis loss in the alternating magnetic field, when considering equivalent sine waves, the magnetic flux lags behind the magnetizing current by the angle of hysteretic lag α, and the e.m.f. of rotation, which is in phase with the magnetic flux, therefore, lags behind the current, that is the current leads the e.m.f. of rotation, and so at a certain definite speed compensation for the lag due to the e.m.f. of self-induction in the motor takes place by the lead of the e.m.f. of rotation ahead of the magnetizing current, which in this case is the main current of the motor. This feature is found in nearly all types of single-phase commutator motors, that is at a certain high speed, when neglecting commutation losses, the current is in phase with the impressed e.m.f. (and at still higher speed leading), and when considering equivalent sine waves the power factor is unity. Considering the actual wave shape, however, there remains a wattless component which represents the wave-shape distortion caused by the hysteretic cycle of the magnetic field. It also follows that in all such single-phase commutator motors a certain wave-shape distortion must take place, since the e.m.f. of rotation is of the same wave shape as the magnetic field flux, but the magnetic field flux and the current differ in wave shape by the wave-shape distortion represented in the hysteretic cycle of the magnetic structure.

At given speed a, the power factor is a maximum for that value of c, where:

$$\frac{d}{dc}(\tan\varphi)=o$$

substituting (17), and suppressing quantities of higher order, this gives:

$$c=\frac{rx^1+xr^1}{az^2}+\sqrt{\frac{xx^1+rr^1}{z^2}+\left(\frac{rx^1-xr^1}{az^2}\right)^2}$$

or approximately, for higher speeds a:

$$c=\sqrt{\frac{xx^1+rr^1}{z}} \qquad (20)$$

Since $Z^1<Z$, condition of good power factor of an uncompensated single-phase series motor is: $c<1$, that is, low field excitation and high armature reaction. Let, for instance, $Z=1-10j$, $Z^1=.25-2.5j$, it is: $a=.5$, or the number of effective armature turns equals twice the number of effective field turns.

As an instance are shown, in Fig. 15, with the speed a as abscissæ, and for values up to above double synchronism, the characteristic curves of a single-phase series motor of the constants:

$e=800$ volts.
$Z=1-10j$ ohms
$Z^1=.25-2.5j$ ohms
$Z_1=.1-.3j$ ohms
$Z_0=.4-1.2j$ ohms
$Z_4=30-30j$ ohms, hence: $\lambda=.18-.15j$; $\lambda^1=.045-.038j$
$c=.5$

hence:

$$I = \frac{800}{(1.03 + 4.27a + .35a^2) - j(5.19 - .98a - .49a^2)}$$

$$P = \frac{640a\,(4.23 + .25a)}{(1.03 + 4.27a + .35a^2)^2 + (5.19 - .98a - .49a^2)^2}$$

As seen, at very high speeds, power factor p and efficiency y reach very good values.

The curves are similar to those of the direct-current series motor, except that with increasing speed, current, torque and power fall off rather slower, that is, the motor tends more toward racing at light load.

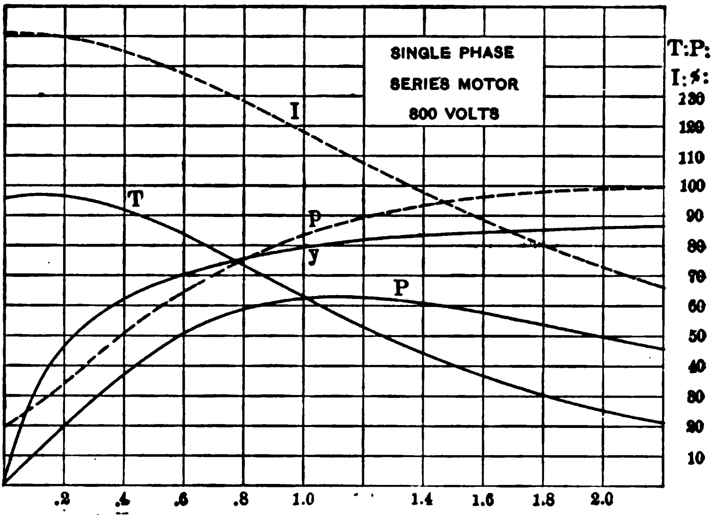

FIG. 15.

(2) *Compensated Series Motor* (*Eickemeyer Motor*).

To secure good power factors in a single-phase series motor, a low field self-inductance, that is low number of field exciting turns, is necessary, and, therefore, a high number of armature turns, to get the required output. Increasing the ratio of the armature reaction to field excitation, a limit is reached, where the increase of armature self-inductance overbalances the decrease of field inductance, and the power factor again decreases. In the preceding instance shown in Fig. 15 this limit is reached at an armature reaction equal to about twice the field excitation, and at this proportion the power factor is highest, but still rather poor at low and moderate speeds. Better proportions may possibly be reached by different design, but in this feature the limitation of the plain series motor is found: in the limited armature reaction permissible by armature self-induction. By compensating for the armature reaction and so more or less completely neutralizing its self-induction, a higher ratio of armature reaction to field excitation and so better power factors may be secured. The armature self-induction is compensated by surrounding the armature by a stationary circuit, through which a current passes in opposite direction to the current in the armature. This compensating circuit may either be energized by the main current in series to the armature, or by a secondary current, by closing it upon itself in short-circuit. The compensated series motor then contains a field exciting coil in quadrature position to the armature circuit and a compensating coil in line with the armature circuit. The field may be a polar structure as in the Eickemeyer motor of 1890, or a distributed winding. The compensating circuit preferably has a distributed winding, since it should neutralize the distributed armature winding. Frequently in such motors a uniformly distributed stator winding is used, of which one section is used for field excitation, the other for compensation, by using either separate coils, or the same coil, tapping into it at an angle ω with the direction of the rotor circuit.

When compensating by passing the main current through the compensating circuit in series to the armature circuit, by choosing the number of turns of the compensating circuit, under-compensation, or overcompensation, or complete compensation can be secured. Complete compensation obviously gives the best power factor. Some valuable features, however, are produced by overcompensation.

When compensating by closing the compensating circuit upon itself, as secondary short-circuit, the compensation necessarily is always approximately complete.

(*a*) *Directly Compensated Motor.*

Let in the motor shown diagrammatically in Fig. 16:

$E =$ impressed e.m.f., $I =$ current of the motor,

E_0, I_0, $Z_0 =$ impressed e.m.f., current and self-inductive impedance of field exciting circuit, reduced to the armature circuit by the ratio c of effective field turns to effective armature turns,

E_1, I_1, $Z_1 =$ impressed e.m.f., current and self-inductive impedance of armature circuit,

E_2, I_2, $Z_2 =$ impressed e.m.f., current and self-inductive impedance of (stationary) compensating circuit, reduced to the armature circuit by the ratio of effective turns b,

I_4, $Z_4 =$ current and self-inductive impedance of the short-circuit under the commutator brush, reduced to the armature circuit,

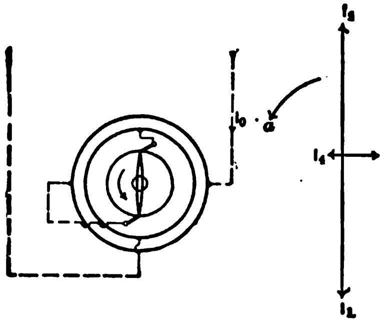

Fig. 16.—Eickemeyer motor direct compensation.

$Z =$ mutual-inductive impedance, constant in all directions,
$Z/Z_4 = \lambda = \lambda_1 - j\lambda_2$.
$a =$ speed.

It is then:

$$E = E_1 + cE_0 + bE_2 \qquad (1)$$

$$I_0 = cI \qquad (2)$$

$$I_1 = I \qquad (3)$$

$$I_2 = bI \qquad (4)$$

Field circuit:

$$E_0 = Z_0 I_0 + Z(I_0 - I_4) \qquad (5)$$

Compensating circuit:

$$E_2 = Z_2 I_2 + Z(I_2 - I_1) \qquad (6)$$

Armature circuit:

$$E_1 = Z_1 I_1 + Z(I_1 - I_2) + jaZ(I_0 - I_4) \qquad (7)$$

Brush short-circuit:

$$o = Z_4 I_4 + Z(I_4 - I_0) + jaZ(I_1 - I_2) \qquad (8)$$

Herefrom follows:

$$I_4 = \lambda I \{ c - ja(1 - b) \} \qquad (9)$$

$$= \lambda c I \text{ approximately} \qquad (10)$$

Main current:

$$I=\frac{E}{\left\{c^2 Z_0+Z_1+b^2 Z_2+Z(1-b)^2\right\}+cZ(c+ja)(1-\lambda)} \qquad (11)$$

$$=\frac{E}{D} \qquad (12)$$

where:

$$D=\left\{c^2Z_0+Z_1+b^2Z_2+Z(1-b)^2\right\}+cZ(c+ja)(1-\lambda) \qquad (13)$$

Short-circuit current under brushes:

$$I_4=\frac{\lambda E\left\{c-ja(1-b)\right\}}{D} \qquad (14)$$

$$=\frac{\lambda cE}{D} \text{ approx.} \qquad (15)$$

e.m.f. of rotation of main armature circuit:

$$E_1{}^1=\frac{jacZE(1-\lambda)}{D} \qquad (16)$$

e.m.f. of rotation of brush short-circuit:

$$E_4{}^1=\frac{jaZ(1-b)E}{D} \qquad (17)$$

Power output:

$$P=/E_1{}^1,\ I/^1+/E_4{}^1,\ I_4/^1.$$

$$=\frac{ace^2}{[D]^2}\left\{/jZ(1-\lambda),\ 1/^1+/jZ(1-b),\ \lambda/^1\right\}$$

$$=\frac{ac\,xe^2}{[D]^2}\left\{1-b\lambda_1-(2-b)\frac{r}{x}\lambda_2\right\} \qquad (18)$$

Torque:

$$T=\frac{cxe^2}{[D]^2}\left\{1-b\lambda_1-(2-b)\frac{r}{x}\lambda^2\right\} \qquad (19)$$

In the equation of the current, (11), $c^2(Z_0+Z)$ is the total impedance of the field, b^2Z_2 is the total impedance of the compensating circuit, $Z_1+Z(1-b)^2$ is the total impedance of the armature, the component $Z(1-b)^2$ being due to incomplete compensation. In the uncompensated motor on its place stands Z^1.

Neglecting the effect of the short-circuit under the brush in equation (11), and substituting for Z, etc., it is:

$$I=\frac{E}{\left\{c^2(r_0+r)+b^2r_2+r_1+(1-b)^2r+acx\right\}-j\left\{c^2(x_0+x)+b^2x_2+x_1+(1-b)^2x-acr\right\}} \qquad (20)$$

hence the angle of lag of the motor:

$$\tan\varphi=\frac{c^2(x_0+x)+b^2x_2+x_1+(1-b)^2x-acr}{c^2(r_0+r)+b^2r_2+r_1+(1-b)^2r+acx} \qquad (21)$$

$\phi=o$, that is, unity power factor is reached at the speed:

$$a=\frac{c^2(x_0+x)+b^2x_2+x_1+(1-b)^2x}{cr} \qquad (22)$$

The explanation hereof is the same as in the preceding chapter.

The term $(1-b)^2 Z$ disappears, that is, complete compensation takes place for: $b=1$.

Substituting $b=1$, gives:

$$I=\frac{E}{\{c^2(r_0+r)+r_2+r_1+acx\}-j\{c^2(x_0+x)+x_2+x_1-acr\}}$$

$$\tan\varphi=\frac{c^2(x_0+x)+x_2+x_1-acr}{c^2(r_0+r)+r^2+r_1+acx}$$

At given speed a, the power factor is a maximum, that is, ϕ a minimum, for the value of c, where:

$$\frac{d}{dc}(\tan\varphi)=o$$

this gives:

$$c=\frac{rx_2-xr_2}{az^2}+\sqrt{\frac{xx_2+rr_2}{z_2}+\left(\frac{rx_2-xr_2}{az^2}\right)^2} \qquad (23)$$

or approximately, for higher values of a:

$$c=\frac{\sqrt{xx_2+rr_2}}{z} \qquad (24)$$

Since the self-inductive impedance Z_2 is very small compared with the exciting impedance Z, c is a small fraction, that is, the armature reaction of the completely compensated motor can be made very much higher than the field excitation. For instance, let: $Z=1-10j$; $Z_2=.13-.4j$, it is: $c=.2$.

The e.m.f. of rotation of the short-circuited coil under the brush:

$$E_4{}^1=\frac{jaZ\,(1-b)\,E}{D} \qquad (17)$$

contains the factor $(1-b)$, hence disappears at complete compensation, $b=1$, and reverses its direction by overcompensation: $b>1$. Hence, by overcompensation a reverse e.m.f. can be inserted into the coil short-circuited under the brushes, and thereby the commutation controlled, that is, sparkless commutation secured, at the expense, however, of some decrease of the power factor.

As instance may be considered a motor of the constants:

$e = 500$ volts,
$Z = 1 - 10j$ ohms,
$Z_1 = .1 - .3j$ ohms,
$Z_2 = .13 - .4j$ ohms,
$Z_0 = .4 - 1.2j$ ohms,
$Z_4 = 30 - 30j$ ohms,

Hence: $\lambda = .18 - .15j$
$c = .25$

hence:

$$I = \frac{500}{(.4+2.01a) - j\,(1.28 - .58a)}$$

$$P = \frac{502.5a}{(.4+2.01a)^2 + (1.28 - .58a)^2}$$

Since the curves of this motor are almost identical with those of the inductively compensated motor, they are not given.

(*b.*) *Inductively Compensated Motor.*

Let, in the motor shown diagrammatically in Fig. 17 the denotations be the same as in (*a.*), the directly compensated motor, except that now I_2 is a separate, secondary current, and not $= bI$, and $E_2 = o$. It is then:

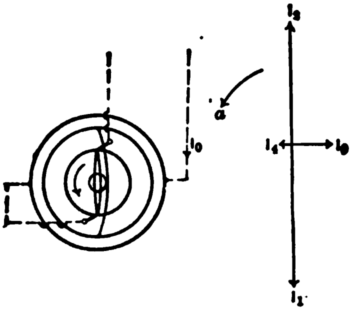

FIG. 17.—EICKEMEYER MOTOR INDUCTIVE COMPENSATION.

$$E = E_1 + cE_0, \qquad (1)$$

$$I_0 = cI, \qquad (2)$$

$$I_1 = I, \qquad (3)$$

Field circuit:

$$E_0 = Z_0 I_0 + Z\,(I_0 - I_4) \qquad (4)$$

Armature circuit:

$$E_1 = Z_1 I_1 + Z \ (I_1 - I_2) + jaZ \ (I_0 - I_4) \tag{5}$$

Compensating circuit:

$$o = Z_2 I_2 + Z \ (I_2 - I_1)$$

Short-circuit under brush:

$$o = Z_4 I_4 + Z \ (I_4 - I_0) + jaZ \ (I_1 - I_2) \tag{7}$$

From (6) follows:

$$I_2 = \frac{Z}{Z + Z_2} I \tag{8}$$

from (7):

$$I_4 = \lambda I \left(c - ja \frac{Z_2}{Z + Z_2} \right) \tag{9}$$

hence substituted into equations (1) to (5):

Main current:

$$I = \frac{E}{c^2 Z_0 + Z_1 + \frac{ZZ_2}{Z + Z_2} + cZ \ (c + ja) \ (1 - \lambda)} \tag{10}$$

$$= \frac{E}{D} \tag{11}$$

where:

$$D = c^2 Z_0 + Z_1 + \frac{ZZ_2}{Z + Z_2} + cZ \ (c + ja) \ (1 - \lambda) \tag{12}$$

Short-circuit current under commutator brush:

$$I_4 = \frac{\lambda E \left(c - ja \frac{Z_2}{Z + Z_2} \right)}{D} \tag{13}$$

$$= \frac{\lambda c E}{D} \text{ approx.} \tag{14}$$

E.m.f. of rotation of main circuit:

$$E_1^1 = \frac{jacE \ (1 - \lambda)}{D} \tag{15}$$

E.m.f. of rotation of armature short-circuited coil:

$$E_4^1 = \frac{jaZ_2 E}{D} \tag{16}$$

hence very small.

Power output, suppressing terms of secondary magnitude:

$$P = \frac{acxe^2}{[D]^2} \left(1 - \lambda_1 - \frac{r}{x} \lambda_2 \right) \tag{17}$$

Torque:

$$T = \frac{cxe^2}{[D]^2} \left(1 - \lambda_1 - \frac{r}{x} \lambda_2 \right) \tag{18}$$

As seen, these equations contain: $\frac{ZZ_2}{Z+Z_2}$ instead of: $b^2 Z_2 + (1-b)^2 Z$ of the directly compensated motor, which latter, for $b=1$, gives Z_2. Since Z_2 is small compared with Z, $\frac{ZZ_2}{Z+Z_2}$ is almost identical with Z_2, inductive compensation gives almost identically the same results as complete direct compensation, and all conclusions derived under (*a.*) for the case of complete compensation: $b=1$, apply to the case of inductive compensation.

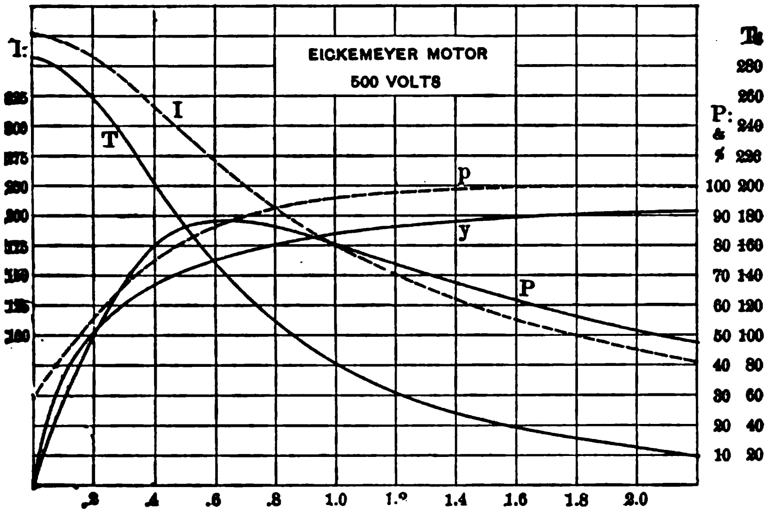

FIG. 18.

As instance are shown, in Fig. 18, with the speed a as abscissæ, the curves of an inductively compensated motor of the constants:

$e = 500$ volts,
$Z = 1 - 10j$ ohms,
$Z_1 = .1 - .3j$ ohms,
$Z_2 = .13 - .4j$ ohms,
$Z_0 = .4 - 1.2j$ ohms,
$Z_3 = 30 - 30j$ ohms, hence: $\lambda = .18 - .15j$
$c = .25$

Hence:

$$I = \frac{500}{(.39+2.01a) - j\,(1.27-58j)}$$

$$P = \frac{502.5a}{(.39+2.01a)^2 - (1.27-.58)^2}$$

Interesting is the very high power factor reached already at low speed: 80 per cent below half synchronism. At speed: $a = 2.19$ unity power factor is reached.

The starting torque is very large, and with increase of speed the torque falls rapidly, very similar as in a direct-current series motor.

(3) *Repulsion Motor* (*Thomson Motor*).

In Prof. E. Thomson's single-phase repulsion motor the stator is supplied with the main current, the rotor short-circuited upon itself through the commutator brushes under an angle with the axis of the stator circuit.

Amongst the single-phase commutator motors this repulsion motor takes a separate and distinctive position by its magnetic characteristics and their effect on commutation, so that single-phase commutator motors may be divided into series motors and repulsion motors. While both types of motors have similar speed characteristics, the magnetic flux of the repulsion motor is an elliptically rotating flux, while that of the series motor is essentially an alternating flux. In the series motors treated in the preceding, the magnetic flux in the axis of the rotor circuit is either negligible, in the compensated motor, or as magnetic flux of armature reaction in phase with the main magnetic flux. The e.m.f. induced in the armature coil short-circuited under the brush, by its rotation, is, therefore, either negligible or in phase with the main flux, while that induced by the alternation of the flux enclosed by the short-circuited coil is in quadrature with the main flux, and so with the e.m.f. of rotation, and the short-circuited coil is the seat of an active e.m.f. at all speeds. In the repulsion motor, the magnetic flux in the direction of the axis of the armature circuit is in quadrature with the current and thereby the flux at right angles with the armature circuit, but the former is constant, the latter varying inversely with the speed. The e.m.f. induced by rotation in the coil short-circuited under the commutator brush is in phase with the quadrature field of the motor, while the e.m.f. of alternation is in quadrature with the main field, and since the two fields are in quadrature with each other, the two e.m.f's. induced in the short-circuited coil are in opposition to each other, that is neutralize each other more or less completely. At synchronism the two e.m.f's. are equal and opposite, the neutralization complete and commutation, therefore, theoretically perfect.

The repulsion motor can be constructed with distributed or with polar stator winding. Since, however, compensation takes place of the armature reaction by the primary current and the secondary current flowing in opposite direction, and the rotating m.m.f. of the motor can produce a uniformly revolving (circular or elliptic) magnetic field only in a structure of uniform reluctance, polar winding gives decidedly inferior characteristics and a distributed stator winding is, therefore, assumed in the following. With polar construction, different exciting impedances Z and Z^1 have to be introduced in the two quadrature directions.

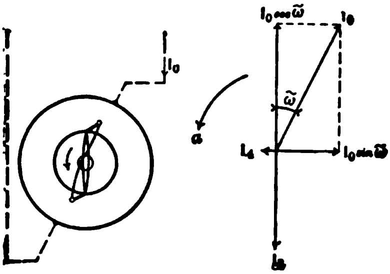

FIG. 19.—THOMSON MOTOR.

Let, in a repulsion motor:

E_0, I_0, Z_0 = impressed e.m.f., current and self-inductive impedance of primary or stator circuit,

I_1, Z_1 = current and self-inductive impedance of secondary or rotor circuit, reduced to primary by the ratio of effective turns,

I_4, Z_4 = current and self-inductive impedance of short-circuit under brush, reduced to primary circuit,

Z = mutual-inductive impedance,

$Z/Z_4 = \lambda = \lambda_1 - j\lambda_2$,

a = speed, as fraction of synchronism,

ω = angle between axis of primary and secondary circuit, or angle of brush shift.

It is then, in the motor shown diagrammatically in Fig. 19.

Stator:

$$E_0 = Z_0 I_0 + Z_0 \ (I_0 - I_1 \cos \omega - I_4 \sin \omega) \qquad (1)$$

Rotor:

$$o = Z_1 I_1 + Z_1 \ (I_1 - I_0 \cos \omega) + jaZ \ (I_0 \sin \omega - I_4) \qquad (2)$$

Short-circuit under brush:

$$o = Z_4 I_4 + Z_4 \ (I_4 - I_0 \sin \omega) + jaZ \ (I_1 - I_0 \cos \omega) \qquad (3)$$

hence:

$$I_4 = \lambda \left\{ I_0 (\sin \omega + ja \cos \omega) - ja I_1 \right\} \qquad (4)$$

and, substituting (4) in (2):

$$I_1 = I_0 Z \frac{(\cos a - ja \sin \omega) - a\lambda (a \cos \omega - j \sin \omega)}{Z + Z_1 - a_2 \lambda Z} \qquad (5)$$

substituting (4) and (5) in (1):

$$I_0 = \frac{E_0}{Z} \frac{Z_1 + Z(1 - a_2 \lambda)}{Z_0 + Z_1 + Z \sin \omega (\sin \omega + ja \cos \omega)(1 - \lambda)} \qquad (6)$$

or, denoting:

$$D = Z_0 + Z_1 + Z \sin \omega \ (\sin \omega + ja \cos \omega) \ (1 - \lambda) \qquad (7)$$

Primary or main current:

$$I_0 = \frac{E_0 \left\{ Z_1 + Z(1 - a_2 \lambda) \right\}}{Z D} \qquad (8)$$

Secondary current:

$$I_1 = E_0 \frac{\left\{ (\cos \omega - ja \sin \omega) - a\lambda (a \cos \omega - j \sin \omega) \right\}}{D} \qquad (9)$$

Short-circuit current under brush:

$$I_4 = \frac{\lambda E_0 (1 - a_2) \sin \omega}{D} \qquad (10)$$

E.m.f. of rotation of main armature circuit:

$$E_1{}^1 = jaZ \ (I_0 \sin \omega - I_4)$$

$$= jaE_0 \sin \omega \frac{Z_1 + Z(1 - \lambda)}{D}$$

E.m.f. of rotation of short-circuit under brush:

$$E_4{}^1 = jaZ \ (I_1 - I_0 \cos \omega)$$

$$\left. \begin{aligned} &= \frac{a E_0 \left\{ a Z (1 - \lambda) \sin \omega - j Z_1 \cos \omega \right\}}{D} \\ &= \frac{a_2 E_0 Z \sin \omega}{D} \quad \text{approx.} \end{aligned} \right\} \qquad (11)$$

The power output is:

$$P = /E_1{}^1, I_1/^1 + /E_4{}^1, I_4/^1$$

$$= \frac{a e_0{}^2 \sin \omega}{[D]^2} \Big\{ /j \left\{ Z_1 + Z(1 - \lambda) \right\}, (\cos \omega \, Z j a \sin \omega) - a\lambda (a \cos \omega$$

$$- j \sin \omega) /^1 + a (1 - a^2) \sin \omega / Z, \lambda /^1 \Big\}$$

$$= \frac{a e^2{}_0 \sin \omega}{[D]^2} \Big\{ /j \ (Z_1 + Z), \cos \omega - ja \sin \omega /^1 - \cos \omega /jZ\lambda, 1/^1 +$$

$$a \sin \omega / Z\lambda, 1/^1 - a^2 \cos \omega /jZ, \lambda/^1 + a \sin \omega /Z, \lambda/_1 + a \ (1 - a^2)$$

$$\sin \omega /Z, \lambda /^1 \Big\}$$

$$= \frac{a e_0^2 \sin \omega}{[D]^2} \Big\{ (x + x_1) \cos \omega - a (r + r_1) \sin \omega - \lambda_1 (x (1 + a^2) \cos \omega = ra (Z - a^2) \sin \omega) - \lambda_2 (1 - a^2)(r \cos \omega - ax \sin \omega) \Big\} \quad (12)$$

As seen, in the repulsion motor, sin ω takes the place of c, the ratio of field exciting turns to armature turns, of the series motor. I_3 sin ω is the field exciting or magnetizing, I_0 cos ω the compensating circuit.

At synchronism: $a = 1$, it is:

$I_4 = o,$

that is, at synchronous speed, the short-circuit current under the commutator brushes of the repulsion motor is zero, and the commutation perfect.

It is then:

$$I_0 = \frac{E_0}{Z} \frac{Z_1 + Z(1 - \lambda)}{Z_0 + Z_1 + Z \sin \omega (\sin \omega + j \cos \omega)(1 - \lambda)}$$

or approximately, neglecting Z_0, and Z_1:

$$I_0 = \frac{E_0}{Z \sin \omega (\sin \omega + j \cos \omega)} \quad (13)$$

and, absolute:

$$i_0 = \frac{e_0}{z \sin \omega} \quad (14)$$

and the power factor:

$$\left. \begin{aligned} p &= \cos (\alpha + \omega - 90^\circ) \\ \text{where: } \tan \alpha &= \frac{x}{r} \end{aligned} \right\} \quad (15)$$

The secondary current is:

$$I_1 = \frac{E_0 (\cos \omega - j \sin \omega)}{Z \sin \omega (\sin \omega + j \cos \omega)} \quad (16)$$

or absolute:

$$i_1 = \frac{e_0}{z \sin \omega} \quad (17)$$

hence, at synchronism the secondary current equals the primary current, and leads it by angle ω.

The power is, at synchronism, approximately:

$$P = \frac{e_0^2}{z^2 \sin^2 \omega} \Big\{ (x + x_1) \cos \omega - (r + r_1) \sin \omega \Big\} \quad (18)$$

that is, the effect of the short-circuit under the brushes disappeared.

Since the repulsion motor contains the factor $(1 - a^2)$ in the short-circuit current under the brush, I_4, which does not appear in the series motor, within the range where this factor is small, that is, near synchronism and below synchronism, the short-circuit current is less, and the commutation, other things being equal, better in the repulsion than in the series motor. Considerably above synchronism, however, where $[1 - a^2] > 1$, the short-circuit current of the repulsion motor becomes large, and the commutation inferior to that of the series motor. Thus the repulsion motor is specially suited for the range of speed from standstill up to somewhat above synchronism, where the plain series motor is unsuitable by its lower power factor.

Neglecting the effect of commutation, it is:

$$I_0 = \frac{E_0}{Z}\,\frac{Z_0 + Z_1 + Z\sin\omega\,(\sin\omega + ja\cos\omega)}{Z_1 + Z} \qquad (19)$$

$$I_1 = \frac{E_0(\cos\omega + ja\sin\omega)}{Z_0 + Z_1 + Z\sin\omega\,(\sin\omega + ja\cos\omega)} \qquad (20)$$

or approximately:

$$I_0 = \frac{E_0}{Z_0 + Z_1 + Z\sin\omega\,(\sin\omega + ja\cos\omega)} \qquad (21)$$

$$= \frac{E_0}{r_0 + r_1 + r\sin^2\omega + ax\sin\omega\cos\omega) - j\,(x_0 + x_1 + x\sin^2\omega - ra\sin\omega\cos\omega)} \qquad (22)$$

or, absolute:

$$i_0 = \frac{e_0}{[D]} \qquad (23)$$

$$i_1 = \frac{e_0}{[D]}\sqrt{\cos^2\omega + a^2\sin^2\omega} = \frac{e_0}{[D]}\sqrt{1 - (1 - a^2)\sin^2\omega} \qquad (24)$$

hence, up to synchronism: $a < 1$, the secondary current is less than the primary current, at synchronism: $a = 1$, both currents are equal and above synchronism: $a > 1$, the secondary current is greater than the primary and does the magnetizing of the motor field.

The secondary current leads the primary current by the angle:

$$\tan\delta = a\tan\omega \qquad (25)$$

The phase angle of the motor is, approximately, and neglecting the effect of commutation:

$$\tan\varphi = \frac{x_0 + x_1 + x\sin^2\omega - ar\sin\omega\cos\omega}{r_0 + r_1 + r\sin^2\omega + ax\sin\omega\cos\omega} \qquad (26)$$

The power factor is a maximum, or the angle of lag ϕ a minimum, for the brush angle ω, where:

$$\frac{d}{d\omega}(\tan\varphi) = o$$

Neglecting secondary quantities this gives:

$$\sin \omega = \frac{r\,(x_0 + x_1) - x\,(r_0 + r_1)}{a z^2} + \sqrt{\frac{r(r_0 + r_1) + x(x_0 + x_1)}{z^2} + \left(\frac{r(x_0 + x_1) - x(r_0 + r_1)}{a z^2}\right)^2} \qquad (27)$$

hence, for: $a = 1$ or synchronism, if: $Z = 1 - 10j$; $Z_0 = Z_1 = .1 - .3j$, it is:

$\sin \omega = .235$

$\omega = 13.6$ deg.

This agrees with experimental evidence.

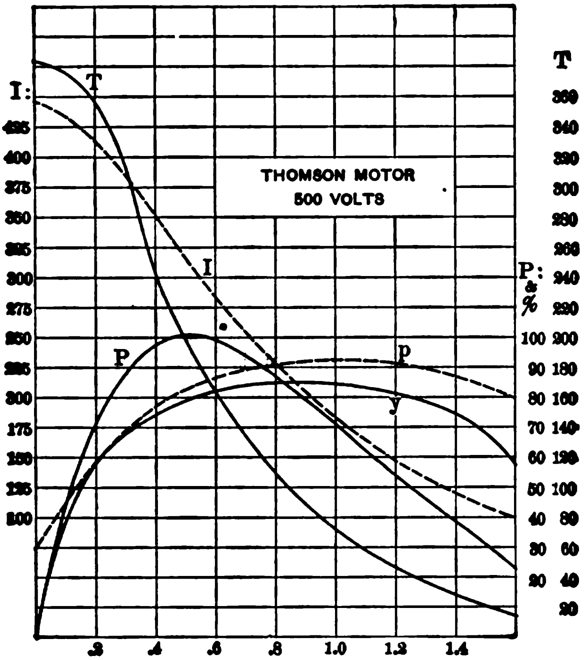

Fig. 20.

As instance are given, in Fig. 20, with the speed a as abscissæ, the characteristic curves of a repulsion motor of the constants:

$e_0 = 500$ volts,

$Z = 1 - 10j$ ohms,

$Z_0 = Z_1 = .1 - .3$ ohms,

$Z_4 = 30 - 30j$ ohms, hence: $= .18 - .15j$,

$\omega = 14$ deg., or: $\sin \omega = .25$; $\cos \omega = .97$.

Hence:

$$I_0 = 500 \frac{(1 - .175a^2) + j(.007 + .145a^2)}{(.335 + 1.89a) - j(1.07 - .545a)} \text{ amps.}$$

$$T = \frac{478 + 13.8a - 94.2a^2 - 24.7a^3}{(.335 + 1.89a)^2 + (1.07 - .545a)^2} \text{ synchr. kw}$$

As seen, the torque curve is extremely steep, that is, the starting torque higher than in any other motor, and torque and power become zero at a definite speed, 1.88 times synchronism. Power factor and efficiency are extremely high at low speeds, but begin to fall off beyond synchronism, though this falling off can greatly be reduced by limiting I_4.

V.

In the diagrams showing as instances the characteristic curves of different types of motors: polyphase and single-phase induction, polyphase series, single-phase series, compensated series or Eickemeyer motor, and repulsion or Thomson motor, the constants have, so far as possible, been chosen so as to represent the same motor structure: that is, to permit a direct comparison of the types, one and the same motor is assumed as operated as any of the different types, after making the changes in its electric and magnetic disposition necessary for this purpose.

In comparing the power factors it is interesting to note that the maximum power factors of the commutator motors are decidedly higher than those of the corresponding induction motors, and that, therefore, the same power factor as in the induction motor can be secured in the commutator motor with a much larger air gap between the stator and rotor. This is a very decided advantage, especially for railway work where induction motor air-gaps are mechanically extremely undesirable and unsafe.

In Figs. 21 and 22 are shown for comparison, with the speed as abscissæ, the torque and power of all the different motors. In Fig. 21 all the torque curves are reduced to equal torque at 95 per cent of synchronism. In Fig. 22 all the power curves to the same maximum output. Not too much stress, however, must be laid on these comparative curves since the characteristics of each motor may be varied to a considerable extent by the design, for instance, a motor designed for the highest possible efficiency, or highest starting torque, or best power factor, etc. Some general conclusions, however, can be drawn from these curves.

In the induction motors the torque curve is rising with the speed, in the commutator motors decreasing. The commutator motors, therefore, give maximum torque in starting and at low speed. The induction motors are operative efficiently only in a narrow speed range below synchronism, but unstable below this; that is the motor either slows down and comes to rest or accelerates with in-

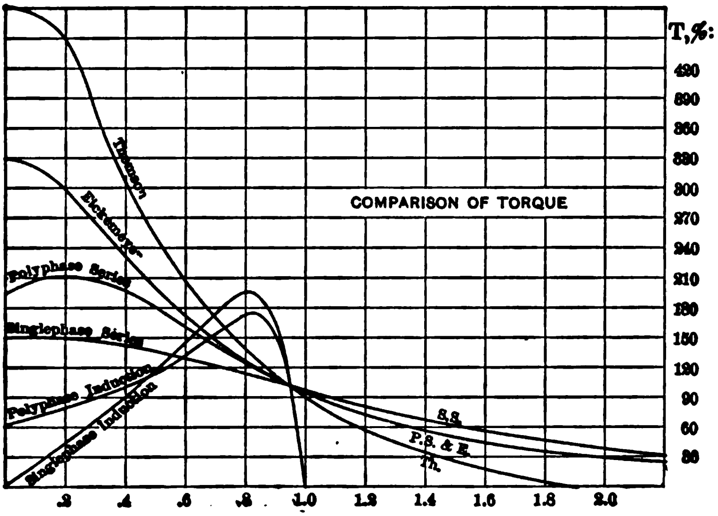

FIG. 21.

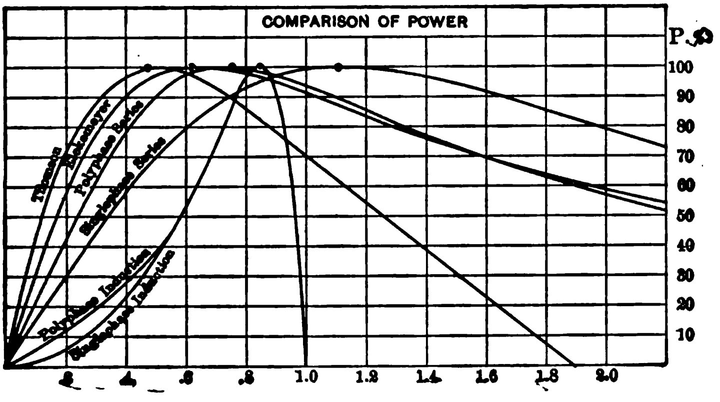

FIG. 22.

creasing rapidity until it approaches synchronism. At synchronism the torque and power of the induction motor reverse. High torque at low speeds can be secured only at a sacrifice of efficiency by armature resistance.

The induction motors are, therefore, essentially constant speed motors.

The repulsion motor shows the highest starting torque and the most rapid decrease of torque and power with increase of speed and reaches zero torque and power at a definite speed.

The single-phase series motor shows of all the commutator motors the lowest torque in starting, the highest at high speed; that is, its torque decreases least with increase of speed, so that in the case illustrated it almost approaches a constant torque motor.

The compensated motor is intermediate between the repulsion and series motor, but rather nearer to the former at low and to the latter at high speeds; that is, its torque is high in starting and at low speeds, but does not fall off as rapidly at high speeds as that of the repulsion motor.

To conclude, then, the induction motors are essentially constant-speed motors. The repulsion motor is a low-speed motor, the series motor a high-speed motor, while the compensated or Eickemeyer motor is intermediate between the repulsion and series motor, approaching the former at low, the latter at high speeds.

CHAIRMAN DUNCAN: **The next paper is on "Single-Phase Motors," by Mr. Max Déri, which will be abstracted by Mr. Slichter.**

SINGLE-PHASE MOTORS.

BY MAX DÉRI.

The single-phase motor has assumed of late an increasing importance since it has become known that it is not only applicable to traction, but possesses a peculiar adaptability thereto on account of the simplicity of the design, which permits of the use of high tension, and also on account of superior regulating and speed control.

It is obvious that we refer only to the single-phase motor with commutator, for the induction motor without commutator (the so-called asynchronous single-phase motor), to which we refer in this paper only for the purpose of comparison and criticism, cannot be seriously considered as a traction motor. Although views as to commutator machines for single-phase currents have become much clarified of late, and much of the prejudicial bias against them overcome, yet exact knowledge as to the internal phenomena of these machines, particularly those of commutation, is still very limited.

In this paper an attempt will be made to present a comprehensive review of the essential functions and relations of modern single-phase motors, in order to facilitate a comparison of the working conditions and commutating requirements of the different systems. The presentation of some new points of view may assist the understanding, and the many-sided and practical value of single-phase motors can be demonstrated still better by citing several hitherto unknown methods of construction.

The life of a motor system depends, above all, upon good commutation. The doubt as to the possibility of satisfactory commutation was the main cause why the value of the commutator motor and its adaptability to alternating-current did not receive appreciation. In the second place should be considered the capacity to develop sufficient torque at a moderate speed and with as high a power factor as possible. There are systems, as will be shown, which are far superior in this respect to the alternating-current series motor, and which also in comparison with the direct-current motor leave little to be desired. Such machines, which can be designated collectively under the name "Induction motors with commutators," have two fields, one of which induces the energy current, which in connection with the other field, according to phase and space relation, produces the torque.

The generation of power currents by induction (transformation) presents the great advantage that the machines can receive high tension directly; furthermore, there follows the consequence, important in many respects, that the commutation takes place in the secondary circuit, i. e., the low-tension circuit.

The following observations are based upon the two types of series motors: First, the usual arrangement shown in Fig. 1, in which the armature with commutator and the magnetic field are connected in series across the line as in the series direct-current motor; and, secondly, the arrangement shown in Fig. 2, in which the armature carrying the induced currents and the stator winding producing the field are connected in series, and short-circuited, form a closed secondary circuit.

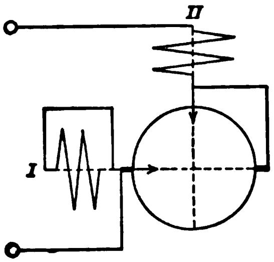

Fig. 1

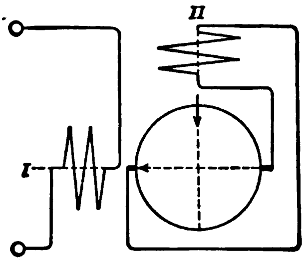

Fig. 2

In the first type, in which primary currents are commutated (Fig. 1), the self-induction of the armature is eliminated, for example, by a short-circuited winding on the stator, and which lies in the axis *I* of the brushes.

In Fig. 2 a transformer is combined with a motor. F_1 is the flux of the transformer, which the stator winding, *I*, constitutes with the armature, the former being connected to the main circuit. The brushes are short-circuited around the stator *II* so that the power currents in the armature produce the flux F_2. This latter field is actually the real field of the motor, because it lies in quadrature with the power currents and in conjunction with them develops the torque. The motor is in the secondary circuit, and only secondary currents are commutated, and the potential across the brushes in the direction of the axis, *I*, can be established with any desired ratio of pressure reduction. (In the deductions which follow, for the sake of simplicity, the ratio is assumed as 1 to 1).

The triangle of e.m.f's. — Fig. 3 — shows the relation between the several quantities in the series motor. $\overline{ab}$ represents the line potential with respect to phase and amount or the e.m.f. (E) between the brushes induced by the field, F_1. The phase of the transformer flux, F_1, whose amount is measured by $\overline{bc}$ or $\overline{ab}$ respectively, lies at right angles to these vectors, and for the primary series motor in the direction $\overline{ad}$, and for the secondary series motor in the direction $\overline{ad_2}$.

In both cases F_2 is excited by the armature current (power current I), F_2 and I are, therefore, always in phase. At any speed n, expressed as a fraction of synchronous speed, the e.m.f., E_a, induced in the armature, as a result of rotation in the field F_2, is in phase with this flux and, therefore, also in phase with the power current producing this flux. This e.m.f. $\overline{bc}$ is so represented that the exciting potential E_m, i. e., the potential necessary to excite the flux F_2, is at right angles to the phase of the current $\overline{ac}$.

In the phase direction $\overline{bc}$ is also found the ohmic drop Ir. The magnitude of this drop, which is of little importance in the relation and phase of the working quantities, as also the potential in the direction $\overline{bc}$ which is necessary to excite the stray field, will be left out of consideration in order not to render difficult the consideration of the general questions. These omitted quantities can be considered later, in the well-known way, in calculating the efficiency, temperature rise, etc., etc.

The triangle $\overline{abc}$ is the diagram of the series motor, and with its aid all the quantities involved can be deduced. In this diagram the phase angle δ assumes particular importance, not only for the determination of the power factor, but also to indicate the relation between the various quantities involved.

$$F_1 : \frac{1}{Z}\,\overline{bc}, \text{ or}: \frac{1}{Z}\,\overline{ab};\ F_2 : \frac{1}{Z}\,\overline{ac};\ I : \frac{\rho}{Z_2^{\,2}}\,ac$$

The sign : is that of proportionality; Z_1 and Z_2 the respective number of turns, although not variable, are given in order to indicate the dependence of the flux upon them. The same is true of the magnetic resistance ρ, which is only slightly variable between practical limits. The length $\overline{ac}$ is, therefore, the measure of both the flux F_2 and approximately also of the current I, the phase directions of both falling in $\overline{bc}$.

The torque $T : \frac{\rho Z_1}{Z_2^3} \overline{a\,c}^2$

The speed $n : \left(\frac{Z_2}{Z_1}\right)\frac{\overline{bc}}{\overline{a\,c}}$

The actual power output of the motor $P : \left(\frac{\rho}{Z_2^2}\right)\overline{a\,c} \times \overline{b\,c}$

The internal power factor $\cos\delta : \overline{bc}$.

Making $\overline{ab} = E$ and expressing above quantities as functions of the angle δ,

$I : E \sin\delta$; $T : E^2 \sin^2\delta$; $P : E^2 \sin\delta \cos\delta$, and $n : \operatorname{cotg}\delta$.

The apparent power output $E \times I : E^2 \sin\delta$.

If we project $\overline{c}$ on $\overline{ab}$, according to the above for $E = ab = 1$, $P : \overline{cg}$; $E \times I : \overline{ac}$; $T : \overline{ag}$.

In Fig. 4 the quantities T, P and $\cos\delta$ are constructed as functions of the speed, as $n : \cot\delta$, referred to a constant $\sin\delta$, is used as the axis of abscissæ. It appears clearly, from these curves, how rapidly T diminishes with increasing speed. In the case of the primary motor $\delta = \varphi$. In the case of the secondary series motor, it is necessary also to know the phase of the primary current. For this purpose we proceed according to Fig. 5 as follows:

The magnetizing current of the field F, in relation to the number of effective armature turns Z_1 is $i : \frac{\rho}{Z_1^2} \overline{ab}$, its phase is at right angles to $\overline{ab}$. If we lay down this constant value, in the ratio $\frac{\overline{bc}}{ac}$ then $\overline{cc^1}$ becomes the component of pressure by which the phase of the primary current $\overline{bc^1}$ is determined. The difference in phase between the primary and secondary currents is φ_1, and $\cos\varphi = \cos(\delta + \varphi_1)$ is the external power factor of the system.

The magnitude of $\overline{cc^1}$ is proportional to $\cot\delta$ and consequently to n. Similarly as in Fig. 4, referring to $\sin\delta$ as constant, we obtain the geometric locus of the points c^1 as a curve which at first gradually diverges from the circular arc in going from $\overline{b}$ toward a, then rapidly diverges and finally becomes assymptotic to $\overline{ad}$. The point of counter curvature of this curve corresponds to the values of δ and n at which $\cos\varphi$ is a maximum.

In the secondary series motor $\cos\varphi = 1$ cannot be reached; $\cos\varphi$ in the case of primary and $\cos\delta$ in the case of the secondary motor can only approach the value unity in the case of an ideal no-load operation.

As regards the process of commutation, we shall investigate in addition to the so-called reactance voltage, also the e.m.f's. induced in the short-circuited turns by the fluxes F_1 and F_2. These e.m.f's. are usually of a higher order, quantitatively, than the reactance voltage produced by the variation of contact between brush and commutator for the latter, as in the case of direct-current machines, is determined only by the stray field which is interlinked with the short-circuited turns, while the former are due to the total flux. The coil, short-circuited during commutation, is interlinked with the flux F_2 and at the same time cuts the field

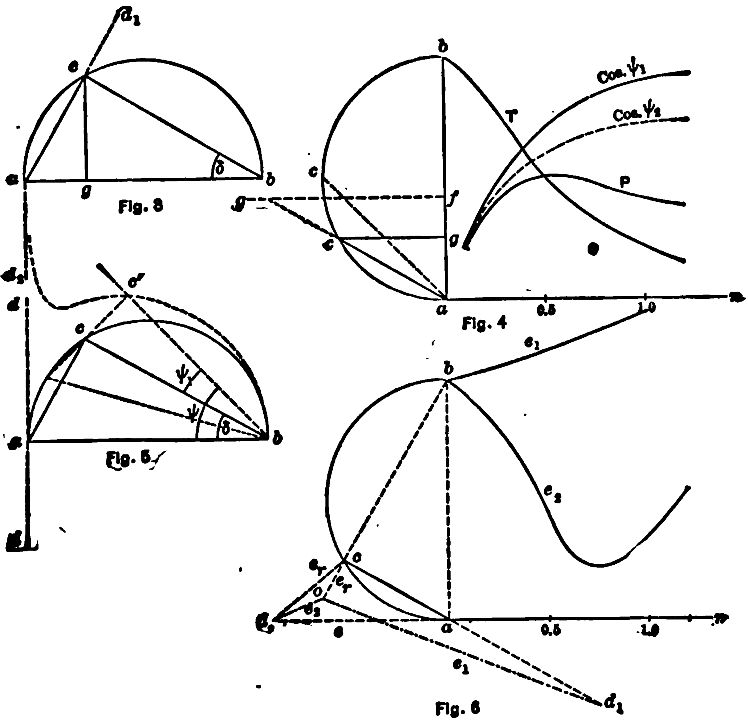

Fig. 3

Fig. 4

Fig. 5

Fig. 6

flux F_1 in its densest zone with a speed corresponding to n. There are, therefore, induced in the coil two different e.m.f's. both of the same frequency: i. e., $e_1 : F_2$ independent of the speed, proportional to F_2, with the phase of which it is in quadrature; and the $e_c : nF_1$, proportional to the speed and to F_1 and in phase with F_1.

The diagram of these e.m.f's. can be derived directly from the e.m.f. triangle Fig. 3, as shown in Fig. 6.

Let $\overline{ab}$ represent the measure of the e.m.f. e_1 corresponding to F_2 maximum and for a certain speed n : cotg δ. Draw the triangle $\overline{abc}$. The phase direction of F_2 is $\overline{bc}$, e_1 is at right angles to it and proportional to F_2 and hence determined by $\overline{ac}$ in dimension and phase. The magnitude of e_c in the direction of F_1, is $\overline{aa}$, at the speed n for instance.

For the primary series motor $\overline{ad}_1 : \frac{\overline{bc}^2}{\overline{ac}}$ for the secondary $\overline{ad}_2 = \frac{\overline{bc}}{\overline{ac}}$. The resultant e_0 of the e.m.f's. is cd_1 or cd_2 respectively.

As far as the reactance voltage e_r is concerned, its phase coincides with the current phase, being in the direction $\overline{bc}$, and quantitatively ${}_r : nI : E_a$ (on a scale approximately 0.1 — 0.2 $\overline{bc}$). From the diagram it appears that in the case of the primary motor, e_r and e_0 are always at right angles to each other, whereas in the case of the secondary motor the obtuse phase angle is variable and only at practicable speeds e_r and e_0 are opposed to one another. In the case of the secondary commutation we, therefore, arrive at an advantageous compensation of the reactance. The result of all three e.m.f's. in the short-circuited winding, e measured by $\overline{od}_1$ or $\overline{od}_2$ respectively must be considered in the commutation as the cause of sparking.

In Fig. 6 curves of e are shown for both methods of connecting the series motor. One sees that e in the case of the primary series motor (e_1) deviates but little from its initial value, and increases at greater speeds. In the case of the secondary series motor, on the contrary e_2 falls considerably below its initial value and is a minimum at a speed which lies within the limits of the usual operating speeds. The latter, therefore, commutates considerably better than the primary motor in which good commutation is out of the question.

We shall investigate in a similar way the repulsion motor in

Fig. 7. The stator winding is connected to the line and the brushes, inclined to the axis *Y* at an angle *α*, are short-circuited. The brush axis is indicated as *X*. We shall not proceed with the investigation of the operation of this motor according to the method usually followed of resolving the fields, e.m.f's. and ampere-turns into components as functions of sine and cosine *α*, but we shall proceed in other ways which are simpler and unobjectionable.

We may proceed in two ways: According to Fig. 8, we can divide the stator winding, which we may assume as uniformly distributed over the circumference of a closed stator, into two groups connected in series with the same current flowing through them and which exert and are subjected to the same effect as the combined system. The four groups of windings on the stator, as shown in the figure, are so connected as to produce, by the current flowing in all of them, the flux in the direction of the arrow, and to generate the field with the axis *Y*. In the distribution of the lines of force and the amount of magnetizing current, there must be taken into account, in addition to the magnetic resistance of the entire flux, the reaction of that part of the armature circuit which is short-circuited between the brushes. None of the effects suffer any change if we consider, as connected in the order shown, the ampere-turns *I* whose axis coincides with *X*, and the ampere-turns *II*, whose axis is perpendicular to *X*. Only the sequence of the single elements in the series has been changed, which is without any importance on the result. We have, therefore, two stator windings *I* and *II*, in general with different number of turns and also of different magnetic resistance, and the arc covered by the windings and the polar arc are unequal. The axis of the two windings are perpendicular to each other. We can, therefore, construct the diagram Fig. 9.

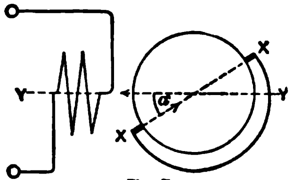

Fig. 7

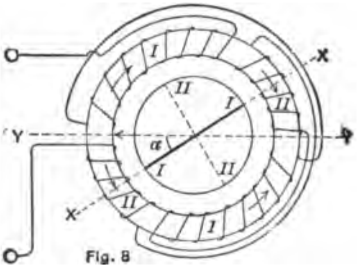

Fig. 8

We can proceed in another way in accordance with Fig. 10. In accordance therewith, the armature winding is divided into four groups which are connected in pairs *I* and *I*, then *II* and *II* in parallel, and the two pairs connected in series are closed on themselves. The division is such that the groups connected together when traversed by the current produce the same magnetic field in the direction of the arrows and corresponding with the brush axis *X*, as would the entire armature winding when short-circuited through the brushes. It appears, therefore, that the armature phenomena are as follows: In winding *I* an e.m.f is induced by the coaxial stator winding, which e.m.f. is equal to that of the entire armature; winding *I* forms a circuit closed through winding *II*, hence excites a flux in the latter which is free from any armature reaction. The diagram of this arrangement, in accordance with the foregoing analysis, is shown in Fig. 11.

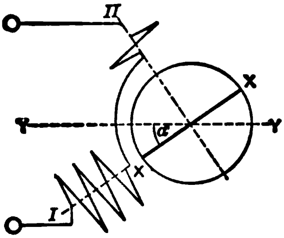

Fig. 9

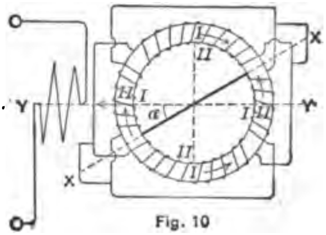

Fig. 10

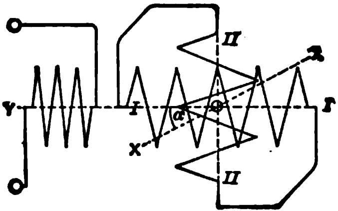

Fig. 11

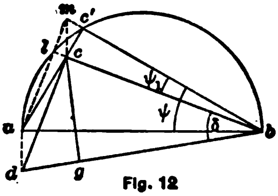

Fig. 12

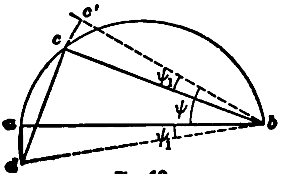

Fig. 13

This diagram differs from the arrangement shown in Fig. 2 in that the winding exciting the field is not on the stator but on the rotor. Whether the armature rotates in a field excited by fixed stator windings or by rotor windings amounts to the same inducing effect, provided only that in the latter case the axis of the exciting windings is held fixed by brushes.

According to the first arrangement the coils *I* are the inducing winding, and according to the second they are the induced winding; the coils *II*, however, on account of being at right angles to *X* or *Y*, respectively, can neither exert nor receive any induction. The ratio of the number of turns $\frac{Z_1}{Z_2}$ is $\frac{90^\circ - a}{a}$; the ratio of the poles faces the reciprocal $\frac{a_1}{90_0 - a}$. This alone sufficiently indicates the importance of the brush position, represented by the angle a and its effect on the flux, torque, etc. It appears also that by a variation of this angle by turning the brushes, all of the secondary quantities and their functions can be varied.

In Fig. 12 the armature current *I* in amount and phase is determined graphically by the following considerations:

$\overline{abc'}$ is the diagram of the primary pressures, $\overline{ab}$ the terminal pressure, $\overline{bc}'$ the e.m.f. of the armature and also the pressure of the stator winding *I*, and ac^1 that of the stator winding *II*. F_1 is proportional to $\overline{bc'}$ and in the direction $\overline{ac}^1$; the same is true of i. The component of the armature e.m.f. which, induced by the components F_2, belonging to the exciting current, i, is proportional to F_2 and to n: $\frac{\overline{bc'^2}}{ac}$ and can be measured by $\overline{cc'}$. Then $\overline{bc}$ is the component of the armature e.m.f. belonging to the exciting current *I* and, therefore, also the direction of *I*. The angle φ_1 lying between $\overline{bc}'$ and $\overline{bc}$ indicates the phase difference between primary and secondary current. If we prolong $\overline{bc}$ until it cuts the circle in l and we draw through l the line $\overline{am}$ until it cuts $\overline{bc'}$ prolonged, then, owing to the equality of the angles, $\overline{am} = \left(\frac{bc}{\overline{bc'}}\right) ac'$; $\overline{am}$ is, therefore, the measure of *I*, which is parallel and equal to $\overline{cd}$, produces the right-angled triangle $\overline{bcd}$ similar to $\overline{bc'a}$. The first is the diagram of the e.m.f's corresponding to the current *I*. The connection $\overline{ad}$ can be proven to be always perpendicular to $\overline{ab}$, and, $ad : n \left(\frac{Z_2}{Z_1}\right) \overline{ab} \,.\, \overline{bc}$ and $\overline{cd}$ are the quantities which are a measure of the torque and capacity because they depend on the armature current and on the component of the field which is in same phase with it.

We are obviously led to the same result if in investigation of the repulsion motor we proceed according to Figs. 10 and 11. The following consideration is much simpler than the foregoing and leads directly to the diagram of Fig. 13.

This is also the proof and confirmation of the result of the previous deductions. In this case the internal circuit consists of the two rotor windings I and II. In winding I the e.m.f $E:\overline{ab}$ is induced by a constant F_1. On rotating the armature the winding I cuts the flux *II,* and winding *II* the flux *I.* The e.m.f's. induced as a result of the rotation have the phase direction of the inducing fields. $E_a' . \overline{bc}$ is of the same phase as *I;* the e.m.f. in winding *II* E_k is at right angles to $\overline{ab}$.

$$E_k : \overline{ad} : nZ_2 F : n \left(\frac{Z_2}{Z_1}\right) \overline{ab}\cdot$$

The polygon of e.m.f's. is $\overline{abcda}$ in which $\overline{ad}$ is a compensating e.m.f. proportional to the speed, adding itself geometrically to the line pressure.

We can indicate the important quantities by Fig. 14, by constructing $\overline{ad:}\,n$ perpendicular to $\overline{ab}$, drawing the semi-circle around $\overline{bd}$, and determining the point $\overline{c}$ according to n ; cot δ . The quantities $\overline{bc, cd}$ and also $\overline{cd}$ and $\overline{ag}$ will vary in the ratio $1:\sqrt{1+n_2\left(\frac{Z_2}{Z_1}\right)^2}$ T and P will also increase with corresponding coefficients. The output of the repulsion motor will be as great as corresponds to the line pressure, and consequently at a given

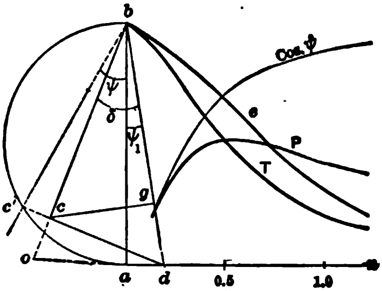

Fig. 14.

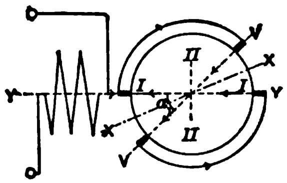

Fig. 15

speed as great as in the case of the primary and greater than in the case of the secondary series motor.

Since the compensating e.m.f. furnishes a part of the field excitation, it is necessary to provide a less number of ampere-turns externally in the ratio $\frac{\overline{ac}}{cd}$ as shown in Fig. 14. It can be shown that $\overline{ac} = \overline{bd} \sin(\delta - \varphi_1)$ while $\overline{cd} = bd \sin \delta$. For small values of δ in which $\overline{cd}$ still has a considerable value, $\overline{ac}$ may become small.

In addition, the compensating effect of $\overline{ad}$ is manifested by the fact that the phase difference between the power current and the e.m.f. is diminished by the angle φ_1. The phase shifting which takes place in the transformer I is to a certain extent balanced by the compensation. Cos φ will be about the same as in the case of the primary series motor and will, therefore, approach closer to the maximum value than in the case of the secondary series motor.

The commutation phenomena in the case of the repulsion motor can be represented by consideration similar to the foregoing, taking into account, however, that the e.m.f's. e_1 and e_c are induced by those fluxes, which, according to the analysis of Fig. 9, correspond to the number of turns Z_1 and Z_2. Therefore Fig. 14 shows also on the proper scale the diagram of e.m.f's. in the short-circuited winding. In amount and phase direction e_1: $\overline{cd}$, e_c : $\overline{ad}$ and e_0 : $\overline{ac}$; $\overline{ao}$ is, therefore, the e.m.f., e, resultant of all three. $\overline{ad}$ is proportional to the speed. We can, therefore, project the values of c as ordinates upon n. The curve shows the dependence of e upon n. e is, therefore, a maximum at starting (just as in the case of the series motor $e : \overline{ab}$), diminishes rapidly, however, with increasing speed and reaches at a certain speed a minimum, which is less than the reactance voltage.

The compensating e.m.f. of the repulsion motor depends upon the ratio $\frac{Z_2}{Z_1}$, hence upon $\frac{a}{90^\circ - a}$. On the other hand, the torque and energy of this motor is inversely proportional to the number of turns, i. e., inversely proportional to Z_2 or to higher powers of Z_2. Herein lies the weakness of the ordinary repulsion motor. It is not at all sufficient, as was originally believed, to shift the brushes by 45 deg. (i. e., one quarter of the polar distance), which would correspond to the ratio $\frac{Z_2}{Z_1} = 1$. The e.m.f. induced while at rest in the winding I would be barely sufficient to excite the field $F'_2 = F_1$ with the current $I = i$. The maximum power current would be i, hence the starting power too small and the output insufficient. Consequently it is necessary to make the angle α much less than 45 deg. in order to obtain sufficient torque. In reality the angle is chosen at about 25 deg. to 20 deg., corresponding to a value $\frac{Z_2}{Z_1} = 0.40$ to 0.30. In order, therefore, to obtain a greater output one sacrifices a part of the compensating effect.

The repulsion motor is, nevertheless, a very useful machine, particularly if the windings are carried out in two parts, as shown in the diagram, Fig. 9. With the aid of a switching arrangement, reversal of direction and control is easily made by the inversion and variation of the field of force. Another and more convenient method for the reversal and control within the widest limits consists in varying the ratio $\frac{Z_2}{Z_1}$ by shifting the brushes. In order to obtain the maximum output, it would be necessary to make α so small that it would embrace only two to three commutator bars, which would, however, make the motor unreliable in operation and commutation. On this account the output of the repulsion motor is limited; in other words, dependent upon the number of the commutator bars and the size of the commutator.

We will now refer to an arrangement devised by the author according to Fig. 15, in which all of the characteristics of the repulsion motor are left substantially undisturbed, permitting, however, the angle α to be made twice as large as with the usual arrangement. One pair of brushes is placed in the Y axis and another pair at the angle in the V axis. The two pairs of brushes are connected as shown, so that they embrace the obtuse angle $(180 - \alpha)$. The effect of this arrangement can be judged if one imagines an armature in the Y axis connected, as shown in series and in closed circuit with another armature in the V axis. The ratio of the number of turns $\frac{Z_2}{Z_1}$ in accordance with the diagrammatic analysis is in this case $\frac{\alpha_1}{180^\circ - \alpha_1}$. If this ratio and the resulting output are to be of the same value as before, i. e., $= \frac{\alpha}{90^\circ - \alpha}$, then will $\alpha_1 = 2\alpha$.

The brushes have to carry the same load in this arrangement as in the case of the ordinary repulsion motor with the same power current and cross-section of all brushes. The number of brushes need not be increased if with the proper winding of the armature fewer brushes are used than the number of poles, for instance, for eight poles, two positive and two negative poles have two brushes each.

This arrangement is particularly adapted to controlling by brush shifting, perhaps by shifting the *V* brushes alone. According to the above presentation a compensating effect is obtained either by exciting the field by primary current, one component of which is the magnetizing current for the flux F_1, or by placing the windings which excite the field and which are a part of the main circuit on the armature and subjecting them to induction by F_1.

Both of these causes of the compensating effect are contained in the arrangement of Fig. 16, which shows the so-called compensated motor of the Union Elektrizitäts-Gesellschaft. The brushes in the axis *I* are short-circuited. The diagonal brushes in this axis *II* are traversed, on account of the series connection with the stator, by the main current, either directly or at a transformed potential through the insertion of a transformer. The armature carries the power current in short-circuit and rotates in the field of force excited by the primary current in the armature between the diagonal brushes.

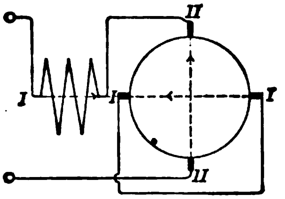

Fig. 16

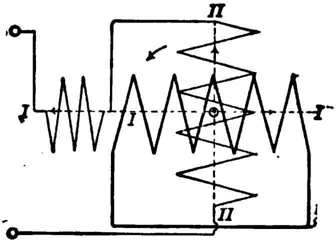

Fig. 17

The actions in the two axes of the armature do not interfere with one another notwithstanding that they occur in a common winding, because the axes lines are in neutral positions relatively to each other. Considering that the axes are held fast in the armature by the brushes, the arrangement can also be represented by the diagram of Fig. 17.

The diagram of the working current is similar to that of the repulsion motor.

Fig. 18 shows the polygon of e.m.f's. $\overline{abcda}$ with relation to the working current. The e.m.f. of the armature coil I, which is reflected in the stator winding, is made up of $E_a : \overline{bc''}$ and $E_0 : \overline{ak}$. These e.m.f's. are generated by the rotation of the coil in the two components of the field F_2, one of which is excited by I, the other by i. The e.m.f., $E_n : \overline{kd}$, is induced in the armature coil II on account of its rotation in the field F_1; on the other hand, $E_m : \overline{ac''}$ is consumed in exciting the field of force and the stray field. E_0 and E_n have the direction $\overline{ad}$; $\overline{ab}$ and $\overline{bd}$ form the angle γ.

In order to construct the diagram, with relation to the working current, $\overline{ad}$ is drawn at right angles to $\overline{ab}$ ($ad : \tan\gamma : n \left(\frac{Z_2}{Z_1}\right) \overline{ab}$). On bd as the total useful e.m.f., the work polygon is constructed for $n : \cot\delta$, in which all quantities $\overline{ad}$, $\overline{bc}$ and $\overline{cd}$ are referred to the phase and amount of the working current I. Not only is the phase displacement and the drop in voltage caused by the transformation, compensated for in this way, but the primary diagram also receives a favorable displacement.

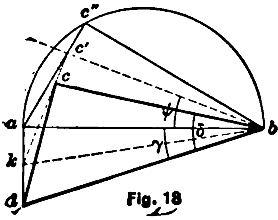

Fig. 18

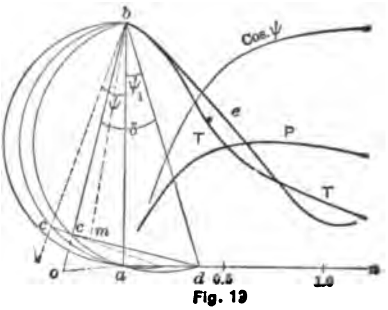

Fig. 19

On the assumption of the direct connection in series between the stator winding and exciting winding, $\overline{ak}$ and $\overline{kd}$ are equal in amount, $ad : \tan\gamma$ is, therefore, twice as large, and the compensating effect more powerful in the same proportion than in the repulsion motor. $\overline{bc'}$ shows the direction of the primary current; ac' is the measure of the exciting e.m.f. to be supplied externally.

By the insertion of the series transformer the compensation can be varied together with the ratio $\frac{Z_2}{Z_1}$ Still greater is the variation if with the aid of a potential regulator the number of turns in both be varied simultaneously in opposite directions.

The example in Fig. 19 shows the stronger influence of $\overline{ad}$ upon cos δ, T and P. One can see that cos φ approaches the value of unity more rapidly than in the case of the repulsion motor, and. becomes unity at a practicable speed.

The exciting voltage $\overline{ac^1}$ which is supplied externally diminishes rapidly in this arrangement and can reach zero, in which case the field excitation is accomplished by the compensating e.m.f. alone.

As for the commutation, it is necessary to judge the performance of the brushes in the axis I carrying the working current, in a way similar to that of the repulsion motor, but the fundamentally different phenomena which takes place in connection with the exciter brushes must be investigated from a special point of view. Fig. 19, which shows the e curve for the brushes carrying the working current indicates that the commutation at normal speed is favorable; on starting, however, and at low speeds the same difficulties exist as in the case of the repulsion and series motors. In order to judge of the performance of the exciter brushes, we have to consider that the turns short-circuited by these brushes are part of a winding which is already short-circuited by the brushes in the axis I. The latter short-circuiting with full contact of the brushes can be considered as constant in comparison with the very variable short-circuiting of the individual turns by the leading and trailing brushes. The pressure diagram of the armature (*bcmb* in Fig. 18) is composed of the e.m.f's. induced by F^1 and generated as a result of the rotation in the entire field of force, and also of the small $\overline{cm}$ which represents the exciting e.m.f. for the stray field in the armature. The same relations hold also for the e.m.f's. in the commutating coil, which are induced under similar conditions as the whole armature winding in the axis I. Only the scale of the vectors is different in the ratio of the number of turns and the local distribution of the field of force (about in the ratio $\frac{\pi}{2}\frac{Z_0}{Z_1}$).

During the period of commutation the e.m.f., $\overline{cm}$, exciting the stray field, and, therefore, the exciting current, will vary but little. In addition there will appear a small reactance pressure. The latter is unimportant in the production of sparking, because the exciting current, which varies with the contact of the brushes II, which as a rule is weaker than the working current, finds an equalizing shunt circuit in the short-circuited connection of the brushes I. The influence of the residual e.m.f., e, on the commutation is doubtless small. The commutation under the exciting brushes proceeds without difficulty and requires no special care or consideration.

The so-called compensated single-phase motor represents on the whole an improved repulsion motor. In comparison it shows, however, some disadvantages, because in addition to the double system of brushes, a special transformer for excitation and special arrangements for regulation are necessary.

If we wish to investigate in the same manner the ordinary single-phase induction motor having a squirrel cage armature and no commutator, we recognize an analogy with the previously described arrangements which becomes more complete when we consider both pairs of brushes as separated from the stator circuit, and each pair as short-circuited on itself, as indicated in diagram, Fig. 20.

In order to proceed from this arrangement to the induction motor, it is only necessary to imagine instead of the armature short-circuited by the brushes in two diagonal directions, two diagonally-placed short-circuited coils, or as a further simplification a single short-circuited coil effective in both directions.

The diagram of e.m.f's. is shown in Fig. 21. In the axis I, the e.m.f. $\overline{ab}$ is produced by the line voltage or F_1. There will be induced an e.m.f. $\overline{ac}$ in the axis II in proportion to the speed and in phase with the generating flux I, hence at right angles to $\overline{ab}$. The currents corresponding thereto excite a cross-flux which penetrates through the rotor and stator. These magnetizing currents as well as the cross-flux F_2 excited by them have the direction $\overline{ad}$.

The direction $\overline{ad}$ diverges but little from $\overline{ab}$ (in contradistinction to the previous treatment, this acute angle cannot be neglected, nor can the ohmic drop, because both are important working factors of this motor). Having the same phase direction, there is generated in the axis I of the armature winding at a certain speed, an e.m.f. $\overline{ae}$, in phase with F_2 and proportional to n^2. Out of the resultant e.m.f. $\overline{ae}$, there appear the ohmic drop $\overline{bf}$ and at right angles thereto the e.m.f. $\overline{ef}$ exciting the stray field in the armature. I: $\overline{ef}$, the phase of the working current is $\overline{bf}$. F_2: n $\overline{ab}$, the phase of the field $\overline{ae}$. The angle β between the direction of these two phases, whose cosine is a measure of T, will be disadvantageously large with the exception of small values of $\overline{ef}$ near to synchronism. The same is true in reference to φ, which is greater by $(\varphi_1+\gamma)$ than the angle previously referred to. The power factor will be poor between rest and a speed slightly under synchronism. The motor can, therefore, operate advantageously only at nearly synchronous speed, but even then only with limited output, because at this speed a small e.m.f. $\overline{be}$ remains, and the working current is, therefore, weak. The triangle $a^1\ bc^1$ shows the work diagram of the induction motor and contains the quantities T, P and cos δ.

These considerations confirm the well-known fact that the induction motor without commutator for single-phase current is an undesirable machine — quite independent of the fact that it has no

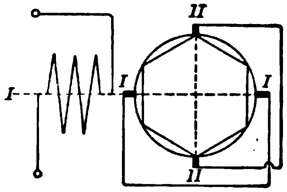

Fig. 20

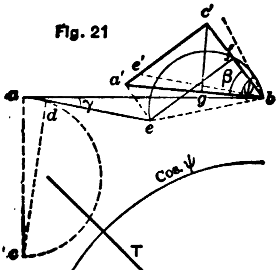

Fig. 21

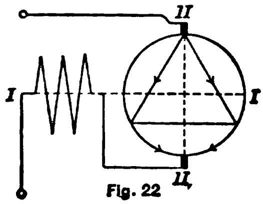

Fig. 22

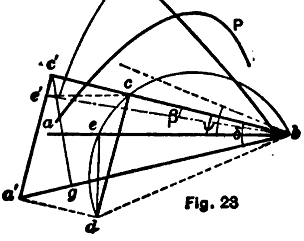

Fig. 23

starting torque, so as to start itself, and because it admits of no external control on account of its being exclusively self-exciting.

As an appendix to these considerations the author submits his arrangement which shows the application of the commutator and the externally excited field in combination with the closed circuit armature.

Fig. 22 is the diagrammatic representation of this motor and Fig. 23 the vector diagram.

The armature winding is closed for the smallest possible number of phases, which must be different from the number of poles. The commutator carries the exciter brushes at right angles to *I* in the axis *II*. The brushes are connected directly or by means of a transformer in series with the stator winding. The working currents are induced by F_1 in the short-circuited armature without brushes. In spite of the short-circuiting the excitation of F_2 in the armature winding can take place as the exciting currents flow partly through turns of the armature and partly through short-circuiting connections, as indicated in the diagram by the arrows and as represented in Fig. 24 more clearly in the case of a four-pole armature having a six-phase short. The field flux is developed of variable density in different parts of the pole faces but with definite polarity. The field excited by a part of the armature winding and held fixed by the brushes attracts the short-circuit currents whereby the armature is set in motion. With increasing speed there appears not only the compensating e.m.f. previously referred to but moreover an exciting e.m.f. which has its seat in the closed circuit winding. The machine constitutes to a certain extent an externally excited and consequently externally controllable induction motor.

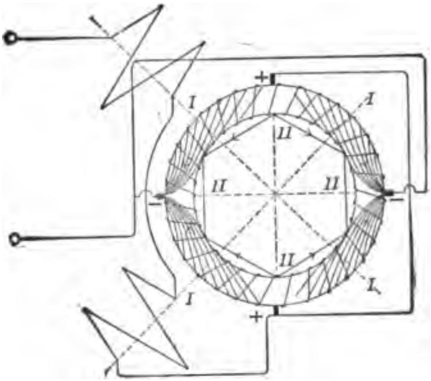

Fig. 24

The e.m.f. polygon is according to Fig. 23 $\overline{ab}\,\overline{cdea}$. $\overline{ae}$ is the e.m.f. induced by rotation in the self-excited field, $\overline{bc}$ the e.m.f. induced by rotation in the externally excited field F_2 in phase with *J*, and $\overline{de}$ that induced by rotation in *F*, as well as in the component of F_2 in phase therewith and $\overline{cd}$ the exciting e.m.f. consumed in the main circuit. Under these conditions we have neglected the angle γ which characterizes the phase of the self-excitation, as in the analogous diagrams of the other commutator motors.

In this case also appears the compensating effect of e.m.f. $\overline{de}$, to improve the power factor as well as the power output. This e.m.f. has, moreover, a favorable effect on the operations which take place in the short-circuit of the induction motor, as the phase direction of the working current $\overline{bc}$ is brought near to the direction of $\overline{ce^1}$ which is the direction of the cross-flux, self-excited in the short-circuit armature, and which direction departs but slightly from $\overline{ab}$. The angle β between the working current — and the total flux ($\overline{be^1}$ representing the resultant of the e.m.f. values, which correspond to both the externally-excited and the self-excited flux) will be small. Consequently both parts of the combined motor, even at speeds much below synchronism, are found to be operating under favorable conditions. Cos φ can be made equal to unity or nearly so, just as in the case of the compensated motor. The triangle a^1bc^1 is the work diagram from which the quantities T, P and cos δ are obtained.

The quantitative relation of the functions are as follows:

1. In the total machine: $E : \overline{ab}$ and $I : \overline{de}$;

2. In the externally-excited machine: $E_a : nI : \overline{bc}$, $E_k : n^2I : \overline{de}$;

3. In the self-excited machine i. e., in the induction motor, $E_1 : n^3I : \overline{ae}$. The total flux F_2 is composed of the externally excited component $(: J)$ and the self-excited component $(: \frac{E_1}{n} : n^2I)$; and at ordinary speeds is nearly equal to the sum of these values. The exciting e.m.f. necessary to expend $E_m : \overline{ce} : \overline{bd} \sin (\varphi - \varphi_1)$, which is measured between the exciter brushes is practically small and can also become zero. $T : (1 + n^2)I^2$; $P : n(i + n^2)I^2$ and

$$I : \frac{E}{n^3 + \sqrt{1 + n^2 - n^4}}$$

This kind of motor is far superior to all the commutator motors previously described as regards commutation. Brushes carrying main working currents are not used; therefore, all commutator difficulties at starting and at low speeds disappear entirely. For this reason the motor becomes nearly independent of the armature current. Therefore, from this standpoint machines can be built in units of any desired size quite the same as with polyphase motors. The commutation at the exciting brushes is, as previously shown, very smooth, particularly in this case, because the turns in closed circuit under the brushes are really parts of closed circuits and because the currents which flow through the brushes have only to furnish a small part of the excitation; they need, therefore, be comparatively small for this reason and especially because the brush e.m.f. $\overline{ce}$ will be very small at normal speeds.

The commutator for this reason can be made much narrower, an advantage which is important in connection with the fitting into car bodies; of equal advantage is the possibility of using a comparatively small number of brushes. In principle, this motor is an induction motor which transmits external energy by means of transformation to a simple rotor; the torque and speed can nevertheless vary, and any variation can be produced which is necessary for the control of vehicles or cars. The motor can be started with considerable torque, and its power factor can be made nearly unity. By this combination we have an externally excited, compensated induction motor.

Chairman Duncan: The next paper is by M. Latour, who is fortunately here and will read it himself.

ALTERNATING-CURRENT MACHINES WITH GRAMME COMMUTATORS.

BY MARIUS LATOUR, *Delegate of Société Internationale des Électriciens.*

If we refer to the technical literature of four or five years ago we shall notice that the problems; the solution of which was sought by engineers applying themselves to the study of alternating-current machinery, were:

1). The development of alternators in which all difficulties in parallel running should be done away with.

2). The construction of generators of constant voltage.

3). The construction of motors working with a good efficiency at all speeds, and starting under load with single-phase current.

4). The construction of non-synchronous motors working with a power factor equal to unity.

It was about that time that I began to take an interest in the application of the Gramme commutator to alternating-current machines. I have thus been led to a new system of electrical machinery which might take the place, either as generators or motors, of the machines used nowadays and solve, from the technical point of view, all the problems set forth.

The description of alternating-current machines comprising a Gramme commutator is comparatively old. Indeed, it is to be traced back to Messrs. Elihu Thomson, Wightman, and Wilson. However, owing partly to the essential phenomena exhibited in direct-current armatures traversed by alternating currents not being very well known, partly to the little interest taken by electricians in these phenomena, partly to the bad opinion that had been formed of the Gramme commutator used in connection with alternating currents, the arrangements proposed by those inventors were left without much industrial value.

I soon realized that the use of the Gramme commutator with alternating currents was full of capabilities and I have been able to realize the machines concerning which I shall say a few words.

All these machines have a uniform appearance, due to their comprising a stator with a winding distributed in slots, and a rotor similar to a direct-current armature with a commutator. These machines are:

1). The panchronous self-exciting polyphase generator.
2). The panchronous self-exciting single-phase generator.
3). The polyphase motor at variable speed with a power factor equal to unity.
4). The compensated single-phase motor.
5). The repulsion motor.
6). The single-phase series motor with perfect commutation.

1. *The Self-Exciting Polyphase Generator.*

This generator is represented in its two most interesting shapes by Figs. 1 and 2, the former showing the shunt connection, and the latter the compound connection. *S* is the stator, *R* the rotor with commutator, and *t* the transformer for supplying the rotor. Such generators are connected to a network like direct-current generators, without any synchronizing operation. The compounded alternator, when well regulated, works at constant voltage whatever may be the inductive or non-inductive load on each phase separately.

2. *The Self-Exciting Single-Phase Generator.*

This generator is represented in its two most interesting shapes by Figs. 1_1 and 2_1. In order to allow self-excitation two sets of brushes *c d* are short-circuited on one another. In reality, for the sake of commutation, it is preferable to have several sets of brushes short-circuited on one another, as represented by Fig. 3. The self-exciting single-phase generator has, above the ordinary generator, besides the two advantages regarding the easier parallel running and the perfect compounding, that of admitting a perfect rotary field without any harmonic field likely to weaken the efficiency.

3. *The Polyphase Motor at Variable Speed with a Power Factor Equal to Unity.*

This motor corresponds to Fig. 1 (representing the shunt connection of the panchronous generator), the transformation ratio of the transformer *t* being supposed to be arbitrary and variable. The speed of the motor may be regulated by changing the transformation ratio of the transformer. The power put into play in the transformer is the larger, the greater the slip of the motor. Such a motor may work with a power factor equal to unity at normal speed.

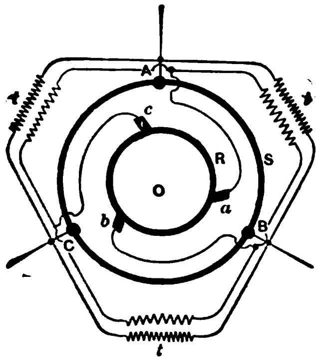

Fig. 1

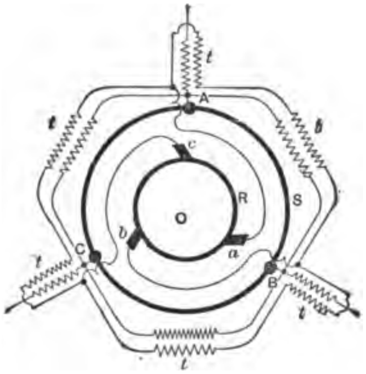

Fig. 2

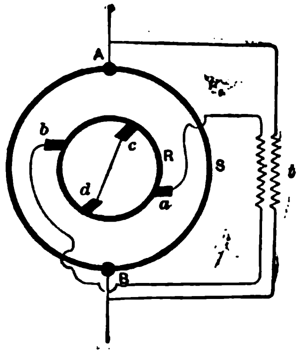

Fig. 1_1

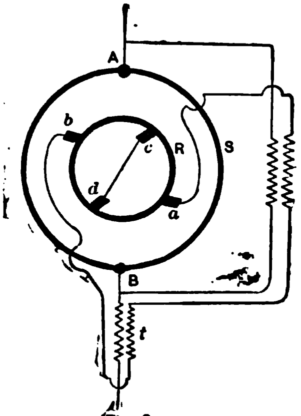

Fig. 2_1

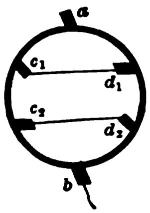

Fig. 3

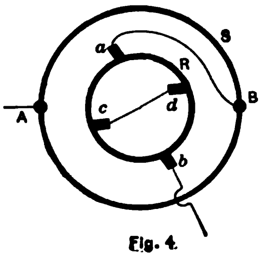

Fig. 4

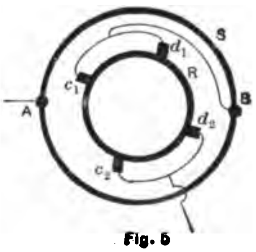

Fig. 5

4. *The Compensated Single-Phase Series Motor.*

This type of motor is represented under its two forms by Figs. 4 and 5. Such a motor works at every speed with good efficiency. The power factor is equal to unity at normal speed, and magnetizing current may be delivered to the network, if desired.

5. *The Repulsion Motor, the Stator of Which Has a Distributed Winding.*

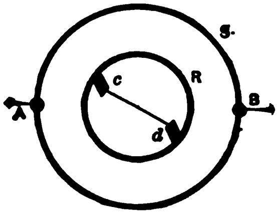

Fig. 6

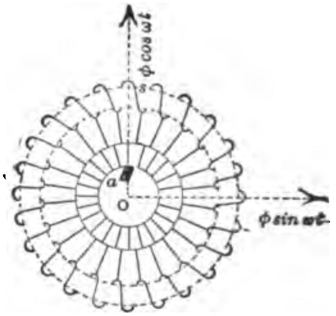

Fig. 7

This type of motor, represented by Fig. 6, has the general characteristics of the compensated series motor, but its power factor is lower and the leakage has in this motor a much worse influence.

All the machines of which I have just spoken have a common property regarding the commutation, viz., that if they are properly designed they work with a perfect commutation in the vicinity of synchronism, owing to the existence or the formation of a perfect rotary field. This property, which I have demonstrated for each machine successively, although at first questioned, is now recognized.

Let us consider (Fig. 7) a direct-current armature which is revolving under the action of a rotary field in a stator like that of an induction motor. The rotary field may be excited partly or completely, either from the stator or from the direct-current armature itself if this is traversed by alternating current.

Let us consider a section s, which is short-circuited under a brush a. The revolving field may be considered as the resultant of two alternating fields, the first one $\phi \sin \omega t$ in a direction perpendicular to $o\ a$; the second one $\phi \cos \omega t$ in the direction $o\ a$ itself.

Now the section *s* is the seat of two e.m.f.s. The first one is produced ***in a static way*** by the variation of the field, ϕ sin ωt, and is equal to

$$e_1 = - \omega \frac{\psi}{2} \cos \omega t.$$

The second one is produced *in a dynamic way,* by the movement of the section *s* under the field ϕ cos ωt, and is equal to

$$e_2 = \omega_1 \frac{\psi}{2} \cos \omega t,$$

if the armature is revolving at the angular speed ω_1.

These two e.m.fs. are opposite, and at synchronism ($\omega_1 = \omega$) counterbalance one another. The section *s* not being any longer the seat of any resultant e.m.f., the commutation under the brush *a* will be perfect, whatever the current under this brush may be.

This consideration leads easily to the conception of a device for avoiding sparking in the straight single-phase series motor. I wrote a paper upon this device a few years ago, and Mr. Maurice Milch, working independently on the same line, has reached the same result.

6. *The single-phase series motor with perfect commutation.*

We shall consider at first a single-phase series motor, the field of which is wound like a direct-current armature (Fig. 8). The motor being operated with continuous current, in order to obtain the best commutation the brushes must be located so that the resultant field of the motor *O* ϕ sin ωt is perpendicular to the line *a b*. When operated with single-phase current, if the induction is low enough, the power factor of the motor will be pretty high. In order to reverse the direction of rotation of the motor without shifting the

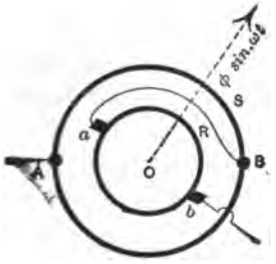

Fig. 8

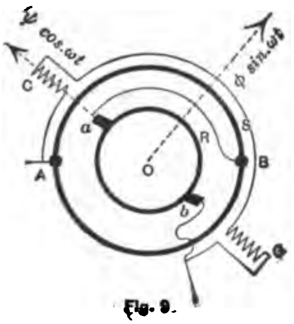

Fig. 9.

brushes, it will be possible to change the position of the terminals *A B* on the periphery of the stator.

Such a construction represents the best it is possible to obtain with the straight single-phase series motor, as I pointed out two years ago at a time when polar projections were still used.

But for the single-phase series motor there is no speed for which a perfect commutation is secured. The variation of the field of the motor induces at any speed an e.m.f. in the short-circuited sections, and owing to this very important reason, I think the series motor is, for larger capacities, inferior to the repulsion motor and to the compensated type.

Yet we can improve it in this way: An auxiliary field $\Psi \cos \omega t$ is produced above the short-circuited sections, which field lags 90 deg. behind the main field, $\phi \sin \omega t$, of the motor. (See Fig. 9.) Conforming with the explanation I have given above, it is easy to see that the new e.m.f. induced in the short-circuited sections *in a dynamic way* by the movement of these sections under the auxiliary field $\Psi \cos \omega t$, may counterbalance at a certain speed the e.m.f. induced in a static way by the variation of the main field $\phi \sin \omega t$.

The auxiliary field may be excited with special coils *c c* shunt connected to the motor, these coils encompassing only a few slots.

We realize now that four types of motors are possible for single-phase traction: The repulsion type, the straight series motor, the compensated type, and the type with an auxiliary field. The future will decide which is the best.

CHAIRMAN DUNCAN: The next paper will be on "The Theory and Operation of Repulsion Motors," by Mr. Bragstad, and will be abstracted by Mr. Steinmetz.

THEORY AND OPERATION OF THE REPULSION MOTOR.

BY O. S. BRAGSTAD.

Commutator motors for alternating current have become of great interest within recent years. The main reason for this is the demand for a motor for single-phase alternating current for the operation of electric railways; but such motors will also find a broad field for other purposes where speed regulation is required.

Of special interest in the older forms of alternating commutator motors is the repulsion motor, important in itself as also in that it marks a transition to the different forms of compensated motors.

In the following I will develop a general theory of the repulsion motor, and that under the usual assumptions that the magnetic resistance is constant for all magnetic circuits, and that the iron losses are proportional to the square of the induction. We will not consider the processes under the commutator brushes and in the armature coils short-circuited by the brushes.

PRINCIPAL EQUATION.

Fig. 1 shows the diagram of the motor. W_s is the stator and W_r the rotor winding. The angle of displacement relative to the shaft, $Y - Y$, of the stator winding is α. We further take:

$\underset{\cdot}{I}_s$ the stator current according to strength and phase,

$\underset{\cdot}{I}_r$ the rotor current according to strength and phase,

$\underset{\cdot}{E}_s'$ the induced e.m.f. according to strength and phase, in the stator winding, we get the following relation:[1]

$$^{1})\,\underset{\cdot}{E}'_s = -Z_a(\underset{\cdot}{I}_s + \underset{\cdot}{I}_r \cos \alpha) = \underset{\cdot}{I}_m z_a.$$

In this we assume the effective number of windings of the stator winding and of the rotor winding to be alike. $Z_a = r_a - jx_a$ can be designated as the exciting impedance of the motor and is given through the magnetic resistance of the main power current of the same, whereby r_a is so determined, that $E_s'^2 \dfrac{r_a}{r_a^2 + x_s^2} = E_s'^2 \dfrac{r_a}{Z_a^2}$ is

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[1] The period below the letter indicates that the value is a *vector* of determinable phase.

equal to the iron effect. $\underset{\cdot}{I}_m$ is the resulting current in the Y **axis,** or the magnetizing current in this axis. In the rotor winding there is induced between the brushes through the same power current:

1). Statically $E'^r_y = \underset{\cdot}{E}'_s \cos a = - Z_a (\underset{\cdot}{I}_s + \underset{\cdot}{I}_r \cos a) = - Z_a I_m \cos a.$

2). Dynamically through the rotation:

$$\underset{\cdot}{E}'_{ryd} = -j \frac{u}{c} \underset{\cdot}{E}_s \sin a = \frac{u}{c} j Z_a (\underset{\cdot}{I}_s + \underset{\cdot}{I}_r \cos a) \sin a = \frac{u}{c} j Z_a \underset{\cdot}{I}_m \sin a$$

where u is the number of periods of the rotor rotation.

c, number of periods of the current,

$j = \sqrt{-1}$.

The prefixed sign depends on the direction of rotation chosen.

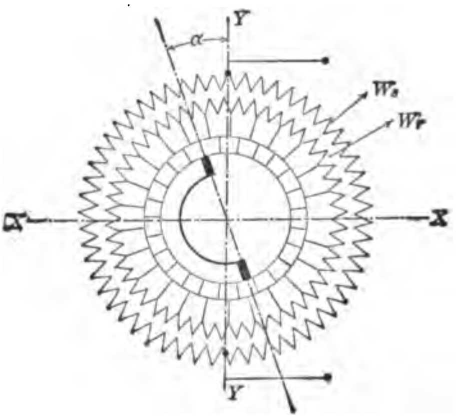

Fig. 1.

The rotor current generates a power current in the X — **axis,** perpendicularly to the axis of the stator winding. The e.m.f. induced by this power current is between the brushes:

1). Static

$$3)\quad \underset{\cdot}{E}'_{rx} = - Z_a \underset{\cdot}{I}_r \sin^2 a.$$

2). Dynamic, through the rotation

$$4)\quad \underset{\cdot}{E}'_{rxd} = j \frac{u}{c} \underset{\cdot}{E}'_{rx} \cos a = - \frac{u}{c} j Z_a \underset{\cdot}{I}_r \sin a \cos a.$$

The prefixed sign must be the reverse in equation 4 to what it is in equation 2.

From 2 and 4 follows

$$\underset{\cdot}{E}'_{ryd} + \underset{\cdot}{E}'_{rxd} = j \frac{u}{c} Z_a \underset{\cdot}{I}_s \sin a.$$

The field generated by the rotor current $\underset{\cdot}{I}_r$ thus produces no dynamic e.m.f., which also follows from the fact that the same runs along the brushes.

The entire e.m.f. induced in the rotor must be equal to the rotor current, $\underset{\cdot}{I}_r$ times the impedance of the rotor winding, which we will designate by Z_r. We, therefore, have

$$-Z_a \underset{\cdot}{I}_s \cos a - Z_a \underset{\cdot}{I}_r \cos^2 a - Z_a \underset{\cdot}{I}_r \sin^2 a + \frac{u}{c} j Z_a \underset{\cdot}{I}_s \sin a = \underset{\cdot}{I}_r Z_r$$

$$\underset{\cdot}{I}_r (Z_a + Z_r) = -\underset{\cdot}{I}_s \left(\cos a - \frac{u}{c} j \sin a\right) Z_a$$

$$\text{I)}\quad \underset{\cdot}{I}_r = -\frac{Z_a}{Z_t}\left(\cos a - \frac{u}{c} j \sin a\right) \underset{\cdot}{I}_s$$

and

$$\text{II)}\quad \underset{\cdot}{E}'_s = -\left(Z_a - \frac{Z_a^2}{Z_t}\left(\cos^2 a - \frac{u}{c} j \sin a \cos a\right)\right) \underset{\cdot}{I}_s$$

where

$$Z_t = Z_a + Z_r.$$

Let us designate by $\underset{\cdot}{Z}_s$ the impedance of the stator winding;

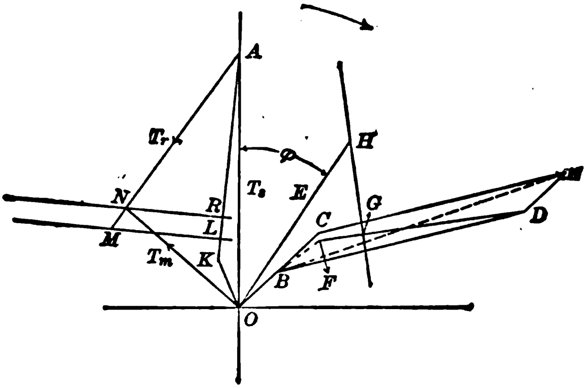

Fig. 2.

then the corresponding e.m.f. is equal to $-\underset{\cdot}{I}_s \underset{\cdot}{Z}_s$, and the entire e.m.f. in the stator winding

$$\underset{\cdot}{E}' = \underset{\cdot}{E}'_s - \underset{\cdot}{I}_s Z_s.$$

Or if we introduce instead of the e.m.f. the terminal pressure, $\underset{\cdot}{E} = -E'$, we have

$$\text{III)}\quad \underset{\cdot}{E} = \underset{\cdot}{I}_s \left(Z_s + Z_a - \frac{Z_a^2}{Z_t}\left(\cos^2 a - \frac{u}{c} j \sin a \cos a\right)\right).$$

From this we get for a given constant stator current $I_s = \underset{\cdot}{I}_s$, the pressure diagram shown in Fig. 2. We assume the direction of rotation of the vectors to be to the right and carry $OA = I_s$ onto the vertical axis. If we further have

$$OB = I_s Z_s$$
$$OC = DE = I_s Z_r$$
$$BD = CE = I_s Z_a$$

we have

$$BE = I_s (Z_a + Z_r) = I_s Z_t$$
$$FD = \frac{Z_a^2}{Z_t} I_s \text{ and } BF = \frac{Z_a Z_r}{Z_t} I_s$$

whereby we make the triangle BFD similar to the triangle BCE. We determine a point G on the straight line FD, so that $\frac{DG}{DF} = \cos^2 \alpha$, draw a perpendicular line to DF at G and make $GU = \frac{u}{c} DF \sin \alpha \cos \alpha$. OU then represents the terminal pressure E of the motor for the respective number of revolutions u, and φ is the angle of lag of the current. At standstill of the motor $(u = o)$ point U coincides with G. OG is, therefore, the terminal pressure at standstill. With increasing positive speed the terminal point of the pressure vector OU moves upwardly on the perpendicular. When reversing the direction of rotation, the point moves downwardly. The machine is then converted into a generator.

Through equation 1 we can also easily find the rotor current I_r in the diagram. We make similar the triangles OKA, BCE, and BFD,

$$\frac{AL}{AK} = \cos \alpha$$

and set up at point L a vertical line LM on AK. On this vertical line we mark off the distance $LM = \frac{u}{c} \sin \alpha \, AK$, then we have for the respective number of revolutions u $AM = I_r$ according to quantity and phase. The terminal point of the vector I_r moves with a variable number of revolutions on a straight line similarly to the vector of the terminal pressure. If we make $AN = AM \cos \alpha$, then $ON = I_s + I_r \cos \alpha = I_m$ (see equation 1). ON thus represents the magnetizing current. With a variable number of revolutions u, point N moves on a straight line NR perpendicular to AK, and $AR = AK \cos^2 \alpha$. It is seen that the two figures. $OKRAN$ and $BFGDU$, are alike, and that every length of the second has developed from the corresponding length of the first through multiplication by z_a and rotation about an angle equal to arc by $\frac{x_a}{r_a}$. Furthermore, the latter figure is displaced from the initial point by the length $OB = I_s Z_s$.

Whilst in a series motor with constant current the field remains constant and the e.m.f. proportional to the speed is dynamically developed through the rotation speed of the induced (armature) winding, we have in the repulsion motor in the primary winding, because the same is stationary, only a statically induced e.m.f. and the change of the same with the speed is caused by a corresponding change of the field in the axis of the stator winding. This change is proportional to GU in the diagram. The field in the X axis is proportional to $I_r \sin a$ and likewise increases with the speed.

Moment of Rotation, Output, and Degree of Efficiency.

The moment of rotation which acts on the armature is obtained if we multiply the pressure, produced in an axis of the armature winding through the static induction, by the current component displaced thereto by 90 deg. in the second perpendicular axis. The moment of rotation is then obtained, expressed in the number of watts which the same would put out at synchronism. If we arbitrarily assume the two vertical axes, we must as a general rule carry out two multiplications and add up the two products.

Here we must consider every axis once as current axis and then as pressure axis. If, however, we so chose the two perpendicular axes that either the current or the pressure becomes zero in one axis, then one of the two products disappears and we need make but one multiplication.

In the present case we put the one axis through the armature brushes and the second one perpendicularly thereto. The current in the direction of the second axis is then zero, and we only need to form the product from the pressure in the perpendicular direction to the armature brushes and the rotor current displaced relative thereto by 90 deg.

This pressure is

$$Z_a \underset{\cdot}{I}_s \sin a = \frac{z_a}{Z_t} \underset{\cdot}{I}_s Z_t \sin a,$$

and the rotor current is

$$\underset{\cdot}{I}_r = -\frac{Z_a}{Z_t} \left(\cos a - \frac{u}{c} j \sin a\right) \underset{\cdot}{I}_s$$

The product is obtained as the imaginary part of the product, after having changed the prefixed sign of the imaginary current component. We so chose the phase of $\dot{I}_s$, that $\frac{Z_a}{Z_t}\dot{I}_s$ **becomes** actually equal to $\frac{z_a}{z_t} I_s$, where

$$z_a = \sqrt{r_a^2 + x_a^2} \text{ and } z_t = \sqrt{r_t^2 + x_t^2}$$

The moment of rotation is then

$$D = \left(I_s \frac{z_a}{z_t}\right)^2, \text{imaginary part of } \left(-\cos a - \frac{u}{c} j \sin a\right) \left(r_t - j x_t\right) \sin a$$

$$\text{IV}\Big)\, D = \left(I_s \frac{z_a}{z_t}\right)^2 \left(x_t \sin a . \cos a - \frac{u}{c} r_t \sin^2 a\right)$$

We can then determine by differentiation the brush angle a, **for** which the moment of rotation for a given current I_s becomes a maximum. We get

$$5) \qquad \tan 2 a = \frac{x_t}{r_t} \, \frac{c}{u}$$

At the start $u = o$, thus $\tan 2 a = \infty$ $a = 45$ deg. With an increasing speed a is somewhat decreased. At synchronism $(u = c)$ we get

$$5_a) \qquad \tan 2 a = \frac{x_t}{r_t}.$$

With $a = 45$ deg. the moment of starting **is**

$$6) \qquad D_k = \left(I_s \frac{z_a}{z_t}\right)^2 \frac{x_t}{2}$$

and the moment at synchronism

$$7) \qquad D_s = \left(I_s \frac{z_a}{z_t}\right)^2 \frac{x_t - r_t}{2}$$

The energy transformed into mechanical **work is found simply** by multiplying the moment of rotation by $\frac{u}{c}$. It is thus

$$\text{V}\Big)\, W_m = \frac{u}{c} D = \left(I_s \frac{z_a}{z_t}\right)^2 \left(\frac{u}{c} x_t \sin a \cos a - \left(\frac{u}{c}\right)^2 r_t \sin^2 a\right).$$

According to equation III we have for the terminal **pressure, if** we put $\dot{I}_s = I_s$

$$\text{III}_a\Big)\, \dot{E} = I_s \left(Z_s + Z_a - Z\left(\cos^2 a - \frac{u}{c} j \sin a \cos a\right)\right)$$

$$= I_s \left(Z_g - Z\left(\cos^2 a - \frac{u}{c} j \sin a \cos a\right)\right)$$

$$= I_s \left(r_g - r \cos^2 a + \frac{u}{c} x \sin a \cos a - j\left(x_g - x \cos^2 a - \frac{u}{c} r \sin a \cos a\right)\right)$$

$$= I_s \left(r_k + \frac{u}{c} x \sin a \cos a - j\left(x_k - \frac{u}{c} r \sin a \cos a\right)\right).$$

The following abbreviations have here been introduced:

$$\frac{Z_a^2}{Z_t} = Z = r - jx \quad \left(\text{constant section } FD \text{ in Fig. 2}\right)$$

$$Z_s + Z_a = r_s + r_a - j\,(x_s + x_a)$$

$$= Z_g = r_g - j\,x_g \quad (\text{constant section } OD \text{ in Fig. 2})$$

$$Z_g - Z \cos^2 a = r_g - r \cos^2 a - j\,(x_g - x \cos^2 a)$$

$$= Z_k = r_k - j\,x_k \quad (\text{section } OG \text{ in Fig. 2})$$

Z_k is the impedance of the motor at standstill (short-circuit impedance), and is dependent on angle a.

For $a = o$ we have

$$Z_k = Z_s + \frac{Z_a Z_r}{Z_t} \quad (\text{section } OF \text{ in Fig. 2.})$$

With an increasing angle of displacement of the brushes, the terminal point of the vector Z_k moves on the straight line FD from F to D. For $a = 90$ deg. we have

$$Z_k = Z_s + Z_a = Z_g \quad (\text{section } OD \text{ in Fig. 2}).$$

From equation V we can determine the number of revolutions u_e for which the output of the motor becomes naught. The same is

$$9) \qquad \frac{u_e}{c} = \frac{x_t}{r_t} \frac{\cos a}{\sin a}$$

For this no-load point we get the phase displacement φ_e by putting the above value of $\frac{u_e}{c}$ into equation IIIa. We get

$$10) \qquad \tan \varphi_e = \frac{x_k - \frac{x_t}{r_t} r \cos^2 a}{r_k + \frac{x_t}{r_t} x \cos^2 a} = \frac{x_e}{r_e}.$$

$Z_e = r_e - jx_e$ can be designated as the no-load impedance of the motor. We can also put

$$Z_e = r_g - \left(r - \frac{x_t}{r_t} x\right) \cos^2 a - j\left(x_g - \left(x + \frac{x_t}{r_t} r\right) \cos^2 a\right)$$

$$= Z_g - \left(r - jx\right) \left(1 - j\,\frac{x_t}{r_t}\right) \cos^2 a$$

$$11) \qquad = Z_g - Z\left(1 - j\frac{x_t}{r_t}\right) \cos^2 a$$

From this we immediately get the following construction of Z_e

(Fig. 3). We make $OB = Z_e$ and $BE = Z_t = r_t - j x_t$ equal to the geometrical sum of BD and DE, whereby $BD = Z_a$ and $DE = Z_r$. Thereupon we draw the line $DF = Z = \frac{Z_a^2}{Z_t}$ and set up at F, a vertical FS. The angle FDS becomes equal to arc $\tan \frac{x_t}{r_t}$ and $\frac{DT}{DS} = \cos^2 a$. OT is then the vector of the no-load impedance. The terminal point of the vector of the short-circuit impedance is G and this point is the projection of point T onto section $Z = DF$. For $a =$ 90 deg., $\cos a = o$, the no-load point S coincides with the short-circuit point G in point D. With the decrease of angle a, the no-load point moves toward S and the short-circuit point toward F.

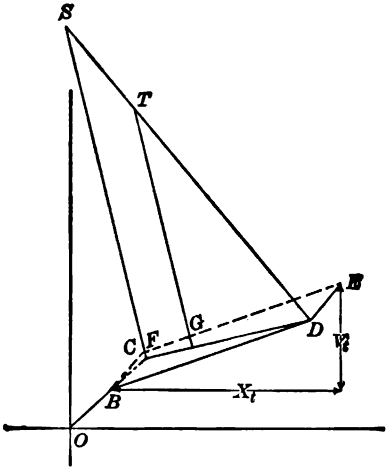

FIG. 3.

From equation V we find the maximum output of the motor for a constant current, if

$$x_t \sin a \cos a - 2 \frac{u}{c} r_t \sin^2 a = o$$

12) $$\frac{u}{c} = \frac{1}{2} \frac{x_t}{r_t} \frac{\cos a}{\sin a}.$$

The maximum output with constant current, therefore, occurs when the motor has half of the no-load speed (see equation 9). This maximum output would be

13) $$W_{m\,max} = \left(I_s \frac{z_a}{z_t}\right)^2 \cdot \frac{1}{2} \frac{x_t^2}{r_t} \cos^2 a$$

If we introduce the number of revolutions for the maximum output into equation III$_a$), we have

$$E = I_s \left(r_k + \frac{1}{2}\frac{x_t}{r_t} x \cos^2 a - j\left(x_k - \frac{1}{2}\frac{x_t}{r_t} r \cos^2 a\right)\right.$$

Or in consideration of equation 10:

$$E = I_s \left(\tfrac{1}{2}(r_k + r_e) - j\left(\tfrac{1}{2}(x_k + x_e)\right)\right). \tag{14}$$

This result also follows directly from the fact that the point for maximum output lies in the middle between the short-circuit point and the no-load point.

The general expression for the electric power supplied to the motor is

$$\begin{aligned} W_e &= I_s^2 \left(r_g - r \cos^2 a + \frac{u}{c} x \sin a \cos a\right) \\ &= I_s^2 \left(r_k + \frac{u}{c} x \sin a \cos a\right) \end{aligned} \tag{15}$$

The degree of efficiency is thus

$$\eta = \frac{W_m}{W_e} = \frac{z_a^2 \left(\frac{u}{c} x_t \sin a \cos a - \frac{u^2}{c^2} r_t \sin^2 a\right)}{z_t^2 \left(r_k + \frac{u}{c} x \sin a \cos a\right)} \tag{16}$$

By differentiation we find from this the number of revolutions foi the maximum degree of efficiency

$$\frac{u}{c} = -\frac{r_k}{x \sin a \cos a} \pm \sqrt{\frac{r_k^2}{x^2 \sin^2 a \cos^2 a} + \frac{r_k x_t}{r_t x \sin^2 a}}$$

The negative prefix of the root would apply to the operation as generator. We here take the positive. The expression can be easily reduced to the following:

$$\frac{u}{c} = \frac{\sqrt{r_k r_e} - r_k}{x \sin a \cos a} \tag{17}$$

This expression for the most favorable number of revolutions introduced into equation 16 gives for the maximum degree of efficiency the following value:

$$\eta_{max} = \frac{z_a^2}{z_t^2} \frac{(2 r_k r_t + x_t x \cos^2 a)\sqrt{r_k r_e} - 2 r_t r_k r_e}{x^2 \cos^2 a \sqrt{r_k r_e}} \tag{18}$$

The values for the most favorable number of revolutions (17), and for the corresponding degree of efficiency (18) are, as is seen, independent of the chosen current strength and of the terminal pressure. If the current strength is assumed, we find the terminal pressure through the introduction of the respective number of revolutions into equation III_a. We likewise obtain the output of the motor by introducing the number of revolutions into equation V.

OUTPUT DIAGRAM WITH CONSTANT TERMINAL PRESSURE.

The mode of operation of the motor, assuming a constant current, can be quite plainly seen in the pressure diagram of Fig. 2. This diagram is useless, however, when it is a question of examining the action of the motor with a constant terminal pressure. We will now also develop a diagram for this case.

In equation III_a we assume the terminal pressure to be real, in that we put $\underset{\cdot}{E} = E$ but we allow the current vector to take any arbitrary phase. Equation III_a then reads

$$III_b) \; \underset{\cdot}{E} = \underset{\cdot}{I}_s \left(r_k + \frac{u}{c}\, x \sin a \cos a - j\left(x_r - \frac{u}{c}\, r \sin a \cos a\right)\right)$$

For the current $\underset{\cdot}{I}_s$ we will introduce the two components, the real one η parallel to e and the imaginary one ζ, perpendicular to e. We thus put

$$\underset{\cdot}{I}_s = \eta + j\,\xi$$

Because the imaginary must disappear on the right side of equation III_b), we have

$$19) \quad \xi \left(r_k + \frac{u}{c}\, x \sin a \cos a\right) = \eta \left(x_r - \frac{u}{c}\, r \sin a \cos a\right)$$

and from this

$$19_a) \quad \frac{u}{c}\left(\xi x + \eta r\right) \sin a \cos a = \eta\, x_k - \xi\, r_k$$

From this we can deduce the following two equations:

$$\eta \frac{u}{c}\, x \sin a \cos a = \frac{\eta^2 x_k - \xi\, \eta\, r_k}{\xi x + \eta r}\, x$$

$$\xi \frac{u}{c}\, r \sin a \cos a = \frac{\xi\, \eta\, x_k - \xi^2 r}{\xi x + \eta r}\, r.$$

If we introduce these two values into equation 19, we get:

$$e\,(\xi x + \eta r) = (\xi^2 + \eta^2)\,(r\, r_k + x\, x_k)$$

or

$$VI) \quad I_s^2 = \xi^2 + \eta^2 = e\, \frac{\xi x + \eta r}{r\, r_k + x\, x_k}$$

If we consider ξ as abscissa and η as ordinate in a rectangular co-ordinate system, then this equation represents a circle. The same goes through the initial point of the co-ordinates and has the radius

$$20)\qquad R = E\frac{\sqrt{r^2+x^2}}{2\,(r\,r_k+x\,x_k)} = E\frac{z}{2\,(r\,r_k+x\,x_k)}$$

The co-ordinates of the central point are

$$21)\qquad \begin{cases} \text{Abscissæ } m = E\dfrac{x}{2\,(r\,r_k+x\,x_k)} \\ \text{Ordinates } u = E\dfrac{r}{2\,(r\,r_k+x\,x_k)} \end{cases}$$

With constant terminal pressure we thus have the current vector according to strength and phase as the distance from the initial point to a circle. By means of this circle we can follow the work in the motor. We will first consider the number of revolutions, or what is the same, the relation $\frac{u}{c}$.

According to equation 19_a we have

$$22)\qquad \frac{u}{c} = \frac{\eta\,x_k - \xi\,r_k}{\sin a\cos a\,(\xi\,x+\eta\,r)} = \frac{L_1}{\sin a\cos a\,L_2}$$

Here we have $\eta\,x_k - \xi\,r_k = L_1 = o$ a straight line through the initial point of the co-ordinate system. According to equation 19, $\frac{\eta}{\xi} = \frac{r_k}{x_k}$ with $u = o$. The straight line $L_1 = o$ thus goes through the short-circuit point of the motor. The short-circuit current is *OK* in Fig. 4.

$\xi\,x + \eta\,r = L_2 = o$ is likewise a straight line, which stands perpendicularly on the connecting line (central line) between the origin of co-ordinates and the central point of the circle. This line is, therefore, a tangent at the initial point. Every vector is a ray in a group of rays, and has the equation

$$\frac{u}{c}\sin a\cos a\,L_2 - L_1 = o.$$

For $u = c$ the equation of the ray (synchronous line) is $L_3 = \sin a\cos a\,L_2 - L_1 = \eta\,(r\sin a\cos a - x_k) + \xi\,(x\sin a\cos a + r_k) = o.$

For any point P of the circle, $\frac{u}{c}$ is the double relation between the four rays and the same is cut off on a transverse line, thus

$$\frac{u}{c} = \frac{\dfrac{a\,b}{a\,c}}{\dfrac{d\,b}{d\,c}} \qquad \text{(see Fig. 4.)}$$

If we draw the transverse line parallel to the straight line $L_2 = o$, then the double relation passes over into the single relation and we get

$$\frac{u}{c} = \frac{a^1 b^1}{d^1 b^1}.$$

We can, therefore, read on the transverse line parallel to the straight line $L_2 = o$ the speed of rotation for every current.

The synchronous line $L_3 = o$ can be constructed as follows: Over the section $FD = z$ as diameter we describe a circle and mark off the brush angle $a = GDT$ in point D. The synchronous line then runs through point T. A perpendicular line from T onto section FD cuts the latter in point G; OG is the short-circuit impedance of the motor with the two components $r_k = r_g - r \cos^2 a$ and $x_k = x_g - x \cos^2 a$. The short-circuit line $L_1 = o$ thus goes through point G. The short-circuit point K on the diagram circle is an inverse point to point G, in that OK is proportional to $\frac{1}{O\,G}$. A modification of the brush angle a changes the size of the diagram circle and the position of the short-circuit point K as also the position of the synchronous line $L_3 = o$. If a is made so large, that the synchronous line becomes a tangent to the circle over FD, synchronous speed occurs with the smallest phase displacement. When G moves toward F, if, therefore, a is reduced, the short-circuit point K continually moves higher on the circle; the losses are thus increased. At the same time, however, the diameter of the diagram circle and therewith the maximum output of the motor are increased. The question as to the most favorable brush displacement angle can thus be answered in very many different ways according to the special result which is to be obtained. By means of the diagram in Fig. 4, we can easily find the most favorable brush position for a given case.

We will now see how we can represent the moment of rotation in the diagram. According to equation IV

$$D = \left(\frac{z_a}{z_t}\right)^2 I_s^2 \left(x_t \sin a \cos a - \frac{u}{c} r_t \sin^2 a\right).$$

In accordance to the circle equation VI, we have however

$$I_s^2 = \frac{E\,(\xi\,x + \eta\,r)}{r\,r_k + x\,x_k} = \frac{2\,R}{z}(\xi\,x + \eta\,r)$$

and according to equation 22

$$\frac{u}{c} = \frac{\eta\,x_k - \xi\,r_k}{\sin a \cos a\,(\xi\,x + \eta\,r)} = \frac{L_1}{\sin a \cos a\,L_2}$$

Introducing this for the moment of rotation we get

$$23)\quad \begin{cases} D = \left(\frac{z_a}{z_t}\right)^2 \frac{2\,R}{z}\, r_t \frac{\sin a}{\cos a}\left(\xi\left(r_k + \frac{x_t}{r_t}\, x \cos^2 a\right)\right. \\ \qquad \left. - \eta\left(x_k - \frac{x_t}{r_t} \cos^2 a\right)\right) \\ \quad = \left(\frac{z_a}{z_t}\right)^2 \frac{2\,R}{z}\, r_t \frac{\sin a}{\cos a}\left(\xi\, r_e - \eta\, x_e\right) \\ \quad = \left(\frac{z_a}{z_t}\right)^2 \frac{2\,R}{z}\, r_t \frac{\sin a}{\cos a}\; L_4 \end{cases}$$

The straight line $\xi\, r_e - \eta\, x_e = L_4 = o$ is the no-load line, the construction of which we have given in Fig. 3.

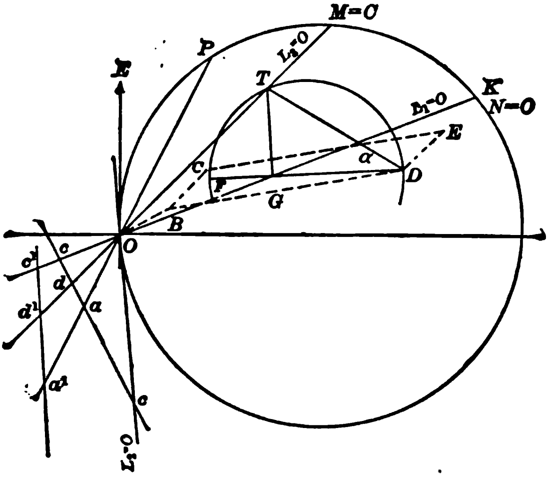

FIG. 4.

The moment of rotation is at any point proportional to the distance of the same from the no-load line. In short-circuit the current is

$$I_k^2 = \frac{E^2}{(r_g - r\cos^2 a)^2 + (x_g - x\cos^2 a)^2} = \frac{E^2}{r_k^2 + x_k^2}$$

The starting moment is, therefore,

$$24)\qquad D_k = \left(\frac{z_a}{z_t}\right)^2 I_k^2\, x_t \sin a \cos a$$

$$= \left(\frac{z_a}{z_t}\right)^2 \frac{E^2 x_t \sin a \cos a}{(r_g - r\cos^2 a)^2 + (x_g - x\cos^2 a)^2}$$

Hereby the measure for the determination of the moment of rotation is given by the distance from the no-load line for every point.

We will now introduce the relation between the moment of rotation in watts relative to synchronism and the introduced watts. This is

$$25)\qquad \delta = \frac{D}{W_e} = \left(\frac{z_a}{z_t}\right)^2 \frac{2\,R\,r_t}{z\xi}\,\frac{\sin a}{\cos a}\,\frac{\xi\,r_e - \eta\,x_e}{\eta}$$

At starting we have

$$26)\qquad \delta_k = \frac{D_k}{W_{ek}} = \left(\frac{z_a}{z_t}\right)^2 \frac{x_t}{r_k} \sin a \cos a.$$

It is seen that δ is the double relation in a group of vectors consisting of the abscissæ axis ($\eta = o$), the no-load line ($L_4 = o$) and the short-circuit line ($L_1 = o$). Because in this group of vectors the double relation is given for the short-circuit line as equal δ^-, the same can be at once determined for any vector δ. If in Fig. 5, $L_1 = o$ is the short-circuit line and $L_4 = o$ the no-load line, if further the straight line ac is drawn parallel to the abscissæ axis, we have for a vector through the center point P

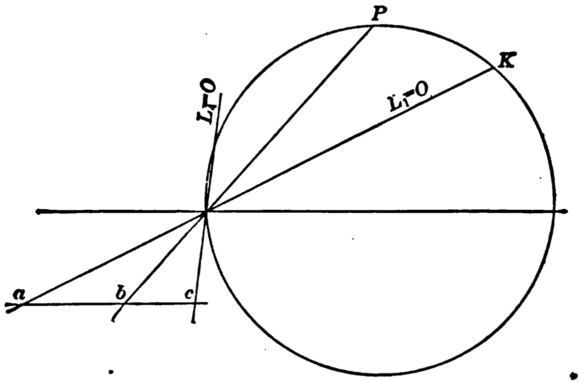

FIG. 5.

$$\frac{\delta}{\delta_k} = \frac{c\,b}{c\,a}$$

Thus if we make $ca = \delta_k$, we have

$$\delta = cb.$$

Because now, through the two constructions given in Figs. 4 and 5, the values $\frac{u}{c}$ and $\delta = \frac{D}{W_e}$ can be read off for every point of the diagram by carrying the current vector to the respective point, we have also given us at once for every point the efficiency of the motor; for the efficiency is

27)
$$\eta = \frac{W_n}{W_e} = \frac{\frac{u}{c} D}{W_e} = \frac{u}{c}\delta.$$

We thus need only multiply the two values read off.

If the diagram is to be constructed for a motor only *planned,* the separate reactances and resistances can be calculated and they need only be introduced properly into the given formula. Some abbreviations and omissions are then permissible not introduced here, on account of their general character.

If the motor is already constructed, the diagram can be determined by some measured values and we can thus get at the mode of working of the motor without the necessity of carrying out a complete brake test. Different methods may be followed, of which only a few examples are to be here given.

If we measure at standstill the impedance between the primary terminals, first with a brush displacement $\alpha = o$ and then with $\alpha = 90$ deg. (or what is the same, with open secondary circuit), we get the two points F and D in Fig. 4. Thereby we have the line $L_2 = o$, and for any brush angle α the short-circuit point with the short-circuit line $L_1 = o$, the synchronous line $L_3 = o$, and according to the construction given in Fig. 3 the no-load line $L_4 = o$ and the no-load point. The circle is furthermore determined in that its center point must lie on a line parallel to FD through the initial point. The only feature lacking in order to make the diagram complete is the scale to give us the moment of rotation and thereby the determination of the degree of efficiency. The same can be most simply obtained by measuring the torque D^k at standstill and with any brush angle α. If now we put according to equation 26

$$\delta_k \frac{D_k}{W_{ek}} = a\,c \qquad \text{(see Fig. 5)}$$

where W_{ek} is the electric power supplied at standstill with the respective brush position α, then for any brush position and any speed $\frac{u}{c}$, for which the power supplied is W_e, the moment of rotation $D = \delta W_e = bc\,W_e$
and the degree of efficiency

$$\eta = \frac{u}{c} \cdot \frac{D}{W_e} = \frac{u}{c}\,\delta = \frac{u}{c} \cdot b\,a.$$

For another brush angle a^1 with the short-circuit resistance r_k^1 and the section a^1c^1 between the short-circuit and no-load line we have according to equation 26

$$\frac{\delta_k}{\delta_k^1} = \frac{r_k}{r_k^1} \frac{\sin a^1 \cos a^1}{\sin a \cos a}$$

We would thus have to put for this angle

$$\delta_k^1 = a^1 c^1 = \frac{r_k}{r^1_k} \frac{\sin a^1 \cos a^1}{\sin a \cos a} a c$$

$$D = \delta^1 W_e = b^1 c^1 W_e.$$

From this we must determine the moment of rotation and the efficiency for any brush angle a^1, when the moment of torque for an angle a has been determined.

MAXIMUM OUTPUT WITH CONSTANT TERMINAL PRESSURE.

In accordance with equations 22 and 23, we have

$$\frac{u}{c} \frac{\eta x_k - \xi r_k}{\sin a \cos a (\xi x + \eta r)} = \frac{2 R}{z} \frac{\eta x_k - \xi r_k}{\sin a \cos a I_s^2}$$

$$D = \left(\frac{z_a}{z_t}\right)^2 \frac{2 R}{z} r_t \frac{\sin a}{\cos a} \left(\xi r_e - \eta x_e\right).$$

We thus have

$$W_m = \left(\frac{z_a}{z_t}\right)^2 \left(\frac{2 R}{z}\right)^2 \frac{r_t}{\cos^2 a} \frac{(\eta x_k - \xi r_k)(\xi r_e - \eta x_e)}{I_s^2}$$

If we put

$$\cos \varphi_k = \frac{r_k}{z_k}; \ \sin \varphi_k = \frac{x_k}{z_k}$$

$$\cos \varphi_e = \frac{r_e}{z_e}; \ \sin \varphi_e = \frac{x_e}{z_e}$$

$$\cos \varphi = \frac{\eta}{I_s}; \ \sin \varphi = \frac{\xi}{I_r}$$

then φ_k = angle between short-circuit line and ordinate axis
φ_e = angle between no-load line and ordinate axis
φ = phase displacement of the current

and we have

$$28) \quad W_m = \left(\frac{z_e}{z_t}\right)^2 \left(\frac{2R}{z}\right)^2 \frac{r_t z_k z_e}{\cos^2 a} \sin (\varphi_k - \varphi) \sin (\varphi - \varphi_e)$$

The mechanical output is, therefore, a maximum, when

$$\varphi_k - \varphi = \varphi - \varphi_e$$

or

$$29) \quad \varphi = \frac{\varphi_k + \varphi_e}{2}.$$

The output of the motor is a maximum, when the phase displacement angle has the arithmetical mean value of the two-phase displacement angles at short-circuit and at no-load. If we put down the short-circuit line as

$$\eta \frac{x_k}{z_k} - \xi \frac{r_k}{z_k} = 0$$

and the no-load line as

$$\xi \frac{r_e}{z_e} - \eta \frac{x_e}{z_e} = 0$$

then the equation of the current vector at maximum output is

$$30) \qquad \xi \left(\frac{r_e}{z_e} + \frac{r_k}{z_k}\right) - \eta \left(\frac{x_e}{z_e} + \frac{x_k}{z_k}\right) = 0$$

or

$$31) \qquad \xi (r_e z_k + r_k z_e) - \eta (x_e z_k + x_k z_e) = 0$$

We combine this with the circle equation

$$\xi^2 + \eta^2 = E \frac{\xi x + \eta r}{r r_k + x x_k}$$

and we get

$$\eta \Big((x_e z_k + x_k z_e)^2 + (r_e z_k + r_k z_e)^2)$$

$$= E \frac{x (x_e z_k + x_k z_e) + r (r_e z_k + r_r z_e)}{r r_k + x x_k}\Big).$$

$$(r_e z_k + r_k z_e) = E \frac{z_k (x x_e + r r_e) + z_e (x x_k + r r_k)}{r r_k + x x_k} (r_e z_k + r_k z_e)$$

We have

$$x x_e + r r_e = x \left(x_k - \frac{x_t}{r_t} r \cos^2 a\right) + r \left(r_k + \frac{x_t}{r_t} x \cos^2 a\right) = x x_k + r r_k$$

Hence

$$\eta = E \frac{(z_k + z_e)(r_e z_k + r_k z_e)}{(x_e z_k + x_k z_e)^2 + (r_e z_k + r_k z_e)^2}$$

$$\xi = E \frac{(z_k + z_e)(x_e z_k + x_k z_e)}{(x_e z_k + x_k z_e)^2 + (r_e z_k + r_k z_e)^2}$$

η and ξ are watt and wattless current at maximum output. The output factor with this output is

$$32) \qquad \cos \varphi = \frac{r_e z_k + r_k z_e}{\sqrt{(x_e z_k + x_k z_e)^2 + (r_e z_k + r_k z_e)^2}}$$

The number of revolutions with maximum output is found as follows

$$\frac{v}{c} = \frac{\eta x_k - \xi r_k}{\sin a \cos a (\eta r + \xi x)}$$

$$= \frac{x_k (r_e z_k + r_k z_e) - r_k (x_e z_k + x_k z_e)}{\sin a \cos a \left[r (r_e z_k + r_k z_e) + x (x_e z_k + x_k z_e)\right]}$$

$$= \frac{z_k (x_k r_e - r_k x_e)}{\sin a \cos a \left[z_k (r r_e + x x_e) + z_e (r r_k + x x_k)\right]}$$

$$= \frac{z_k (x_k r_e - r_k x_e)}{\sin a \cos a \, (z_k + z_e) \, (r r_k + x x_k)}$$

Now we have

$$\frac{x_k r_e - r_k x_e}{\sin a \cos a \, (r r_k + x x_k)} = \frac{x_t}{r_t} \cot a = \frac{u_e}{c}$$

where u_e is the number of revolutions at no-load (equation 9). Thus we have with maximum output

$$33) \qquad \frac{u}{c} = \frac{z_k}{z_u + z_e} \frac{u_e}{c}.$$

The moment of rotation with maximum output is

$$D = \left(\frac{z_a}{z_t}\right)^2 \frac{2R}{z} r_t \frac{\sin a}{\cos a} (\xi r_e - \eta x_e) \quad \text{(Equation 28)}$$

where for ξ and η we must introduce the current component for this maximum output. We then have

$$\xi r_e - \eta x_e = E \frac{(z_k + z_e)(r_e x_k - x_e r_k) z_e}{(x_o x_k + x_k z_e)^2 + (r_o z_k + r_k z_e)^2}$$

$$= z_k^2 z_o (z_k + z_e) \frac{r_o E \dfrac{x_k}{z_k^2} - x_e E \dfrac{r_k}{z_k^2}}{(x_e z_k + x_k z_e)^2 + (r_e z_k + r_k z_e)^2}$$

Here $E \dfrac{x_k}{z_k^2}$ and $E \dfrac{r_k}{z_k^2}$ are the current components when the motor is at standstill and the torque is

$$D_k = \left(\frac{z_a}{z_t}\right)^2 \frac{2R}{z} r_t \cdot \frac{\sin a}{\cos a} \left(r_e E \frac{x_k}{z_k^2} - x_e E \frac{r_k}{z_k^2}\right)$$

Consequently the moment of rotation for maximum output is

$$34) \quad \begin{cases} D = D_k \dfrac{z_k^2 z_e (z_k + z_e)}{(x_e z_k + x_k z_e)^2 + (r_e z_k + r_k z_e)^2} \\ \quad = D_k \dfrac{z_k (z_k + z_e)}{z (z_k z_e + x_k x_e + r_k r_e)} \end{cases}$$

The output itself is

$$35) \qquad W_{m\,max} = D \frac{u}{c} = D_k \frac{z_k^2 \cdot \dfrac{u_e}{c}}{z (z_k z_e + x_k x_e + r_k r_e)}$$

We finally find the efficiency for the maximum output

$$36)\qquad \eta = \frac{W_{m\,max}}{W_e} = \frac{D_k}{E^2} \frac{z_k{}^3 z_e \frac{v_e}{c}}{(r_e z_k + r_k z_e)(z_k + z_e)}$$

For the use of the formula indicated in the last section in considering a motor design, it is only necessary to make no-load measurements at standstill of the impedance Z_k and the torque D_k and at no-load, of the impedance Z_e and the number of revolutions v_e.

Dr. Duncan: The next paper is on "The Theory of the Compensated Repulsion Motor," by Mr. Danielson of Sweden, and will also be abstracted by Mr. Steinmetz.

THEORY OF THE COMPENSATED REPULSION MOTOR.

BY ERNST DANIELSON.

Of late there has been a great deal written about the compensated repulsion motor, which fairly may be considered the most modern type of motor in the present electrical industry. Not only analytical but also graphical methods have been given for explaining its qualities. It appears, however, that a complete analytical treatment, considering the leakage — that is to say, formulas for the calculation of current, torque and lag with known voltage, brush position and speed — have not as yet been published. In this paper the author will present the formulas which are used by The Allmänna Svenska Elektriska Aktiebolaget of Westerås, Sweden, for figuring such motors, and which have given results in good agreement with actual tests.

It should be mentioned before entering into details, that in the following theory the magnetic losses are neglected and that accordingly the magnetic vector is considered the same as the resulting ampere-turns. When using the formulas given below, it is therefore necessary, when aiming at the utmost accuracy, to apply a correction for these losses.

Referring to Fig. 1, let $I_k \sin at$

be the current on short-circuit, assuming the direction as the position when the current is flowing *in the winding* from c to d;

$$a = 2\pi N; \ (N = \text{frequency}).$$

This current creates leaking lines of force, viz., lines of force, viz., lines cutting only the rotor windings:

$$= \xi n_r I_k \sin at$$

n_r = Conductors round rotor,

ξ = Leakage co-efficient.

These lines of force induce on short-circuit an e.m.f.

$$= - \xi n_r^2 I_k . N . \cos at \ 10^{-8} \text{ volts.}$$

The lines of force in the direction $c\,d$ which enter from the rotor into the stator we designate,

$$= B . \sin (at + \beta)$$

and those which in direction $b\ a$ cut the rotor winding (sum of leaking and useful lines),

$$= A.\ \sin\ (at + \alpha).$$

In these two last formulas, A and B are *the lines per pole,* and β and α the difference of phase of these lines and the current I . The lines B induce in the short-circuit an e.m.f.,

$$= -B\,N\,n_r \cos\ (at + \beta)\ 10^{-8} \text{ volts.}$$

The lines A induce in the same circuit on account of the motion (this assumed clockwise),

$$= A.\ N_1.\ n_r \sin\ (at + \alpha).\ 10^{-8} \text{ volts.}$$

N_1 being the speed (in frequency). In the last two formulas it is assumed that the rotor winding is either two-pole or series-connected, so that each conductor carries a current $= \frac{I_k}{2}$. If now $r =$ ohmic resistance of short-circuit, then

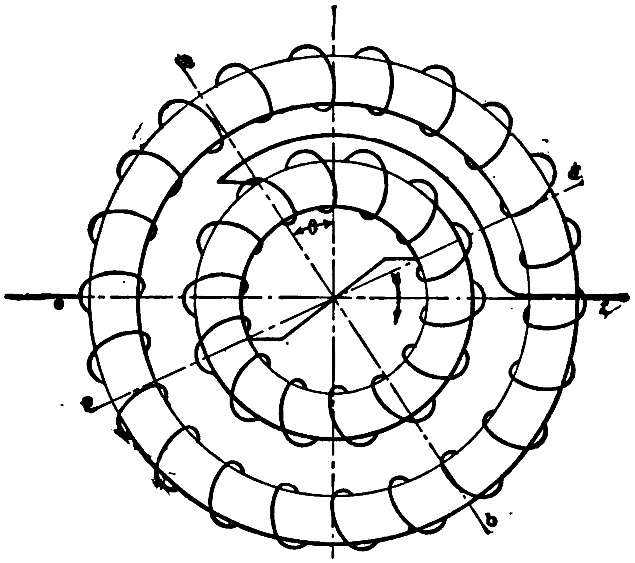

Fig. 1.

$$I_k r \sin at\ 10^8 = A.\ N_1.\ n_r \sin\ (at + \alpha) - B.\ n_r \cos\ (at + \beta) - \xi n_r^2 I_k N \cos at$$

This equation must be valid for any value on t, accordingly,

$$I_k.\ r.\ 10^8 = A.\ N_1.\ n_r \cos \alpha + B.\ N\,n_r \sin \beta. \qquad (1)$$

$$A.\ N_1.\ \sin \alpha = B.\ N.\ \cos \beta + \xi.\ n_r\ I_k.\ N. \qquad (\ )$$

In the stator circuit there flows a current, the phase of which is the same as that of the lines of force A, these lines being caused only by this current. This current we may represent by

$$I.\sin(at+\alpha).$$

The direction is positive when the current in the rotor winding flows *from b to a.* This current causes following lines of force:

I. Lines of force cutting only the rotor windings:

$$=\xi.n_r.I.\sin(at+\alpha)$$

in direction $b\ a$.

II. Lines of force cutting both rotor- and stator-winding in direction b a:

$$=\zeta.\mathrm{I}.\sin(at+\alpha)\,(n_r-n_s.\sin\theta)$$

ζ is a co-efficient depending on the geometrical form of the machine and the permeability of the iron; n_s = number of conductors on stator, the same assumption being made as for n_r, viz., that each conductor carries a current $=\frac{\mathrm{I}}{2}$. θ = angle of brush position (see Fig. 1).

The sum of these lines of force must equal $A.\sin(at+\alpha)$. Accordingly

$$A=I.\left[\zeta\,(n_r-n_s.\sin\theta)+\xi.n_r\right]$$

$$\text{or:}\quad A=I.D$$

$$\text{if:}\quad D=\zeta.\,(n_r-n_s.\sin\theta)+\xi.n_r.$$

The lines cutting both stator and rotor winding in direction $c\ d$ are caused by the combined influence of ampere-turns in stator and rotor. Hence:

$$B.\sin(at+\beta)=$$
$$\zeta\,[n_s.I.\sin(at+\alpha).\cos\theta+I_k.n_r.\sin at]\ldots \quad (1)$$

This equation is valid for any value of the angle $a\,t$, therefore:

$$\sin at\,(B.\cos\beta-\zeta.n_s\,I.\cos\theta-\zeta.n_r\,I_k)=0\ldots\ldots \quad (2)$$
$$\cos at\,(B.\sin\beta-\zeta.n_s\,I.\sin\alpha.\cos\theta)=0\ldots\ldots\ldots\ldots \quad (3)$$

and

$$B.\cos\beta-\zeta.n_s\,I.\cos\alpha.\cos\theta-\zeta.n_r\,I_k=0\ldots\ldots \quad (4)$$
$$B.\sin\beta-\zeta.n_s\,I.\sin\alpha.\cos\theta=0\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

The equations 1, 2, 3, 4 and 5 contain, besides I, five unknown quantities A, B, α, β and I_k, and hence give values of these expressed in I and known numbers.

Now combining equations (1) and (2), then (1) with (4), and afterward eliminating B by means of (5) and A by means of (3), we get:

$$\cot a = \frac{\dfrac{N_1 . r . D}{\zeta . N} . 10^8 - N . n_r{}^2 . n_s . \cos\theta\,(\zeta + \xi)}{r . n_s . \cos\theta . 10^8 + N_1 . n_r{}^2 . D\left(1 + \dfrac{\xi}{\zeta}\right)} \ldots \quad (6)$$

$$\cot\beta = \frac{D . N_1}{\zeta . n_s . \cos\theta}\left[\frac{1}{N} - \frac{\xi . n_r^2 . \cot a}{r . 10^8}\right] - \frac{N . n_r^2 . \xi}{r . 10^8} \ldots . \quad (7)$$

These equations show that α and β are independent of the current.

From (4) and (5) we obtain

$$B = \frac{\zeta . n_s . I . \sin a . \cos\theta}{\sin\beta} \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

$$I_k = \frac{n_s . I . \sin a . \cos\theta}{n_r}(\cot\beta - \cot\alpha) \ldots\ldots \quad (9)$$

In the stator circuit, the induced e.m.f's. are:

I. In the rotor winding, by the lines of force along c d:

$$= -[\xi . n_r . I_k . \sin at + B . \sin(at + \beta)] . N_1 . n_r . 10^{-8}.$$

II. In the rotor winding, by the lines of force along b a:

$$= -A . \cos(at + a) . N . n_r . 10^{-8}.$$

III. In the stator winding, by the lines of force along b a:

$$= \zeta . I . \cos(at + a)\,(n_r - n_s . \sin\theta) . N . n_s . \sin\theta . 10^{-8}.$$

IV. In the stator winding, by the lines of force along c d:

$$= -B . \cos(at + \beta) . N . n_s . \cos\theta . 10^{-8}.$$

V. In the stator winding, by self-induction:

$$= -I . \cos(at + \alpha)\, n_s^2\, \lambda . N\, 10^{-8}.$$

λ = Leakage co-efficient corresponding to ξ.

VI. Influence of ohmic resistance:

$$= -I . \sin(at + \alpha) . R.$$

R = total resistance of stator circuit (including rotor winding, brushes, etc.). If now the machine acts as a motor, then the impressed e.m.f. must equal the sum of above six expressions with opposite signs.

Accordingly, if E = voltage at terminals of motor (amplitude), and γ its phase:

$$\begin{aligned} -E \sin(at + \gamma) . 10^8 = {} & -I . \sin(at + \alpha) . R . 10^8 . \\ & - I . \cos(at + \alpha)\, n_s^2 . \lambda . N - B . \cos(at + \beta) . N . n_s \cos\theta \\ & + \zeta . I . \cos(at + \alpha)\,(n_r - n_s . \sin\theta) . N . n_s . \sin\theta \\ & - A . \cos(at + \alpha) . N . n_r \\ & - [\xi . n_r . I_k . \sin at + B . \sin(at + \beta)]\, N_1 . n_r \ldots\ldots . \quad (10) \end{aligned}$$

Now substituting for A, B and I_k their values [equations (3), (8), (9)]

$$\frac{E}{I}.\sin(at+\gamma) = R.\sin(at+\alpha) + V.\cos(at+\alpha)$$
$$+ W.\cos(at+\beta) + U.\sin(at+\beta) + T.\sin at \ldots\ldots \quad (11)$$

in which

$$V = [n_s^2.\lambda.N - \zeta.N.n_s.\sin\theta\,(n_r - n_s\sin\theta) + N.n_r D].10^{-8}$$
$$W = \zeta.n_s^2.\sin\alpha.\cos^2\theta.N.10^{-8}$$
$$U = \zeta.n_s.\sin\alpha.\cos\theta.N_1.n_r.10^{-8}$$
$$T = \xi.n_r.N_1.n_s.\cos\theta\,(\cot\beta - \cot\alpha).10^{-8}.$$

Developing the goniometric functions of the sums $(at+\alpha)$ and $(at+\beta)$ and considering that the equation (11) is valid for any value of at we get:

$$I = \frac{E}{\sqrt{P^2+Q^2}} \ldots\ldots\ldots\ldots\ldots\ldots \quad (12)$$

and
$$\tan\gamma = \frac{P}{Q},$$

in which expressions

$$P = R.\sin\alpha + V.\cos\alpha + W.\cot\beta + U$$
$$Q = R.\cos\alpha - V.\sin\alpha - W + U.\cot\beta + T.\sin\alpha.$$

These equations give values of current and λ when voltage, frequency and speed are known.

Though I and E have been defined as amplitudes of current and e.m.f. the equation (12) of course also holds good for effective values.

The angle by which the current I is in advance being α and γ, the angle by which the terminal voltage is in advance, both relating to the same epoch, then the angle of lag of current behind e.m.f. is

$$\varphi = \lambda - \alpha.$$

CALCULATION OF TORQUE.

I. Torque from lines of force along $a\,d$ and current I, clockwise:

$$= B.\sin(at+\beta).\,n_r.\,I.\sin(at+\alpha).\,p.\,\frac{0.1}{2\pi}.$$

dynes at 1 cm radius, p = number of pairs of poles.

The integrated average value during a period calculated from above expressions is

$$= \frac{B.\,I.\cos(\alpha-\beta).\,n_r.\,p.\,0.1}{4.\pi}.$$

II. Torque from lines of force along *ba* and current I_k, clockwise:

$$= - \zeta .\ I.\ \sin\ (at + \alpha)\ (n_r - n_s \sin\ \theta).\ n_r I_k .\ \sin\ at.\ p. \frac{0.1}{4\pi}$$

dynes at 1 cm radius. Average value

$$= - \frac{\zeta .\ I.\ (n_r - n_s .\ \sin\ \theta).\ n_r .\ I_k .\ \cos\ \alpha.\ p.\ 0.1}{4.\pi}.$$

The resulting torque is the sum of the above expressions. Substituting for I_k and B their values, we obtain:

$$\frac{\zeta .\ I^2 . n_s .\ \sin \alpha . \cos \alpha . \cos \theta\ p}{40.\pi} \left[\begin{array}{l} n_r\ (\tan \alpha + \cot\ \alpha) \\ \quad + n_s .\ \sin \theta\ (\cot \beta - \cot \alpha) \end{array} \right]$$

and expressed in kilograms at 1 meter radius with current expressed in effective amperes, after some transformation:

$$K = 1.625\ .\ 10^{-10}\ \zeta .\ I_e^2 .\ n_s .\ \cos \theta .\ p.\ [n_r + n_s .\ \sin \theta$$
$$(\sin\ \alpha .\ \cos\ \alpha .\ \cot\ \beta - \cos^2 \alpha)].$$

The formulæ thus obtained suffice for figuring the behavior of a motor, if its design is given. The magnetic induction in the directions *b a* and *c d* can also be calculated, and accordingly corrections can be made for the iron losses.

Motors of this kind are generally used for such purposes where it is necessary that they can work in both directions. This being the case, it is of advantage to arrange the machinery in such a way that no shifting of brushes is necessary. If θ is made $= 0$, the position of the brushes is perfectly symmetrical and accordingly allows the motor to run in any direction. But if $\theta = 0$, the formulas are also greatly simplified. At the end of the paper a summary of the formulas is given, not only in their most general form, but also for $\theta = 0$.

MAXIMUM TORQUE AT START.

Supposing that from the reasons just stated, we use the arrangement with a symmetrical brush position $(\theta = 0)$; then it is of interest to investigate what relation n_r should have to n_s, the latter being given, in order to get maximum starting torque.

Accordingly, a motor with known n_s, ζ, ξ, etc., is given; for what value of n_r is the maximum torque obtained at $N_1 = 0$?

Substitute in the formulas,

$$\theta = 0;\ N_1 = 0;\ n_r = n_s .\ c \text{ then}$$
$$D = c.\ n_s\ (\zeta + \xi)$$

$$\cot \alpha = \frac{- N.\, c^2.\, n_s^2.\, (\zeta + \xi)}{r.\, 10^8}$$

$$\cot \beta = - \frac{N.\, c^2.\, n_s^2.\, \xi}{r.\, 10^8}$$

$$V = N.\, n_s.^2 \left[\lambda + c^2 (\zeta + \xi)\right]$$

The angle α (difference of phase of stator and rotor current) is at starting a little less than 180 degs. Accordingly, we may write,

$$\sin \alpha = - \frac{1}{\cot \alpha}$$

$$W = \frac{\zeta.\, r.\, 10^8}{c^2 (\zeta + \xi)}$$

$$U = 0$$

$$T = 0.$$

If we now neglect the quantities which contain r and R, then,

$$I_s = \frac{E^2}{\left\{ N.\, n_s^2 \left[\lambda + c^2 (\zeta + \xi)\right] \cos \alpha - \frac{\zeta.\, N.\, n_s^2\, \xi}{\zeta + \xi} \right\}^2 + \left\{ N.\, n_s^2 \left[\lambda + c^2 (\zeta + \xi)\right] \sin \alpha \right\}^2}.$$

Seeing now that α is a trifle less than 180 degs., then $\cos \alpha = \sim -1$ and $\sin \alpha = \sim 0$

The denominator, therefore, becomes:

$$\left\{ N.\, n_s^2 \right\}^2 . \quad \left\{ \left[\lambda + c_2 (\zeta + \xi)\right] + \frac{\zeta.\, \xi}{\zeta + \xi} \right\}^2$$

and the expression for the torque is

$$K = \frac{c}{\left[\lambda + c^2 (\zeta. + \xi) + \frac{\zeta.\, \xi}{\zeta + \xi}\right]^2} \times \text{a constant.}$$

Differentiating:

$$\frac{dK}{dc} = \left[\lambda + c^2 (\zeta + \xi) + \frac{\zeta\, \xi.}{\zeta + \xi}\right]^2 - 4c^2 \left[\lambda + c^2 (\zeta + \xi) + \frac{\zeta.\, \xi}{\zeta + \xi}\right] (\zeta + \xi) = 0$$

(denominator of differential coefficient omitted, not possibly being $= 0$).

As now the expressions in brackets could not be $= 0$ (containing only positive quantities), then for maximum torque:

$$\lambda + c^2 . (\zeta + \xi) + \frac{\zeta\, .\, \xi}{\zeta + \xi} - 4c^2 (\zeta + \xi) = 0$$

$$\therefore c = \sqrt{\frac{\lambda + \frac{\zeta\, .\, \xi}{\zeta + \xi}}{3 (\zeta + \xi)}} .$$

If $\lambda = \xi$ and small in comparison to ζ, then

$$c = 0.82\sqrt{\frac{\xi}{\zeta}}.$$

For a railway motor, which for mechanical reasons cannot have a very small air-gap, $\frac{\xi}{\zeta}$ may come out something like 1/20 which corresponds to $c = 0.183$. *Accordingly, the number of conductors on rotor should be* 1/5—1/6 *of the number of conductors on stator.*

At starting $\frac{\xi}{\zeta}$ often may, on account of saturation of iron, increase up to 1/6; this would correspond to $c = 0.82\sqrt{1/6} = 0.335$ or the *number of rotor conductors is about one-third of the stator conductors.*

MAXIMUM TORQUE PER VOLTAMPERE AT START.

It may be of still more interest to investigate what relation n_r must have to n_s in order to obtain the *maximum torque per voltampere* at start. That is to say, if the voltage is kept constant, the *maximum torque per ampere at start.* The expression for this quantity is easily obtained:

$$\delta = \frac{c}{\lambda + c^2 . (\zeta + \xi) + \frac{\zeta . \xi}{\zeta + \xi}}$$

$$\text{For } \delta = \text{maximum}\,; \frac{d\,\delta}{d\,c} = 0$$

$$\therefore \frac{d\delta}{d c} = \lambda + c^2 . (\zeta + \xi) + \frac{\zeta . \xi}{\zeta + \xi} - 2\,c^2 (\zeta + \xi) = 0$$

$$c = \sqrt{\frac{\lambda + \frac{\zeta . \xi}{\zeta + \xi}}{\zeta + \xi}}$$

or if $\xi = \lambda$ and small compared with ζ,

$$c = 1.41\sqrt{\frac{\xi}{\zeta}}$$

For $\frac{\xi}{\zeta} = \sim \frac{1}{6}$ then $c = \sim 0.57$; For $\frac{\xi}{\zeta} = \sim \frac{1}{20}$

then $c = \sim 0.32$. *Accordingly, if we wish to obtain the greatest economy with current at start, the number of rotor conductors must be chosen larger than if the greatest torque is aimed at.*

It should be pointed out that for other reasons (considerations as to lag, etc.), the number of rotor conductors often must be somewhat modified.

Finally, the results of experiments with a motor of this kind will be given. The machine was made by the Allmänna Svenska Elektriska Aktiebolaget, Westerås, and tested in their works.

The stator of this experimental machine (see Fig. 2) had 72 half-open slots, each containing 12 conductors of 2.5 mm diameter. The winding was divided in two groups which were connected in parallel. The rotor had 49 slots with 6 wires of 2.8 mm diameter. Winding, series drum. Number of poles, 4. Air-gap, 1 mm. Frequency, 27. Voltage, 200.

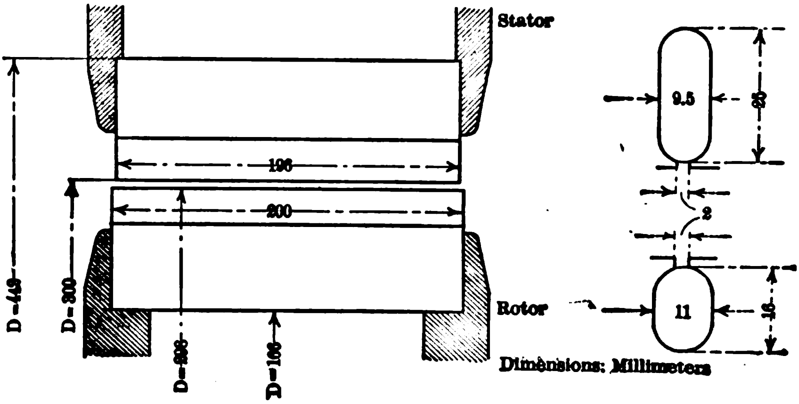

FIG. 2.

Calculation of ζ.

A current in the rotor winding $= I$ causes a flow of lines in the air-gap (neglecting iron) per pole:

$$\frac{n_r}{4} \cdot \frac{I}{2} \cdot 1.25 \cdot \frac{1}{0.2} \cdot 459 \cdot \frac{1}{2}$$

(459 = area of 1 pole).

Accordingly:

$$\zeta \cdot I \cdot n_r = \frac{n_r}{4} \cdot \frac{I}{2} \cdot 1.25 \cdot \frac{1}{0.2} \cdot 459 \cdot \frac{1}{2}$$

$$\zeta = 180$$

Calculation of $\xi = \lambda$.

The constants of *Hobart* (see Elektrotechnische Zeitschrift No. 46, 1903), are used:

$$\xi . I . n_r = \frac{I}{2} . \frac{n_r}{4} (20 \times 0.93 + 0.4 \times 30) . 2$$

20 = length of one conductor in iron in cms.

30 = free length of one conductor in iron in cms.

0.93 = Hobart's constant.

0.4 = Hobart's constant.

The constants ζ and ξ obtained from actual measurement (by measuring voltage and primary current with brushes removed entirely in one case and complete short-circuit in the other case) are:

$\zeta = 208$; $\xi = 7.1$.

Other constants are:

$N = 27$; $r = 0.15$; $R = 0.68$; $E = 200$; $n_s = 864$; $n_r = 294$.

Calculating from these constants and with $\theta = O$, the curves in full line (Fig. 3) are obtained. The dotted lines represent the experimental values.

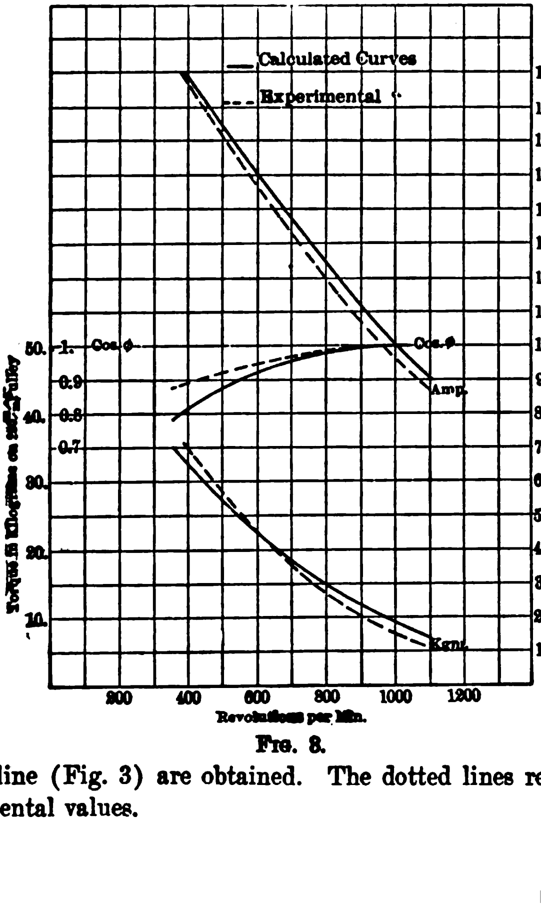

FIG. 3.

APPENDIX.

SUMMARY OF FORMULAS.

General Formulas.

$$D = \zeta\,(n_r - n_s \sin\theta) + \xi.\,n_r$$

$$\cot\alpha = \frac{\dfrac{N_1\,r\,D.\,10^8}{\zeta.\,N} - N\,n_r^2\,n_s \cos\theta\,(\xi + \zeta)}{r\,n_s \cos\theta\,.10^8 + N_1\,n_r^2\,D\left(1 + \dfrac{\xi}{\zeta}\right)}$$

$$\cot\beta = \frac{D.\,N_1}{\zeta\,n_s \cos\theta}\left[\frac{1}{N} - \frac{\xi\,n_r^2 \cot\alpha}{r.\,10^8}\right] - \frac{N\,n_r^2\,\xi}{r.\,10^8}$$

$$V = [n_s\,\lambda\,N - \zeta\,N\,n_s \sin\theta\,(n_r - n_s \sin\theta) + N\,n_r\,D].10^{-8}$$

$$W = \zeta\,n_s^2 \sin\alpha \cos^2\theta\,N.\,10^{-8}$$

$$U = \zeta\,n_s \sin\alpha \cos\theta\,N_1\,n_r\,.10^{-8}$$

$$T = \xi\,n_r\,N_1\,n_s \cos\theta\,(\cot\beta - \cot\alpha)\,.10^{-8}$$

$$P = R.\,\sin\alpha + V.\,\cos\alpha + W.\,\cot\beta + U$$

$$Q = R.\,\cos\alpha - V \sin\alpha - W + U.\,\cot\beta + T \sin\alpha$$

$$tan = \frac{P}{Q}$$

$$\varphi = \gamma - \alpha$$

$$I_e = \frac{E_e}{\sqrt{P^2 + Q^2}}$$

$$I_{ek} = \frac{n_s\,I_e.\,\sin\alpha.\,\cos\theta\,(\cot\beta - \cot\alpha)}{n_r}$$

$$K = 1.625.\,10^{-10}.\,\zeta\,I_e^2.\,n_s \cos\theta.\,p\,[n_r + n_s \sin\theta\,(\sin\alpha.\,\cos\alpha \cot\beta - \cos^2\alpha)]$$

Special Formulas.

for $\theta = 0$.

$$D = n_r\,(\zeta + \xi)$$

$$\cot\alpha = \frac{\dfrac{N_1\,r\,D.\,10^8}{\zeta\,N} - N\,n_r^{\,2}\,n_s\,(\zeta + \xi)}{r\,n_s\,10^8 + N_1\,n_r^{\,2}\,D\left(1 + \dfrac{\xi}{\zeta}\right)}$$

$$\cot\beta = \frac{D.\,N_1}{\zeta\,n_s}\left[\frac{1}{N} - \frac{\xi.\,n_r^{\,2}.\,\cot\alpha}{r.\,10^8}\right] - \frac{N\,n_r^{\,2}\,\xi}{r.\,10^8}$$

$$V = [n_s^{\,2}\,\lambda\,N + N\,n_r\,D].\,10^{-8}$$

$$W = \zeta.\,n_s^{\,2} \sin\alpha\,N.\,10^{-8}$$

$$U = \zeta.\,n_s.\,\sin\alpha.\,N_1\,n_r.\,10^{-8}$$

$$T = \xi\,n_r\,N_1\,n_s\,(\cot\beta - \cot\alpha).\,10^{-8}$$

$$P = R.\,\sin\alpha + V \cos\alpha + W \cot\beta + U$$

$$Q = R.\cos\alpha - V\sin\alpha - W + U\cot\beta + T\sin\alpha.$$

$$\tan\gamma = \frac{P}{Q}$$

$$\varphi = \gamma - \alpha$$

$$I_e = \frac{E_e}{\sqrt{P^2 + Q^2}}$$

$$I_{ek} = \frac{n_s I_e . \sin\alpha\,(\cot\beta - \cot\alpha)}{n_r}$$

$$K = 1.625 .\ 10^{-10}\,\zeta .\ I_e{}^2 n_s p\, n_r$$

Notation.

D = a coefficient.

n_r = number of conductors round rotor, provided the winding is such that each conductor carries half of current on short-circuit. If the rotor has a six-pole parallel winding, then n_r = active conductors divided by three.

n_s = number of conductors on stator, provided that each conductor carries half of total current.

ζ = coefficient of magnetization; $\zeta\, n_s$ = number of lines of force per pole at one ampere in stator circuit, with no current in rotor.

ξ = coefficient of leakage; $\xi\, n_r$ = leaking lines per pole at one ampere on short-circuit.

λ = leaking cofficient for stator.

θ = angle of brush position.

α = angle of lag between current in stator circuit and short-circuit.

β = angle of lag between lines of force along $b\ c$ and short-circuited current.

N = frequency.

N_1 = speed expressed in frequency (at synchronous speed $N_1 = N$).

r = resistance of rotor circuit including short-circuit.

R = resistance of short-circuit including rotor winding.

V, W, U, T, P and Q = coefficients.

I_e = stator current (effective value).

I_{ek} = short-circuited current (effective value).

E_e = impressed e.m.f. (effective value).

K = torque in kilograms at 1 meter radius.

CHAIRMAN DUNCAN: The next paper will be by Mr. P. M. Lincoln, on "Single-Phase Railway Transmission and Distribution Problems."

TRANSMISSION AND DISTRIBUTING PROBLEMS PECULIAR TO THE SINGLE-PHASE RAILWAY.

BY PAUL M. LINCOLN.

Up to the present time practically all long distance power transmission has been carried on with three-phase currents on account of the obvious advantages due to its use. The use of single-phase currents, however, introduces practically no new elements into the transmission problem. Its effect is to simplify the arrangements both of the line and the translating apparatus at the ends of the line. On the line two conductors instead of three will be used with a corresponding reduction in the number of insulators. At the terminals one transformer will take the place of a group of three and the switching apparatus is very greatly simplified.

One apparent handicap under which the single-phase line labors is the apparent fact that to transmit a given amount of power a given distance with a given loss requires more copper single-phase than three-phase in the ratio of 4 to 3. If we assume that the voltage between the single-phase terminals is equal to that between any two of the three-phase terminals, this apparent fact holds. Under normal conditions of operation, however, this assumption is not fair to the single-phase line. It is evident that so far as the transmission line is concerned, the true criterion of voltage strain is that which exists between any conductor and ground and not the voltage between conductors. It is further evident that under normal conditions ground potential will exist at the geometric center of the electric system. For instance, ground potential for the single-phase line will exist at a point midway between the terminals as shown at (*a*) Fig. 1, while in the three-phase system it will exist at the geometric center of the triangle as shown at (*b*). With the same terminal voltage, therefore, the insulation strain between any terminal and ground will be the greater in the three-phase system in the ratio of 2 to $\sqrt{3}$. But if the terminal voltage be so adjusted that the insulation strains to ground be made the same, then to transmit a given amount of power a given distance at a given loss will require for the single-phase line an amount of copper no greater than that required by the three-phase line. In other words, for equal insulation strains on the line the terminal voltage of the single-phase system may be greater than that of the three-phase system in the ratio of 2 to $\sqrt{3}$.

It may be well to draw attention to the fact that the above observation holds good only for the normal condition, that is, the condition that ground potential occurs at the geometrical center of the system. If one of the conductors becomes grounded an abnormal condition arises and the insulation strain becomes equal to the terminal voltage. Under this condition, however, the three-phase system suffers the disadvantage of having the insulation on two conductors subjected to a strain equal to terminal voltage, while in the single-phase system only one conductor is so subjected.

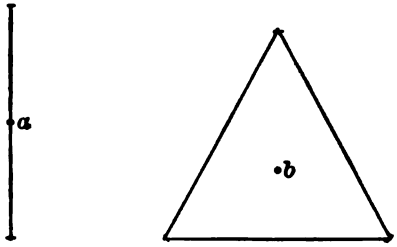

FIG. 1.

On account of the fact that a polyphase generator is for a given output much lighter and cheaper than a single-phase generator, it becomes of advantage, so far as the generating plant is concerned, to derive the single-phase currents necessary for operating a single-phase railway from polyphase generators. The saving in cost of generators thus effected amounts to approximately 30 per cent. In order to secure this advantage it is necessary to use a switchboard and transformer equipment which is somewhat more complicated and expensive than would be the case with single-phase generators, but as a rule not sufficiently so to prevent a greater economy in the use of polyphase generators over single-phase. For this purpose the two-phase generator is in general preferable to the three-phase since it is easier generally speaking to divide a given amount of single-phase load into two parts than into three parts. Three-phase generators can, of course, be used but a balanced condition of load is obviously more difficult to secure.

The use of single-phase current from two wires of a three-phase line also involves a tendency to produce disturbances in neighboring telephone and other circuits, which is not apparent at first thought. Under the normal condition of operation of a three-phase circuit the sum of the static potentials of the three phases is always zero at any and every instant of time. Therefore, static induction on neighboring wires is due only to the fact that different distances necessarily exist between the disturbed circuit and each conductor of the three-phase circuit, and, therefore, is matter which can be corrected by proper transpositions. If, however, one of the three wires be taken away, as may be the case with a single-phase from a three-phase circuit, the sum of the static potentials no longer remains at zero and static induction will take place on neighboring circuits without the possibility of correction by any method of transposition.

In other words, two conductors of a three-phase circuit will under neighboring circuits equal to about one-half that which would be occasioned by the three conductors under the abnormal condition arising when one of them becomes grounded. Therefore, if there is any danger of disturbing neighboring circuits by static induction, it is advisable on this account to use three distinct two-conductor circuits rather than the alternative of taking single-phase from the three conductors of a three-phase circuit. An alternative is to carry all three of the conductors to all points to be served. This often involves running three wires where two would carry the load simply for the purpose of obtaining the static influence due to this third wire. Since the static influence is independent of the material of the wire and also largely independent of the size of the wire, this third conductor need not necessarily be as expensive in first cost as the other two constituting the working circuit.

In general, therefore, the transmission problem is changed but little by the adoption of single-phase in the place of three-phase. But when we come to the problem of the distribution of alternating current to cars on trains along the line of a railway we find a material difference between this and its counterpart, the distribution of direct current to railways. In the following discussion it is assumed that the general arrangement of the typical alternating-current railway will be practically the same that is now followed in the typical direct-current railway. That is, the system will consist of a generating station sending out the required energy at a high voltage. At various points along the line this high-voltage energy will be transformed down to the voltage that has been selected as the trolley voltage and fed directly into the trolley. The general arrangement of the alternating and direct-current systems is, therefore, very similar. The main differences between the two systems are, first, the elimination of a trolley voltage limit except that set by considerations of insulation and safety; and second, the elimination of rotary converters from the sub-stations and the consequent elimination for the necessity of constant attendance.

Assuming that in any given case the trolley voltage is fixed, there will still remain two variables to be determined, first, the cross-section of the trolley copper, and second, the distance between transforming stations. These two quantities are evidently interdependent. That is, a variation in one requires, in order to render a given service, a variation in the other. For instance, if we increase the number of feeding points the cross-section of copper to convey a given amount of power with a given loss is decreased.

The considerations upon which these quantities should be determined may evidently be classed under the following heads:

1. Maximum economy.
2. Voltage drop.
3. Insurance against accident.
4. Mechanical considerations.
5. Avoidance of undue multiplicity of stations.

1. MAXIMUM ECONOMY.

It is evident that a cross-section of copper and a distance between transforming stations should be used which will give the maximum economy, provided the limit as thus set does not fall beyond that as absolutely fixed by other considerations. Kelvin's law gives us a basis for the calculation of the most economical cross-section of copper. As is well known, this cross-section is dependent only on the cost of power, the cost of conductors in place, the load factor and the interest and depreciation on the investment for conductors. Knowing the above factors, we may derive at once the density of current per unit of cross-section of copper which will be most economical. This current density per unit of cross-section is entirely independent of the distance power is to be transmitted as well as the amount of power and the transmitting voltage. Once having derived the most economical density of current per sq. in., it is easy by making certain other assumptions to fix the most economical distance between transforming stations as well as the proper size of copper. The most economical distance between stations is given by the following formula:

$$D = .00314 \sqrt{\frac{KVA}{WP}}$$

in which

D = distance between adjacent transforming station in miles.

K = the cost of a single transforming station in dollars.

V = trolley voltage.

A = most economical current density in amperes per sq. in. as derived from the conditions mentioned above.

W = average apparent kilowatts used per mile of road.

P = price of copper in cents per pound.

This formula is simply another method of saying that to make first cost a minimum the cost of the trolley stations should be made equal to the cost of the trolley copper. Knowing the values of A, D and W the cross-section (in circular mils) of the trolley is, of course, fixed by the expression

$$cm = \frac{6.35 \times 10^8 DW.}{VA}$$

To derive the above expression for distance between stations the assumption is made that the cost of a transforming station is independent of its capacity, an assumption which of course is not strictly true, but one which is not so far from the truth as appears at first sight. The total cost of a transforming station is made up of transformers, auxiliary apparatus and building. The cost of the building and the auxiliary apparatus will remain practically stationary for large variations of capacity. The cost of the transformer item, of course, decreases with decreased capacity, but decrement in cost is not nearly so great as the decrement in capacity. Further, the decrement in capacity to render a given service will be less than the decrement in distance between stations. For when a car or train is opposite a given transformer station practically all of the energy to operate it must come from that transformer station. Within wide limits too the maximum load on any transformer station will be that due to a single car or train. The maximum load on any transformer station is, therefore, within wide limits, independent of its spacing, and, therefore, independent of its capacity. Closer spacing only limits the element time during which the load pulls on a transformer station, and not the element of maximum load. Since the capacity of a transformer station should be adjusted to the root mean square load and not to the average load, it follows as stated above that the decrement of capacity in transformer stations is not proportional to the decrement of spacing.

As indicated above, however, the consideration of economy should be allowed to fix these quantities only when they fall within the limits as fixed by other considerations.

2. VOLTAGE DROP.

It is of course essential that sufficient voltage exists at the car to operate it and it is preferable that the fluctuation of voltage be within the limit of successful incandescent lighting; and in the spacing of transformer stations and the choice of trolley wire the dictation of economy may have to be modified by the dictation of allowable drop. In comparing the question of voltage drops in an alternating-current railway line with those of a direct-current railway line, two marked differences obtain, one an advantage to the alternating system of distribution and one a disadvantage. An advantage for the alternating system accrues from the general fact that alternating voltages are capable of being transformed with comparative ease and high efficiency. It is possible, therefore, to install an apparatus on an alternating-current car whereby any voltage drop that occurs may be compensated for.

On the other hand, the alternating system labors under the disadvantage that inductive drops which are peculiar to the alternating system are added to the ohmic drop which is the only element to be considered in the direct-current system. The amount by which the total drop is increased by this inductive effect is dependent of course upon the size of trolley wire, its distance from its return, the nature of the return, the frequency and the power factor of the load. The general statement may be made, however, that with 25 cycles, the usual height of trolley wire, the usual power factors that will be met in practice and sizes of trolley wire not exceeding No. 4 — the total drop in the trolley line will rarely be more than the ohmic drop increased by 50 per cent. This figure assumes that the term "ohmic drop" takes into consideration the additional loss that alternating current causes in the return rail circuit over that caused by direct current.

3. Insurance.

A second point which should be borne in mind when determining the size of trolley and the distance between stations, and which may require a modification of these quantities as fixed by consideration of economy, is the possibility of the temporary breakdown of any transformer station. These elements should be so chosen that in this event operation of cars or trains past the disabled station may be effected from adjacent stations. This condition may fairly be considered as an abnormal one, however, and so long as operation under this condition still remains possible the questions of economy and drop may be lost sight of in that section where the abnormal condition exists. An arrangement of transformer stations which may be suggested in this connection is one in which a reasonable amount of spare capacity is provided by making each transformer station a certain percentage larger than necessary to take care of its normal load, and only providing a single transformer in a station. In case of the disablement of any station, its load can be taken care of by the adjacent stations until such time as the transformer can be replaced.

4. Mechanical Considerations.

This point is sufficiently covered by the consideration that the trolley wire must be on the one hand of sufficient size to make a strong mechanical structure, and on the other hand not of so large a cross-section as to make the supporting structure unduly heavy. The size dictated by maximum economy must, therefore, be subject to the modification of mechanical fitness.

5. Danger of Multiplicity of Stations.

In viewing this problem from the standpoint of the high-tension line it must be borne in mind that every point at which it is necessary to tap the line and take power becomes a point of danger, a point where accidents may happen. And the higher the high-tension voltage the more difficult and expensive it becomes to take power from the line, and the greater becomes the liability of danger. This point becomes a good reason for reducing the number of transformer stations to a minimum.

It may be easily gathered from the above discussion that there is no golden rule for the determination of the spacing and capacity of transformer stations or the size of the conductor. It is, like most other engineering problems, a matter of compromise between various elements, some of which point in one direction and some in the other, and a matter which must be determined by engineering judgment rather than by any inflexible law.

Chairman Steinmetz: The next paper is on "Alternating vs. Direct-Current Traction," by Prof. Dr. F. Niethammer. This is a very general paper and it is impossible to abstract it. It is in the hands of the members of the sections and it will be considered as read by title.

ALTERNATING *vs.* DIRECT-CURRENT TRACTION.*

BY PROF. DR. F. NIETHAMMER.

Even if one considers only serious proposals, there will be found available quite a considerable number of electric railway systems which might be used. None of the known systems possess, however, advantages or features of such a kind as to render it able to replace all others. This fact becomes specially conspicuous, if an electric railway is desired which is adapted equally well to all the various services occurring in railway practice, viz., short and long lines, high and low speeds, short and long distances between stations, heavy and light traffic.

At the present time the following electric systems may be considered:

1. DIRECT-CURRENT RAILWAYS.

a. *Two-wire systems.*— Constant pressure from 500 to 1000 volts on the train, the return circuit being the rails. Motors with large inputs and moderate speeds may, however, safely be built for pressures up to 2000 volts, by using double commutators if necessary, or by grouping several motors in series.

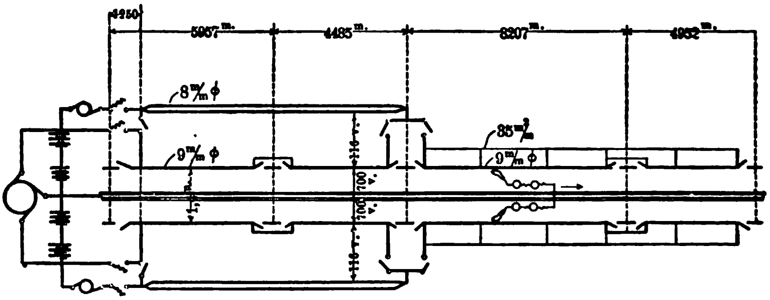

FIG. 1.— THREE-WIRE DISTRIBUTION SYSTEM (KRIZIK, PRAG).

b. *Three-wire systems.*— Constant pressure up to 2×1200=2400 volts (Line built by Thury, Geneva; City & South London Rail-

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* As I did not think it advisable to change the paper as it originally ran, I add an appendix containing the most recent progress. The author treats the above subject in a much more complete way in a German book "Die elektrischen Bahnsysteme der Gegenwart." As to single-phase railway motors see also *Electrical Magazine*, October and November, 1904.

way with 4×500 volts). 2×2000 volts seem to be a safe limit for this system. Each train may either be fed by one branch of the three-wire net-work, in which case the pressure per train is half of the whole voltage, and only *one* trolley is necessary; or each train may take the whole voltage by two trolleys the connection of two motor groups being grounded and the rails being the neutral conductor. (Fig. 1.)

By installing boosters or direct-current transformers in the central station or along the line, the distance which may be covered by the simple direct-current system may be somewhat enlarged; the same result may be arrived at by using storage batteries at some feeding points of the line.

c. *Direct-current railways with transmission by three-phase currents.*— The direct-current pressures on the trains remain the same as under (*a*) and (*b*); the three-phase voltages go as high as 60,000, transformation being by rotaries or motor generators. The transmission may also be effected by the direct-current system with constant current and variable voltage up to 30,000 volts (Thury).

In all the cases mentioned, the simple series motor is almost exclusively used, with the exception of mountain railways with low constant speed. For the latter case the shunt motor is preferable, as this type is able to return energy to the line.

2. THREE-PHASE RAILWAYS.

Induction motors on the train. Safe trolley wire voltages are 500 to 3000 (5000) volts, the pressure of 10,000 volts of the Berlin-Zossen high speed line being only experimental. The transmission may use pressures up to 60,000 volts which are reduced by stationary transformers preferably of the oil type.— Of some interest for three-phase lines is the compensated polyphase induction motor with commutator, which has been proposed for this work.

3. SINGLE-PHASE COMMUTATOR MOTORS.

The highest trolley wire voltage advisable at present is about 6000 volts, though the Maschinenfabrik Oerlikon proposes and is using 15,000 volts on an experimental line, which involves less risk for a system with one trolley wire than for a system with two or three. There are available for traction three types of single-phase motors: The series motor (Westinghouse Company, General Electric Company), the repulsion motor (Brown, Boveri & Cie) and the compensated or series-repulsion type (Winter-Eichberg, Union E. G.).

The following systems are of sufficient practical interest to be mentioned, but they cannot be considered serious competitors to the foregoing.

4. CURRENT CHANGERS.

Converters or electric generators *on the train.*

a. *Ward-Leonard system* and shunting locomotive of the Maschinenfabrik Oerlikon. The train takes single-phase current at high voltage from the trolley line and transforms it into direct current by a high-speed motor-generator set. By changing the small exciting current of the direct-current generator, speed control of the train may be accomplished, and during retardation energy may be returned to the line. The main drawback of this excellent system is the excessive weight and price of the motor generator, which weighs more than all car motors together.

b. *Combination of steam engines, steam turbines or oil (petroleum) engines with direct-connected direct-current generators.*—Regulating is done as in case *a.* Of this type is the old Heilmann locomotive and a new car of the North Eastern Railway in England, which latter contains a horizontal oil engine directly connected to a compound generator of 55 kilowatts 300 to 550 volts and 420 to 480 revolutions per minute.

5. SINGLE-PHASE INDUCTION MOTORS.

First proposed by C. E. L. Brown but having little chances of being applied practically.

a. Stator and rotor both revolve; the stator is brought up to speed without load. By gradually retarding the stator by means of a brake, the rotor which is connected to the car wheels is put in motion.

b. The induction motor is started empty and connected to the car wheel through a flexible friction clutch.

c. Stator and rotor are connected with a device capable of storing up energy, which device absorbs or delivers energy at will, i. e., an air compressor (B. J. Arnold) or oil pumps with variable stroke (Swinburne) or water pumps (Siemens & Halske). This system possesses the advantage of ability to operate for short distances without connection to the electric supply circuits.

6. CONSTANT DIRECT-CURRENT SYSTEM.

Various trains are switched in series by a double trolley wire system. The total voltage is variable, and it is proposed to go as high as 30,000 volts. The constant-current system is, however, too complicated and unreliable for distributing purposes, though it is excellent for transmission lines. Speed variation and starting would be very economical and returning energy to the line very simple. The continuous losses in the line would, however, be considerable.

7. MOTOR CARS WITH STORAGE BATTERIES.

Independent of every outside source of current and always ready for service. Such locomotives are heavy[1] and expensive and serve only for factory or shunting purposes or for short lines with light and constant traffic and with low acceleration. The mixed service using partly storage batteries and partly overhead line has entirely failed. There were also proposed railway plants combining storage batteries with single-phase induction motors. Starting is done by the battery, free running and charging by the transformed single-phase current.

The above-mentioned systems should be compared with regard to first cost, operating expenses, reliability and safety in service. This comparison is to be made for lines of few kilometers in length (street railways) and for hundreds and thousands of kilometers (main lines), for speeds of 10 km per hour up to 100 and 150 km; for accelerations of 0.1 *m* per sec.^{2} to more than 1 *m* per sec.^{2}, the retardation being even higher by 20 to 40 per cent. The train weights vary from 5 tons to about 2000, and the number of horse-power per train from 10 to 4000. There are lines with only 10 trains a day, on others the trains follow at intervals of 3 minutes. In one case the stations are separated by a distance of only 200 meters, on others more than 100 km. In the first case the whole service is starting, coasting and braking; in the other case free running is of most importance. Either motor cars with multiple unit control for motors distributed over the whole train or locomotives may be used. Electric traction is specially qualified for motor car service of passenger as well as of freight trains which service requires frequent short trains of variable length. Electric

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[1] A storage battery locomotive for a whole train weight of 100 tons for 16 km an hour weighs 26.8 tons; the storage battery absorbs 10 tons and the remaining electric equipment 4.3 tons.

motors are also able to haul heavier trains than steam engines and to exceed the latter in speed. (Baltimore-Ohio 1600 tons trains. New York Central trains of 2×2200 horse-power, max. 2×2800 horse-power.) Single motor cars take more watts per ton-km than long trains. A very hard problem is offered by motor cars which must be used for short and long distances between stations, for low and high speeds, and for short and long lines and for light and heavy service at the same time. For this service, however, electricy is better adapted than steam.

The main data for usual railway traffic may be taken from the following table, which gives the limiting values corresponding to light and heavy traffic:

TABLE. I.

TRACTION DATA.

Kind of railway.	Max. speed km per hour.	Motors.			Number of cars with motors.	Number of cars without motors.	Weight of train, tons.	Acceleration m. (p. sec.)²	Distance of stations in km.
		Number.	HP per motor.	HP total.					
Street railways, with radial lengths of 1 to 30 km from center and gauges of 600 to 1.435 mm..	10 to 30	1 to 2	10 to 60	10 to 100	1	0 to 3	5 to 25	0.1 to 0.3	0.1 to 0.3
Industrial and mine locomotives, gauge 500 to 1,435 mm.........	8 to 20	1 to 4	5 to 50	10 to 200	1	....	20 to 500	small	....
Elevated and underground, 10 to 40 km length, multiple unit.....	30 to 90	2 to 8	30 to 250	60 to 1,500	2 to 3	1 to 5	60 to 250	0.4 to 1.0	0.2 to 2
Suburban and interurban service, 10 to 200 km radial length, multiple unit.....................	30 to 120	2 to 8	30 to 200	60 to 1,500	1 to 3	1 to 5	30 to 300	0,2 to 0.7	2 to 15
Main lines locomotives { freight trains....	10 to 40	2 to 8	50 to 500	100 to 3,000	1 to 2	many	50 to 2,000 (mostly 150 to 500)	0.05 to 0.2	2 to 50
passenger trains.	20 to 70	2 and more	40 to 400	80 to 1,500	1 and more	many	40 to 500 (mostly 60 to 200)	0.1 to 0.3	2 to 20
express trains...	70 to 150	2 and more	100 to 500	300 to 3,000	1 and more	3 and more	100 to 500 (mostly 150 to 250)	0.2 to 0.5	10 to 300
(Steep) Gothard line, 26% grade freight .... passenger....................... express	 20 30 40	 4 4 4	 145 175 200	 580 700 800	 1 1 1	 many " "	 350 280 260	 very small " "	 3 to 20 3 to 10 5 to 20
Mountain Ry.....................	5 to 10	1 to 2	50 to 150	50 to 300	1	1 to 2	10 to 30	very small	1 to 5

TABLE I — TRACTION DATA (*Concluded*).

Kind of railway.	Max. speed km per hour.	Motors.			Number of cars with motors.	Number of cars without motors.	Weight of train, tons.	Acceleration m. (p. sec.)^2	Distance of stations in km.
		Number.	HP per motor.	HP total.					
Example									
Berlin elevated (direct current)	50	2×3	60	360	2	1	70	0.7	0.3 to 2
New York subway............	about 50	2×3	200	1,200	3	2	about 160	0.7	0.5 to 2
(direct current)............	" 90	2×5	200	2,000	5	3	" 260	....	....
Milan-Portocerisio (direct current)	90	4	150	600	1	1	80	0.35	2 to 10
Valtellina (three-phase)..........	....	(concat.)	....	....	....	....	75	0.16	2 to 10
passenger........................	64	4	150	300	1	many	....	....	....
freight	32	4	150	600	....	....	300 (10% grade)	....	....
new locomotive..............	64	2	600	1,200	1	many	250	0.16	2 to 10
	32	2	450	900	....	....	400	....	....
	(concat.)	....	....	....	....	....	....	....	....
Burgdorf-Thun (three-phase)									
passengers........................	36	4	60	240	1	1	55	0.25	1 to 4
freight	18	2	150	300	1	many	130 (25% grade.)	0.1	....
Direct current									
Baltimore and Ohio locomotives	16	2×4	225	2×900	1	many	1,600 (10% grade)	....	....
New York Central..............	110	4	550	2,200 or 4,400	1	"	550	about 0.7	....

The energy input, the watts per ton-km grow with increasing speed, i. e., an increase from 32 to 128 km per hour means an increase of input of 45 per cent per ton-km. High acceleration certainly requires lowest total watt consumption for starting, but it causes excessively high starting currents, necessitating large and expensive motors and drawing excessive loads from the central station. For short distances between stations it is most economical to run very fast up to a high speed, if admissible, and to coast as long as possible without current. The maximum acceleration depends upon the allowable shock to passengers when starting; much more than 1 m (per sec.)^2 will not be permissible. The best method is to increase acceleration gradually when starting and to let it die out finally without any shock.

Undoubtedly a reasonable electric railway service can be offered in economical competition with steam. On the Italian line from Milan to Porto Cerisio (130 km direct length, 70-ton trains, acceleration 0.35 m (per sec.)^2 and speed of 90 km), the introduction of electric service has increased the number of travellers 2½ times, the train-km 4 times and the trains per day have grown to 120 from about 20 during steam service. The receipts and profits obtained render this line the most economical in all Italy, though steam is used for generating electricity. Most favorable to electric traction are most urban and suburban lines, railways with dense traffic or those so located that the traffic could not be increased without an additional line, railway tracks with long tunnels and heavy grades and lines which are in the neighborhood of coal mines and water powers.

A comparison of the various electric systems should comprise the whole electric equipment, viz.: *a.* Motors and gearing; *b.* regulating and braking devices; *c.* current-collecting devices; *d.* central stations and sub-station equipments.

MOTORS.

The characteristic features of railway motors are,

1. Mechanical reliability.
2. Maximum pressure possible on motor terminals and maximum pressure at the trolley.
3. Sparking on commutator or collector.
4. Weight per horse-power at a definite speed.
5. Space occupied by motor.

With heavy train loads, high speeds and great accelerations it is often extremely difficult to make sufficient space available on the car truck for the large motors required. The room available increases with increasing diameter of the wheels and with broader gauges. It is a fact, that on a 300-mm gauge only 15-hp motors are possible, on a 700-mm gauge only 90 horse-power, on 1000-mm gauge about 150 horse-power and on normal gauge 250 horse-power.

6. Efficiency at full and partial loads.

7. Starting losses of the motor.

8. Power factor at full load, partial loads and at starting.

9. Heating for normal continuous running and for frequent starting.

10. Starting torque and possibility of producing high acceleration; current consumption for a definite starting torque.

11. Efficiency of acceleration.

12. Speed variation; losses and efficiencies at variable speeds. Steadiness of regulation. Speed characteristic for variable loads.

13. Braking on resistances and return of power into the line, when coasting or on grades.

The direct-current series motor has an air-gap of 2.5 to 7 mm for usual armature diameters of 300 to 600 mm, the upper gap being smaller by ½ to 1 mm than the lower. Experience on hundreds of thousands of such motors prove that this air-gap is absolutely safe and that there is no danger of sticking. The direct-current armature winding, with open slots and carefully wound separate coils, as well as the commutator, may be insulated in an absolutely reliable way for voltages up to 2000. The field winding has no high potential between its terminals and is easily protected against the frame, whilst the field winding of shunt motors, being subject to full pressure, is much more liable to break down.

The induction motor, if only that type without commutator is considered, must have an air-gap from 1 to 3 mm in depth for usual railway motors, according to size, in order to secure a satisfactory power factor and a sufficient overload capacity. The Valtellina motors with a rotor diameter of 800 mm have an air-gap of 2 mm. Values for other machines may be taken from Table II. According to the long practical experiences of Brown, Boveri & Cie., and of Ganz & Company, this small air-gap has never given rise to trouble, when the bearings are liberally designed. C. E. L. Brown has successfully used automatic ring lubrification for three-phase motors. Nearly closed slots should preferably be used to get smooth cylindrical surfaces along the air-gap, which makes it a necessity to wind the coils by hand. This type of winding with closed mica tubes in the slots and end connections well protected by bronze caps has never caused trouble on the Burgdorf-Thun or the Valtellina line. Special care must be given to the crossings of the end connections, but insulation may be obtained to withstand easily pressures up to 5000 volts. High voltage motors must, however, be very liberally dimensioned to keep down heating which deteriorates insulation. It may be of advantage to put the stators of two three-phase motors in series to reduce the voltage per motor (Fig. 2).

The air-gap of the single-phase commutator motor must also be rather small, though larger than with the three-phase motor, i. e., 3 mm for a rotor diameter of 450 mm. Commutator motors, the rotors of which are not fed directly from the line, are the best machines for high voltages up to 8000 volts, as all crossings of the end-connections can be easily avoided. For equal line voltage the single-phase motor in comparison with the direct-current motor is at a disadvantage in that there is an active e.m.f. across not only the armature but also the field coils.

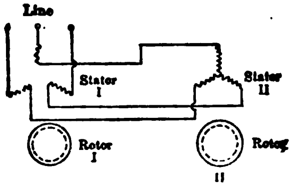


Fig. 2.— Stators in series.

The trolley voltage of all alternating current equipments of the single or polyphase type may be lowered at will by transformers on the car, if on account of limited space or due to troubles on the commutator, one is bound to use low voltage motors. That means, however, additional weight and expense, though the transformers may be used for regulating purposes at the same time.

The frame of single or polyphase motors can hardly be split, as is frequently done with direct-current machines. The joints might give rise to noise. As, however, even for direct-current motors in limited space the splitting of the frame is being abandoned in favor of the box frame, this fact is not of much importance. From Fig. 3 which represents a single-phase commutator motor of the Union Company, Berlin, for 50 horse-power, 800 rev. p. min., 40 periods, 6 poles, 400 volts, it may, however, be seen that the splitting of an alternating current motor is not an entire impossibility. Single-phase winding is more favorable yet, as no coils have to be cut. The laminated field of alternating-current motors is less rigid than that of the direct-current machine, so that an additional solid frame becomes necessary. For direct-current motors which must undergo rapid variations of the magnetic flux and of the speed or which must be quickly braked, a laminated frame would, however, also be of advantage.

The greatest drawback of direct-current motors is the difficulty of commutation. Sparking in the neutral zone is due to the reactance voltage of the short-circuited coils and to the voltage induced by the distorted main field. The distortion may be kept low by using a high number of field ampere turns and high saturations of teeth and pole shoes. The reactance is small for low speed motors, for short armatures, for small currents per armature circuit, and for commutators with many segments. Flashover is produced by high voltages per segment and by current rushes, when at high speeds the current circuit is suddenly opened and closed again. These are the reasons why direct-current motors have not been built as yet for more than 1000 volts, though larger low-speed types may successfully be designed for about 2000 volts. To raise the trolley voltage, several motors may be switched in series, but this scheme has the drawback that when some wheels with motors are slipping and others not, one or several motors may get the full voltage at their terminals and be burned out. The series motor is, of course, much less liable to sparking than the shunt motor, as the reactance does not vary much with load and speed, besides that armature and field ampere-

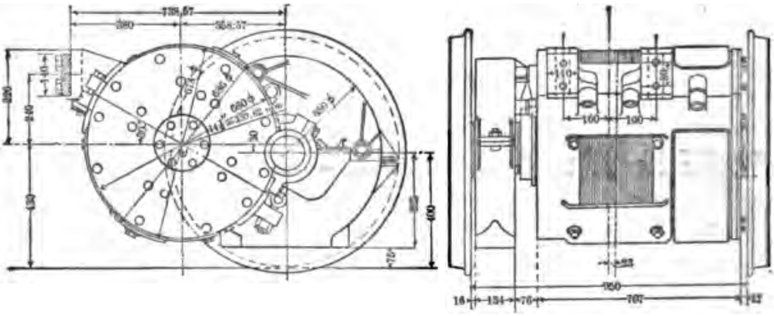
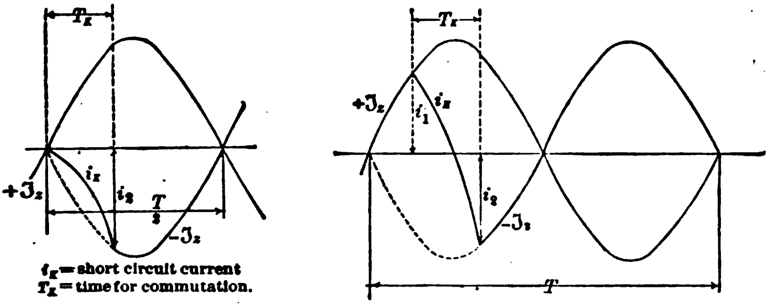


FIG. 3.—50-HP SINGLE-PHASE MOTOR, UNION COMPANY.

turns increase together. This commutation trouble is the most serious handicap to the direct-current motor, as it limits the extension of its supply lines.

The three-phase motor has no commutation problems. The space for the three slip rings with carbon brushes is, however, not smaller than that for a commutator. Even the commutator for compensated polyphase motors is easily designed, as it is a mere frequency changer with low voltage. With regard to sparking, single-phase commutator motors offer the greatest difficulties. First of all, an alternating current has to be commutated, a process which changes every moment (Figs. 4 to 6). Sparking is due not only to the reactance voltage (e_r) and the voltage (e_a) induced by the main field during rotation, but to a transformer voltage e_1 which is induced by the oscillations of the main field independent of speed and which produces a high short-circuit energy. By using low commutator voltages (smaller than 200 volts). a high number of commutator bars preferably with multiple parallel winding, by selecting thin brushes



FIGS. 4 AND 5. — COMMUTATION CHARACTERISTICS.

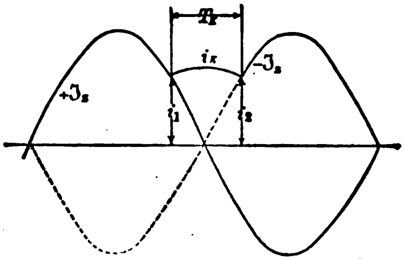


FIG. 6 — COMMUTATION CHARACTERISTICS.

(minimum 6 to 10 mm), by inserting high resistances into the short-circuited coils, by reducing the main field and by building only motors for small outputs and small periodicities, the transformer voltage, e_1, may be kept sufficiently low. The reactance voltage, e_4 is cut down by the same expedients as used for direct-current motors. Equalizers and auxiliary commutation poles may be of advantage, but there will rarely be space available for them. By a double (horseshoe) pole excited by the main current opposite to the short-circuited coil, one may neutralize the whole transformer effect. The General Electric Company uses a distributed field winding to neutralize the reactance voltage similar to the Ryan winding of direct current machinery.

The repulsion motor and the compensated motor (Fig. 7) have this advantage that for synchronism, and in its neighborhood, a regular rotating field is built up, replacing the pulsating alternating fields. Near synchronism the transformer effect in the coils under the brush is, therefore, eliminated and the commutation is similar to that of direct-current machine. Flashing over on the brushes of a repulsion motor seems next to impossible and even for other commutator motors flashover appears less probable, as self-induction damps away sudden current rushes and the laminated stator frame facilitates the rapid building up of magnetic fields.

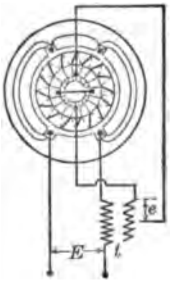


FIG. 7.— COMPENSATED MOTOR.

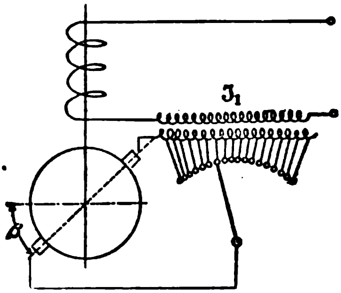


FIG. 8.— STARTING COMMUTATOR MOTOR.

When starting, all commutator motors are equally bad and one of the best schemes besides those already mentioned is to use a series transformer for the armature circuit (Fig. 8) which cuts down the starting field, allowing at the same time any intensity of the starting current. For repulsion motors, the same effect is possible by shifting the brushes toward the position of complete transformer action (brush axis in line with field axis). The main field at starting may also be prevented from rising too much by choosing the iron inductions very high.

The distortion of the field by armature reaction and the wattless voltage component produced by it may easily be neutralized for the single-phase series motor by a field winding, the axis of which coincides with the armature cross-field and which may be short-circuited or in series with the armature current circuit. Figs. 9 and 10 show this arrangement as used by Ganz & Company 15 years ago. Finzi splits the poles for the same purpose and cuts down the polar arc. Blathy of Ganz & Company also used some 15 years ago high tooth inductions[2] and ohmic and inductive resistances between armature winding and commutator, sometimes imbedded in the slots.

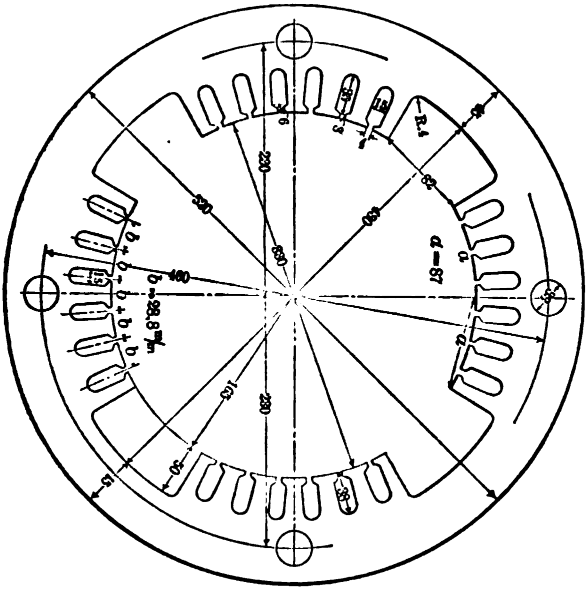


FIG. 9.— STATOR PUNCHING.

A stator with definite projecting poles has the advantage of cutting down the reactance voltage in the short-circuited armature coils and gives rise to smaller armature cross-field, which means a better power factor than with a distributed winding imbedded in slots equally spread round the whole circumference. This is the reason why series motors should always have definite poles, while

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[2] Lamme proposes high pole-shoe induction.

the good operation of repulsion motors depends upon the full development of the armature cross-field to get a rotating field at synchronism. Repulsion motors must, therefore, have a distributed winding. The better leakage factor of the last-mentioned winding is outbalanced by the better voltage factor or winding efficiency of a concentrated winding.

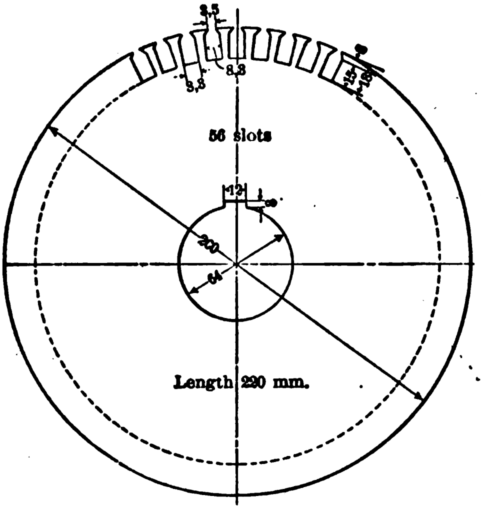

FIG. 10.— ROTOR PUNCHING.

Table II shows weight, outside dimensions, air-gap, efficiency, etc., of a great many railway motors of the direct-current, three-phase and single-phase type, most of which are in actual service:

TABLE II.

DATA OF RAILWAY MOTORS.

a. *Direct Current.*

Number	Manufacturer.	HP.	Rev. p. min.	Volts.	Gear ratio.	Gauge in mm.	Weight in kg.			Height mm.	Breadth without gear mm.	Length without gear mm.	Armature diameter mm.	Air-gap in mm.	Efficiency.		Power factor.
							Total.	Without gear.	Armat.						Motor alone.	With gear.	
1	G. E. Co., N. Y....	21	450	500	1:4.8	1,000	780	680	....	540	540	590	280	......	......	78.2	....
2	Oerlikon	24	......	....	....	....	....	....	....	600	650	700	335	2.5	......	......	....
3	Brown, Boveri....	25	800	550	1:5	1,000	1,000	....	....	700	550	800	....	......	85	......	....
4	Ganz & Co........	25	560	500	1:4.87	1,200	1,000	....	....	615	670	960	406	3	......	......	....
5	G. E. Co..........	27	700	500	1:4.8	600	700	....	....	580	510	430	350	......	......	81.6	....
6	Alioth............	31	600	500	1:4.2	1,000	770	....	....	620	660	770	330	3	84	81	....
7	"	38	480	350	1:4.1	1,000	890	....	....	640	670	770	380	4	83	80	....
8	G. E. Co..........	38	520	500	....	normal	1,070	950	250	640	680	1,000	370	......	......	83.5	....
9	Siemens-Halske..	39	430	500	1:4.8	normal	1,560	1,400	308	670	670	1,100	340	......	......	......	....
10	Ganz & Co........	45	750	500	1:3	normal	1,750	....	....	740	....	1,100	....	......	......	......	....
11	A. E. G..........	50	500	500	1:3.2	1,250	1,233	1,075	....	625	740	930	....	......	......	......	....
12	Schuckert........	54	600	....	....	normal	1,780	1,530	....	620	650	1,100	....	......	......	......	....
13	Westinghouse....	55	475	500	1:3.5	normal	1,360	1,220	330	610	610	1,160	....	......	......	......	....
14	Siemens-Halske.. (Elevated Berlin)	52	800	750	1:4.1	normal	1,580	1,400	....	660	660	1,070	342	3.5	85	......	....
15	G. E. Co..........	65	540	500	1:4.5	normal	1,600	1,400	350	700	740	1,100	....	......	......	86.5	....
16	Alioth............	65	450	750	1:4.3	1,000	1,350	....	....	640	730	770	420	5	81.5	87.5	....
17	Siemens-Halske.. (Wannsee)	70	260	600	no gear	normal	1,100	3,000	....	....	....	....	....	......	......	......	....
18	Westinghouse....	75	500	500	1:2.3	normal	2,000	1,800	....	700	720	1,150	400	......	84	88	....
19	Eborall..........	80	710	500	....	normal	1,530	....	....	720	950	830	....	6.4	......	88.5	....
20	G. E. Co..........	80	500	500	1:4.3	normal	1,800	1,600	500	740	710	1,100	450	4.4	......	88.5	....
21	Brown, Boveri.... (Open)	85	700	275	1:13.6	1,000	....	2,000	....	950	1,000	1,300	450	7	92	......	Open shunt motor (Mountain Ry.)
22	Rieter............	90	450	375	1:4.1	1,000	1,700	....	....	750	700	730	440	4.5	85	89	....
23	Oerlikon	100	550	900	....	1,000	1,700	....	440	685	740	780	415	2.5	......	......	....
24	Siemens-Halske..	100	370	600	1:4.5	normal	2,250	2,000	550	....	....	....	....	......	......	......	....
25	Westinghouse....	100	435	500	1:2.4	normal	2,400	2,270	610	750	750	1,250	....	......	......	......	....
25a	Oester-Union....	100	700	600	1:12.2	normal	....	1,900	....	990	1,050	1,300	500	2.5	......	93	Open shunt motor (Mountain Ry.)
26	Dick, Kerr........	110	570	500	1:2.9	normal	1,820	1,640	....	....	....	....	....	......	......	......	....
27	G. E. Co..........	125	540	650	1:4.9	normal	1,990	1,790	600	740	730	1,100	460	8.95	......	89	....

TABLE II — (*Continued*).

Number.	Manufacturer.	HP.	Rev. p. min.	Volts.	Gear ratio.	Gauge in mm.	Weight in kg.			Height mm.	Breadth without gear mm.	Length without gear mm.	Armature diameter mm.	Air-gap in mm.	Efficiency.		Power factor.
							Total.	With-out gear.	Armat.						Motor alone.	With gear.	
28	Thury............ (Open)	125	400	4×600	1:4	normal	3,050	... .	....	900	1,150	1,500	750	......	92	......	Six poles
28a	Siemens..........	50	330	600	1:1	normal	....	2,500	....	....	....	....	520	5	83	......	....
28b	Siemens..........	80	360	500	1:6.3	1,000	....	4,000	....	....	....	....	500	6	85	......	Mountain Ry.
28c	Siemens..........	140	430	530	1:9.2	1,000	....	4,800	....	....	....	....	500	7.5	86	......	" "
29	Schuckert........	150	330	500	1:1	normal	4,750	....	....	....	....	....	....	......	......	......	....
30	Westinghouse....	150	550	500	1:2.9	normal	2,400	2,250	670	735	830	1,260	....	......	......	......	....
31	Oerlikon..........	150	450	750	1:4	normal	3,050	2,700	840	900	1,000	1,070	550	4	......	84.5	....
32	Siemens-Halske .	155	610	750	1:4.5	normal	2,900	2,670	700	....	....	....	....	......	......	......	....
33	Dick, Kerr.......	150	470	500	....	normal	2,800	....	....	920	850	1,070	420	......	......	......	....
34	G. E. Co..........	165	570	500	1:2.5	normal	2,400	2,200	700	740	660	1,000	450	......	......	87	....
35	G. E. Co.......... (N. Y. Subway)	200	500	600	....	normal	2,800	....	....	740	790	1,080	....	5.5	......	90.5	....
36	Westinghouse.... (Subway)	200	500	600	....	normal	3,000	....	870	740	....	1,150	500	......	......	......	....
37	G. E. Co.......... (Central London)	200	190	500	no gear	normal	5,400	....	1,350	820	1,160	1,340	570	7	91.3	......	....
38	Siemens-Halske .	210	520	750	1:4.7	1,000	6,100	4,800	1,900	....	....	....	500	......	......	......	....
39	Oerlikon..........	220	645	500	....	normal	3,000	2,600	760	....	....	....	....	......	......	......	....
40	G. E. Co..........	250	360	500	1:4.1	normal	3,700	3,600	1,100	960	760	1,030	600	7	......	87	....
40a	G. E. Co..........	550	300	600	1:1	normal	....	....	....	....	....	....	760	......	92	......	....
	b. *Three-phase.*																
41	Brown, Boveri...	35	400	500	1:3.8	1,000	....	830	....	900	700	700	450	1.25	85	......	0.75 for 40 periods.
42	" " ...	35	480	750	1:3.6	1,000	....	960	....	900	700	750	410	1.25	87	......	0.80 for 32 "
43	" " ...	60	600	750	1:3	normal	....	1,500	....	1,000	780	1,000	500	1.5	88	84	0.85 for 40 "
44	" " ...	75	650	750	1:16	1,000	....	2,000	....	1,020	1,045	1,255	640	1.5	91	......	0.88 for 32 "
45	Eborall	80	717	500	....	normal	1,700	....	....	1,020	1,020	1,030	440	1.8	......	90	0.835 for 50 "
46	Brown, Boveri...	90	800	500	1:12	1,000	....	2,050	....	860	1,040	1,030	640	1.5	91	......	0.88 for 40 "
47	Oerlikon.......... (Open)	120	750	500	1:12.6	1,000	....	2,100	+300for exciter	1,050	1,050	1,050	600	1.2	92	......	0.90 for 40 "
48	Brown, Boveri...	150	760	500	1:11.6	1,000	....	2,700	....	1,180	1,040	1,050	640	1.5	91	......	0.90 for 40 "
49	" " ...	150	300	750	1:1.88	normal	....	4,000	....	1,700	1,860	1,050	1,200	3	92	......	0.85 for 40 "
50	Siemens-Halske .	200	900	10,000	1:2	normal	....	4,100	....	1,150	1,150	1,100	680	1.5	90	......	0.90 for 50 "
51	Ganz & Co........	250	300	3,000	no gear	normal	....	3,800	....	1,160	1,160	1,300	800	2	93	......	93 for 15 "
52	Siemens-Halske .	250	900	1,000	no gear	normal	....	4,000	....	1,040	1,040	1,800	720	2.5	92	......	94 for 50 "

53	A. E. G	250	960	435	no gear	normal	cooled	3,200	....	960	960	1,160	584	......	......	......	94 for 50 "
54	Ganz & Co.......	500	225	3,000	no gear	normal	....	6,500	....	....	....	....	....	......	93	......	93 for 15 "
55	"	600	225	3,000	cranks	normal	....	12,400	....	1,725	1,775	1,800	1,400	2	......	......	93 for 15 "
	Double motors.	450	112	....	1:1	....	....	....	....	....	....	....	....	......	......	......	....

c. *Single-phase commutator motors.*

56	Finzi	27	700	750	1:4.8	1,000	800	....	....	....	....	....	....	......	......	76	90 for 18 periods (straight series)
56b	Oerlikon.........	35	1,000	250	....	....	1,000	....	....	....	....	....	....	1	82	......	....
56a	Union E. G.......	50	300	400	1:5.07	1,000	1,240	....	....	600	690	820	....	......	......	75	ca 95 for 40 periods.
57	Union E. G.......	120	700	6,000	1:4	normal	2,360	2,700	....	750	920	1,052	ca 450	3	87	83	ca 95 for 25 periods. (Winter Eichberg)
57a	Westinghouse ...	150	200	300	....	normal	....	2,500	....	....	....	....	....	......	......	......	....
58	Oerlikon.........	145	300	200 (15,000)	....	normal	....	3,000	....	....	....	....	....	......	......	......	15 periods (straight series motors).
59	Oerlikon.........	200	450	200 (15,000)	....	normal	....	3,400	....	....	....	....	....	......	......	......	15 periods (straight series motors).
60	Oerlikon.........	200	650	400	1:3.1	normal	....	3,000	....	1,250	1,250	1,150	750	......	92	......	15 periods (series motor), 96%.

For equal output, speed and voltage the direct-current motor has usually the smallest weight, is cheaper and takes less space than all its rivals. The reasons are: That the field is solid and there are no lagging currents, the concentrated field winding is very simple and it needs no inactive frame, the inductions in all iron parts may be very high, in the teeth up to 27,000 lines per cm^2, in the core 15,000 to 20,000, in pole and yoke the same,[3] whilst alternating-current motors cannot at all reach these values on account of the high wattless magnetizing current. Three-phase motors with variable poles or concatenated motors have even higher weights. The commutator of single-phase motors must be larger than that for direct-current machines on account of the much higher commutator losses and because the voltage must be kept very low (less than 200 volts). If both a single-phase and a direct-current motor are laid out for the same maximum field flux Φ_{max} and the same effective current I, the normal torque T_a of the alternating-current motor becomes

$$T_a = \frac{1}{\pi}\int_0^{\pi} \Phi_{max.} \cdot I \cdot \sqrt{2} \cdot \sin^2 a\, d\, a = 0.71\, \Phi_{max} \cdot I$$

and that of the direct-current type T_d

$$T_d = \Phi_{max} \,.\, I$$

That means for the same torque and output the single-phase motor must be 30 per cent larger. For placing a motor into the car truck, a cylindrical body (alternating-current motors) is less practical than a prismatic one (direct-current). As on varying grades and during starting the three-phase motor absorbs more energy than other motors, it must be larger and more expensive for this reason also.

The efficiency of direct-current motors is sometimes somewhat smaller than that of three-phase motors, which result is due exclusively to the much smaller air-gap with the latter machine. For the same air-gap and for open slots, the three-phase motor must have a lower efficiency. Single-phase commutator motors have a poorer efficiency than direct-current and three-phase motors; with partial loads the efficiency is especially very low. The losses of the single-phase motor usually amount to 15–35 per cent more than those of the direct-current type. The increase of losses is due to ad-

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[3] The current densities are 5 to 7 amps. per mm^2 in the armature and 2 to 3 in the field, in three-phase motor 4 to 5.

ditional iron losses in the field and armature at standstill and when running, and furthermore, to the energy loss in the coils short-circuited by the brushes. For the straight series motor, there may be additional losses in resistances of the commutator connections and in auxiliary windings. The repulsion motor has the advantage that the iron losses in the rotor are zero for synchronous speed.

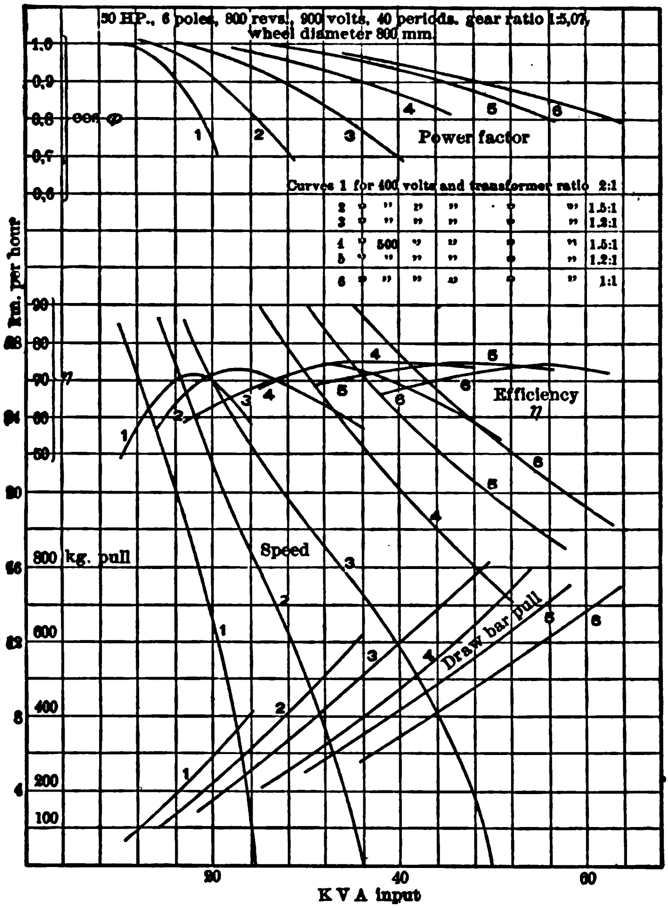

Fig. 11.—Characteristic curves compensated series motor.

Fig. 11 represents all characteristic curves of the compensated single-phase motor the outline of which is given in Fig. 3. Fig. 7 shows the way of connecting up the motor. The curves marked 1 to 5 correspond to a variable ratio of the series transformer.

While with alternating-current motors the number of poles is fixed by the synchronous speed or for the series motor by about double synchronous speed, and by periodicity, which is usually kept low to reduce the number of poles, nearly all direct-current motors have four poles, rarely six. The tendency to building high-voltage motors makes the use of only two poles advisable. This scheme, which is used by the General Electric Company for the 550-horse-power motors of the new locomotives of the New York Central, allows the utilization of the available space in an excellent manner, by laying the pole axis horizontally and leaving all the height for the armature and commutator diameter. The whole length of the car axle is free for the armature as the field and brush yokes are closed outside the wheels. Almost all direct-current motors have six to twelve coils per slot, which means a number of commutator bars equal to three to six times the number of slots, which makes them cheaper and safer than three-phase motors for which a large number of slots is desirable in order to obtain a good power factor.

The *power factor* of three-phase motors is kept high by using high speeds and low periodicities, which render generators and transformers more expensive, but are favorable for the line. For railways with the exception of high speed lines only periodicities lower than 25 are suitable. For given volume and rotor diameter, nearly closed slots produce a better power factor than closed slots. By using a three-phase commutator on the rotor, the phase displacement, which increases the first cost of the whole plant, may be almost entirely compensated.

The *power factor* of single-phase commutator motor equals usually or even excels that of three-phase motors and reaches values of 0.95 or more. But it is necessary or advisable to use frequencies of 25 and less and small air-gaps which may, however, be somewhat larger than with three-phase motors. The ratio field ampere-turns[4] to armature ampere-turns must be small, f. i., 20 to 27; for the repulsion motor this ratio is changed at will by shifting the brushes. For the series motor the normal speed must be equal to one and one-half to two and one-half times the synchronous speed (Westinghouse 1.8 times) and the cross-field must be compensated.

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[4] The old Ganz motors built 15 years ago had an armature voltage 30 per cent higher than the field voltage, and with them was used a switch to vary the number of field coils; a transformer for the exciting current is also mentioned in the patent.

The series motor which is built with many poles in comparison with the repulsion motor increases continuously its power factor, when the speed surpasses synchronism, whilst the repulsion motor has its maximum near synchronism. For partial loads the power factor of the repulsion motor is better, for normal speed there is no essential difference. By inserting a series transformer in the armature circuit of the compensated motor, one may obtain cos $\phi = 1$ for various speeds.

Table III gives an interesting comparison of power factor and efficiency for three-phase motors and various methods of regulating them:

TABLE III.

Full speed.	Half speed.				
	Concatenated motors.	Variable number of poles.	Rotor resistance.	Primary compensator.	Variable frequency.
Efficiency 81	—	—	—	50	— } Same motor.
83	—	—	43	—	87
86	—	74	—	—	—
85	75	80	—	—	—
90	81	86	—	—	—
93	85	89	—	—	—
Power factor 85	60	60	85	75	85
93	77	84	93	85	93

With light loads the power factor of three-phase motors is usually very poor, and the mean value is sometimes as low as 0.5. For starting however the cos ϕ is 0.8 to 0.95. The opposite is the case for single-phase motors, the power factor at starting is extremely low, about 0.3, increasing with speed and decreasing with load.

Of all motors the direct current shows by far the smallest losses in the motor itself when starting with same torque, mainly because the iron losses are zero at standstill and the starting current is least for a given torque. From this fact it results that a direct-current motor heats least, when frequently started.

The following Table IV gives a comparison of the motor losses at starting for various types of motors and starting arrangements.

TABLE IV.

Motor losses for a complete run of a 160-ton train on an elevated railway at a speed of 30 km and a distance between stations of about 1300 metres. Motors 250 to 300 hp.

System*	Direct current.			Three-phase rheostatic control.			Three-phase† star-mesh-connection rheostatic control.			Three-phase concatenated motors.				Single-phase commutator motors series motor.			Single-phase commutator motor compensated type.		
After seconds	0	18	61	0	33	76	0	33	76	0	16	33	76	0	18	61	0	18	61
Iron losses in watts	0	1,000	500	1,300	1,100	1,000	3,500	3,000	1.000	2,500	2,500	1,300	1,000	1,000	2,000	2,000	1,000	1,500	1,300
Copper losses in watts	3,000	3,000	1,000	4,500	4,500	500	1,200	1,200	500	7,000	7,000	2,500	500	4,000	4,000	2,000	3,500	3,500	1,500
Mean total losses in watts	3,500		2,300	5,700		1,500	4,450		1,500	9,500	3,800		1,500	5,500		4,500	4,700		3,500
Time in seconds	18		43	33		44	33		44	16	16		44	18		43	18		43
Losses × seconds = watt-seconds	63,000		99,000	188,000		66,000	144,000		66,000	155,000	62,000		66,000	99,000		194,000	85,000		152,000
	162,000			249,000			210,000			323,000				293,000			237,000		
Ratio of total losses in watt seconds.	1			1.53			1.29			1.98				1.80			1.46		

* A motor with a variable number of poles will give slightly better results than concatenation.

† The stator winding is mesh connected for starting and star connected for free running, which necessitates a rather complicated switching device.

Remark: For case 1, 5 and 6 coasting of 15 records is supposed, for the other cases there is no coasting. The time for the whole run is the same in all cases.

Since in the direct-current motor most of the losses are produced far away from the motor surface, the capability for radiating heat is better for the alternate-current motor and best for the three-phase machine. For equal losses the difference in favor of the three-phase motor may amount to 25 per cent. The distributed winding is also better for cooling than the mummified concentrated field coils, for which latter copper strips on edge are best.

In heavy locomotives or motor cars for high acceleration, it may occur that there is not sufficient space for the necessary motor capacity at a predetermined rise of temperature. This limit is much sooner reached by three-phase and single-phase motors than by direct-current motors, and of all motors concatenation is worst in this respect. In extreme cases artificial cooling becomes necessary. The air of the running train may be directed by special pipes and chimneys on the surface of the motors and starters. If it is possible to use openings covered by gauze or perforated sheets at both ends of the motor, one may drive an air draught through the motor by the ventilating ducts of the armature, thereby throwing the heated air to the outer surface. The new G. E. motors for the New York Subway are ventilated similar to Fig. 12 by means of air entering near the back bearing and passing through armature ducts of variable breadth over the field coils and escaping through holes in the yoke. The waste air of the universally used air-brake may also serve for cooling purposes; the pressure of the air must, however, be kept very low to avoid the creeping of oil. If there is sufficient space on the shaft, there may be added a fan to the motor. Reichel proposed to install these fans inside the secondary motors of a concatenated group, and to cool the main motors from these fans.

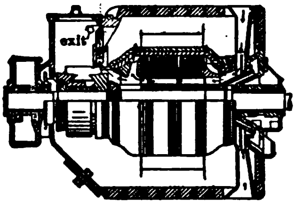

FIG. 12.— G. E. CO. MOTOR.

There are other means for saving space: Siemens & Halske (German patent 131,299) propose to put the commutator outside the car frame to leave all the space inside available for the armature. In this case, however, the axle must be hollow and many connections through the bearings are necessary. This scheme may, however, be much better realized for the three slip rings of three-phase motors, as may be seen from Fig. 13, which shows the very interesting concatenated motors of Ganz and Company for the new Valtellina locomotives. (Each motor for 600 horse-power, 225 revs. p. min., concatenated 500 horse-power, 112 revs. p. min., 15 periods, 3000 volts.) To best utilize the given height, the projecting poles of direct current and single-phase motors must be arranged at 45 deg. on an octagonal frame with two sides horizontal; the most favorable design for getting a large armature diameter is to use a bipolar frame putting the poles horizontally and closing the yoke with its bearings outside the frame as is done by the General Elec-

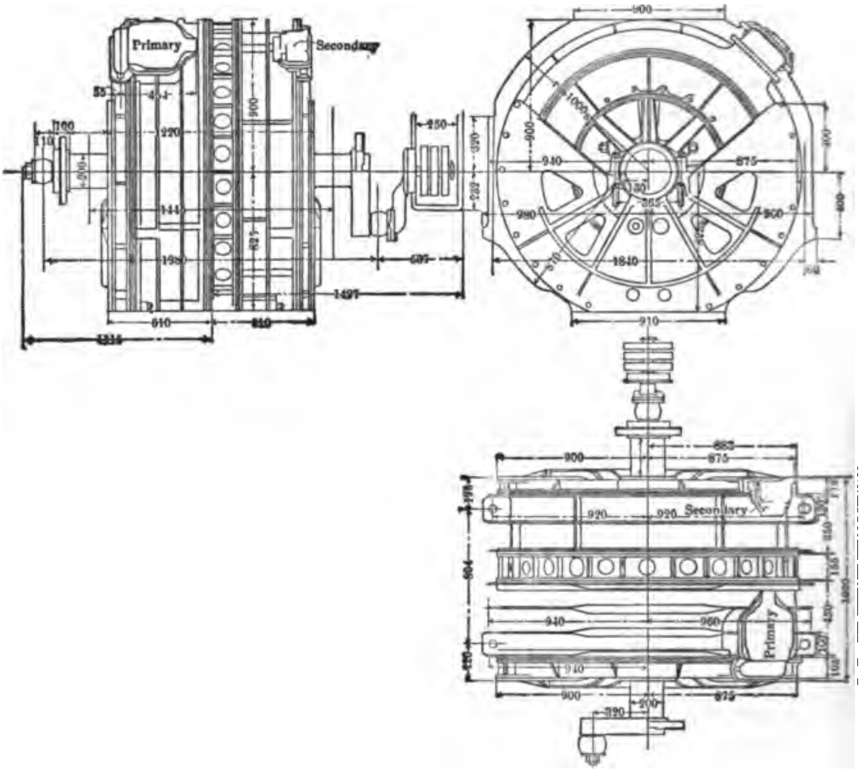

FIG. 13.—CONCATENATED MOTOR, VALTELLINA LOCOMOTIVE.

tric Company for the New York Central motors. Kandò cuts off a segment of the cylindrical stator iron of three-phase motor at the lower side. (Fig. 13.) On locomotives there is sometimes sufficient space to put the motors above the car truck, the design being much simplified thereby. There are, in fact, cases where the motors may be of the open type, if they are well protected inside the car box (Jungfrau locomotives). As soon as it becomes possible to build reliable ball bearings, these may be used to reduce the space absorbed by the bearings. The last expedient in cases of limited space consists in insulating the motors by heat and fireproof materials, such as mica and asbestos, and allowing a temperature rise of 100 deg. or more, though the commutators will hardly withstand these temperatures continuously.

The *starting torque* of motors for high accelerations may be three to ten times larger than the torque for free running, whilst for slow speed trains there is no great difference between these two torques. The best motor for accelerations higher than 0.5 m $(\text{per sec.})^2$ is undoubtedly the direct current motor which starts very economically against any torque taking less than two and one-half times the normal current for three times the normal torque. All three-phase railway motors in actual service have low accelerations, smaller than 0.3 m $(\text{per sec.})^2$; the large locomotives and motor cars on the Valtellina lines have only 0.16, though tests were made up to 0.45 m $(\text{per sec.})^2$. Three-phase motors can yield specially high starting torques only by adopting complicated switching devices (mesh-star connection) or heavy regulating transformers, or by sacrificing the best running conditions (bad power factor for free running). This holds specially good for lines with very variable grades. Concatenated motors give only 50 to 70 per cent more maximum torque than the primary motor alone if one does not increase the motor voltage for concatenated working. It is, therefore, reasonable never to switch concatenated motors in multiple, but to leave the secondary motors idle for full speed. Moreover the acceleration up to 50 per cent of synchronism must be double of the value after 50 per cent of synchronism which is also true for the mesh-star connection.

The starting torque of the single-phase motor is for a given voltage the highest possible torque just as for the direct-current motor. On account of sparking difficulties and self-induction, the maximum torque is, however, smaller, but may be three to five times the normal torque for well-designed types. The starting current is nearly entirely wattless, but is only about two to two and one-half times normal current for three times the normal torque. When starting very slowly with a large torque by a strong field, the short-circuit effect under the brushes may burn out the motor. The torque of a single-phase motor, which is 30 per cent smaller than that of a corresponding direct-current motor is not constant as is true with direct and three-phase current machines, but varies between a maximum and zero with double the periodicity of the line current. The mean value of the torque is only half of the maximum, which fact is very important for the limit of slipping of the wheels. The wheels slip when the mean useful torque is only half of the maximum torque which is proportional to the adhesion of the wheels. This limit will, however, be reached only in very few practical cases.

The starting torque of the direct-current series motor is independent of the terminal voltage, whilst the torque of the three-phase and single-phase motor is proportional to the square of the line voltage. This fact is specially dangerous for starting several trains at a time on a steep grade. The single-phase commutator motors have such a high starting torque that they may do their service, in emergency cases, with 40 per cent of the full line voltage. A disadvantage with the three-phase motor is due to the fact that its breakdown torque occurs at a slip of about 10 per cent coming to standstill when overloaded and absorbing a high wattless current and developing no torque and thus being liable to be burned out in that way.

For frequent starting the watt consumption, or economy of the whole starting period, that means the efficiency of acceleration, is of utmost importance. Direct-current equipments are started by series parallel control, resistances are in circuit only for a short time as the motors accelerate a long time without resistances. In principle the single-phase motor can be started with the smallest losses, as they need no resistances. Starting transformers absorb, however, continuously a certain amount of energy and the efficiency of the motor itself is low. The most economical way of stating consists in brush shifting (Brown, Boveri & Cie). The following Tables V and VI contain a comparison of the starting losses of various systems:

TABLE V.

Total starting losses for one entire trip of an elevated train of about 160 tons, distance about 1300 m, mean speed = 30 km p. h.

	Direct current series parallel 2 motor-groups.	Three-phase.				Single-phase commutator motors (starting transformer or brush shifting).
		Simple.	Mesh-star.	Concatenated motors.	Variable number of poles.	
Mean kw hours on car	1.00	1.35	1.50	1.17	1.10	0.90 to 1.20
Mean kvA hours on car ..	1.00	1.55	1.85	1.67	1.55	1.10 to 1.50

For smaller distance the values become worse for three-phase equipments and better for single-phase motors.

TABLE VI.

Maximum efficiency of acceleration for a usual 80-ton elevated train.

Direct current.					Three-phase.				
Only rheostatic control without acceleration on the speed characteristic.	Only rheostatic control with acceleration on the speed characteristic.	Series-parallel and acceleration on speed characteristic, 2 motors.	Series-parallel and acceleration on speed characteristic, 4 motors.	Ward-Leonard voltage regulation.**	Rheostatic control throughout.	Rheostatic control ⅛ of starting time free running.	Concatenated motors.*	Variable number of poles.	Single-phase commutator motors.
43%	65%	75%	78%	70 to 75%	43%	55%	59 to 67%	55 to 65%	70 to 80%

* On the Valtellina line a value of 65% under specially favorable circumstances was measured.
** Including motor-generator.

Changing the direction of rotation is easily done for direct and single-phase current motors by crossing the connections of the armature; for high-voltage single-phase motors this ought to be arranged in the low-voltage secondary of a series transformer (Fig. 9) or a safe reversing oil switch becomes desirable. Three-phase motors may be reversed by interchanging the primary wires, whilst the repulsion motor, whose armature is only in inductive connection with the line, must be reversed either by shifting the brushes through about a polepitch (Brown, Boveri & Company) or by shifting the line connections to the stator winding by about a polepitch or by using two primary windings.

The direct current and the single-phase series motor vary in *speed* automatically about inversely proportional to the load with the effect that for variable torque the input and current consumption does not materially fluctuate, though this property is not used to its full extent in the direct-current motor, as may be seen from the following table:

TABLE VII.

Current	**1.9**	**1.6**	**1**	**0.73**	**0.58**	**0.38 of normal.**
Speed..........	**0.75**	**0.90**	**1.0**	**1.15**	**1.40**	**1.90 for direct current.**
Speed..........	**....**	**0.70**	**1.0**	**1.30**	**1.8**	**2.5 for single-phase.**
Torque.........	**2.6**	**1.8**	**1.0**	**0.60**	**0.30**	**0.10 for direct current.**
Torque.........	**....**	**1.65**	**1.0**	**0.70**	**0.50**	**0.35 for single-phase.**
Output	**1.9**	**1.6**	**1.0**	**0.73**	**0.58**	**0.38 for direct current.**
Output	**....**	**1.2**	**1.0**	**0.92**	**0.90**	**0.88 for single-phase.**

The three-phase motor and direct-current shunt motor have practically constant speeds for all loads and grades. On long lines with constant grades or on mountain railways this quality is no direct disadvantage, as the timetable is independent of the length of the trains and the motorman may quietly leave his regulating switches alone all along the trip. One may even state that the series motor in a certain sense is unable to make up for delays which usually occur with overloaded trains, in which latter case the series motors diminishes its speed. But practice proves that the motorman can easily avoid delays by making the best of the variable speed characteristic of the series motor according to the variable grades of his line. Of course on three-phase lines the main current may be interrupted for intervals, either to increase speed when descending or to reduce speed when ascending. Concatenated motors possess in themselves an additional possibility of varying the schedule time. The inherent constant speed quality, however, means high current consumption on grades and when starting compared with series motor characteristics. Moreover the direct-current motor has very economical means for speed variation through wide ranges and the single-phase motors possess this quality even to a higher degree.

Speed variation of the three-phase motor is possible by one of the following methods:

1. Ohmic resistances inserted into the rotor circuit, the regulation of speed depends, however, from the torque used for a given resistance and is very uneconomical. Large resistances become necessary and small speeds at small torques are hardly possible. The higher the resistance, the more the three-phase motors acquire the variable speed quality of the series motor.

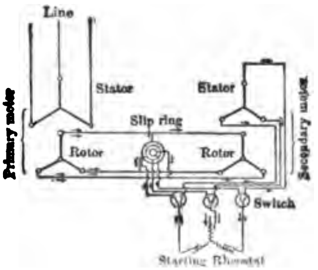

FIG. 14.—CONCATENATED MOTOR CONNECTIONS.

2. Concatenation of motors which has been admirably perfected by Ganz & Company. This company uses double motors in one frame (Fig. 13) uniting primary and secondary motors on one shaft needing only three slip-rings for both motors (Fig. 14). The secondary motor is never in circuit for full speed and may be specially dimensioned for concatenation. The well-known reproaches made against concatenation are: Bad power factor and bad efficiency for half speed (see Table III), increase of weight, space and heating. The maximum torque of concatenated motors is rarely more than 50 per cent greater than that of one primary motor. The starting and switching devices are rather complicated. Ganz & Company have decidedly reduced these difficulties to a minimum by building the double motors and by using a frequency of 15 periods. Efficiency and power factor are both as high as 93 per cent (without gears) for full

speed; 85 per cent efficiency and 77 per cent power factor for half speed; including gear loss the efficiency is still 80 per cent for half speed. Such an equipment is certainly not inferior to a single-phase car for full and half speeds. The Ganz motors have very high overload capacities enabling them to exert high drawbar pulls in tandem connection. The complication of the car wiring and of the starting devices has been avoided by using only three sliprings for two motors and by adopting very simple and safe liquid resistances (Fig. 15). In recent tenders Ganz & Company propose only one secondary motor for three primary motors reducing the dead weight materially.

Brown, Boveri & Cie have two heavy three-phase locomotives for the Valtellina line under construction. The two motors of each have

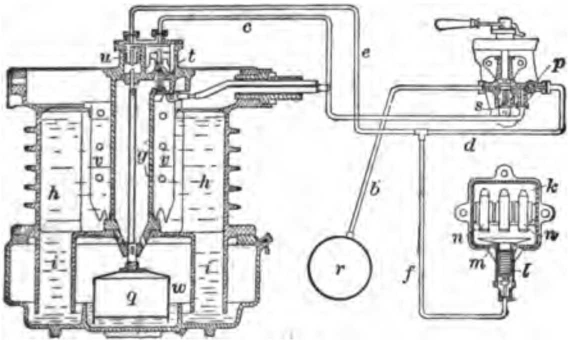

FIG. 15.—LIQUID RESISTANCE, GANZ CO.

450 horsepower and will be regulated by varying the number of poles from 16 to 8; drawbar pull 6000 kg for 37 km an hour and 3500 kg for 74 km, maximum pull for half speed 9000 kg. This scheme promises higher efficiency, higher torque for half speed, and less space than concatenation. These motors need, however, 5 or 6 sliprings per motor, if resistances have to be in the rotor circuit above and below 50 per cent of synchronism. The resistances will be metallic in this case, not liquid. The type of winding for varying the number of poles must be a multiple parallel loop winding with 2×3 terminals (Fig. 16). The winding pitch is only 60 to 75 per cent of the polepitch at the high speed and 120 to 150 per cent of the polepitch at the low speed. Concatenated motors with a different number of poles or motors with more than two numbers of poles are surely too complicated for railway work. Variable frequencies

would certainly give a very economical speed variation, but the complication and the increase of price of the central station or substation and of the line are prohibitive.

Brown, Boveri & Cie have installed a variable gear ratio on their Burgdorf Thun locomotives, which makes two economical speeds 18 and 36 km possible.

Most direct-current equipments possess series-parallel control either with two or four motor groups giving a very efficient speed variation, as the efficiency at half voltage or a quarter voltage is only 1 to 5 per cent lower than for full voltage. Double commutators may fulfill the same purpose. An increase of speed may easily be effectuated by shunting the field, in which case the efficiency is even better than for normal speed. Commutation troubles may, however, prohibit the extensive use of this method.

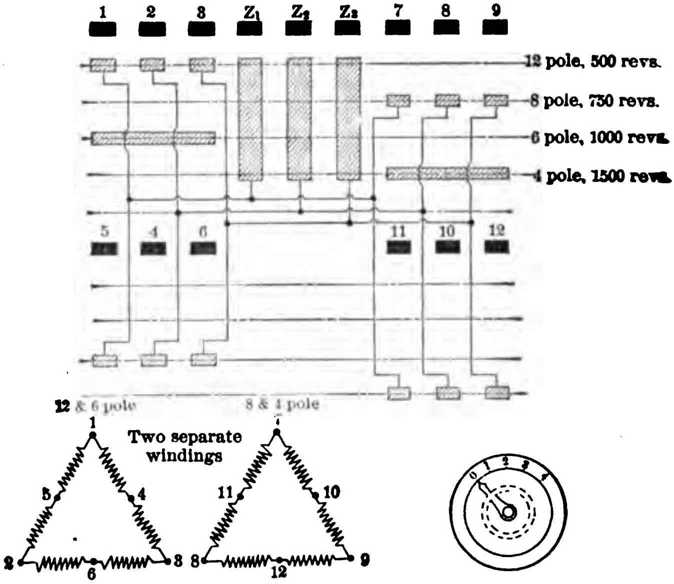

FIG. 16.— VARIABLE POLE MOTOR CONNECTIONS.

The single-phase commutator motor has in principle the most ideal and economical as well as the most uniform speed variation, by the use of regulating transformers in the primary or secondary circuit of the motor or by brush shifting or by varying the connections between the line and a series of taps on the primary winding. The last two methods are specially suitable for repulsion motors.

All these methods work with good efficiency and good power factor for many speeds. The continuous losses in the regulating transformers, however, decrease the total efficiency of the equipment. In fact, the single-phase regulation is not more economical than that with a four motor direct-current equipment. The losses are specially high for straight single-phase series motors using an auto-transformer, a potential regulator and balancing transformers. Series transformers, as used by Winter and Eichberg to supply only the small exciting current of the armature, are decidedly preferable to regulating transformers, and the best scheme seems to be shifting of the brushes or the shifting of the taps on the primary winding as used for repulsion motors. The three-phase motor could be very economically regulated by providing a polyphase commutator on the rotor and a three-phase transformer to change the size and phase of the rotor voltage, but this scheme is somewhat complicated and is not suitable for railway work.

If a direct-current series motor whose field connections are reversed, is separated from the line and short-circuited or switched on resistances, it will act as a *brake,* the effect depending upon the speed and the resistance in circuit. The series motor is, however, unable to return energy to the line. By arranging a small exciter which just yields the small exciting voltage of the series winding and the full exciting current, returning of energy could be easily effectuated. The best motor for energy returning is the direct-current shunt motor which acts as a generator without making necessary any switching. The simple field regulation enables the shunt motor to work as generator and motor within a very wide range of speed; without any change the shunt motor works also on resistances or as a short-circuited brake. On mountain railways the braking on resistances is, however, rarely desirable, as the resistances on the locomotives become too cumbersome and heavy (*i. e.,* 2000 kg on an 11-ton engine). If other motor cars are on the line, the downgoing shunt motor feeds the ascending. If there is only one car on the line, the energy returned will speed up the generators and will be only troublesome. One may provide resistance, in parallel with the generators, to absorb the superfluous energy, but by far the best method is to install storage batteries in the sub-stations which are charged by the descending cars.

The three-phase motor has braking qualities similar to those of the direct-current shunt motor, but throughout a very restricted range. The three-phase motor returns energy only for speeds above synchronism, that means, within a very narrow range and the energy cannot be stored up. Braking on resistances independently from the line is only possible by an additional exciter. The range of returning energy may be somewhat increased by applying concatenated motors, but this advantage must be very expensively paid for, besides the fact exists that a short-circuited concatenated group only acts as generator between 50 and 75 per cent of synchronism and then again above synchronism. By inserting resistances in the rotor of the secondary motor this range may be slightly increased. On level lines as encountered on elevated roads not more than 10 per cent of the stored up energy can be returned by concatenated motors. On lines with many steep grades and dense traffic, the returned energy may be more and become of decided advantage.

For mountain railways the three-phase motors have been frequently used (Jungfrau, Gornergrat & Engelberg), but it does seem not to have been a complete success, as new mountain lines (Vesuvius, Opcima Triest) are not equipped with three-phase motors but with direct-current shunt motors. The main reasons are that for the three-phase motor the downgoing speed must be higher than the ascending one which is prohibited by most railway regulations and that the energy of the descending car cannot be stored up, neither of which reasons is applicable to the shunt motor. There are very ingenious schemes for perfecting the three-phase motor for steep grades. The Maschinenfabrik Oerlikon switched the motors on their Jungfrau locomotive No. 3 in the upward sense for going downward in such a way that the primary field revolved against the rotor rotation. By inserting resistances into the rotor, in which the frequency is higher than in the line, any speed between standstill and full speed may be obtained, but the resistances must dissipate twice the energy braked and the line has to provide just as much energy for descending as for ascending. The next step was to use a special direct-current exciter directly connected to the motor shaft for braking, the motor works as a three-phase synchronous generator. The A. E. G. had arranged a storage battery for the same purpose on its high-speed car. If three-phase currents must be used, the simplest scheme would be to take the compensated three-phase motor with commutator on one side and sliprings on the other, which acts as generator at will (newest Jungfrau locomotive[5] of

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[5] The brushes on the commutator of these motors are automatically lifted, when the locomotive is connected to the line. The speed may be cut down to 5 per cent of full speed.

Brown, Boveri & Company), though it is inferior to the direct-current shunt motor.

Those single-phase commutator motors, the armature and field of which are interconnected directly or through a transformer, may be separated from the line, and caused to work on resistances as single-phase generators of variable frequency. The return of energy to the line is possible only by rather complicated switching devices, such as changing the variable speed feature into a constant speed one or, in other words, by creating a shunt motor or a separately excited motor. This may be done practically by feeding field and armature from a transformer having a series of taps which are changed according to speed and load. (Fig. 17, Union motor.) If the repulsion motor is driven backwards, it acts as a brake; by varying the brush angle any braking torque may be produced and even at low speeds energy may be returned to the line.

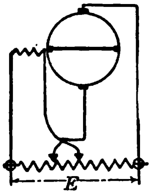

FIG. 17.—CONNECTIONS OF MOTOR USED AS GENERATOR.

For returning energy at speeds from the highest down almost to standstill, the most perfect system is a direct-current equipment with two double-commutator motors, with a combined series and shunt-field winding and regulating resistances in series with the shunt field and in parallel with the series field. For the highest speed, the four commutators are in multiple and the field weakest; for the lowest speed, all commutators are in series, the field strongest. This scheme is, however, too complicated for practical railway service.

Motors which are regularly and frequently used for braking purposes must be much more liberally laid out and they are more liable to injuries than those used simply for haulage.

The shunt motor which has several very valuable features for braking and speed variation has the great fault which rather excludes it from most railway services in that it is almost unsuitable for parallel running. This adverse criticism must be made concerning all motors with constant speed characteristics including the three-phase motor. If by chance the wheel diameters are not identical in general, if the slip in speed is not equal or if the magnetic characteristics of two shunt motors or of two three-phase motors[6] are slightly different (not the same air-gap or not the same permeabilities), one motor takes more of the whole load than the other. It may even happen that one motor acts as generator, deriving its energy from the other which must carry the whole load, causing a break-down and throwing the locomotive from the rails. This has actually occurred on mountain railways. For emergency cases rail tongs must, therefore, be provided which prevent the derailing of the locomotive. For the shunt motor, there may be used the following remedies: Two shunt regulators may be used, one for each motor, adjusted in a manner such as to equalize the load. The adjustment is, of course, different for an ascending and a descending car, and it must be modified before reversing. A scheme installed by the Austrian Union Company on their locomotives for Opcima-Triest seems to possess many advantages (Fig. 18). The two armature terminals of same polarity are connected by a small regulating resistance, and the lever of this resistance is grounded, the rail being the return conductor. By adjusting this resistance which takes at most 2 per cent of the whole voltage, the load in any case may be equally distributed. The position of the lever is different for motor and for generator action. The automatic breaker in the trolley circuit cannot be used for avoiding overloads, as the current does not flow to the line and as the armature circuit is not allowed to contain a circuit breaker, as it would render emergency braking very dubious. Brown, Boveri & Cie arrange a friction clutch between each motor and the axle, which transmits only a certain maximum torque. The simple remedy of using only *motors in series* is not to be recommended as on steep lines it happens that

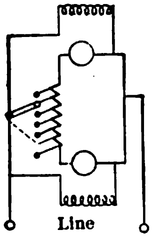

FIG. 18.—EQUALIZING SHUNT MOTORS.

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[6] For three-phase motors that means different magnetizing and different short-circuit current.

one wheel slips and the other stands still, in which case the former motor is subjected to the whole voltage and may burn out.

Cars with direct-current equipments may be run on lines with variable voltage, if the motors are connected only in series on one part of the line and only in multiple on the other, or by adopting double commutator motors. The trolley line voltage of three-phase and single-phase cars may be varied at will, if a stationary transformer is provided on the car, which transformer, however, increases the weight of the equipment considerably. The Austrian Union Company is just completing a suburban single-phase line, starting from Innsbruck, which is fed at 400 volts inside the town and at 2700 volts outside. Single-phase cars may even be run over direct-current tracks, though a good single-phase motor usually is a pretty bad direct-current machine; for the repulsion motor this is a specially bad case. Moreover the primary and secondary motor voltage rarely agrees with the direct-current line voltage and a special set of starting resistances must be provided, or the single-phase equipment must use rheostatic control, which is very uneconomical. Best is series-parallel control in this case.

Motor Gearing.

In most cases the motors drive the car axle by

1 a *single gear* of cylindrical tooth wheels with ratios of 1:1 to 1:5 which withstand the wear of 8000 to 200,000 train-km. In few cases one finds

2 *cogged wheels* (Alioth) or double and treble threaded *worm gears* (Maschinenfabrik Oerlikon), which in some cases allow a better disposal of the available space. For very low speeds *double gear* becomes necessary, *i. e.,* Jungfrau and other mountain locomotives.

3. The *direct coupling* of motor and axle may either be

(a) *rigid* (Central London, Siemens & Halske high speed car, new locomotives for New York Central) or

(b) *elastic,* by means of a hollow shaft and a flexible coupling (Heilmann Locomotive, A. E. G. high speed car, Valtellina locomotives of Ganz & Company). The rigid connection of the armature on the car axle has up to the present not been a complete success, but the method with the hollow shaft and coupling is decidedly complicated and entails the waste of much precious space. Siemens & Halske support the frame of their rigidly connected motors from the truck by means of springs, by which the bearings are pressed against the axle from below, an oil cushion on the upper half of the bearing boxes damping vertical shocks of the frame. From Fig. 19 one may get an idea of the design of the Valtellina motors for 250 horse-power, 300 revolutions, 3000 volts, with a hollow shaft and a flexible coupling. The new 550-hp motors of the General Electric Company are rigidly fixed on the axle, but the frame may freely move in the vertical direction, as the motor has only two poles, one at each side, and the pole shoes have plain vertical surfaces. For motors mounted on the car axle, special care is necessary to exclude oil and dirt from the motor windings.

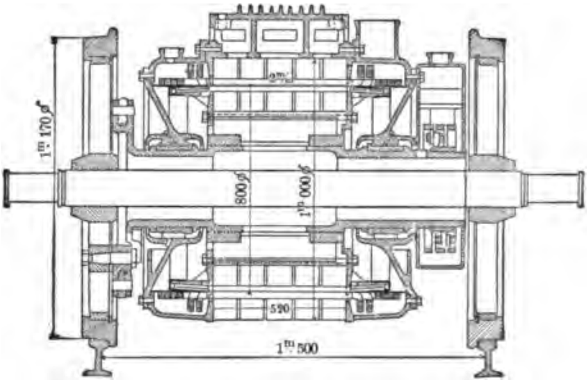

FIG. 19.—VALTELLINA GEARLESS MOTOR.

4. Driving by *cranks* and *connecting rods*,—well known from steam locomotives—was probably first proposed for electric locomotives by Eickemeyer, and first used by Brown, Boveri & Cie. The location of the motors above the axle is decidedly facilitated by this mode of driving. Very disagreeable vertical and other movements and shocks, such as are incident to steam driving, can hardly be avoided when this construction is used. Ganz & Company have laid out a special arrangement for their new Valtellina locomotives (Fig. 20), the crank turning point being supported in such a way as to allow vertical movements. The General Electric Company possess a patent on the arrangement (Fig. 21), in which two double

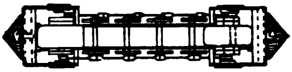

FIG. 21. LOCOMOTIVE WITH CONNECTING RODS.

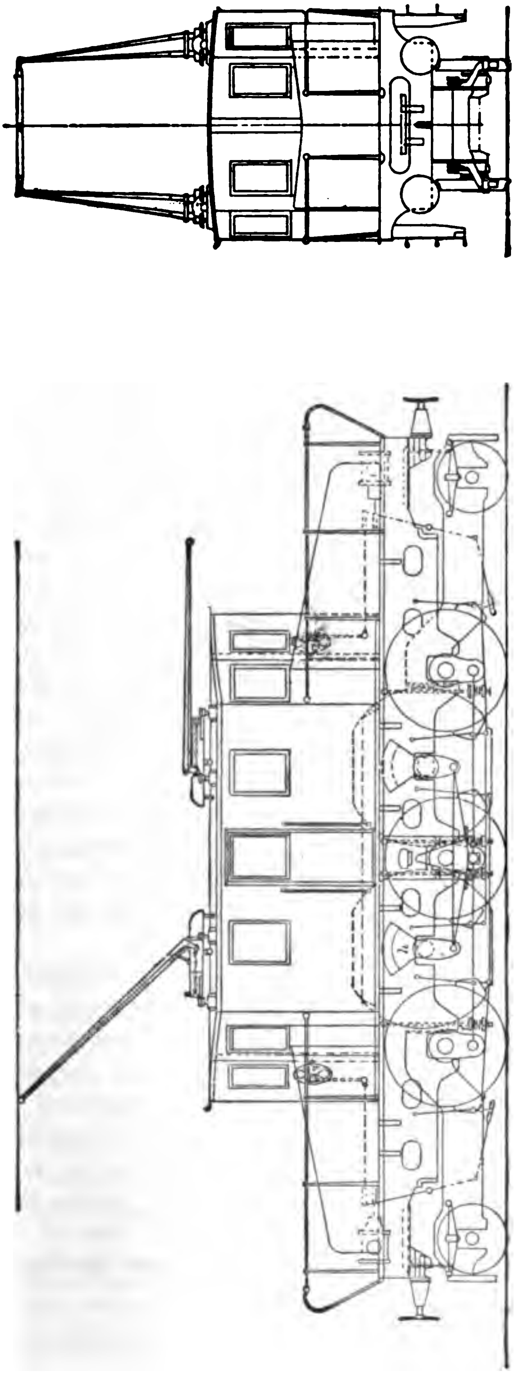

FIG. 20.—VALTELLINA LOCOMOTIVE.

commutator motors are mounted at the end of the locomotive and four axles are joined by cranks and connecting rods.

Starters.

For starting are used

(a) Metallic or liquid resistances combined with series parallel control;

(b) Transformers or autotransformers with taps or potential regulators,— mainly for single-phase motors;

(c) Brush shifting for repulsion motors (Brown, Boveri & Cie). The last method is undoubtedly the cheapest.

Regulating transformers for single-phase motors are heavier and more expensive than starting resistances, even if high iron inductions (15,000 per cm^2) and high copper densities (3 to 5 amp. per mm^2) are adopted. They should be submerged in oil or artificially cooled by compressed air. If series transformers (Fig. 8) are used for the armature alone, the size and weight are materially reduced. The heaviest are the potential regulators which must be provided with a short-circuited coil to neutralize the cross-field or self-induction of the armature. They allow, however, a very steady regulation, and avoid all contacts liable to spark; the higher the line current, the smaller is the range of voltage control. The main difficulty in the design of the usual regulating transformers with taps is due to the necessity for a reliable switch dial which works sparklessly. The best scheme seems to involve a solid snap switch which interrupts the current for a moment, when jumping from one tap to the next thus avoiding all auxiliary contacts and the short-circuiting of coils and eliminating the use of resistances or inductances.

For various reasons three-phase starting resistances must be heavier and more voluminous than direct-current starters. To this is probably due the fact that liquid resistances have been thought more desirable for three-phase than for direct-current railways. Though at first sight a liquid resistance seems to be mechanically much poorer than solid parcels of nickeline strips or castiron grids, the dimensions of which may be very much reduced by forced air cooling (Jungfrau line) or by placing them into oil tanks, the designs of Ganz & Company and those of the A. E. G. high-speed car are of practical interest, and the first mentioned design[7] (Fig. 15) has operated satisfactorily for years. The principle involved in their construction consists in using stationary electrodes within a tank into which the liquid is forced either by air pressure or by a rotating pump. The time consumed in starting may be varied by regulating the air pressure or by adjusting a throttle valve (Fig. 15). The electrodes consist of solid parcels of iron sheets which may be readily replaced. For frequent starting and shunting purposes, the liquid tanks must be very liberally dimensioned; it is desirable that the motorman control the resistance according to a main current ammeter, to avoid current rushes. The outer surface of the tank is provided with cooling ribs. The overload capacity of liquid starters is very high, as when the water is evaporating, an immense amount of heat may be absorbed. There is, however, the drawback that the water level may oscillate and that the evaporated water must regularly be replaced (2 liters on 500 km for the Valtellina line). On very cold days freezing is possible. To avoid a heavy current rush before short-circuiting the liquid starter, it is necessary that the electrodes have such a shape as to finally reduce the resistance to a value less than that of the armature.

The starting switches may be,

1. *Cylindrical controllers* with contacts for reversing and series-parallel control, and for the control of resistances or transformer coils, sometimes provided with flat dials at the lower end for field regulation.

2. *Multiple unit control* with a series of single switches actuated by electromagnets or by compressed air pistons.

3. *Liquid starters.*— For small inputs, the cylindrical controllers are in almost universal use. For three-phase equipments, they become heavier and more voluminous, on account of the increased number of contacts, which number may be somewhat diminished by using two-phase rotors. The multiple-unit system has been developed for direct current by the General Electric Company (electromagnetic switches), by the Westinghouse Company and the Siemens Schuckert Werke (electropneumatic control), for single-phase cars by the Union E. G. Berlin, the system resembling very much the direct-current control of the G. E. Company. The electromagnets, however, must be

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[7] Fig. 15 shows the original design of the Ganz rheostat which has been changed somewhat in its details; *p* is the throttle valve, *k* the short-circuiting switch of the rheostat.

laminated, and for the primary circuit, high-tension oil switches must be used. As alternate-current electromagnets are known to have various bad qualities, it seems to be a good plan to propose direct-current control from a small storage battery or electropneumatic control for single-phase cars. For three-phase equipments multiple-unit control has never been used or proposed,[8] on account of its being rather complicated. Moreover the tendency of three-phase railways is toward locomotives and not toward the use of a series of motor cars in a train. On account of the many wires and contacts for three-phase current liquid starters with pneumatic control have come to the front, as already stated. The liquid resistance does away with the great number of contacts and the sparking troubles of switches for heavy currents, allowing a very steady regulation and occupying only a moderate amount of space. Several single-phase or direct-current motors in multiple may be equipped with one common starting resistance if desired, whilst this arrangement is not possible with three-phase motors, unless the relative position of all parallel rotors is *continuously* identical, which condition seems impossible to be obtained. When this is not the case, the rotors may be partly short-circuited by the cross-connections.

In the following Table VIII I have tried to make a comparison of the weight of various starting devices.

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[8] There are several patents on polyphase multiple control granted to the G. E. Co. four years ago.

TABLE VIII.

a. *Direct current.*

Builder.	Motors.			Weight of starting devices in kg.
	Volts.	H. P.	Weight, kg.	
Krizik Prague....	2x650	4x30	4x935	Entire electric equipment per car without motors: 1,560.
G. E. Co...........	500	1x27	700	1 controller and resistance: 160.
Alioth............	500	2x31	2x770	Entire electric equipment without motors: 960.
Alioth............	500	4x38	4x890	Entire electric equipment without motors: 3,600.
Westinghouse....	500	2x55	2x1,360	2 controllers and resistances: 660.
G. E. Co..........	500	2x65	2x1,600	2 controllers and resistances: 600.
Alioth............	500	2x65	2x1,350	Entire electric equipment without motors: 4,100.
G. E. Co..........	500	2x80	2x1,800	2 controllers and resistances: 700.
Thury............	4x600	4x125	4x3,600	Entire electric equipment without motors: 6,600.
Westinghouse....	500	2x150	2x2,400	2 controllers and resistances: 750.
G. E. Co..........	600	2x165	2x2,400	Weight of whole control apparatus: 1,000 (multiple unit).
Westinghouse....	600	2x150	2x2,400	Weight of whole control apparatus (including small battery): 800 (multiple unit).

b. *Three-phase currents.*

Builder.	Volts.	H. P.	Weight, kg.	Weight of starting devices in kg.
Brown, Boveri....	500	2x25	2x830	Entire electric equipment without motors: 1,500.
Brown, Boveri....	750	2x150	2x4,000	2 controllers and starting resistances: 2,000.
Siemens & Halske	10,000	2x200	2x4,100	Entire electric equipment without motors: 8,800 (metallic resistances).
Siemen & Halske.	10,000	4x250	4x4,000	Metallic resistances 5,000, controllers 4,800, transformers for 10,000 | 1,000 volts: 12,000.
A. E. G...........	10,000	4x250	4x3,200	Liquid starters 4,800, transformers 6,400.
Ganz & Co........	3,000	2x600	2x12,500	Entire electric equipment without motors: 7,000 (liquid starters).

c. *Single-phase current.*

Builder.	Volts.	H. P.	Weight, kg.	Weight of starting devices in kg.
Finzi.............	500	1x27	1x800	Transformer 300.
Union............	2,700	2x50	2x1,240	Transformer 2,700 | 400 volt: 630 kg (oil type), regulating transformers: 2 × 315 kg.
Union............	6,000	2x100	2x2,360	Regulating transformers 1,100 kg. whole electric equipment without motors 1,800 kg.
Oerlikon	14,000	4x145	4x3,000	Transformers 5,600 kg, apparatus and switches 800, trolley 1,200.
Oerlikon	14,000	4x200	4x3,400	Transformers 3,400 kg, apparatus and switches 900, trolley 1,200.

For the repulsion motor with brush snifting no special starting devices are necessary.

For operating whistles and brakes, electricity is not directly applicable, and, in most cases, compressed air must be used for this purpose. The air brakes and the main controllers should be so interconnected that applying the brakes instantly interrupts the main current. The air compressor should be driven electrically and should run noiseless, which latter condition seems to be most easily obtained when slide valves are used. On steep grades there should be provided electromagnetic rail brakes, or a braking rack should be placed along the rails. To avoid derailing on mountain railways, rail tongs are desirable. In order to eliminate the possibility of racing on steep grades, there should be provided a device which prevents the motorman's leaving his car or train if he has not first put the controller-handle on the short-circuit braking point.

Although universally used, the scheme of lighting the trains directly from the trolley line is a bad one. Periodicities below 40 give a flickering light, unless very low voltages and thick filaments are used. The question of train lighting is, however, not so important as to render useless a system which, though defective in this one respect, is first class in all others, it being possible, in any event, to provide for lighting the train from some source independent of the trolley circuit.

Current Collectors and Line.

The problem of collecting current from the line is one of the most difficult in electric traction. While direct-current and single-phase equipments using the rails as return require but a single conductor, three-phase and certain other three-wire cars necessitate at least two-line wires, which drawback to such equipments in some cases is so serious as to prohibit their use. The two conductors may be installed either above the center of the line beside each other in the same height or in different heights, or beside the line one above the other, the current collector sliding from the side, or one wire may be on each side of the line (Fig. 22). The lateral current collection avoids the oscillation of the current collector, arising from the deflection of the wire, but if the wires hang above each other, short-circuits may easily occur. As far as my experiences go, there seems to be no difficulty in collecting current for single-phase lines for voltages up to 6000. For three-phase lines the limit, as derived from the experiences on the Valtellina line with humid tunnels, sharp curves and steep grades seems to be 3000 volts. For equal line voltage the voltage drop of the line which influences very much the starting torque of alternate-current motors is much greater for three-phase and single-phase currents than for direct current and on account of phase displacement, the equivalent current is also higher. The increase of voltage drop is the higher, the higher the frequency. The resistance of the iron rails for alternating current amounts to between 3 and 15 times the value for direct current on account of the skin effect. A high voltage drop in the rails causes electrolytic effects for direct current and telephone or telegraph disturbances for direct and alternate currents. For this reason special return wires may become necessary (fourth rail), which must be frequently connected to the main rails, and which, for alternate currents, should be as close to the other trolley wires as possible. Kapp proposed to place boosting dynamos or transformers between two consecutive rails at various spots. The Maschinenfabrik Oerlikon is using a separate return wire along the rails and puts the boosting transformers into this special wire, the primary of the transformer being in the overhead conductor. In this way the voltage drop of the return wire which

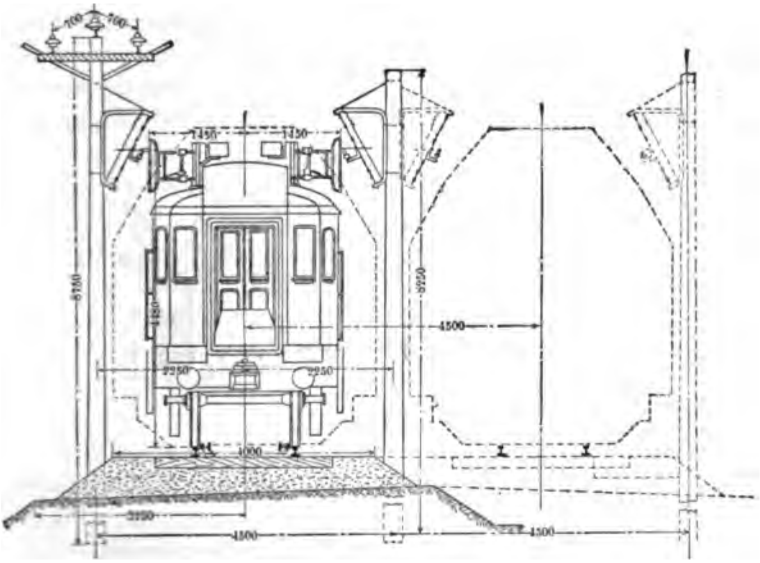

FIG. 22.— HIGH POTENTIAL OVERHEAD CONSTRUCTION OF SIEMENS & HALSKE.

is regularly connected to the rails is reduced to naught and the drop is transferred to the overhead wire, the drop of which is correspondingly increased. If high trolley voltage or the boosting scheme of Oerlikon is used, railbonds are no longer a necessity; they are, therefore, omitted in a new single-phase line of the Austrian Union Company with 2700 volts.

The current collectors used nowadays are:

1. The *trolley wheel* with overhead conductor consisting of a circular or an 8-shaped profile-wire, suitable for about 200 amp. voltages below 1000, and speeds not exceeding 80 km an hour. The trolley wire may hang just above the line or on the side of it (lateral trolley), as the trolley arm is hinged upon a vertical bolt; the height of the wire above the line may also vary considerably. A disadvantage is the hammering of the wheel against the wire and the frequent derailing, which may be somewhat reduced by using very light and elastic trolley arms, the movements of which may be damped by various springs or air and oil cushions. For currents greater than 200 amp., two trolleys may be adopted.

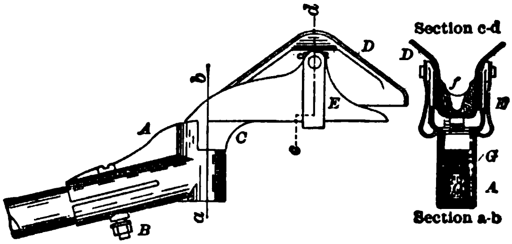

FIG. 23.— TROLLEY SHOE.

The wheel may be replaced by a sliding shoe on the end of the trolley arm (Fig. 23), the inside of which may be covered with aluminum (Jungfrau railway). The ability to collect current is increased in this way, but the deterioration of the wire is augmented.

2. The *sliding bow* consists of a tube of brass or aluminum containing a V-shaped groove and stands with axis perpendicular to the trolley wire. To get a larger surface of contact, Brown, Boveri & Company have given a triangular cross-section to the bow (Fig. 24), one plain surface of which is continuously on the wire. The inside of the tube may be filled with grease. The bow may carry 100 amp. for voltages up to 10,000 or 200 amp. for low voltages; sliding on two overhead wires 300 amp. may be safely

FIG. 25.— EXPERIMENTAL SIEMENS' HIGH-VOLTAGE LOCOMOTIVE.

collected at 1000 volts or less. The line equipment, especially the overhead switches, are much simpler for the bow than for the trolley wheel; there is no derailing. The bow automatically adjusts itself for forward and backward movements which feature is very important for shunting. The bow is probably the best current collector devised for high speeds, in which case it may be as light and elastic as possible; the pressure on the wire should not exceed 2 to 4 kg, and several springs acting after each other must neutralize shocks and prevent the interruption of the contact by the bow. The wind pressure must be compensated by wings. The satisfactory result of the current collection on the experimental[9] Siemens high speed car at 10,000 volts and 100 amp. per wire is due to the lateral sliding of the bow (Fig. 25[10]), avoiding thereby the movements due to the deflection of the wire, to the great elasticity produced by three consecutive springs and to the small weight of the cross-bar of the bow (650 grammes) and to the *very* small pressure of only 2½ to 3 kg; on three-phase lines one may apply either two separate bows beside or behind each other or *one* bow the cross-bar of which consists of two insulated pieces (Brown, Boveri & Company) (Fig. 26).

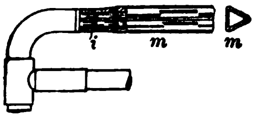

FIG. 24.— SLIDING SHOE OF BROWN, BOVERI & CO.

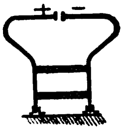

FIG. 26.— DOUBLE BOW.

3. Most of the good qualities of the bow are also to be found in the new original current collector of the *Machinenfabrik Oerlikon* (Fig. 27) consisting of a *curved rod* of brass tubing sliding on the lateral overhead wire from above, when running on the free line. At stations and in tunnels, or wherever it is desired, the rod makes contact from below *exactly* as the bow. The turning of the rod through an angle of nearly 270 deg. is effectuated either by hand or pneumatically. There are 2 × 2 rods on each locomotive, which may collect the current from either of the two wires on each side of the line. In this way one wire may be repaired,

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[9] The treble bow is of course much too cumbersome to suit for regular service.

[10] Consisting of a brass tube with aluminum filling.

while the other is working. The repairs of the wire and of the current collector are quickly made and do not necessitate the use of a turret car which blocks up the line. Without any serious sparking, the rod collects full current while the locomotive travels at full speed from a section with 15,000 volts to a line section which is interrupted by the semaphore.

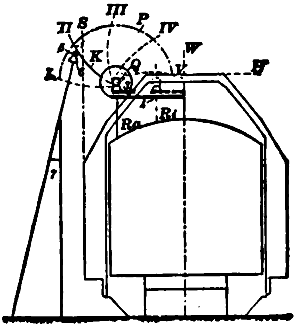

FIG. 27.—OERLIKON CURRENT COLLECTOR.

4. The *cylindrical roller collector* somewhat resembles the one of the bow type, the cross-bar consisting, however, of a rotating roller usually running on ball bearings. On the Valtellina locomotives this roller for 3000 volts and 200 amp. per wire makes 4000 revolutions a minute and consists of two copper tubes or two steel tubes electrolytically covered with copper, insulated from each other by impregnated wood. The tubes have to be replaced after a service of about 15,000 train-km. There is one roller collector for forward running and one for backward movement (Fig. 20), each being controlled by compressed air. The roller is usually heavier and less elastic than the bow. To avoid the hammering effect of the deflection of the wire, Ganz & Company propose to use two trolley wires (Fig. 28) which cross each other, the support of one wire being at the spot where the other has the deepest deflection.

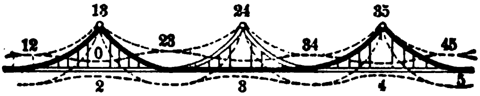

FIG. 28.—GANZ & CO. TROLLEY SUSPENSION.

Overhead wires should not be fastened rigidly but in an elastic manner, to avoid break-downs of the wires by the hammering effect of the collector, which effect increases with the speed. The Union Company fastens the trolley wire for their single-phase lines to a special suspension wire, at distances of 3 to 4 metres, by vertical wires of variable length, obtaining an almost straight trolley wire with unnoticeable deflection (Figs. 29, 30 and 31). For voltages above 1000 double insulation of the trolley wire is to recommended.

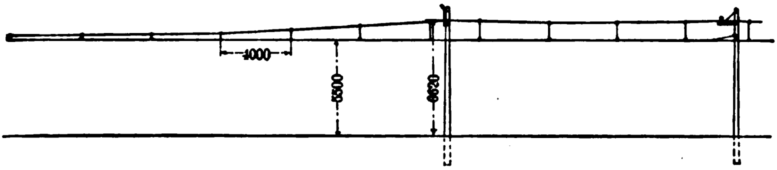

FIG. 29.—UNION CO. TROLLEY SUSPENSION.

5. From the *third rail* the sliding shoe which is usually pressed on the rail from above by its own weight, or by springs or pneumatically from the side or from below, may collect currents of more than 2000 amp. For heavy currents this is the cheapest and most durable scheme yet proposed, though for alternate currents, the increase of the resistance by skin effect is very objectionable. The main difficulty which makes the third rail prohibitive for

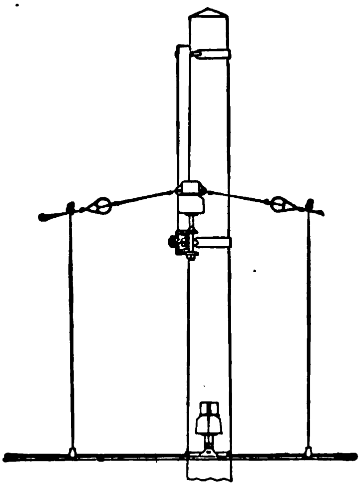

FIG. 30.—TROLLEY SUSPENSION.

three-phase lines is the necessity for the thorough protection of the live rail, mainly at stations. It is, however, possible to cover the third rail at stations by wooden boards leaving only a narrow crevice for connection with the shoe (Baltimore & Ohio Ry). If the shoe projects laterally from the car, the third rail may easily be protected by overhanging boards in such a way as to eliminate danger to operators and officials when crossing the rails. Too much protecting, however, prevents rapid inspection. On the Fribourg-Murten line (Switzerland) the third rail was allowed only for the free line, at the stations two bows and two overhead wires were prescribed, complicating the system materially. During the erection of the third rail, special care must be taken to allow for heat extension and to prevent the movement of the rail. Overhead conductors for heavy currents above 500 amps. would necessitate very expensive framework and a conductor having the shape either of a usual rail or of a U iron or two Z irons. The elevated railway of Elberfeld is using such an overhead rail and the Baltimore & Ohio Ry. formerly used an overhead tube which, however, has been discarded.

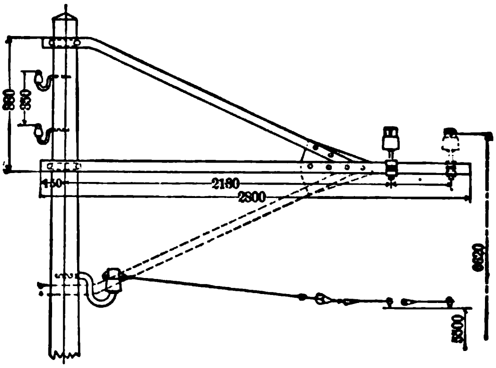

FIG. 31.— TROLLEY SUSPENSION.

If the same car has to run on tracks with different voltages, two different kinds of current collectors must be provided. On the line already mentioned with 400 and 2700 volts single-phase, the Austrian Union Company has installed a high bow for high tension and a low bow for low tension. The trolley wire at the end of the low voltage track is gradually raised and the low bow automatically looses the trolley wire.

Disagreeable disturbances are caused on trolley wires and third rails by *ice and sleet.* A mechanical remedy consists in using scrapers and metal brushes which, however, deteriorate the conductor; it is also not always sufficiently effective. On heavy third rails may be applied certain chemicals, as calcium chloride, as they readily melt all ice and sleet, the soft mass being easily swept away by brushes on the motor car. Electric heating, though somewhat expensive, has also proved a success, as on the Burgdorf Thun railway. The line is short-circuited with low voltage only as long as is necessary to soften the ice; the sliding bow sweeps it away afterward. A thin coat of varnish on the trolley wire may prevent the formation of ice without disturbing the collection of current. It is noteworthy that ice not only depends from the lower side of the wire, but it forms on the upper side also.

In overhead switches of three-phase lines either both wires or at least one must be entirely omitted and replaced by insulated pieces, to avoid crossings of conductors of different phases (Fig. 32, of Brown, Boveri & Cie). One should, therefore, always provide at least two current collectors on the motor cars, spacing them at a distance somewhat greater than the length of the overhead switch. It is bad practice to be compelled to pass all switches without current, as it necessitates special attention on the part of the motorman and means low acceleration and very inconvenient shunting. It is advantageous to have at least one phase running all through the switches (Fig. 32), as in this case the motors continue to work as single-phase machines; starting is, of course, excluded. On third-rail tracks there occur similar interruptions along street crossings; at least two sets of shoes are, therefore, necessary at each end of the car. The intersecting roads should cross at a small angle, and the third rail should continue on different sides of the line beyond the crossing.

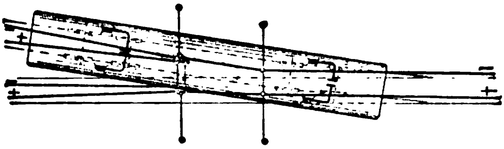

FIG. 32.— OVERHEAD SWITCH.

The following characteristic features seem desirable in a current collector for universal use: Running and shunting in both directions must be possible without reversing the position of the collector. There must be neither hammering of wire nor breaking of contact at high speed. The current collector must not be able to destroy the line construction and must be incapable of being derailed during service. Repairs of the collector and of the line must be quickly made without interrupting the regular service. This necessitates either the simple direct-current system for voltages less than 1000, or for high voltage single-phase railways two separate trolley lines have to be erected on both sides of the line (Maschinenfabrik Oerlikon). Simplicity of the line and of the switches which must be crossed with full current on dictates the use of only one current-collecting conductor. High voltages from 3000 upwards seem absolutely necessary for long lines.

Central Stations and Sub-stations.

The generators and transformers for single and polyphase railways must be designed for the apparent input of the railway motors, that is, for the kilovoltamperes which are considerably higher than the kilowatts. The low power factor of the current entails a much higher voltage drop than current at unity power factor, which feature is specially bad for alternate-current motors so sensitive to voltage variations. The mean power factor on three-phase lines is sometimes as low as 50 per cent, and during starting it is even lower for single-phase motors. Single-phase generators and transformers are larger and more expensive than those of the polyphase type. It is, of course, possible, or even necessary, to use two-phase generators for single-phase lines, but both phases will always be far from equally loaded. Generators and sub-stations must be able for moments to deliver the maximum output, which in some cases may be more than 10 times the mean value on long lines with light traffic, but which in other cases may fall down to only 50 per cent above the mean value. If in the sub-stations of direct-current railways storage batteries are provided, the converters and generators may be very much reduced in size and price, having to yield only mean values. Storage batteries are, however, expensive in first cost and in service, and their efficiency is only about 75 per cent, but they decidedly increase the reliability of the service and in most cases reduce the first cost of the plant and materially diminish the operating expenses. In three-phase or single-phase plants storage batteries would be possible only by installing rotaries which would have to work alternately as direct and as inverted converters, a very complicated scheme. By using very heavy fly-wheels and a great speed variation of the prime movers between no load and full load, the power rushes may be kept away from the prime movers but not from the electric generators and transformers. The dropping of the speed in the central station when trains are started is quite favorable to alternating currents, as the periodicity is reduced thereby. A somewhat better scheme would be the use of high speed fly-wheel sets, electrically driven and influenced by the load in such a way as to be charged in the shape of kinetic energy, when the line runs at light loads, and discharged when much energy is needed on the line. Such sets must have a wide range of speed variation; but up to the present they have been successfully built only for direct-current net-works.

As long as direct-current pressures have to be kept lower than 1000 volts, the most serious drawback to direct-current equipments, besides the expensive feeders and trolley lines, is the large sub-stations with rotating machinery. These latter cost more for installation and maintenance than stationary transformers of the self-cooled oil type, which type is best for railway service up to 500 k. v. a., as they easily give 4 to 5 times the normal output for a short period, if the normal maximum voltage drop is not higher than 1½ to 2 per cent. Rotaries for low periodicities (10 to 25) with a good reactance voltage or provided with auxiliary commutation poles should stand a momentary overload of 100 to 200 per cent. But, as a matter of fact, there are many cases in which even for long lines direct-current railways are not much more expensive in first cost than single or three-phase equipments, and the operating expenses are very often in favor of direct-current, the substations amounting only to about 15 per cent of the price of the whole plant. By increasing the direct-current voltage or by the invention of reliable stationary converters for transforming three-phase into direct current, the conditions would even become more favorable to direct current.

As the voltage drop influences considerably the torque of all alternate-current motors the generators and transformers must be so designed as to give a very good voltage regulation at inductive loads. The Valtellina generators yield a short-circuit current six times the normal current with full load excitation and are guaranteed to stand that current for two minutes. Compound generators or even those of the overcompounded type would be very desirable for single and three-phase lines, but there is no satisfactory and reliable type on the market; all of the known compensated generators are complicated and are surely not able to successfully withstand the severe conditions of railway service. There are, however, excellent automatic voltage regulators on the market, which work nearly instantaneously, and which seem to be well adapted for railway plants (Tirril regulator of the G. E. Company and the Thury regulator of the Cie de l'Industrie El. Geneva).

For equal trolley voltage and equal voltage drop, the sub-stations must be closer together for alternate than for direct-current equipments. For a dense traffic and direct-current voltages above 1000 it is often better practice to use exclusively central stations, eliminating the expensive sub-stations. On main lines the transmission voltage ought to be as high as possible, 60,000 volts according to the present development of the art, to get a uniform load. The trolley voltage of 3000 to 8000 may be transformed in substations at distances of 30 to 60 km which may be increased to 100 or 150 km for 15,000 volts. For the production of high voltage direct current at 1500 to 4000 volts, low speed generators must be used, preferably two or more in series, or machines of the double commutator type may be employed. These arrangements facilitate also the connection of the neutral wire for a three-wire net-work. Rotaries for voltages above 1000 should be fed by alternate currents of low periodicity, say 10 to 15; double commutators and auxiliary commutating poles may be desirable.

Years ago direct current was declared entirely unsuitable for long lines and heavy traffic; today many give up three-phase and direct current to use only single-phase of which we know very little as yet, from a practical standpoint. I believe that all three systems may counterbalance each other; yet each of them lacks some desirable features. Direct current is restricted to low train voltages and needs expensive sub-stations; three-phase railways make two trolley wires necessary, are very sensitive to voltage variations and badly overload the central stations; the last two disadvantages are more or less applicable also to single-phase lines, which possess the additional troubles on the commutator and the low efficiency. None of the systems offers the possibility of running through parts of the line independently of an outside current source. Up to the present neither of the other systems is known to be as reliable and safe as the direct current. The first costs of the car equipments are throughout higher for three and single-phase than for direct current; for equal voltage the line equipment is cheapest for direct current; but the possibility of using high trolley voltages for alternate currents shifts the result essentially in favor of single and three-phase currents, mainly of the former. The sub-stations are more expensive for direct current, while the central station costs least for direct current. As to the operating expenses, the cost of attendance for the sub-stations is unfavorable to direct current. The result of serious comparisons between the systems shows usually a difference in first cost of not over 10 to 25 per cent and the difference in operating expenses is even less and in many cases the results are in favor of direct current. Between three-phase and single-phase there is no essential difference as to price, single-phase having the advantage of simplicity and the possibility of higher trolley voltage, but possesses the disadvantage of needing a commutator.

For long lines and heavy trains with low accelerations, three-phase equipments will always have good chances, especially if through trains are arranged and all shunting is done by special engines. On urban and suburban lines, direct current is entirely sufficient and satisfactory, though a reliable single-phase motor will be a hard competitor, as single-phase equipments may be arranged to suit long and short lines at the same time.

Hundreds of thousands of motor cars with direct-current equipments, at voltages from 500 to 1000, manufactured by all important electric concerns of the world, at the head of which the General Electric Company, Schenectady, must be mentioned, have been for many years in regular and highly successful service on street railways, on elevated and underground railways, on mountain railways, on suburban and interurban lines, with heavy and light traffic, with low and high speeds. Most of them with motor outputs from 20 to 300 horse-power have also proved to be a decided financial success. But even the heaviest locomotives of the world with pretty high speeds will successfully operate with direct-current equipments at 750 volts, I mean the New York Central engines of 2200 horse-power and the hauling locomotives of 2 × 1000 horse-power of the Baltimore & Ohio Ry. for 1600-ton trains. There is also a high voltage direct-current line in regular service in France built by Thury at 2 × 1200 volts and with 4 motors of 125 horse-power per locomotive.

Three-phase equipments have been adopted on two or three street railways, on several mountain railways and on two main lines, viz., the Burgdorf Thun line (Brown, Boveri & Company) with 200 to 300 horse-power per train, speeds up to 36 km and accelerations of 0.24 m (per sec.)[2] besides that on the Valtellina Railway in Italy where locomotives are running now with 1200 horse-power and speeds up to 64 km with accelerations of 0.16 m (per sec.).[2] Besides the experimental work on the Berlin Zossen line, all the three-phase railways are due to Brown, Boveri & Cie and Ganz & Company. The last concern has orders for two more three-phase lines in Canada and in England with 1000 and 600 volts at the trolley wire and locomotives of about 200 horse-power.

There are only a few single-phase railways in service as yet. There is the short track on a suburban line of Berlin (Spindlerfelde) equipped by the Union Company with motor cars having four motors of 120 horse-power each, 6000 volts at the train and pretty high acceleration. Moreover there is the Stubaithalbahn in Austria, a tourist line with light traffic, also equipped by the Union Company with motor cars having two motors of 50 horse-power each and 2700 volts on the trolley. Another line equipped by the same concern with similar cars will operate in Belgium (Borinage). The Siemens-Schuckert Werke are building the Oberammergau Railway in in Bavaria, a short, steep line with light traffic, and the Westinghouse Company has two interurban lines of over 250 km total length under construction (Fort Wayne and Indianapolis). Many single-phase projects and tenders have been worked out and offered, mainly for urban, suburban and interurban lines, with motors from 30 to 150 horse-power, and the Union Company goes even as high as 300 horse-power. Thus it may be expected that the next few months and years may tell us many a practical tale and may prove to be markstones in the development of long distance and heavy electric railways.

APPENDIX.

While this paper is being printed, various facts, mainly relating to single-phase traction, have become known which should be mentioned here. Besides the various heavy three-phase locomotives with motors in concatenation and with variable number of poles, there has been placed an order to equip a locomotive with four single-phase commutator motors of the Finzi type, each motor for 100 horse-power at 15 cycles and 300 volts.

Speaking of starters, I mentioned that Brown and Boveri are perfecting a single-phase system using the repulsion motor and doing all regulation by brush shifting. This scheme, proposed by Max Deri, is described in the Swiss patent 28964. The motor has two systems of brushes, and for a bipolar motor four brush sets. One system has its axis coinciding with that of the stator field; the other system is shifted by an angle which is nearly zero at standstill and is increased corresponding to torque and speed. Both systems may be shifted, one alternately remaining in the field axis; starting, regulating and braking being effectuated in this simple way. One brush set of one system is directly connected with the nearest set of the other system.

The Lahmeyer Company of Frankfort is also developing a compensated repulsion-motor for railway purposes. On the commutator, supposed bipolar, there are four brush sets 90 degrees apart from each other. The first and second brush set is interconnected by a short-circuit and the third and fourth as well. The connecting points are closed on the secondary winding of a regulating transformer whose primary is fed by the line in multiple with the field winding, the secondary windings having a series of taps. The working conditions are similar to those of the compensated motor Fig. 7.

In a great many cases alternating-current lines will be extensions of existing direct-current networks, giving rise to these two important conditions:

1. The alternating-current motors must be fed from the existing high-tension three-phase transmission line at 25 cycles. As to this point, there is no difficulty either for three-phase or for single-phase car equipments; in the last case it is advisable to transform the three-phase into two-phase currents by conveniently connecting up the line transformers, and to feed the trolley line sections alternately by the two phases.

2. The more difficult condition is to equip line and cars in such a way that all vehicles may be equally well fed by high-tension alternating current and direct current. The fulfillment of this condition is the most characteristic feature of the recently-opened Schenectady extension line of the General Electric Company, which I need not to describe in detail here. It is interesting that this company with the widest and most thorough experience in electric traction has given up the repulsion motor to use the series motor with a distributed compensating winding shifted by half a pole-pitch against the main field winding and in series with the main current. This auxiliary winding resembles the well-known Ryan winding of direct-current machines, neutralizing, as far as I see, the armature cross ampere-turns as well as the reactance voltage of the short-circuited coils. The motor has no projecting poles but a two-phase winding equally distributed in slots. Both the 600 volts direct current and the 2200 volts alternate current are collected by trolley wheels, the high-tension by a lateral trolley, both trolley wires being on the same poles. The 50-hp motors for 200 volts across terminals seem to have an air-gap of 2 mm or more. The step-down transformer, which is not used for regulation, is cooled by air draught. The total motor efficiency as a single-phase motor is smaller by 5 per cent than in direct-current working; the power factor is 90 to 95 per cent. The kilovolt-amperes input for a complete run on the suburban line are nearly 50 per cent higher for alternating current than for direct current. Starting and regulation are effectuated for both currents by the same series-parallel control using the same five resistances and the same controller, the efficiency of acceleration being somewhat smaller than for voltage control.

Ganz & Company are just building a three-phase line in Canada where, as I am informed, the same condition has to be fulfilled, viz., the same cars have to run on three-phase and direct-current lines. Probably the motors are equipped with three slip-rings and a commutator on the same rotor shaft, both being connected to the same armature winding; the three-phase voltage is reduced to the corresponding value by transformers and fed to the slip-rings, the stator serving as field for the direct-current service and as induced secondary for the three-phase work. For both services the same liquid starter may be used. The stator winding should preferably be two-phase.

The Oerlikon Company has published data on a single-phase series motor of 200 horse-power, 650 r. p. m., 15 periods and 250 volts. It has eight projecting poles; between them eight smaller commutating poles excited by the main current are arranged, neutralizing the cross-field and the reactance voltage. High iron inductions and equalizers for the multiple armature winding are used. The motor may just as well be worked by direct current.

DISCUSSION.

CHAIRMAN DUNCAN: General discussion on the subject of the foregoing papers is now open.

Mr. E. KILBURN SCOTT: The advocacy of single-phase as opposed to three-phase systems always strikes me in this way — if you ask a man to build an engine with a uniform turning movement, he will supply you with a three-crank engine, and if you use only one of the cylinders, that is, only one line of parts, you will be considered more or less incompetent. Now, every three-phase generator, and every induction motor is analogous to the three-crank engine, and if used single-phase only, it is roughly equivalent to using the single crank.

One point which strikes me as being very favorable to three-phase, is that if you have the transformers connected in delta, and one of them breaks down, the other two carry the load. On the other hand, in a single-phase transmission and distribution, for whatever purpose, if the transformer breaks down, the circuit is opened.

Regarding the question of the utilization of alternating currents for power — if single-phase is being used, the magnetic field and, therefore, the torque pulsates with each alteration, whereas with three-phase, as with direct currents, the torque and, therefore, the draw-bar pull is steady.

Assume for a moment a locomotive for a freight train and suppose a draw-bar pull of ten tons is required. In steam locomotive practice, the locomotive will weigh about five times the amount of the draw-bar pull; or, say, fifty tons. With direct-current motors as with three-phase motors, the locomotive will also weigh say fifty tons, since it has a constant torque; but with single-phase motors, because the torque is variable, it must weigh eighty-five, or perhaps one hundred tons, depending on the character of the particular motor used. I do not want to go further at this time into the alternating-current problem, as applied to traction; but the above three points, are, I think, pertinent to the discussion on Mr. Lincoln's paper.

Mr. B. G. LAMME: In dealing with the problem of single-phase railway motors with electrical engineers during the past two or three years, I have found that their opinions are based largely on such experience as they have had with other types of alternating-current motors. They apparently make no distinction between one type of alternating motor and another, and there have been a number of points brought up regarding which I find there is considerable confusion in their minds. One of these points, mentioned in Mr. Steinmetz' paper, is that of the large air-gap permissible with the single-phase commutator-type motor. I find that a great many engineers cannot understand why a single-phase commutator-type motor can have a larger air-gap than an induction motor of the same speed and capacity, and still have a higher power factor. I have explained this point in a non-mathematical way which seemed to be satisfactory to them, and which they can check for themselves if they so desire. This explanation is as follows:

Take a polyphase motor of any of the well-known types, but preferably of the collector-ring type, for convenience. Run the machine at full speed, and note the no-load current or magnetizing current. Then open one circuit; so that the primary or field of the motor is operated on single-phase, and it will be noted that the motor takes practically the same total apparent input as before. This is, if it is a two-phase motor, for example, and one-phase is opened, the remaining phase takes twice as much current as before. Therefore, as regards total amount of magnetizing current required, it apparently makes no difference whether the induction motor is operated polyphase or single-phase.

Next, if the secondary circuit of the motor is opened, the motor still being run at full speed, it will be noted that with *all* phases connected, the magnetizing current supplied the motor remains as before; but with only one-phase on the primary, the total magnetizing current of the motor drops to one-half, while with the secondary closed, the total current was the same for either single-phase or polyphase. This indicates at once that with the secondary closed the large magnetizing current with one-phase on the primary is a direct result of the closed or short-circuited secondary, for closing the secondary winding on itself at once doubles the total magnetizing current of the single-phase primary. Any armature which has a winding not short-circuited on itself will, when placed in this primary, have the same effect as the open secondary in the above illustration. An armature or secondary element, with a direct-current type of winding, has the same effect as the open secondary, as such a winding is not closed or short-circuited on itself in the sense that an induction-motor secondary winding is closed on itself. Therefore, it follows that a single-phase motor with a secondary or armature with a direct-current type of winding will absorb only one-half as much magnetizing current in its primary or field, as would be taken by a single-phase motor or polyphase motor of the induction type. It is, therefore, evident as the magnetizing current is only one-half of that of the corresponding induction motor, the air-gap can be very much increased if the commutator-type motor is allowed to take the same magnetizing current as the induction type.

A second point which I have found required considerable explanation is the fact that the series type of single-phase motor can give a very large starting torque with a poor power-factor. Experience of electrical engineers has been founded on induction-motor practice, in which a low power-factor at start means, in general, rather poor starting torque. They consequently believe that poor power-factors and poor torque at start go together. They do not comprehend that there is one great difference between the series type of single-phase motor and the induction motor, single-phase and polyphase, and that is that in the series type of motor, the current taken by the motor represents torque without regard to the power-factor. That is, the magnetizing and other wattless components of the current represent starting torque just as well as the energy component. In the induction motor on the other hand, the magnetizing and other wattless components of the current supplied to the motor represent no torque, and it is only the energy component of the current that can represent torque. Therefore, if the induction motor has a low power-factor at start, it means a low energy component, and, therefore, of the total current supplied but a small proportion represents torque. High torque in the induction motor at start must be obtained by high losses, represented by resistance losses in the secondary or armature circuit of the motor. On the other hand as mentioned above, in the series type of single-phase motor, high torque at start does not mean high losses, as the wattless component assists in developing torque. Therefore, for railway work where induction-type motors are used, rheostatic control is always used in order to obtain high energy loss at start for obtaining the necessary high starting torque, but with single-phase railway motors of the series type, it is only necessary to get the required current through the motor for the desired torque, as in the direct-current series motor, and the voltage at the terminals of the motor can be adjusted to that required to send the necessary current through the motor. Full-load current through the motor will give full-load torque, without regard to the voltage supplied, and if this full load current can be supplied to the motor at much lower than full-load voltage, then full-load torque will be obtained in such motors with much less than full-load input. If half full-load voltage, for example, is required to send full-load current through the motor at start, then full-load torque will be obtained with one-half the normal input of the motor, and furthermore this reduced input will be at a relatively low power-factor. This lower power-factor at start would have considerable effect on the transmission system, but it is compensated for by the reduced input at start.

In Mr. Steinmetz' paper, where he gives comparisons of the different types of commutator motors, he refers to them as the plain series, the directly compensated, and the induced compensated. My experience has been almost entirely with the directly compensated, and that is practically the only method that the company which I represent has been using. Before the American Institute last winter, in a discussion on this subject, I referred to this type under a different term. I spoke of it as a " straight series motor ", describing it as one with all the windings in series. That was intended to distinguish it from the motor with the compensating winding short-circuited on itself. My experience has shown that such a winding is not the equal of the type where the neutralizing or balancing winding is in series with the other windings. I have also found that the best results on the average are obtained with the neutralizing winding just balancing the armature winding, not over or under compensated, and one measure for testing our compensating windings has been to put a short-circuiting connection across the terminals of the neutralizing winding. When this winding is properly proportioned, but very little current will be obtained through the short-circuiting wire.

Dr. C. P. Steinmetz: In regard to the question raised of the relative advantages of single-phase and polyphase motors,—the induction type of motor — the single-phase motor tends to synchronize much more strongly than the polyphase motor. That is, the range of efficient operation in the single-phase motor is much more limited, and by deviating from synchronous speed, the torque and power fall off very much more rapidly in the single-phase induction motor then in the polyphase motor; so that while a polyphase induction motor could still be used for railroad work, where rapid and frequent acceleration is not demanded, the single-phase induction motor is out of the question for this work, except by methods as Mr. Arnold has shown us here so nicely, whereby the motor is really not required to start and accelerate with the train. The reverse condition, however, is found with the commutator motor. Investigation of all the very many different forms of alternating commutator motors has shown me that the tendency of the single-phase commutator motor to cover efficiently a very wide range of speed is much more marked than in the polyphase commutator motor. This can well be understood. In any motor the torque is produced by the action of a magnetic field on the resultant current flowing in the rotor in quadrature position to the magnetic field. In the polyphase motor, where you have a stator polyphase field, the magnetic flux in the direction of the effective field is necessarily determined by the impressed e.m.f. and so limited. In the single-phase commutator motor, however, there is a direction in quadrature to the magnetomotive force of the impressed primary circuit, where no limit exists to the magnetic flux, except magnetic saturation, and in this direction a magnetic field can be produced which is not limited by the impressed e.m.f., but varies more or less in inverse proportion to the speed; so that such a single-phase commutator motor can be made to give the characteristic of the direct-current series motor; that is, to give a torque proportional approximately to the square of the current, while in the polyphase motor the tendency is always in the direction of a torque only proportional to the current. Going down, then, to low speeds and starting, you find that, other things being equal, the single-phase commutator motor gives the better torque efficiency as compared with the polyphase commutator motor, while the reverse is the case with the induction motor.

As regards the comparison with the single-cylinder and multiple-cylinder steam engine, after all the single-cylinder steam engine when running is not inferior in this respect to the three-cylinder steam engine, and, in fact, even now-a-days, there are steam engines built and operated at the highest efficiency which are, as far as this feature is concerned, single-cylinder engines; that is, where the multiple expansion is carried out in several cylinders connected in tandem, where, therefore, you get the pulsating torque. The objection to the single-cylinder characteristic is that the frequency of impulses varies with the speed, and is very low at low speed and results in a dead point at stand-still. But this is not the case in a single-phase motor, where the frequency of impulses is constant, is the impressed frequency of alternations, and not the frequency of speed, as with the steam engine, and is so high that the motor cannot be built with as low momentum, as low mass, to give a noticeable variation of speed, due to the successive impulses of torque.

As regards the system of distribution, whether polyphase, three-phase or single-phase, for electric railroading,—for general distribution, polyphase systems are used almost exclusively in this country. That is, for many years we have been impressed and educated to consider this as the proper thing. I understand it is not quite so broad. Single-phase systems are still used there to a considerable extent. The polyphase system has a decided advantage in stationary motor work: the polyphase stationary motor, of the induction or synchronous type, is decidedly superior to the single-phase motor, and will remain so, and that is the foremost value and importance of the polyphase system. The polyphase generator is a little smaller, a little more efficient than the single-phase generator. I do not believe, however, that the difference in generators is so essential as to throw the balance in favor of the polyphase system. But it is in the motor work. In every other respect the single-phase system is simpler and more reliable, and even if the three-phase system by the use of three transformers connected in delta gives the result that if any one of the transformers burns out, the other two can maintain the service: in the single-phase system by using two transformers, which means larger units, and a better arrangement, if one burns out, the other one can maintain the service, so you still have an advantage.

Mr. E. Kilburn Scott: It has to be switched in.

Dr. Steinmetz: Switching, controlling, everything is simpler, and more convenient, in the single-phase system than in the polyphase system, and my opinion is that if it were not for the question of motors, the polyphase system would never have reached its present standing.

Now, when you come to railway work, and the commutator motor, this question changes, and the advantage of the polyphase system becomes a disadvantage. The motor must be a single-phase motor, and you must run a single-phase system from a polyphase generating system. Now we can indeed do that by distributing the railway load on the different phases, operating a two-track road from a two-phase system by having one track on one-phase and the other track on the other phase, or cutting the road up into sections and connecting the sections with the different phases. In railroading, the foremost condition is absolute reliability regardless of everything else. Now, as soon as you cut up the system in different phases, where two tracks are in different phases, any switch or transfer device from track to track leads to difficulties. If you cut the road up into sections, you must have a dead section between the two longer than the longest train that ever will be run, otherwise you are liable to run the same train on the two different phases, getting a dead short-circuit. I think it is objectionable to have any possibility of a place on the road where a train may get stalled and be unable to proceed, and I think these objections may lead us again to consider the single-phase generator, and I believe if the single-phase generator is taken up with the modern engineering methods, with modern experience in design, we can get a single-phase generator which, while probably not exactly as small and efficient as the three-phase, will nevertheless be so close to it, that it will fully fill the requirements, and my personal opinion is that if you run railroads with single-phase motors, if there are no other conditions to be met, the best way would be to generate your power single-phase and transmit it single-phase and operate the whole system on the same circuit with the greatest possible simplicity, doing away as far as possible with the duplicating of transformers, the duplicating of feeders, the existence of dead sections and the inconvenience in switching or transfer.

Mr. A. H. **Armstrong**: The adoption of either three-phase or the single-phase generators is not a purely engineering question, but it is necessary to consider the commercial aspects of the case as well. There are probably operating in this country some half million kw of rotary converter and three-phase generating apparatus. The object of developing the single-phase railway motor along the lines of 25-cycle supply was that it might utilize so far as possible this half-million kw of apparatus. In advocating, therefore, the single-phase generating and distributing system, we are confronted with the possibility, in many cases even the necessity, of using the supply of power already available. To meet this condition, the company which I represent has devised a scheme of balancing by the three-phase-two-phase step-down transformer connection, making each sub-station balanced in itself, and equally loading the three legs of the usual three-phase distributing system. By this means it is possible to use existing distributing systems, and to consider the claims of stationary motor work in any new system that is considered. The single-phase system of generation and distribution is of course the simplest possible for railway work. It approaches more nearly to the direct-current system of distribution, and is preferable, but many electric railway installations have reached such magnitude, and have so many secondary claims upon them, such as lighting and general power distribution, that the railway interests alone cannot be considered by themselves. Three-phase generating and distributing systems already exist, and must be utilized, and secondary claims will probably influence the introduction of the same class of machinery in the new plants. Thus, while the single-phase system is preferable and simple, considered from the engineering standpoint alone, it is probable that three-phase distribution, or multiphase distribution, will have to be carefully considered even though the motors adopted are of the single-phase type.

Mr. E. **Kilburn Scott**: Mr. Steinmetz, will you tell me where this analogy is wrong? Suppose I go to a carpenter and ask him to make me something to stand upon which shall have the *minimum quantity* of material and the *maximum strength*, he makes me a *three*-legged stool. If he should make it with four legs, which is analogous to two-phase,— well, it might stand on four, but the chances are it will rest on three only, the extra leg in other words being so much wasted work and material. If he should make it with two legs, which I think is analogous to single-phase, it would be in unstable equilibrium.

Mr. **Steinmetz**: But if you make a vehicle with three wheels, a tricycle, you can never get the speed out of it that you can out of a bicycle.

That is, as soon as you get motion and have dynamic conditions things change entirely from static conditions.

Mr. SCOTT: Yes, I see.

CHAIRMAN DUNCAN: We should like to have some further discussion. There are certainly gentlemen present who can add to our information on the subject. Mr. Leonard, we should like to hear something about Mr. Arnold's locomotive. I know you have considered that type.

Mr. H. WARD LEONARD: I believe, Mr. Chairman, that I was the first to urge the idea that single-phase, high-tension generation and distribution were essential for heavy railway work, and as some of the gentlemen present may not understand the system that I proposed, since it was many years ago, I will state briefly that what I proposed was a high-tension single-phase system with a single-phase motor upon the locomotive running at a constant speed, and driving upon the locomotive a generator, which generator would have a separately excited field, by means of which the voltage of the continuous current in the secondary could be varied as desired and reversed, by which means we could secure in the armatures of the propelling motors of the locomotive any desired voltage to accelerate from rest to full speed, with a minimum consumption of watts and with the many advantages of perfect speed control, restoration of energy, etc. Mr. Arnold's proposition follows similar lines, to the point where the shaft of the single-phase motor is reached. From that point he uses compressed air in conjunction with the torque of the single-phase motor, and he secures very many beautiful features and important ones, although, as I believe, at the expense of simplicity. He has one advantage which may have considerable weight, although I believe that it will not be so influential as to be of very great effect, and that is the storage of power for the operation of the train without electric current for a short distance. But a system having reciprocating parts and the complexity due to the necessity of a good many valves and automatic devices, I personally do not think is likely to compare in reliability of service with a single revolving part without separate automatic devices or reciprocating parts. A point in connection with my system which is also likely to be important, perhaps, is that although a high-tension current would preferably be led upon the locomotive, it is led to a single-phase motor which is an entirely separate device and can be entirely insulated at the shaft from the rest of the locomotive, so that we reduce to a minimum the liability of the high-tension energy reaching any portion of the locomotive which has to be handled, or where a person might be exposed to it.

As to the comparative weights and first cost, it is difficult to form a conclusion with any of the data that we have at present at hand as between the air-storage scheme and the transformation at variable voltage, but I should be inclined to expect that the first cost and weight for my system would be rather less than for the other. In that connection I was interested to notice the figures which are given in Prof. Niethammer's paper, on page 237, where Table VIII. gives the weights for the direct-current, three-phase and single-phase apparatus. Considering the three-phase and the single-phase, and putting those figures into the weight per horse-power of the electrical equipment on the locomotive, and putting the kilograms roughly into pounds, we get the following figures: Three-phase, Brown-Boveri, 72 lbs. per h.p.; Siemens & Halske, three-phase, 89 lbs.; A. E. G., three-phase, 53 lbs.; Ganz & Co., three-phase, 60 lbs. Single-phase.— Finzi, 88 lbs.; Union, 73 lbs.; Oerlikon, 60 lbs. This matter of weight is oftentimes an important one, and while considering the weight of transforming apparatus such as Mr. Arnold proposes, and such as I propose, I wish to call attention to the fact that we must not lose sight of the consideration that for the same maximum operating torque with satisfactory commutation the weight of motors on my system will be very materially less than is likely to be realized even after the highest perfection of the single-phase type, and that, therefore, there is quite a little margin of weight at that point available to compensate for the weight of the motor generator. Furthermore, I consider that if my system has any virtue, it lies principally in the direction of the production of a very large amount of power upon a locomotive and the possibility of controlling by very simple means a multiple of very heavy locomotives, where questions of simple, uniform acceleration with a minimum of energy, simplicity and reliability of control and the restoration of energy are considerations that will be very important.

When considering heavy locomotives I think there will be a very great advantage to be found in a system such as mine, which employs motors in which the field of the motor is entirely independent of the armature current. What I mean by that is this,— a heavy locomotive will be worked, and must be worked, to the limit of its maximum tractive effort, and every artifice must be employed to secure the maximum tractive effort from the locomotive,— the same is true, of course, of the steam locomotive, — and the result is the parallel rods of the steam locomotive, which are probably the chief curse of the steam locomotive to-day. They are a necessity in order to secure the maximum tractive effort with a certain weight on drivers. With series motors we will also need parallel rods. If we attempt to leave the parallel rods off it will be evident that with perhaps six or eight drivers on a side, representing six or eight different motors, some one of those, if we push the motors to the limit, will skid before the rest, and when it does so skid we have a condition which is comparable to the skidding of a steam locomotive by too rapid opening of the throttle, and it becomes necessary to stop, go back to the starting condition and try it again. Now, that is due to the fact that a series motor has a speed which is dependent upon its torque, a speed which is dependent upon the current, but if you have a motor with a separately excited field and in which the counter volts balance the impressed volts without any rheostat in that circuit, it is, as you will see, impossible for any racing away of the motor in case any particular motor does tend to skid; which means that with such a system as I suggest we can operate in multiple a number of different motors and secure the effects of an invisible parallel rod, without the mechanical complications and handicaps which that imposes on account of the rigid wheel-base and the consequent difficulties upon the curves. Therefore, I think that the question of heavy locomotive practice will lead strongly in the direction of a separately excited field or some other artifice, which may of course come, which will enable us to secure the effects of the parallel rod electrically, without the mechanical difficulties.

Mr. W. L. Waters: Referring to Mr. Bragstad's paper, or rather to the remark in that paper to which Mr. Steinmetz called attention — that analytical methods are necessary for dealing with problems such as we have in the single-phase motor, and that graphical methods are of little use, it has always seemed to me that it is more a question of a natural trend of a man's mind than that any arbitrary dogmatic statement can be made, either that the analytical or that the graphical method is the only one to use. Speaking from a personal point of view, I have always had to adopt analytical methods to obtain a complete and comprehensive understanding of the problem in the first place, but as soon as it comes to practical designing, I find it necessary to adopt graphical methods and rough approximate rules obtained from experiments. I think that one thing students have always to learn before they can become practical engineers is that designing is not a question of solving differential equations dealing in complex functions and imaginaries, but one of deducing rough rules from experiment, and from previous experience with similar types of machines. As it has been very aptly put — designing is an art, rather than an exact science.

Coming to Mr. Lincoln's paper, I think that Mr. Lincoln hits the nail on the head, when he states that directly you talk about potential to earth, instead of potential between conductors, the single-phase system is on a par with the three-phase. We have got so used to talking about three-phase transmission that we have almost come to believe that no other system of transmission is possible. The original three-phase transmission work, and most of the three-phase distribution work at the present time, has been done with three-phase cables, in which, of course, the potential between conductors decides the strain on the insulation. But, as Mr. Lincoln points out, when we come to modern overhead transmission lines, it is the potential to earth that decides the strain on the insulation, and this being the case the single-phase system is, for overhead work, equal to the three-phase. It seems peculiar that after ten years or so of almost exclusive use of three-phase system, that we now seem likely to return to the original single-phase system, which has been continually advocated by Ferranti and which was used in the first commercial transmission — the 10,000-volt Deptford-London line.

The main disadvantages of the single-phase system are, of course, obvious. That with a single-phase alternator you do not get the full output that the machine is capable of giving, and that the single-phase commutator motor is a much more complicated machine and much more liable to break down than the three-phase induction motor. These disadvantages, however, are not sufficiently serious to prevent the single-phase system from having a wide application.

Dr. Steinmetz: When considering the development of a new field in engineering, we first consider what appears to be the simplest and the best arrangement, and endeavor to introduce that. However, in every case we also must consider the existing state of the art, what has been before and what is there. If a cataclysm to-morrow should wipe out all our civilization except the human intelligence and we should then proceed unfettered by existing things to reconstruct it, we would do very many things differently than we are obliged to do now. One of these features my friend Mr. Armstrong has referred to. While single-phase generation and transmission would be the simplest, the enormous magnitude of existing three-phase plants may lead us to utilize, in generation at least, polyphase systems. It may or it may not. The future alone can show that. There are a number of features with regard to the use of commutator motors in railway work which are of similar character. At least in this country there are very few villages even which do not have a direct-current railway system. After all, the electrification of the steam railway has not made such progress as enthusiasts believed it would ten years ago. Electric locomotives have been introduced and are being introduced, but in most cases you find special requirements, either an underground tunnel or something of similar character. But what has taken place is the exact counterpart of what took place three-quarters of a century ago. The early attempts of the steam locomotive to replace the horse in front of the stage coach were not successful, but a new motive power required new arrangements, and the steam locomotive and the railroad train has been developed. The horse has not disappeared but has been relegated to another field. You see the same taking place now in electric railroading. You do not see in general, at least not yet, the electric motor replacing the steam locomotive, but you see the trolley car paralleling the steam railroad and either taking away a certain class of traffic for which it is much more suited, or developing a traffic of its own. The feature whereby the trolley car, in spite of its usually lower average schedule speed, beats the steam railway train, is the absence of terminal stations and the absence of a time-table. With the steam railroad train you have to go to the depot, and you have to consult beforehand a time-table.

With the interurban electric railway you pick up the car anywhere in the city, either the interurban car directly or a transfer car, and you do not look for a time-table but wait for the next car which comes along in a few minutes. That is, I believe, the main advantage of electric railroading. But as soon as you introduce a motor which is specific for interurban service, for long-distance travel, which cannot run over your city systems, you give up that advantage and you are only on a par with the steam railroad train. Even then we still have great advantages in the rapidity of acceleration, the greater schedule speed we could secure with the same maximum speed, absence of smoke, etc. But all those appear to me minor advantages compared with the advantage of not requiring terminal station and time-table. With the alternating motor, this means adapting the new systems to what exists at the present day. You have to limit the choice of your motor to such types as can be easily applied to both characters of service. Hence, to retain the main advantages of electric railroading, you require a motor that will run equally well on the alternating, long-distance trolley circuit, as on the direct-current city distribution. That is one of the features on which you have to compromise. It means that you must carry the same car, the same motor, with equal efficiency of operation, of acceleration, over the 500-volt city system and over the high-voltage long-distance line. This feature, and this class of service, determines, to a certain extent, the type of motor and gives the preference to the compensated motor or Eickemeyer motor over the repulsion motor, although in its speed-torque characteristics some advantages exist in the latter. For other classes of service, as, for instance, heavy freight service on trunk lines, possibly other types of motors may be preferable. We must consider that at present, after the development of nearly a quarter of a century, one type of motor has been brought forward and everything else dropped to practical oblivion, and that is the direct-current series motor, as most perfectly fulfilling all the requirements of electric railroading as it is at present. This does not mean, however, that it will remain so. For many years all the requirements of alternating motors have been fulfilled by the polyphase induction motor, and still we now demand a single-phase commutator motor. You see, there may be fields which are not touched at present, but which will have to be taken up by the electrical engineer in railroading, and for which a different type of motor may be preferable. All the classes of electric railway service at present, whether it is the city tram car or the rapid transit road, elevated or subway, or the suburban or interurban service, are very similar in their characteristics. They all require a motor which is able to give a very high torque, that is, a very rapid acceleration, sustained up to a considerable speed, and beyond this speed, at the end of the high acceleration, a torque curve which decreases very rapidly but still extends to considerably higher speeds, running down to 20 per cent or less of the torque of acceleration at twice the speed which is reached by full acceleration torque. In addition thereto you require means to operate efficiently at moderate torque and low speeds, which is fulfilled by the series-parallel connection. In city tram car work you have to stop very frequently, at very irregular intervals. Therefore you have to be able to accelerate very rapidly, with heavy acceleration, so as to maintain good schedule speed. You must have rapid acceleration up to considerable speed and then get the benefit of favorable conditions of road by running up to high speed with decreasing torque. The torque must decrease rapidly at high speeds, because otherwise on a level stretch you would either have to cut in and cut out continuously or you would run to such speeds as were beyond your motor capacity. Furthermore, in districts of heavy traffic you have to run slowly. This means series-parallel control. When you come to suburban or interurban service, you have the same characteristic except that the speeds are higher, and the stops less frequent. In rapid transit, you have again the same characteristic, only larger motors and higher speeds. Now, the induction motor gives you also a sustained acceleration but a torque which drops down to zero immediately above the speed reached with full acceleration torque. That is that part of the speed curve from the end of maximum acceleration to the speed of free running (about twice the former speed), or the acceleration on the motor curve, does not exist with the induction motor. Acceleration on the motor curve, however, is the most efficient acceleration. You cannot go beyond synchronous speed and so cannot get the benefit of the track, with the induction motor. Now, you can indeed extend your curve by making synchronism the free running speed. But that means that you have half the rate of acceleration, assuming the same size of motor. or if you desire the same high acceleration, you require twice as large a motor, which obviously is not feasible, because usually you have not the space. Hence, where you have to accelerate rapidly to high speeds, where you have to get the benefit of favorable conditions of the road, the polyphase induction motor is not successful. Under favorable conditions, for instance for the class of work where the acceleration curve does not differ much from the running curve, as on heavy grades, on mountain railways, as mining locomotives, where indeed the character of the work is not railway work but rather elevator work, there the three-phase motor is successful, and there are mountain railways in existence in this country, as well as abroad,— with three-phase induction motors. But that is not regular railway service. The different alternating-current commutator motors give a torque curve very similar to that of the direct-current series motor, except that the torque decreases slightly less with the increase of speed, the torque curve as function of the speed is less steep (the induction motor as stated gives practically a vertical line). The repulsion motor, as stated in my paper, gives the steepest curve; the plain series motor, without compensation, the flattest curve. The result hereof is that with the same speed of free running, the alternating-current commutator motor, with the same acceleration torque, will not sustain the acceleration up to quite the same high speed as the direct-current motor, but will strike the motor curve at a lower speed. This gives a higher efficiency of acceleration, but with the same maximum acceleration, the average acceleration will be less, and so, to get up to the same speed, it will take a slightly longer time with the alternating-commutator motor than with the direct-current series motor, but the acceleration will be more efficient; because the larger part of the acceleration is on the motor curve. Where you are able to increase the maximum acceleration you can get the same average acceleration with the alternating-current motor as with the direct-current series motor, and that at higher efficiency, other things being equal, in the alternating motor, but you have to go to higher maximum values of acceleration. Hence where you are limited by the comfort of the passengers you cannot do that, and, therefore, for some classes of service, where you have to accelerate at the maximum value permitted by the comfort of the passenger, the direct-current series motor gives you a more rapid average acceleration than the ordinary alternating commutator motor. This, however, does not preclude the alternating-current commutator motor being modified so as to give the same characteristic as the direct-current series motor and that is being done. But the motor as it is in service at present gives a torque curve of slightly less steepness than the average direct-current series motor. The counterpart of this lesser steepness of the torque curve of the alternating-commutator motor is that you can run over a wider range of speed with the same resistance, or the same potential.

Mr. **Lamme**: Several points have been brought up since I spoke last, in connection with the fact that we have had to adapt this single-phase railway system to existing conditions. It has been mentioned that single-phase would be preferable to polyphase, both for generation and transmission, but that the system has to be adapted to existing generating plants and that the nearest approach we could make to the ideal system would be to transmit at three-phase from existing stations, transform to two-phase, and feed each of the two phases to the trolley as independent single-phase lines. In connection with the use of single-phase throughout, it may be of interest to go back to the first paper on single-phase railway motors of the commutator type which was presented two years ago this month, before the American Institute. In that paper I called attention to the fact that the Westinghouse Company had taken a contract for a single-phase railway using commutator type motors. Among the various features of the system as described, it should be noted that our proposition was for single-phase throughout, the generators being wound for single-phase 15,000 volts, and feeding directly into the transmission circuit. Step-down transformers were to be used in the sub-stations, or transforming stations, and single-phase current was fed to the trolley circuit and to the motors. That was considered an ideal system, and such an arrangement could be adopted in this particular case because the road was a new one throughout, and was not limited to any extent by existing conditions. But most of the projects which have been brought up since that time have been in connection with existing power-plants, or are roads which expect at some future time to tie up with other plants, so we have been obliged to accept the polyphase generating and transmission plants with the single-phase distribution beyond the power-house, or the transforming stations. Take for example a single-phase road which is now being installed between Cincinnati and Indianapolis. The company installing this had already bought machinery for a three-phase generating plant with direct-current distribution from converters. They changed over to the single-phase system after the machinery was partly completed. It was suggested that a straight single-phase plant throughout would present many advantages, but the customer could not see his way clear to make the change so late in the day. Therefore the customer decided to stick to the three-phase generating and transmitting plant with transformation to two-phase in the sub-stations. The line is divided, one branch being fed from one phase, and the other branch from the other phase. We have found that similar conditions hold true in many other plants. Another condition which came up in some of the earlier projects was that the customers were somewhat doubtful of the single-phase system on account of its novelty, and they took the stand that if they put in three-phase generation and transmission, they would always be in position to adopt rotary converters afterward, if they found it desirable to do so. We have heard but little on this point in the past year or two.

Mr. E. **Kilburn Scott**: How do you change the three-phase into single-phase on the line you speak of?

Mr. **Lamme**: Consider one branch of the line in one direction from the power-house as one phase, and the other branch in the opposite direction as the other phase.

Mr. **Scott**: Can you transform from three-phase to single-phase with transformers? Can it be done like the three-phase two-phase arrangement?

Mr. **Lamme**: Well, that I am not prepared to say. Another feature worth considering in the Baltimore-Annapolis road was the frequency adopted. At that time we proposed a frequency of about two-thirds of what is used at present. That frequency was then considered as the most suitable one taking everything into consideration, as it was better for the motors, transmission line, and for the generators. I still hold to the opinion that for the motors a low frequency is better than a higher frequency, especially for larger capacities of motors, and I think that as we take up heavy locomotive work that this question of a frequency lower than twenty-five cycles will be found of great importance. It is entirely possible than when the steam roads are electrified it will be found advisable to adopt some frequency other than twenty-five cycles. In a great many cases the power-plant requirements for the heavy railroads will be so great compared with existing plants that these systems can adopt their own frequency. It was found that in pushing the lower frequency, it was much the same as in pushing the single-phase. We could not get people to adopt it, largely on account of utilization of existing plants. We found that was the greatest objection to low frequency. We found that even in the case of heavy railroads, with plants of four or five times the capacity of all the other plants in the same district, they nevertheless wished to start out with a frequency which corresponds with that of the smaller plants in the same neighborhood. I think they will pull away from that policy some day.

Another point brought out in the Institute paper referred to was that the type of alternating-current motor to be used was perfectly adapted for operation on direct-current, as it was primarily a high class direct-current machine. It was stated that the complication necessary for operating on both alternating and direct currents was much greater than for either the alternating or direct current alone; because it was necessary to have rather complicated switching devices for throwing from one system to the other, if the combination system was used. At that time it was thought that such an arrangement would be entirely too complicated, and that railway engineers could not possibly accept it; yet within a comparatively short time after the publication of that paper, we found engineers who were willing to consider it, and within the past year contracts have been closed with roads which are to be operated on alternating current on suburban and interurban service and direct current on the city service, and the extra complication of such a system does not seem to be prohibitive to them. The series-parallel connection of motors was considered for this service. We found that on many of the projects there was no particular advantage with such an arrangement. In one large road which we are installing, the service across country will be at a very high speed, and it was found that to get the necessary low speed in the direct-current city lines it was necessary to connect all four motors in series. Therefore, there was no advantage in operating series-parallel on the direct-current part of the road as only the series combination could be used. We, therefore, adopted the combination with four motors in series for the direct-current and four motors in parallel for the alternating service, and speed variation on the alternating service is obtained by means of a number of loops or taps on the lowering transformers. In this way we obtain on the alternating-current service better conditions than could be obtained with series-parallel, as we have more than two efficient running steps and the starting conditions are also better. I think that where the speed on suburban service is comparatively low, it might be possible to use the series-parallel arrangement of motors, with the motors thrown in series on the city service on direct current, but we have found in general that in going into the cities, or through towns which are not of large size, in many cases a similar arrangement has been to put up an extra trolley wire alongside the direct-current trolley wire, this extra wire being supplied with alternating current at about 500 volts. By placing one of the transforming stations near the junction of the suburban and the city service, we can feed the 500-volt city trolley wire from a low voltage tap on the lowering transformer. In this way we can have low-voltage and high-voltage trolleys supplied from the same transforming station. On the lowering transformer on the car itself, we have also a low-voltage tap corresponding to the voltage on the city trolley. When the car is to be changed from the high-voltage trolley to the low-voltage, the circuit is switched over to the low tap on the car transformer and the same control apparatus is used as for the suburban high-voltage service. That has proved to be a very simple arrangement, and it has been adopted on most of the roads which we have sold. About seven or eight roads have been sold which utilize such an arrangement, and very few have so far found necessity for the extra complication which will be required for operation of both alternating and direct currents.

In the preceding discussions, there seems to have been no particular comment on the question of the most suitable frequency. Twenty-five cycles seems to be the most suitable frequency at the present time for commercial work, simply because existing plants have been installed with this frequency. It is possible to go to somewhat higher frequencies successfully with a somewhat larger motor, but with corresponding poorer performance. Better results can be obtained from the motor at lower than twenty-five cycles, but such lower frequency will possibly not be adopted extensively until we get into heavy railroad work. But if we should adopt lower frequency, and thus break loose from existing systems, then will be the time when we can also adopt the straight single-phase system.

Mr. A. H. ARMSTRONG: Mr. Chairman, the product of the engineer is at the best a compromise. With the rest of us, Mr. Lamme has gone through the battle of frequencies, starting at 125 and 130 cycles per second with a gradual reduction to 25 cycles, until we thought the bottom had been struck, but there are certain advantages which perhaps warrant the introduction of 16 2/3 cycles, or even lower. I believe 15 cycles is already in operation on the other side of the water.

Closely allied to the confusion of frequencies, is the babel of voltages. Contrasted with the two accepted standard frequencies of twenty-five and sixty cycles, there are the multitude of standard voltages with their modifications. Voltages are at the best mixed up, and no new distributing system can go in unless it takes account of the voltages existing in neighboring plants with which it may be consolidated at some future theoretical date, a possibility always kept fully in mind by the promoters of the new installation. But in adopting alternating-current motors for railway work, we have an open field so far as trolley voltages are concerned, and I am glad to see that there is a fairly uniform movement toward adopting 2200 and 3300 volts as the two standards. I do not quite see how we can adopt one of these in preference to the other, but it seems necessary perhaps to adopt both of them for the present, and by a gradual course of elimination to settle on one as being the best fitted for general work.

As regards the fitness of the alternating-current motor for railway work or its proper field of action, very little has been said this morning beyond Mr. Steinmetz' remarks, and I would like to supplement them by two or three observations of my own. I have been fortunate in having an insight into the probable plans of a steam-operated road which is going to change over part of its service to electrical operation. The engineers in charge of the work are very progressive, and seem to consider nothing but the alternating-current motor as available.

Another thing that strikes me as instructive is the fact that although they have their own private right of way, their own terminal stations and are entirely isolated from any influences of direct-current city work, they will consider nothing but the operation of alternating-current motors on direct-current circuits. The road is being electrically equipped to take care of the suburban passenger traffic, the changing over of locomotives for handling freight traffic not yet being contemplated. They realize fully that their receipts have been eaten into very heavily by the inroads of parallel electric lines, all of which have the right of way over city streets. The success of these roads is due largely to the fact that they can pick up and discharge passengers on city streets, and the steam road management do not consider it feasible to give up one of the most valuable assets now enjoyed by the electric roads. In operating their system electrically, therefore, they are considering the giving up either in whole or part of their terminal stations and the operation of their cars on their own private right of way between cities and over the city streets at the terminals, in fact duplicating almost exactly the present operation of our city and suburban systems.

Mr. Lamme made a remark about the advisability of installing a separate alternating-current trolley system in small towns en route, although they may have a present tramway system operated by direct current. It seems to me that the trend of progress in alternating-current motor work necessitates that these motors must operate over city systems with direct current. I have a case in mind where a road was to be operated on the suburban sections, some thirty or forty miles, with alternating current, connecting two city systems at the termini. The expense and complication of introducing a separate alternating-current trolley in the cities was very great, the expense not being so much of a consideration as the complications of equipping every street in the city leading to the car barns, and in fact any route liable to be taken by the suburban cars.

In adopting an alternating-current motor system that is applicable to general work, the first consideration is of course to have it operative; the second is to simplify the character of the mechanism and controlling apparatus as much as possible. If a motor control is adopted that will be operative on both alternating-current and direct-current circuits, it may or may not necessitate giving up the advantages of potential control. Simplification would call for plain rheostatic control similar to that employed now in the operation of direct-current motors. In fact, motors are in commercial operation using plain rheostatic series-parallel control both for alternating-current and direct-current circuits, the control being identical in each case, and effected by a standard direct-current controller with slight adaptation, the only change made being the cutting out of the blow-out magnet when alternating currents are used.

Mr. Steinmetz pointed out the advantage enjoyed by alternating-current motors of a more flexible speed-torque curve than that met with in the design of direct-current motors. This makes it possible to accelerate to the full rheostatic point with fewer steps, in less time and with less resistance loss than is possible with direct-current control. It furthermore simplifies greatly the control of motors when operating a combined alternating-current-direct-current system. Ordinarily, series-parallel control is not placed at such a disadvantage in regard to efficiency of acceleration compared with potential control of alternating currents. This is especially true considering the extra apparatus required, if induction-regulator control is used, or the extra complication involved if potential control is effected by taps off the main step-down transformer.

There are two general fields for alternating-current motors presenting themselves for immediate notice; the suburban field, calling for a motor capable of operating with direct current over city streets, because such roads depend upon city traffic and frequent stops for their success; and the second field is either main-line freight work, or the more immediate problem of our mountain grades. In the latter case the road is entirely isolated from any direct-current influences; it does not cater to local passenger traffic, but is used for through haulage only; there are no sentimental resources influencing the adoption of electricity, but it is installed purely from financial considerations of lower operating cost compared with steam locomotives. On this class of road it seems probable that the operation of motors on direct-current circuits will not have any influence in determining the motor to be used. The system is purely alternating throughout, operates at practically a constant output, no accelerating problems are present, and potential control is very convenient and effective for controlling motors.

Mr. Leonard brought up the point of the weight of the alternating-current equipment compared with direct current. At present, such equipments weigh approximately 25 to 30 per cent more than direct-current equipments of equal capacity. This increased weight, while it has an effect upon the first cost of the apparatus, has very little effect upon the operation of such roads as are influenced by the adoption of alternating-current motors. The alternating-current motor is essentially a suburban or high-speed motor, or else a freight motor. It is not intended for city work, not being so well adapted for this class of service as the direct-current motor with its lower internal losses in acceleration.

A car weighing thirty tons, say, with direct-current apparatus, and thirty-three or thirty-four tons with alternating apparatus, will require practically the same energy when operating at a maximum speed of forty-five or fifty miles an hour. In other words, a slight increase in the weight of the car will not greatly influence the watt-hours per ton mile required by that car when effecting a given schedule on our suburban systems. In city work, however, an increase of 10 per cent in the weight of the car calls for fully 10 per cent increase in the energy consumption, due largely to the fact that the wind friction, which is the controlling factor in high-speed service, is almost entirely eliminated at the low speed incident to city traffic, and the energy consumed by the car goes up in direct proportion to its weight. The weight of the alternating-current apparatus, therefore, cannot be brought up as an argument against its adoption in the practical work for which the alternating-current motor is primarily adapted.

Mr. H. Ward Leonard: The closing remark which Mr. Armstrong made was to the effect that for rapid acceleration work the increased weight of the alternating-current motor would be a serious handicap to it, that the increased weight of the car would require increased energy in direct proportion to that increase of weight. I should like to say in reply to that, that that remark is not broadly true, as it would not be true in the case of such systems as restore a considerable portion of the energy required for the acceleration, during the period of retardation, which, of course, is one of the points I urge most strongly in connection with my system.

Mr. P. M. Lincoln: The company which I represent have until recently recommended a trolley voltage no higher than 1100, for the reason that we believe that a voltage of such nature will not require a complete modification of the trolley line insulation. The same style of trolley insulation as is used on the present 500 volts will, we believe, be suitable when properly reinforced for a voltage of 1100 volts alternating. But on going to the higher trolley voltages which have been mentioned, viz., 2200 and 3300, we are of the opinion that the ordinary insulation as at present used on 500 volts will not answer, nor will the type of insulation answer. It will require some new type of trolley insulation. For that reason we have recommended that the trolley voltage be not increased to these higher voltages until a new type of insulation has been developed. That was at the beginning. As it stands now, however, the new types of trolley insulation have been developed, and there is no bar to the increase in trolley voltage to 2200 or 3300. The trolley voltage is bound to increase. As the requirements of the circuit increase the best and the easiest way to take care of it is by increasing the trolley voltage. It is a problem which is bound to come.

I was considerably interested in Mr. Armstrong's remarks concerning the controller for a. c. cars which has been proposed, viz., using the ordinary direct-current controller for alternating currents by simply cutting out the blow-out magnets. It seems to me that that is a step to the rear. A good many years ago when controllers were in their infancy, the blow-out magnet was not used, and in order to make a successful controller the blow-out magnet was almost an absolute necessity.

It has been my experience, as well as the experience of those with whom I have been associated, that it is considerably harder to take care of contacts which are operating with alternating current than of those which are operating with direct current. The alternating current will bite into the contact pieces, other conditions being equal, considerably more than the direct current will. Therefore, I do not see how an ordinary controller which requires a blow-out magnet for direct current is going to operate successfully when used on alternating current without any apparatus to interrupt or to cut down the deleterious effects of the spark. Possibly for small equipments such an arrangement will operate satisfactorily, but when the amount of power involved is large, as it is in the larger sizes of equipments, I do not see how such a scheme of control will operate satisfactorily.

CHAIRMAN DUNCAN: Is there any further discussion, gentlemen? I am asked to remind the sections that to-morrow there will be the meeting at Festival Hall in the World's Fair grounds at 10 o'clock, a joint meeting of the two Institutes and the Congress. If there is no further discussion, gentlemen, the meeting is adjourned.

WEDNESDAY MORNING SESSION, SEPTEMBER 14.

A joint meeting of the American Institute of Electrical Engineers, the Institution of Electrical Engineers of Great Britain, and Section F of the International Electrical Congress, was held at Festival Hall, World's Fair grounds, on Wednesday, September 14, 1904.

President Bion J. Arnold, of the American Institute of Electrical Engineers, called the meeting to order at 10.30 o'clock A. M.

PRESIDENT ARNOLD: This is the second joint meeting of the Institution of Electrical Engineers of Great Britain and of the American Institute of Electrical Engineers. It was our pleasure to meet with the Institution of Great Britain in England, in 1900, and on the grounds of the Paris Exposition, in Paris, having an adjourned meeting there, wherein took place a joint discussion. At that time our British friends were our hosts and at this time it is our pleasure to have them with us in this country. This meeting is a joint meeting, and, therefore, neither institution takes precedence — it is entirely a joint affair and will be presided over by the Executives of both societies, as well as by the presiding officers of Section F, the section of the Congress devoted to electric traction. It is hoped that this will not be the last meeting between the institutions represented, but that we may have many of them in the future at as frequent intervals as practicable.

In accordance with the regulations of the society which I have the honor to represent, it is now my pleasure to deliver the annual address of the President. President Gray will kindly occupy the chair.

President **ARNOLD** then delivered the following address:

THE ELECTRIFICATION OF STEAM RAILROADS.

BY BION J. ARNOLD.

Eleven years ago this summer it was our privilege to meet under the auspices of a great Exposition, located upon the shores of Lake Michigan, organized not only to commemorate the 400th anniversary of the discovery of this country, but also to direct attention to the advancement made in the various fields of the world's activities, and especially in those arts in which we, as workers, were most interested.

To-day we meet under the auspices of another great Exposition, brought into being to commemorate the 100th anniversary of the peaceful acquirement by the Government of the United States of a large portion of the territory now contained within its borders, to have our attention directed to the development of the various industries of this and other countries that have taken place during the intervening years.

For a few years preceding the former Exposition, engineers and others engaged in electrical pursuits had had their energies absorbed in attempting to show the owners of street railways that operation by electricity was cheaper and better than by means of the horse or the cable. We, at that time, had seen the horse practically disappear from street railway service and the cable supplanted in some instances.

The more ambitious engineers were then advocating the use of electricity on elevated railways, and making figures to prove to the owners of such railways that electricity was cheaper in operation and more desirable for such conditions than steam locomotives, then universally used for such work.

At that Exposition was placed in operation an elevated electric road, known as the Columbian Intramural Railway, which, though the city and South London Underground, a road of light equipment, was started some time before, and the Liverpool Overhead Road soon after, was the first practical commercial application on a large scale of electricity for the propulsion of heavy railway trains.

The success of these roads gave the electric railway industry an impetus which has since resulted in the abandonment of steam and the adoption of electricity on every elevated railway now in operation, and practically on all of the underground roads, thus effectually proving the soundness of the theories of those engineers who pinned their faith to the correctness of the conclusions which their figures showed, and who staked their reputations upon the future to prove them true.

The interval between these Expositions has also been one of great activity and development in the field of interurban railways, which has brought into being the extensive use of the alternating-current, rotary-converter, sub-station system of operating direct-current roads, resulting in the interlinking of thousands of cities with each other and intervening points, thus not only affording a new field for the investment of capital but bringing to most of the inhabitants of the territory through which these roads pass greater facilities for the prosecution of business and the widening of their social life.

With the introduction of the suburban railway came an increased volume of passenger travel, induced by the increased facilities, which may well be noted by the managers of great steam railway properties as an example of what may be expected in increased revenue when frequent and pleasant service is available to the public.

The energies of those engaged in electrical industries have thus far been absorbed in fields which now seem to have been naturally theirs, and their success has been such that they now aspire to enter the field occupied by the steam locomotive as a legitimate field of conquest.

The question now is whether this field is one in which the advantages of electricity will be sufficient to overcome the obstacles which seem almost unsurmountable, and enable it to win as it has in the cases cited.

Those who have given the subject little thought or who are unable to analyze it carefully on account of the lack of the technical knowledge necessary to appreciate the difficulties to be overcome, are most apt to predict the early supremacy of the electrically driven train over the steam locomotive.

That the fields referred to have been apparently formidable yet quickly overcome is not necessarily proof, or even good evidence, that the legitimate field of the steam locomotive can be entered and successfully achieved.

Those most familiar with the subject are now prepared to admit that our great steam railway terminals, where many switching locomotives are shunting back and forth continuously, and those portions of the steam roads entering our great cities, where suburban trains are numerous, frequent and comparatively light, can be more economically operated by electricity than by steam. This is evident to most of those engaged in the work, for the reason that it simply means duplicating, on a large scale, the systems which have proven successful in our street railways, operating, as they do, numerous units running at frequent intervals.

Proof that this field is recognized as a legitimate one for electricity is furnished in the examples of steam railway terminals that are now being equipped electrically, such as the lines of the New York Central and Pennsylvania Railroad Companies in the vicinity of New York, involving an expenditure of something over $70,000,000, where not only suburban service will be operated electrically, but where in the case of the New York Central, the main line trains will be brought into the city from points 30 to 40 miles distant.

While these are great examples of electrical operation on steam railroads, and heroic instances of faith on the part of the railway managers in the ability of electricity to successfully meet the conditions of steam railroad work, where the trains are sufficiently frequent, they are by no means conclusive evidence that electrically propelled trains can be made to successfully meet the conditions of trunk line passengers and freight service, the field now so successfully held by the steam locomotive.

The best conditions for electrical success are a great number of units moving at a practically uniform schedule, at equal intervals, within a limited distance.

The legitimate field of the steam locomotive is now one in which there are few but heavy units moving at uneven speeds over long distances at unequal intervals and at high maximum speeds.

The amount of energy transmitted to any great distance and used by electric cars that have been put in use until recently has been small when compared with the amount of energy that it takes to propel a steam railroad train of five or six hundred tons weight at the speeds ordinarily made by such trains.

It may be taken as axiomatic that when investment is taken into consideration, power cannot be produced in a steam central station, under conditions that exist to-day, and transmitted any great distance to a single electrically propelled train, requiring from 1000 to 2000 hp to keep it in motion, as cheaply as a steam locomotive, hitched directly in front of the train will produce the power necessary for its propulsion. Therefore, there must be other reasons than the expected economy in power production to warrant the adoption of electricity on a trunk line railroad unless it can be shown that the trains are frequent enough to make the saving in the cost of producing power greater than the increased fixed charges made necessary by the increased investment due to the adoption of electricity.

There are undoubtedly in existence to-day conditions where water power in abundance is available along the right of way of existing roads, in which the substitution of electricity for steam could be made a paying one, with apparatus now available, even on roads having a comparatively infrequent service, but these are special cases and only tend to prove the correctness of the position, for in these special cases the cost of power would be but little over half the present cost of producing it by means of a central steam-driven station.

The ideal conditions for any trunk line railroad having a traffic heavy enough to warrant the investment in a sufficient number of tracks to properly handle this traffic in such a manner as to get the most efficient service out of its rolling stock, would be to have four or more tracks between terminal points, upon which, in pairs, could be run the different classes of service at uniform rates of speed. Thus, if six tracks were used, the through line, passenger, and express service would be run on one pair of tracks; the local passenger, local express, and local freight service upon another pair of tracks; while the through freight service would be run upon a third pair of tracks, and all the trains upon any pair of tracks would run at the same average speed and stop practically at the same places.

If these conditions could prevail and the traffic were sufficient to warrant this investment in tracks, such a service could be operated more economically and more satisfactorily electrically than by steam.

The difficulty is that few roads in existence have sufficient traffic to warrant such an investment in a permanent way, and the result is that all of their traffic must be handled over one or two tracks, thus necessitating trains of all weights and all speeds running upon the same rails. This results in a tendency to bunch the cars into as few trains as practicable, in order not only to reduce the cost of train service to a minimum but to give the fast-running trains greater headway to allow them to make their time safely. Such an arrangement of trains necessitates the concentration of large amounts of power in single units, which is leading away from the ideal conditions for the application of electricity to the propulsion of trains; and it is this element, combined with the fact that the traffic on most roads is not great enough to warrant the investment necessary in electrical machinery to produce and transmit the power to the distances necessary to keep a few heavy trains in motion, that makes the trunk line railway problem so difficult, as it is more economical to propel these heavy trains by steam-driven locomotives, which are practically portable power-houses.

It being admitted that electricity becomes most economical when a sufficient number of trains are available, and that the steam locomotive is most economical when the trains have become few and heavy, the problem then resolves itself into one of the density of traffic and the question then is: where is the dividing line?

It was my intention to attempt such an analysis of this subject as to be able to formulate some general law which could be readily applied to any given case, and thus enable one to decide whether electrical operation would be more economical than steam in any concrete case.

After carefully analyzing the subject I have become convinced that no general law or formula can be laid down which will apply to all cases, for the reason that the elements entering into different cases vary so greatly that any formula would contain too many variables, dependent upon local conditions, to admit of a general application.

I shall, therefore, only attempt to point out a way in which the dividing line between steam and electricity can be determined after the elements of each case are known.

It will readily be seen that with steam locomotive operation the fixed charges, and cost of fuel and engine labor increase almost directly proportional as the train miles increase, for in this case an additional locomotive means simply a given amount of increased investment, a given amount of increased fuel and labor, and this total investment is least when the number of locomotives is small.

On the other hand, with electricity it is necessary to invest at once a large amount of capital in the power houses and transmission systems, which amount must be great enough to provide for handling the maximum number of trains required upon the line, and unless this number of trains is great enough so that the economy effected in the different method of producing and applying the power is sufficient to offset the increased fixed charges, due to the additional invested capital, it will *not* pay to equip and operate electrically.

Any problem, therefore, must be analyzed for the relative cost in operation. In case this does not show a saving the advisability of equipping electrically will depend entirely upon the probable increased traffic to be derived from the adoption and operation of electrically propelled trains.

That electricity will be generally used on our main railway terminals, and ultimately on our main through lines for passenger and freight service, I am convinced, but I do not anticipate that it will always be adopted on the grounds of economy in operation; neither do I anticipate that it will come rapidly or through the voluntary acts of the owners of steam railroads, except in special instances.

At first the terminals will be equipped for special reasons, due either to the voluntary act on the part of the terminal companies to effect economy in operation, or to public pressure brought to bear upon the owners through an increased demand on the part of the public for better service, on the grounds that the use of the steam locomotive is objectionable in our great cities.

Those roads which run through populous countries will either build new roads, or acquire, for their own protection, those electric railways already built and operating in competition with them, and utilize them as feeders to their through line steam trains. Thus the steam railroad companies will gradually become interested in electric railways and eventually become practically the real owners of them. With these roads operating as feeders to the main line system and with the terminals thus equipped and the public educated to the advantages of riding in electrically equipped cars, the next step will logically be the electrical equipment of the trunk lines between the cities already having electrical terminals.

Thus some favorably located trunk line having a sufficient density of population will feel warranted in equipping electrically, and when this is once done the other roads running between the same competing points must, sooner or later, follow in order to hold their passenger traffic.

This may result in temporarily relegating some roads to freight service, so long as they operate exclusively by steam, but with the increased demand on the part of the public for better and cleaner service will come a corresponding increase in passenger revenue to the roads equipped for handling it until one road after another finds it advantageous to furnish an electric passenger service.

With the terminals and main lines equipped electrically, and the desire on the part of the public for more prompt and effective freight service resembling that which is given by the steam roads in England and on the Continent, due to the great density of population, there will be developed a great high-class freight service conducted in light, swiftly moving electric trains which can be quickly divided and distributed over the surface tracks of our smaller cities, or through underground systems similar to that which is now being built in Chicago. Such a system would soon prove indispensable to the public and a source of great profit to the roads as it is now getting to be to many suburban railways.

This class of freight service would soon prove so large a part of the freight traffic of a road that the operation of the through freight traffic by steam locomotives, though at present cheaper, would in time, as the cost of coal increases, grow less, until those roads operating an electric passenger service would ultimately use electricity exclusively.

It has not seemed advisable to me in an address of this character to attempt to furnish detailed figures to support my theories for the subject is of such general interest that many able men are presenting papers upon it at the International Electrical Congress now in session here, in which papers will be found information of much value to those interested, and from which I believe the correctness of some of my assumptions can be proved.

The principal problem before the electric railway engineer to-day is how to make the most effective use of the high-pressure transmission, and high-tension working conductor and maintain safety of operation.

Experiments conducted during the past year by engineers in this country and abroad have made this problem simpler than it seemed before and to-day we seem reasonably certain of the solution.

Until recently the cost of electrically equipping a trunk line under the standard direct-current, rotary-converter system, has been such as to practically prohibit its adoption, but recent developments in the single-phase alternating-current motor field have made it possible to eliminate a large part of the investment heretofore necessary and the prospects for the application of electricity to long-distance running are better than ever before.

When it is recalled that the rotary converter, which was the means of reducing the cost of long-distance roads, was introduced in 1898, and that within the six years from the time of its adoption through the development of the single-phase motor it has been practically rendered obsolete for heavy railroad work, it will be seen that the dividing line between the steam locomotive and the electrically propelled train has moved several points in favor of the latter, due to the reduction which can now be made in first cost and the saving in operating expenses.

With the single-phase motor and the steam-turbine a reality, the transmission problem almost solved, and with the rapid development of the internal combustion engine now taking place, are we, as engineers, not warranted in believing that we can so combine them into a system which will ultimately supplant the steam locomotive in trunk line, passenger and freight service?

I do not anticipate that all roads will soon adopt electricity, for the steam locomotive will hold its field in this country for many years to come, but I do expect, judging somewhat from "positive knowledge," a remarkable development to soon begin in the electrical equipment of favorably located steam roads.

From Richmond, where the first commercial electric road was built, to the present is but 17 years, yet within that time the horse has been relegated to the past as a serious factor in transportation, the cable has served its usefulness and awaits its end, and the suburban railway has been developed and is now rapidly encroaching upon the field of the steam railroad.

With the terminals of the two greatest roads in the United States now being equipped electrically and with an investment of something more than $4,000,000,000 in electrical industries made within a quarter of a century, we have reason to feel satisfied with the past.

With several of the leading roads in this country, of England, of Sweden, of Switzerland, of Italy, and Australia electrically equipping branch lines and seriously considering changing large portions of their present systems from steam to electricity, we, as personal factors in this great industrial advancement, have every reason to be hopeful for the future.

DISCUSSION.

PRESIDENT ROBERT KAYE GRAY: I do not know whether I am perfectly in order under the American procedure or not, but our habit on the other side, when we receive an address from our President, is to tender him our thanks. As President Arnold has said, during the Paris Exposition we had a joint meeting of the two Institutions, and I am very glad indeed to say that we have in this hall to-day the two gentlemen who presided on that occasion, namely, Mr. Carl Hering and Professor Perry.

I do not think that any one could even have wished to criticise, in any way, the address which has been so ably given by your President, because if any man, either on this side or on the other side of the Atlantic, is preeminent in connection with the subject he has treated, I think it is President Arnold. His name is exceedingly well known to us on the other side, and I think I am not giving away any secret in telling you that the evidence of his work which he has been tendering to us has received a very warm reception there, and the evidence is considered to be the best that can be obtained in relation to the matters with which it deals. I therefore wish, in the name of the Institution of Electrical Engineers of Great Britain, to tender to my colleague, President Arnold, our very sincere thanks for his exceedingly able address; and, with your permission, I will ask the senior Past-president of the Institution of Electrical Engineers of Great Britain to second the motion—Colonel Crompton.

COLONEL R. E. B. CROMPTON: It is with the most heartfelt pleasure that I rise to second the motion of President Gray, that the thanks of the American Institute of Electrical Engineers, as well as our own Institution of England, be given to President Arnold for his address, which I personally feel is worthy of this great occasion—the meeting of the two Institutions.

PRESIDENT GRAY: I presume it is unnecessary to put this motion to the meeting, and I shall put it by acclamation if it meets your approval.

PRESIDENT BION J. ARNOLD: I assure you that your expression of approval is very much appreciated indeed.

We have for our discussion this morning a subject similar to that which I have treated in my address; in fact the address was written as a sort of introduction to the discussion of the subject entitled "Different Methods and Systems of Using Alternating Current in Electric Railway Motors." This subject has received the attention of engineers interested in electric railways for the past three or four years. During the past two years it has received very energetic attention on the part of leading engineers of Europe and this country, and it bids fair to be one of far greater importance as we get more thoroughly into heavy railway work. Since I have talked to you quite a while, notwithstanding the fact that my name appears first on the program to discuss the question, I am going to ask a gentleman to open the discussion who is one of the most distinguished engineers in this country, and one of the most distinguished living authorities in electrical matters. I have the pleasure of introducing Dr. C. P. Steinmetz, of the General

Electric Co. and Past-president of the American Institute of Electrical Engineers.

Dr. C. P. Steinmetz: The problem which we have before us here for discussion—the problem of the direct application of alternating currents to electric railways—is not a new one, but it has become of primary importance and interest in the last few years. The early pioneers in electric rail roading, 10 or 15 years ago, started the development of the alternating-current railway motor, and prominently among them I may mention Mr. R. Eickemeyer and Mr. Vandepoele, who designed alternating motors for railway purposes and investigated their characteristics. However, very little progress was made in this field for many years, for a number of reasons; one being that in those early days frequencies of 125 to 130 cycles were customary, far higher than we are using now and the difficulties of the problem were thereby increased so formidably that advance was necessarily very slow. In addition the very rapid development of the direct-current railway motor fully occupied the attention of all electrical engineers, and therefore the less urgent field of the alternating-current motor was necessarily somewhat sidetracked. Then the alternating-current polyphase induction motor came into the foreground, showed its superiority over other types of motors for stationary work, and impressed the engineers to such an extent that for a long time it overshadowed the work done by the early investigators on the variable-speed alternating-current motor, that is, on motors with series characteristic. Attempts then were made to introduce this very successful polyphase induction motor into electric railway work, attempts which have not been successful to any great extent. In the meantime, in the United States the synchronous converter was developed and became a standard piece of apparatus familiar to everybody—standard as much as the direct-current generator and the alternating-current generator, and experience with such synchronous converters shows that for electric railway work, for the violently fluctuating loads on the railway system, the synchronous converter is superior even to the direct-current generator: the absence of armature reaction, the phase control of pressure feasible in the converter, and corresponding close pressure regulation makes it specially able to withstand and take care of very violent fluctuations of load and to carry overloads which no direct-current generator can carry. This apparatus became standard, and with its introduction the field of the direct-current railway motor—the distances which could be covered by the direct-current railway—was extended practically without limit, and a field opened which has been exploited in the last years, which was the field dreamed of by the early pioneers; the difficulties, however, being overcome, not by the development of the alternating-current motor, but by the development of methods of transmitting alternating currents and transforming them into direct currents along the routes, in synchronous converter substations.

Now, however, in the last year or two, with the still further development of the electric railway we have approached and in many instances reached the limits of applicability of this synchronous converter. The synchronous converter is a piece of machinery which requires sub-stations, requires some attendance, and as a necessary result has a high economical efficiency only where the traffic is sufficiently condensed to warrant the maintenance of sub-stations within relatively short distances from each other. Where the number of trains is less or the power per train greater than can be supplied at 500 volts from sub-stations, without excessive expenditure in line conductors, and too excessive fluctuations of load, pressures are required higher than can be utilized efficiently in direct-current motors, and there we strike the limit of the synchronous converter, and the alternating-current motor has to come in.

Personally I do not believe that the alternating-current motor will make very serious inroads in the field now occupied by the direct-current railway motor. I do not believe that direct-current railway systems will be changed into alternating-current railway systems; but what I expect of the alternating-current railway motor is that it will find a field of its own, a new field; just as when the alternating-current method of distribution was developed in this country, it did not displace the direct-current method of distribution which occupied the centers of our large cities, but it found a field of its own, a field which has gradually developed so as to be equal in importance if not superior to the field occupied by the direct current. Hence, to conclude these remarks, what I expect of the alternating-current railway motor is that it will find and develop a field of its own, that field which the direct-current railway motor cannot reach—suburban and interurban service, long-distance service, secondary railway service.

When considering the technical aspect of the subject before us for discussion to-day, the relative advantages and disadvantages of the direct- and alternating-current railway motors, we have to consider, first, the character of the problem we have to meet in electric propulsion; secondly, the character of the apparatus which we have available to solve these problems; thirdly, the additional features imposed upon the problem, or conditions more or less outside of the problem, as, for instance, the condition of the electrical industry at present, the existing investment in direct-current and in steam railroads, which have to be taken into consideration when discussing any new system of railway propulsion.

Regarding the characteristics of the different types of motors—the direct-current series motor now in universal use for railroad work, the polyphase induction motor proposed, and, to a certain extent, tried in recent years for railway work, a motor eminently successful in stationary work—and the alternating-current single-phase railway motor with commutator, I have in a paper before the International Electrical Congress given the results of a theoretical investigation and discussion of these different motors and shown the speed-torque curves, or characteristic curves of these motors in relation to each other. In Fig. 1 is given a comparison of the typical speed-torque curves of the different types of motors.

In general, the characteristic of the polyphase induction motor is essentially that of a constant-speed motor, with shunt-motor characteristics; that is, it can efficiently operate over a certain limited range of speed only, cannot exceed the synchronous speed, and when operating below its normal speed, it operates less efficiently; that is, when operating at a lower speed than normal, or approximately synchronous as can be done by a rheostat in the secondary circuit, the polyphase induction motor merely wastes that

part of the power corresponding to the difference between its actual speed and synchronous speed. Or, in other words, at low speed the induction motor consumes the same power which it consumes with the same torque at full speed, though its power output is reduced in proportion to the speed, and its efficiency correspondingly.

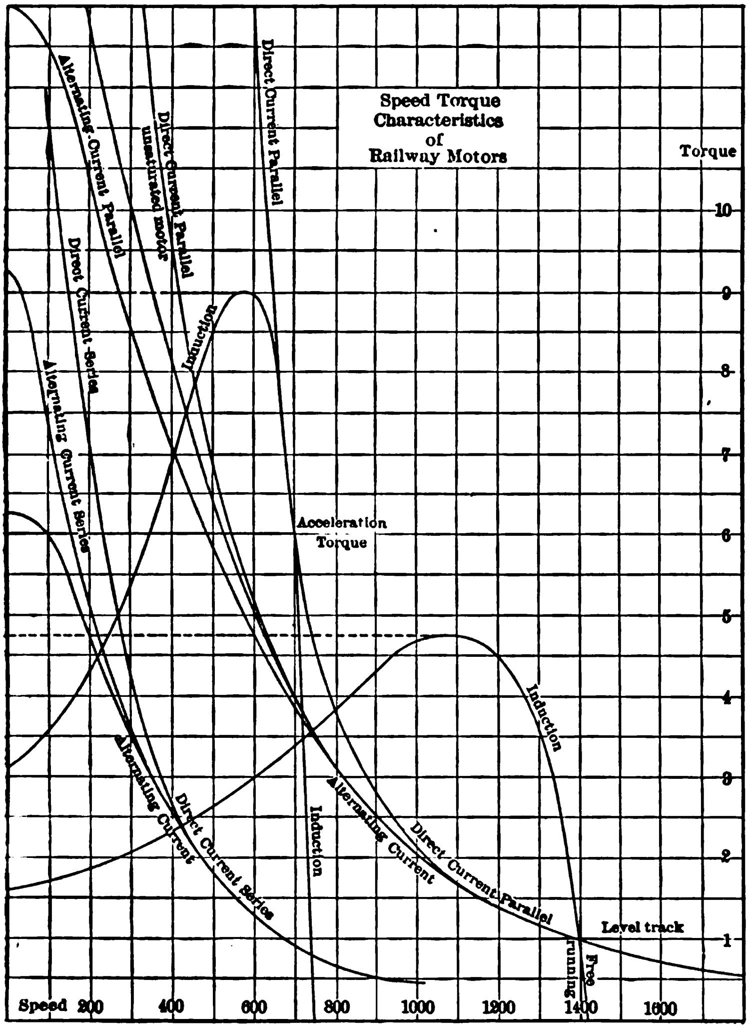

FIG. 1.

In the direct-current series motor the torque developed by the motor decreases with increase of speed, and inversely with increasing load the speed of the motor decreases. The maximum torque of such a motor occurs in

starting. All variable-speed commutator motors. alternating and direct, more or less differ from each other in the rate at which the torque varies with the speed, and that brings us to a consideration of the requirements of electric propulsion.

Important classes of work to which an electric motor may be put in locomotion are: first, city railway or tram car work; secondly, rapid transit service as on elevated and underground roads; thirdly, suburban and interurban service; fourthly, trunk line passenger service; fifthly, long distance freight service, and sixthly, elevator service.

Now, discussing these briefly in succession. The city tram car service is characterized by its frequent stops of irregular duration, at irregular intervals. To maintain good average speed it is therefore essential that the motor should get under way after the stop as rapidly as possible; that is, have a very high starting torque and accelerating torque, and carry this high torque up to a considerable speed. Beyond this speed, then, the torque of the motor should decrease fairly rapidly down to the torque required to run on a level track, which we may assume roughly to be at twice the speed to which the high torque of acceleration should be maintained. In addition thereto, it is necessary that the motor should accelerate efficiently and that it should be able to operate efficiently at low speeds in those city districts where the general traffic is dense and where it is not possible to run at high speeds. The characteristics of this type of motor are pre-eminently given by the direct-current series motor. If we assume the torque required to run on a level track as 1, probably the starting or accelerating torque may be something like six times as high. At that torque we start and run up to considerable speed, and then strike what is called the *motor curve* and after cutting out all regulating devices, accelerate with decreasing velocity up to the free-running speed. Such a curve, that of a typical direct-current railway motor, is given in Fig. I, marked " direct-current parallel " and " direct-current series." The induction motor, although it may accelerate with a high torque, at the end of acceleration, the speed is limited. It accelerates up to or near synchronous speed, and there the torque falls off to zero; and hence that part of the torque curve which is so essential to city tramway work, the curve of running with decreasing torque, from the limit of acceleration to the free-running speed, does not exist in the induction motor. We can indeed reach the free-running speed of a direct-current motor with a polyphase induction motor by gearing it to twice the speed, making synchronism the free-running speed, but this means that the available torque of acceleration, and therefore the rate of getting under way, is reduced by one-half, or, if we make it the same, the motor capacity is twice as great, requiring a motor twice as large. Considering that in this service a very considerable part of the running time is occupied running on approximately level track with torque very small compared with the accelerating torque, we see that the highest possible efficiency of the motor at light load is essential. Here, however, is the place where the induction motor falls down. A polyphase induction motor running at, say, one-tenth of its maximum output runs very uneconomically and with very poor power-factor. So in the polyphase induction motor, when used for railway service, you cannot combine very high acceleration with high efficiency in free running, and with the ability of running efficiently at low speeds, as you can in the direct-current series motor with series-parallel control. Therefore, the induction motor is not suitable to the class of work which we call city service or tram-car work.

The alternating-current commutator motor of which two sets of curves are shown in Fig. 1, marked "alternating-current parallel" and "alternating-current series" has characteristics very closely similar to the direct-current railway motor, except that possibly the variation of torque with the speed is less. That means, with the same decrease of speed the torque does not increase at the same rate as with the direct-current motor; if we assume again the same free-running torque as 1, and the torque of acceleration six times the free-running torque, the direct-current series motor will carry the acceleration torque up to half speed; the alternating-current motor not quite as high. This means with the same maximum acceleration you will strike the motor curve at a lower speed, accelerating on the motor curve, you get under way, then, slightly slower, or to get the same average acceleration you have to start with a higher maximum acceleration. Now, this is an advantage in some cases in so far as you run for a longer period of time and over a wider range of speed on the motor curve, that is without controlling devices, hence in the most efficient manner possible, and thereby make up to a considerable extent for that power which the alternating-current motor inherently loses by its slightly lower efficiency due to the alternating character of the magnetic field, and the losses by magnetic hysteresis in the motor field of the alternating-current motor which do not exist in the direct-current motor. This difference in the speed-torque curve of the alternating-current series motor, compared with the direct-current series motor, is due to the lower magnetic density used in the alternating-motor field, and, at low speeds, also to the e.m.f. of self-induction. The first phenomenon, therefore, also occurs in an unsaturated direct-current series motor (Fig. 1), and such a direct-current series motor therefore has at high and medium speeds the same characteristics as the alternating-current motor. It is undoubtedly true that alternating-current motors can be designed to give very closely the same characteristics as the standard direct-current series motor. However, the motor as it is before us at present reaches the motor curve at a lower speed, therefore with the same maximum acceleration, gives a lower average acceleration up to full speed, or with the same average acceleration requires slightly higher maximum acceleration.

Coming now to the second class of service, rapid transit service, here the problem and the conditions of operation are almost identically the same as in city service, except that the units are larger, the speeds are higher, the stops not as frequent, absolutely, but about just as frequent relatively in comparison to the maximum speed of the motor, so that we can directly apply our considerations to rapid transit service—regarding a comparison of polyphase induction motors of alternating-current commutator motors, and of direct-current motors.

In interurban and suburban work, that is, in railroads running out from the cities far across the country into the suburbs or into other cities, we have a much lesser frequency of stops. That means that rapidity of acceleration is of lesser importance, and we can well get along with a lesser average torque of acceleration, but we must have the same surplus torque as on city service work, or rather a greater surplus torque, because, while in city service and in rapid transit service, where the distances are relatively short, we can count on maintaining fairly constant pressure in the supply system, we cannot to the same extent count on this in interurban and suburban service where we are far away across the country, except by investing much greater sums in line conductors and feeders than is commonly economically desirable or feasible. Hence, in this service the motor should have a greater surplus torque than in city service, so as to get a sufficient margin to start the train or the car under the most severe conditions on an upgrade or an overload, even if the pressure in the system is low. The motor which is most sensitive to pressure variation is the polyphase induction motor. The maximum torque which this motor can give necessarily cannot very much exceed the acceleration torque without badly spoiling the characteristics of the motor either electrically or mechanically; but the maximum torque varies with the square of the pressure and hence rapidly decreases if the pressure of the system is low. In the motors with series characteristics, however, like the single-phase commutator motor, the direct-current series motor, the torque does not depend on the pressure, or rather, while the maximum torque so depends, the theoretical maximum torque which you get from the motor when standing still is so far in excess of the torque of self-destruction, or rather of slipping the car wheels, that it is not reached; and the effect of variation in the supply pressure is merely a variation in the motor speed. That is, if the pressure is low in the system, the direct-current motor and the alternating-current commutator motor run at lower speeds, but still are able to give the same torque, while the polyphase induction motor runs at the same speed, but is not able to give the same margin of torque, and at a certain load falls down or does not start. That means that in designing a system of transmission and distribution for alternating-current commutator motors or direct-current motors we are permitted to design the system for the average drop of pressure in the system while in designing it for induction motor service, we have to take into consideration the maximum drop of pressure in the system which is very much greater that the average.

For interurban and suburban service we require an excess overload in torque, but do not require an acceleration up to high speed. The alternating-current commutator motor appears to be preeminently satisfactory in this work, and there is where I believe it will be used extensively, and where the advantage of a high-pressure trolley and of the absence of substations is specially important.

In trunk line passenger service the rate of acceleration as given at present by the steam locomotive is very much less than every-day practice in electric railway service. So here we do not need this excess acceleration torque sustained up to high speeds. Here, again, we find a field where we may apply the alternating-current commutator motors. The polyphase induction motors could be used if the question of pressure supply did not come in, as I discussed above, and if furthermore the limit in speed of the induction motor was not so objectionable in passenger trunk service, where, more than anywhere else, we desire to get the full benefit of the track by running at the highest safe speeds wherever the track is level. This the induction motor with its limited speed cannot do.

In trunk line freight service, the same considerations come in, except there the speeds are relatively low, the train weights great; and it is more than anywhere essential to have a very large surplus torque available to get under way or to hold the train on a grade. You must, therefore, in this class of service, just as in suburban and interurban service, have a motor running efficiently at light load, but being able to give very high torque, although it does not need to carry this torque up to high speeds. On the contrary, it is not desirable in freight service that the motor should sustain a high torque up to high speeds, because that would mean the consumption of very large power. In freight service the highest possible economy is especially necessary, and the highest possible economy means the least fluctuations of power consumption; that means on up-grades you would desire to go slowly and reduce the power consumption and get the high speeds on the level track.

In mountain railways and such classes of work, the running torque is of the same magnitude as the starting torque, and so the load on the motor is more nearly constant than in any other class of railway work, and on the down-grade the motor is preferably used for braking, by returning power into the line. Here then the polyphase induction motor appears well suited, and is indeed being used successfully. Such service, however, is in its character more nearly akin to elevator service than to railway service.

In the discussion so far I have considered the requirements of the different classes of railway service, irrespective of extraneous conditions. When considering the alternating-current motor and the direct-current motor, we have to take in view what exists at the present time in this country and abroad. There exists the enormous network of steam railroad and of direct-current electric railways. The steam locomotive is a unit of very high efficiency, but a very large unit. It therefore for efficient operation requires the massing of traffic in heavy trains, and results in less frequent but large trains. This has practically rearranged and reorganized the whole system of locomotion by collecting it into a small number of very large units. That is not the most efficient manner of operating electrically propelled vehicles, but rather the contrary. Furthermore, you have to consider that every city and almost every village has a direct-current railway system. Now, the main and most important features by which the electric railway motor and electric propulsion has gained and is gaining rapidly in competition with the steam locomotive, appears to me to be the frequency of headway and the absence of passenger stations, not the speed, which frequently in electric lines is lower than that on steam railroads paralleled by them. The electric railway picks up its passengers anywhere in the city and deposits them anywhere and it does not require them to consult time tables, but runs its cars so frequently that the passenger can always find a car within a few minutes at any point; on the other hand, the steam locomotive requires you to consult a time table and go to a depot. As soon as the electric railway gives up this advantage which I have just mentioned, I believe one of the main advantages of the electric railway over the steam railroad will be lost, and this, therefore, is the feature which has to be kept in view. It means that whatever type of motor may be adopted in interurban or suburban service, etc., it must be able to carry the passengers through the cities over existing railways.

The existing railways are direct-current railways, and I believe will remain so. That means that the long-distance motor, at least the suburban and interurban motor, must be able to run over the direct-current system. Hence, it must be a type of motor equally applicable and capable of operation on a high-pressure alternating-current or on the 500 volt direct-current system.

Taking this for granted the methods of control must also be as simple as possible; that is, the same control for alternating as for direct current. Even if the motor could be used on direct current and alternating current, if we would have to carry a double system of control, one for city service and direct current, the other for long-distance service and alternating current, this would be a very serious handicap. It means that really to solve the problem before us, of extending the electric railway into interurban and suburban service, and into the field now occupied by the steam railroad systems, and into new fields not yet developed, to a large extent not even dreamed of, that we must have a motor which with the same controlling appliances and the same characteristics, can run either on the high-pressure alternating circuits or on the existing direct-current circuits.

Furthermore, the enormous investment in electric railway systems existing at present has all been made, in the large systems, on 25-cycle, three-phase apparatus. That means that we shall have to continue to operate at 25 cycles. It may be preferable, possibly, to run at lower frequencies, or it may be preferable to run at higher frequency in this instance or that instance, but regardless of whether it is preferable or not, if it can be done on 25 cycles, it will have to be done on 25 cycles, and if another frequency had to be used, it would be a very severe handicap to the new system. I am glad to say that there is no doubt that 25 cycles is the frequency best suited to the alternating-current single-phase railway motor.

PRESIDENT GRAY: Dr. Steinmetz' remarks have been so clearly stated and so closely reasoned out that they do not give us much chance for discussion, but I am glad to refer to my English colleague, Professor John Perry, upon whom I call to take part in this discussion.

PROFESSOR JOHN PERRY: I have to confess that I am not prepared to take part in the discussion. We have had the address of President Arnold and this excellent address of Professor Steinmetz, and two such addresses in one morning I think we have never had before. Clearly, they are men who have thoroughly studied the subject, and in view of what they have said, I think what it comes to is this—that everything seems to depend to a very great extent as to what is to occur in connection with the electrification of steam railroads in the next ten years, on the success of the single-phase alternating-current motor. I knew of the progress that had been made by the General Electric Company and the Westinghouse Company, I had heard a great deal about it before leaving the other side, and it is one of the things that I promised myself to learn something about during my visit here. I have not yet been able to do much in the way of getting accurate knowledge on the subject. I have been on a tram-car at Schenectady, the motor of which, I was informed, was driven by direct current and the car ran well; and then I would get on another car, and I was told that the motor was driven by alternating current, and it seemed to run just as well, so that I was not able to acquire any knowledge. I had no means of experimenting or ascertaining what the efficiency of the various arrangements were. Some 10 or 12 years ago I was tremendously interested in the single-phase alternating-current motor, perhaps for a selfish interest, as I had invented a system of traction which required the use of that system. I suppose we are all tremendously interested in this thing, and are all anxious to learn what we can about the alternating-current motor. I wanted to go to the section in which Mr. Steinmetz was giving an account of the work yesterday, but I was told it was my duty to attend a discussion upon the subject of electromagnetic units in another section, and as a man cannot be in two places at once, I had to attend to my duty as it was pointed out to me. In these circumstances, I can only say that I should like to hear the discussion of this subject proceed further before I shall feel able to take any part in it.

PRESIDENT ARNOLD: It has been said that the fame of a scientific man is a quiet fame, but that is the most satisfactory after all. It does not attract the multitude. A man is able to walk in a crowd without being pointed out, which by the way, is a very satisfactory thing to do; but he finds that when he reaches different parts of the world his name has preceded him in the circles in which he moves, so that he after all enjoys in the most satisfactory way the results of his efforts in the particular line of work which he has been following. We have many such men present to-day, and among them is one who has done excellent work in the special line we are discussing this morning. I shall now call upon one of our distinguished engineers and colleagues, Mr. B. G. Lamme, of the Westinghouse Electric & Manufacturing Co., of Pittsburg, to discuss the question further.

MR. B. G. LAMME: Away back in the dark ages of electric traction, about 15 years ago, there was great confusion in the types of apparatus used. There were all kinds of motors and all kinds of apparatus on the car. They only had one property in common—they were all direct-current. After putting a number of these systems into commercial use it was discovered that certain types of apparatus were superior to others, and those particularly interested in the manufacture of such apparatus followed up this matter to ascertain what properties were of the greatest value. It was gradually discovered that one type of motor was taking precedence of all others, namely, the series motor. Practically all development for a certain time was in the direction of the direct-current series motor.

The reasons which led to this were partly based on theory and partly on practice. The series motor gave the effect of a cushion on a car. The motor is inherently a variable-speed machine and automatically varies its speed with the condition of the load. That was discovered to be a matter of first importance in the smooth operation of electric cars. Also the motor automatically increases its torque in a greater proportion than the current, which is of great importance in regard to starting and acceleration. These points were possibly not as well understood at that time as at present, but experience showed that certain equipments were superior to others and development was along that line.

After a few years, when the motors had reached standard proportions and practically but one type was used, a second limitation was discovered; namely, in the transmission conditions. It was found that in the extension of the railway system, the ordinary 550- or 600-volt direct-current system was becoming cumbersome, and it was evident that some method of transmitting power at higher pressure and transforming to lower pressure for utilization would be necessary. The most evident method was naturally to transmit by alternating current and convert to direct current, in order to use existing car equipment. This led to the use of motor-generators, and later to synchronous converters.

The motor-generator was found to fit the existing alternating system fairly well, but in the development of the synchronous converter the manufacturers discovered a great difficulty in existing systems. The frequencies of 125 and 133, which were the standards for many plants, were entirely unsuited for synchronous converters and also not well adapted for synchronous motors. Another frequency, coming into general use, namely, 60 cycles, was found to be possible for use with synchronous converters, but the difficulties of design were very great in that case, and the synchronous converters were rather heavy and cumbersome.

At that time there was fortunately a new frequency adopted which was of prime importance in the development of the synchronous converter, namely, 25 cycles. So far as I know, the origin of that on a large scale, was as follows: in the Niagara Falls power plant, when it was first laid out, the engineers for the power company had arranged for a frequency of 2000 alternations per minute, or 16⅔ cycles per second. They wished to use 8-pole machines, running at 250 revolutions. The company which I represent, which was one of the prominent bidders on the contract, objected seriously to the proposed frequency, as it was considered entirely uncommercial and also not suited for the best design of machine. The engineers of this company recommended 4000 alternations per minute or 33⅓ cycles per second. That was considered extremely low compared with anything then in use. As we could not come to any agreement to use that frequency, we finally compromised on 3000 alternations per minute, or 25 cycles per second, and the first Niagara machines were built in that way. There were various reasons for the adoption of a low frequency, one of which was that commutator type of motors might possibly come into use. Another reason was that it was better adapted to synchronous converters, but it was admitted that 33⅓ cycles would also be satisfactory.

After the Niagara Falls plant was installed, there was then a precedent for the adoption of this frequency for large units, and the manufacturers began to build apparatus of this frequency for the Niagara Falls plant and also adopted it for other plants. This opened quite a field for the synchronous converter and it soon began to be extensively used for railway work, as it was recognized that this was the link needed for extending the direct-current system. Even at the early date of 1893 and 1894 it was believed by many engineers that the synchronous converter was simply a machine to meet an emergency condition, that it would not last, that the time would come when synchronous converters would be dropped from the railway service, but as the most convenient and apparently the best solution of the problem, it was adopted extensively. About that time electric railway service began to be greatly extended and synchronous converters have thus come into very general use. By the use of synchronous converters, the advantages of the alternating-current system in transmission are obtained and the advantages of the direct-current system with the series motor are retained. Distances could be extended indefinitely by increasing the number of synchronous converter stations and raising the pressure of the alternating-current lines.

Shortly after this system came into general use it was recognized that a purely alternating-current system, in which purely alternating current was supplied to the motors, would be advantageous and considerable work was done along that line. The polyphase motor apparently had the field, and naturally the manufacturing companies took up the question of the application of the polyphase motor to traction work. The company which I represent, the Westinghouse Electric & Manufacturing Company, took up this question in an active way about 1895, and built two motors of 75 hp each for traction work. These motors were equipped with collector rings and rheostatic control and tests were made in regard to performance, both with straight rheostatic control and with the new well-known "tandem" control, in which the secondary of one motor is connected to the primary of the other to obtain half-speed conditions. Even with this latter arrangement it was found that the motors would not compare at all favorably with the direct-current motor or the system with the direct-current system using rotary converters, and this work was abandoned. It was recognized that the polyphase motor did not possess the proper series characteristics which long experience had shown to be so necessary for railway work. Other experiments along this line were made, using polyphase motors wound for two or more speeds, and two 100-hp motors were built which were wound for several speeds. While this was better than the other arrangements, it still appeared that this was not a solution of the problem. Previous to this time the company had done some work in the direction of using single phase, but not as a solution of the problem which presented itself in 1895 and later.

In 1892 the question of the use of the commutator type alternating-current motor for railway work was taken up. Two motors of nominally 10 hp each were designed and built. These were built for a frequency of 2000 alternations per minute, or 16⅔ cycles per second. They were mounted on a car and were operated for awhile, but the system was not a success. In the first place the pressure used—400 volts as compared with 550 in the direct-current motor—was rather low. It was considered that as 550 volts was the limit in the direct-current motor, 400 volts would be the limit with alternating current. The motors were tested on a track of iron rails with practically no bonding. The track drops were excessive and the pressure fluctuations were great. The generator used—of about 20 kw capacity—was entirely too small for this work and it was not adapted to handle the inductive loads which were found with alternating-current motors. A series of tests was run and it was finally decided that for city work, for which the system was then laid out, the motor could not compete with the direct-current motor. It was decided, however, that such a type of motor would probably furnish the solution of the heavy railroad problem, but as there was no such heavy railroad problem at that time, the work was dropped for awhile. But in 1897 the question of the use of the commutator type of alternating-current motor was again taken up—this time on a somewhat larger scale. Motors of 50 hp were built for variable-speed work, and given a long series of tests. Then after sufficient experience had been obtained, the work was gradually carried to the larger sizes.

In 1900 and 1901, when the question of the polyphase traction in Europe was so extensively advertised, it became evident that there was actually a demand for an alternating-current railway system. It was therefore decided to continue the previous work with large motors of the commutator type, and two motors of 100 hp were designed and built. For these also, the frequency adopted was 2000 alternations per minute, or 16⅔ cycles per second. This fractional figure was primarily adopted on account of certain steam-engine conditions. It was recognized that an even frequency of 16 or 18 would have been practically as good.

In the earlier work, with the 10-hp motors at the low frequency, it was recognized that it would be absurd to put such a system on the market, as at that time even 25 cycles had not been adopted. The frequencies in common use were 50 or 60 and a drop to 16 cycles was considered prohibitive. In the latter work, as 25 cycles had come into general use, and 15 or 20 cycles had been talked of and proposed by certain companies, it was considered that in view of their advantages for railway work such frequencies should be adopted. The motors were hence built for the above frequency. The results obtained with these large motors were so satisfactory that a contract was taken for a rather large road and the apparatus prepared. Knowing that news of this would soon be abroad, it was decided that the matter should be brought before the American Institute of Electrical Engineers, and a paper was presented on the 26th of September—two years ago—which I believe was the first announcement of the application of the single-phase alternating current to railway motors. There was considerable discussion—mostly criticism—and it was generally considered by the engineering public that the weak point of the system was the commutation. At the present time, however, I believe this is no longer considered as a serious point.

Previous to building the 100-hp motors we had had considerable experience with the commutation of such motors. Besides a long series of tests, we had run 40-hp motors at practically full load on a 60-cycle system for nine months, day and night. At the end of the nine months the commutators were in practically as good condition as in the beginning, showing that the commutator on such machines could be made to have a long life. The conditions of the 60-cycle machines were much worse than on the lower frequency, and the nine months of operation under the condition of steady service probably equalled two or three years of traction service; but the commutator stood up so well that we decided definitely that there was no difficulty on that point.

The principal reasons which led to the adoption of the single-phase motor were stated in the paper above referred to, and were that but one trolley wire would be required and that the motors had the series characteristics.

It was considered that no motor, except one of the commutator type would give suitable characteristics for the service, and it was stated that there were several types of motors, with commutators, which had the proper characteristics. All of these may be classed as series motors, although some of them are combined with transformers and may be considered as transformer series motors, or, under another name, as repulsive motors, and others are pure series motors. The pure series motor is one which can operate on direct current as well as alternating current. The repulsion motor can be modified so as to operate on direct current, but as ordinarily arranged it is not as well adapted for this as the other type. It was recognized in the first undertakings with this system that the motor would probably be required to operate on direct current at times, and the fact that the pure series motor was primarily a direct-current motor of a first-class design was one of the reasons which led us toward the adoption of that type. As both theory and experience indicated that such motors would probably be wound for 200 or 250 volts, it was recognized that the motors would probably have to be operated in series for direct current, and either in series or in parallel for alternating current as might be desired. The arrangement required for permitting operation on direct current as well as alternating are rather complicated, due to the fact that it is necessary to switch from one system to the other in passing from the alternating to the direct current. We did not suppose that the electrical public would consent to such a combination, but since that time we have found that in some instances they do not object seriously to the increased complication.

At the time that the alternating-current system was brought out it was considered that the principal field would be in heavy railway work, because this motor furnished what was considered a general solution of the railway problem; as the railways would have their own terminals and their own rights of way, the system would be an alternating-current system throughout. At the present time, however, roads are being installed which operate primarily on alternating current, but at the terminals and where they pass through intervening towns they operate on direct current.

The direct-current motor has never been considered as entirely suitable for the heavy railway problem, as usually but two speeds, and at most but three speeds can be obtained with four motors, the third speed increasing the complication considerably. With the alternating-current motor of the commutator type any speed can be obtained for locomotive work, because any pressure can be applied to the terminals of the motor. As soon as alternating current is used for motors, we at once have a ready means of pressure transformation. As on locomotives for large capacity the difficulty of handling the current is considered a very prominent one, it was considered that some form of pressure control which varied the pressure without opening the circuit would probably be the best one. One form of pressure control permissible is what is called the induction regulator. This regulator varies the pressure without opening the circuit. The relation of the primary and secondary windings with respect to each other is varied. This gives a means of varying the pressure to the motors and varying the speed of very large motors with no tendency to sparking at the controller. The only time the circuit is opened is at the end of the operation when cutting it off. Therefore it was considered as an important feature in the solution of the general railway problem.

The single-phase system is the one means presented at the present time as the solution of the heavy railway problem. It has all the advantages of the direct-current motor in the variable-speed characteristic, and has also the advantage possessed by alternating current in the ability to use any line pressure desired, and to vary the pressure applied to the motor and thus vary the speed over any range desired. It also has the advantage of permitting a system of control that can be obtained without sparking.

In the adaptation of the alternating-current motor to direct-current service, two 250-volt motors can be connected in series for 500 volts; also in operating on alternating current the motors can be connected in series, if desired, or in parallel. There is a possibility of danger in operating two motors in series in this way on alternating current, or even on ordinary direct current. In ordinary direct-current practice the use of two motors in series for part of the service is common practice, but there is this difference between the direct-current equipment and the alternating-current equipment. In the direct current we have motors wound normally for 500 or 600 volts. When operating in series the motors are connected, two in series, each one receiving 250 volts. Therefore, if one motor should slip its wheels and take the full pressure of the pair, it would still be operating at its normal pressure. But with two 250-volt motors connected across a 500-volt circuit, we have a different condition. In case one motor should take the entire pressure, we should have 500 volts across a 250-volt motor. That condition was considered early, and in the Washington, Baltimore, Annapolis project, a description of which was given in the American Institute paper read two years ago, we showed an arrangement by which this could be avoided. We had balancing transformers connected across the two motors in series. The balancing transformer was across the outside terminals, and a tap from the middle of the transformer was connected between the two motors. In this way equal pressure was supplied to the two motors in series, and the danger of a runaway was thus avoided. It is not yet determined how important this is, but I believe that something like this will be found advisable for the operation of motors in series, especially where high-power motors are used on medium weight cars for high-speed service. Possibly with comparatively low speed, and with very heavy cars, there may not be the same tendency to slip. On the direct-current part of the road, of course, the balancing transformer could not have any effect; but as the direct current is usually a very small part of the service, this danger would be lessened, due to the proportionate time in service.

In the application of the motor to use on both alternating and direct current, we have found some special conditions which affect the arrangement of control. Take, for instance, a large road being installed between Cincinnati and Indianapolis, where it is intended to run on direct current at the terminals and alternating current on the rest of the line. The normal speed on the alternating current part of the line is so great that it would be prohibited in the towns, and it is found that to get the speed down to the desired rate in the city service on the direct-current portion of the road, it is necessary to connect the four motors all in series, and thus no series-parallel arrangement can be used. Pure rheostatic control is therefore necessary in the city. On the suburban part, a switch is used to throw the current from direct to alternating, simply throwing the four motors in parallel, and taps are used on the lowering transformers to get a number of pressures. In that way we get the effect of series-parallel control and even better, by having more than two steps. On a long line it is possibly of no great advantage to have many steps, but as a rule the more steps there are, the easier is the service on the controlling apparatus, and the more running speeds are available.

With regard to the application of the system to locomotives, on the steam roads where the systems are not tied up with existing electric plants, it is probable that in time the railroads will adopt their own pressures, and possibly their own frequency. This may not be 25 cycles but may be somewhat lower. I believe that the electrification of the steam road may be a controlling factor in the change from direct to alternating current in city service. If the large railroads with their own large power plants adopt alternating current throughout, then the towns lying along the roads will in time probably adopt the same power system, and even the large cities will sooner or later adopt the same system. At the present time the railroads, as far as they have gone, have adopted direct current because the cities through which they pass or enter are using direct current. When the railroads make the big end of the project, however, then the cities will adopt what the railroads are using. When this comes about the direct-current railway systems in the cities will be superseded by the alternating.

Mr. C. V. Drysdale: At this late hour in the discussion, I do not propose to take up your time very much, especially as I am afraid that very few of us over in England have had much experience on this important subject. I should like, in the first place, to take this opportunity of congratulating you on this side of the water on having carried this important problem to such an extremely successful issue as has been recently shown in Ballston and in other places. I think this subject has been worked on in several places, yet to America belongs the honor of having constructed the first line of any considerable length working on the single-phase system. We must still further admire the way in which it has been done when we remember that the result has been achieved by getting over the great difficulties that stood in the way of the series motor, and that in so doing it has been found practicable to use the same motive plants on direct- and alternating-current lines. That, in itself, is an enormous advantage over and above that of being able to use the single-phase alternating current.

It would be impossible for anyone to criticize any of the statements that have been made this morning, because they come from gentlemen who have had such exceedingly minute experience in the special branch of the subject, that their remarks must be taken as gospel, at any rate for the present.

My object in taking part in the discussion is rather to bring the matter back to first principles. This subject has been worked upon in many different ways, and although the laminated series motor, which seems to have been the first to give us results, will probably explain and solve the problem, yet there are some interesting questions as to whether there are any other ways of fulfilling the problem which may have other advantages. There is one thing that does not seem always to be kept in view in traction matters, in the starting of the cars, and that is the very simple matter that in the starting of the car you do not require power, you require force; if you wish to get anything into motion, what you require in the first instance is purely force, and until the body moves, it does not require power at all. One of the great advantages which the steam-engine has over any electrical system up to the present time, is the fact that when you first turn the steam into the locomotive you get the pressure on the back of the cylinder and get the starting force without taking any power from the steam. If it were not for the other disadvantages of the locomotive, there is no question that that one point would give it a strong pull over anything we have electrical, because if we turn to the ordinary direct-current motor, we find that we have to use half, or with one motor, the whole, of the full-load power merely to secure a starting torque. This has several objections. Not only is this uneconomical and wasteful of power, but it throws a sudden strain on the general plant, and furthermore has to be wasted in resistances, and these resistances sometimes attain a considerable magnitude. With alternating-current motors these matters are worse, as we have in addition low power-factors and consequently difficulties in regulation.

The time is too short to refer to many other systems, but I will mention one, that known as the Ward-Leonard system, which at first sight appears to be an unworkable one. In the Ward-Leonard system, as I understand it, the system is to use a single-phase motor coupled to a direct-current generator which runs direct current on the locomotive or cars. Of course, the indirectness of the method seems to put it at fault, but on the continent that method has been developed with considerable hope of success, in fact with considerable practical success; and it has this great advantage that by the use of this arrangement you can start—get your starting effort—with very small power taken from your station. In the other system—it is too well known for me to describe it here—you have your single-phase motor continuously running, and you can do the whole of the regulation of your speed, etc., by merely regulating the excitation of the generator. The result is that it is possible to get the full starting effort with only something like one-third or one-quarter of the full-load current on the motors. That is so important a matter, especially in view of the huge trains liable to be thrown on the plant in the large schemes which we are hoping to see realized in the future, that I think we should give that method the consideration which it deserves, although it at first sight appears to be roundabout. In addition to that, we have the magnificent system invented by your President, Mr. Arnold, and I hope we shall hear more of that in the future. My only object in rising was to ask that we should hear as much about these systems as possible.

President Arnold: I am pleased to be put down as one of the speakers on this subject, but Messrs. Steinmetz and Lamme have so thoroughly covered the subject, and Dr. Drysdale has so kindly referred to the other systems known to most of you, that it is not necessary for me to say much more, particularly as the time is growing short.

I will correct one statement by Mr. Lamme, which rather puts me on the defensive. I understood him to state that his announcement of the single-phase motor made in September, 1902, was the first announcement of a single-phase system. I beg to state that in the month of June preceding, I read a paper on a single-phase railway, known as the Lansing, St. Johns & St. Louis Railway, which was built at that time and which I have since put in operation. I do not think it is just for the statement to be placed on record just in the manner in which it was made. I think Mr. Lamme meant to say that his paper was the first formal paper on the subject, but my road was built and almost ready to operate at the time that he made his announcement.

Now, without further discussing the question, I am going to call upon a gentleman whose name is known to all of you, and introducing him, I am reminded of an anecdote about a little negro boy who sat on a log chopping away with a hatchet. A man coming along the road asked him how old he was and the boy answered: "If you goes by what mother says, I'se six, but if you goes by de fun I'se had, I'se 'most a hundred." If you judge the man who is to address you by his looks, he is a young man, but if you judge him by his experience he is "most a hundred," and is the father of the commercial electric railway. I have pleasure in presenting Lieut. Frank J. Sprague.

MR. F. J. SPRAGUE: I feel quite embarrased by this pleasant introduction by our worthy President and the reception which you kindly give me. The subject under discussion is one which I will not enter into at any length to-day, for I see by the hungry and thirsty look on the faces of some of the gentlemen present that one o'clock is near at hand, and that they would probably rather adjourn for luncheon than to listen to any discussions whatever.

The subject on the card is how best to use the alternating current in railway motors. It is largely a technical question. The alternating-current motor is like a somewhat brilliant boy, who being exposed to various diseases has contracted a number of them; he has had a moderate experience in mumps and measles, and a touch of typhoid fever, and the various doctors, many able ones here and elsewhere, have administered, sometimes in homeopathic but oftentimes in allopathic doses, large measures of quinine and other drugs. Whether, as the child grows—and we are all hopeful of that child—and he is subjected to the various climatic conditions of commercial introduction and use, those undercurrents of disease common to all fevers will recur, or whether the child will outlive them and become strong and robust is a matter which must be left to future developments.

There is a larger problem, and I will not take over two minutes to speak of it. It is perhaps a more popular one, but of vital interest to us as engineers who are called upon to advise managers and others as to their financial expenditures, and that is: will electricity be used on trunk lines? Our worthy President, with whom I have the honor to be associated on some important work in that line, is very hopeful, and so am I. But what are the reasons which may dictate the adoption of electricity on trunk lines? Will it be because an economical service cannot be gotten by steam? No. Will it be because there cannot be obtained to-day an efficient service?

Again, no. Will it be because of æsthetic reasons? Distinctly not. If electricity be adopted on any trunk line service it will be because of the hard and fast rule of financial necessity, not because we engineers urge it. It will be because the men who raise the money, run the road and have to provide dividends find that it is the best way to do it, and the reasons which will apply to one road are not necessarily those which will apply to another. It is my belief that some of the largest expenditures, and those most fruitful of return to those who own the steam railroads of the country to-day will be for the purchase and control of competing electric railways which, having in the past acquired franchises of undoubted value which cannot be duplicated, have built up a profitable business which they can hold and which will increase. Many a steam railroad will be better off financially and get bigger returns if it gathers in these franchises and systems, and operates its whole property with proper regard to the needs and capacities of each division than by electrification of its main lines, at least for a long time to come. I know there are one or two gentlemen back of me who feared that I would make some break on the subject, so I will close my remarks. I thank you for your kind attention.

President Arnold: We now desire to hear from a gentleman whose early work is known in many fields, especially in the electric lighting field. His name was carried by one of the leading electrical manufacturing companies for many years and it stands to-day on much of the material that was manufactured in the early days. He is a man who has done much research work, and also considerable experimental work on the repulsion motor, a gentleman whom you all know and whom you recently honored by electing him President of the International Electrical Congress. I have much pleasure in introducing Professor Elihu Thomson.

President Elihu Thomson: It is certainly a pleasure to me to listen to a discussion of this kind in a joint meeting of the Institution of Electrical Engineers of Great Britain, the American Institute of Electrical Engineers, and a Section of the International Electrical Congress. It is gratifying to find that there is so little dissent from the statements which have been made as to the future of alternating-current traction. Many of you will recall, no doubt, that at one time the electrical profession might have been said to have been divided into two camps, the alternating-current camp and the direct-current camp. The gentleman who preceded me was probably at that time more to be found in the direct-current camp than any other. The other gentlemen who have preceded me were to be found in the alternating-current camp. It is a fact, however, and those who have visited the power stations on the circular tour have noticed, that the direct-current men have called in the alternating current to help them out, and combine, therefore, the virtues of the alternating current with the virtues of the direct current.

I was connected in the early days, and am still connected, with an organization which had not many prejudices of one kind or another. We had direct current, we had constant current series arc lights, constant-potential direct-current systems, and when the alternating current came we were ready to take that up without prejudice, and find out what there was in it.

In 1886 we put out our original alternating-current apparatus, and finding that the necessity might perhaps arise for motors on the system, it was at that time I undertook to get a motor for that system, a self-starting alternating-current motor, and the first motor of the repulsion type was made in 1886 and finished in the fall of that year. It was a little affair and was found not to operate very well on the higher frequencies, but by connecting it to a machine, which I was using for electric welding, giving 30 cycles, I found it operated very well and satisfied me as to the general features of the machine. That machine, unfortunately, was sent to an exposition and lost—I could never trace it, and it never came back. The Paris Exposition of 1889 had a couple of examples of machines on a little different basis. One of them, I believe, is in England, at the Royal Institution, and another we have at Lynn. It was a machine which was started as a series alternating-current motor, and as soon as it reached a certain speed the commutator was short-circuited and it became an induction motor. It combined, therefore, the elements of both, but I will admit that the design of such machines in those days was poor. We did not have even the distributed winding; we did not have the arrangements and the proportioning which we have to-day; nevertheless those little motors would give a half-horse power for a moderate-sized motor on 125 cycles, which was the highest frequency used. I merely mention these items as matters of history touching on the discussion. They have nothing to do with the discussion as to the different methods and systems of using alternating current in electric railway motors, but I am a strong believer in the field being open for such work. I believe that not only will the direct-current motor maintain its place, but that certain lines of service which the direct-current motor cannot easily take will undoubtedly be taken by the alternating-current motor for railway service, and the exhibition of a system, which you have been able to see in use, and which adapts itself to the use of both currents, is certainly a very instructive one.

President Arnold: It occurs to me that I may not have put my explanation in regard to Mr. Lamme's statement in just the way it should be put. I think what he meant was that his announcement was the first of a purely single-phase commutator motor system. I think with this correction he will accept my statement. He has not sent me any word, but this additional statement is due him. I think my work was first, but he got in with his announcement in September regarding the single-phase commutator motor.

THURSDAY MORNING SESSION, SEPTEMBER 15.

Chairman Duncan: On account of the general discussions in the other rooms, the papers this morning will simply be read by title.

The following papers were read by title: "The Monorail," by F. P. Behr; "The Railway Booster," by Dr. Rasch; "The Electric Railway," by F. J. Sprague; "Wilkesbarre & Hazleton Railway Co.," by L. B. Stillwell. The section then adjourned.

THE MONORAIL RAILWAY.

BY F. B. BEHR.

For many years eminent engineers, including the great Telford in 1828, have taken great interest in designing single-rail railways, and many patents, covering a variety of forms and combinations, have been taken out, but none of these attempts have been carried to a practical issue until recently. Within a comparatively recent period, however, two systems have been so far perfected as to offer real practical value as means of transportation for passengers and goods.

Of these two systems, one is identified with the author, and the other is known under the name of the Langen system, and is used to connect the towns of Barmen and Elberfelde, Germany. This paper will more especially describe the development and application of the former system. No claim is made by the author of this paper as the originator of the fundamental principle of the system of monorail railway. It is difficult to trace who first suggested it, as there were several almost simultaneous attempts in that direction between the years of 1875 and 1884. His only claim is to having taken up the original idea in 1884, when it was still in its simplest and most primitive shape; to having developed the general ideas and principles of others in designing the practical details; and to having constructed for the first time, in 1886 for steam power and in 1896 for electricity, monorails which have been worked successfully for the carrying of passengers and goods.

The Behr monorail is applicable to three distinct purposes, namely, to light railways in sparsely populated districts and in hilly countries where they would serve as feeders to existing railways, as elevated railways in towns, and as supplementary to existing systems of mail lines all over the world for carrying express passenger traffic, mails and parcels at much higher speeds and with much greater frequency of trains.

The advantages over ordinary lines in the first of these applications, result principally from the possibility of using very sharp curves, avoiding the expense of earthworks and tunnels, and also from the smaller cost of bridges, etc. The result of this economy would be about 50 per cent in hilly countries, in comparison with an ordinary meter gauge railway.

The special principle of the Behr monorail was in 1883 applied by Mr. Charles Lartigue in the construction of some primitive lines in Algeria and Tunis for carrying esparto grass and similar produce, the tractive power being by animals in all cases.

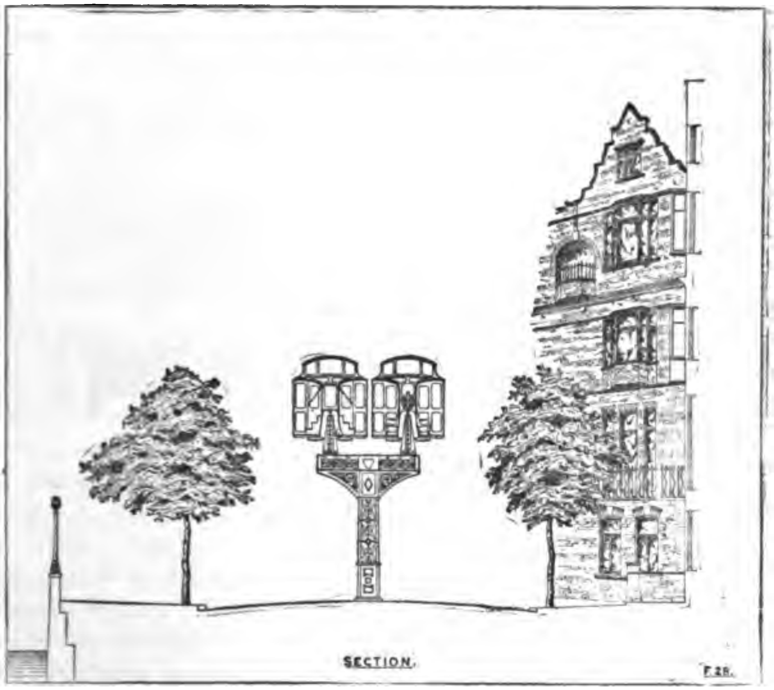

FIG. 1. PROPOSED METROPOLITAN RAILWAY FOR CHELSEA EMBANKMENT, LONDON.

An experimental line was built by the author in London, in the rear of Victoria street, Westminster, in the year 1886, where for the first time locomotives and carriages were run on a monorail. On the section was a gradient of 1 in 10, and for about a year the engine took up this incline, without a rack, one light carriage besides its own weight, showing that the adhesion on this form of railway is considerably greater than on an ordinary two-rail railway, on which on such an incline an engine is hardly able to pull up its own weight.

An act of Parliament for a railway from Listowel to Ballybunion, in Ireland, for regular passenger and goods traffic, was obtained in July, 1887, and the line was passed by the Board of Trade and opened to the public March 1, 1888. It has been working ever since without any difficulty or accidents, and in over 16 years has not been subject to a single claim for compensation of any kind. The line is especially remarkable for its very sharp curves, the smallest having a radius of 54 feet.

The second application, as an elevated railway in towns, is of very great importance, especially in the United States, where such railways are in common use. Elevated railways of this system in towns could be built at a very much smaller cost, with much less obstruction of the ordinary road traffic, requiring much less room on the roads, with much less obstruction of both light and air.

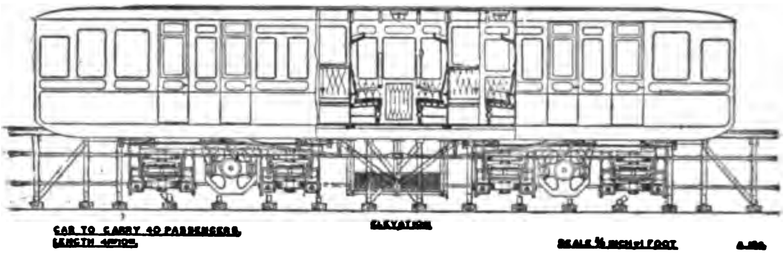

FIG. 2. CAR FOR PROPOSED MANCHESTER AND LIVERPOOL ELECTRIC EXPRESS RAILWAY.

Such a line has been proposed for the Chelsea Embankment, in London, to Putney Bridge. The cost of the line (double track) would be under $200,000 per mile. The system has also been proposed for another metropolitan line in London, about 17 miles long, starting in the west end and going to the city and docks, and nowhere along any street, merely crossing streets. The total cost of this line, double track, is estimated at about $500,000 per mile.

Passing next to the question of high speeds, the great merit of this system for high-speed service is that the cars are absolutely underailable; that it possesses important economic advantages for

FIG. 3. MONORAIL LOCOMOTIVE.

FIG. 4. MONORAIL LINE.

working at very high speeds; and that the rise in grade in approaching stations greatly helps the acceleration of the trains when starting and is of equally great assistance in stopping the trains when approaching a station. The cost of construction of such lines is generally slightly less for a speed of 100 to 110 miles an hour than the cost of an ordinary two-rail railway for speeds of 50 to 60 miles an hour.

There are many causes which contribute to the absolute safety of the system which can only be understood by carefully examining the detailed construction of the carriage as it fits to the track, when it will be observed, among other things, that whereas an ordinary railway carriage is held on the rails by a flange of about three-fourths of an inch in depth, the arrangement of the monorail carriage is really equivalent to a continuous flange of over three feet in depth. A feature of great importance to the passenger is that it is not only a safe way of traveling, but it looks also very safe and produces on the mind of the traveler a feeling of absolute security.

On an experimental elevated high-speed monorail built in 1897, with a carriage weighing about 72 tons, a speed of 84 miles per hour was obtained over curves of 1500 ft. radius, and a speed of 70 miles per hour on an ascent of 1 in 90. It was a much greater feat to attain 84 miles an hour on such a line and on such curves, with straight sections so short that it was impossible to construct a proper parabola between them and the curve, than to attain a speed of 110 miles on a properly constructed monorail, under such conditions as would arise in ordinary railway practice.

This line consisted only of embankments about 25 ft. high and cuttings 20 ft. deep, with a total fall of 130 ft. in 1½ miles. The road was built during a very wet winter in a few months, and worked immediately afterwards during a very wet summer, when considerable portions of the embankments had practically been washed away, and many of the sleepers were really suspended in mid-air. Notwithstanding these conditions, experiments were carried out during a period of over twelve months without a single accident. The line was three miles in length, and formed by two short straight lines joined by two curves at each end, so that continuous runs of any length could be made. But as there was a fall of 130 ft., it was necessary to rise to the same level, so that to develop the speed there was practically only a length of about one and one-half miles, and the highest speed of 84 miles an hour always occurred at the bottom of the incline, at the center of a curve of 1500 ft. radius.

The British Parliament has authorized and the Board of Trade has approved the construction of a monorail between Manchester and Liverpool, on condition that the speed shall not exceed 110 miles an hour. The sharpest curve to which this speed applies has a radius of 1800 ft. The whole of the materials proposed to be used in its construction, above the level of the sleepers, will be of steel. The maintenance will be similar to that on an ordinary railway, as there will be practically no difference in the manner of packing the sleepers or of inspecting the various parts. For the greater security, however, of the workmen employed on the line, the clear space left between two trains passing will be 3 ft., as against 1 ft. 8 in., the space provided between Pullman cars.

All trains will consist of only one car, for reasons of safety, economy in working and construction, and for the convenience of the public. There are three classes of cars designed and approved for this line. The smallest car will carry 40 passengers, the second size 52 and the largest 80. It is proposed to begin the service between Manchester and Liverpool with cars carrying 40 passengers each and running every 10 minutes. The working expenses of this service at 110 miles an hour, including maintenance repairs, management and everything else, are estimated at less than 15 cents per train mile.

The center of gravity of this carriage is at least 12 inches below the top surface of the monorail, as required by the Act of Parliament. The whole working of this line, which will carry, if necessary, 48,000 passengers a day at a speed of 110 miles an hour, doing the whole distance in 20 minutes, is very simple. Collisions are impossible, there are no level crossings, no switches, and notwithstanding the number of passengers carried, there are never more than two carriages on the whole line from end to end.

With regard to the electrical working, full details cannot be given, as the author does not consider that he is especially qualified for that purpose. The joint electrical engineers for the Manchester and Liverpool Railway are Lord Kelvin and Sir W. H. Preece. Following are given, however, some general data:

The distance to be traversed is 34½ miles, without a stop, in 20 minutes. The acceleration at starting is to be 2 ft. per second per second, diminishing to 9 in. per second per second or an average of 1½ ft. per second per second, attaining a speed of 110 miles in 1 minute 47 seconds and in a distance of under 2 miles. The resistance due to friction and air pressure is taken at 45 lbs. per ton at full speed. The coefficient of adhesion is taken at about one-sixth, say 400 lbs. per ton for the worst weather. The total weight of the car is over 40 tons and the weight of the driving wheels is 20 tons; hence the limit of adhesion that can be calculated on these driving wheels under all circumstances is over 200 lbs. per ton plus 15 lbs. per ton weight for air resistance, giving a total of 215 lbs. per ton weight, being more than the weight required, as 140 lbs. per ton is all that is necessary for an acceleration of 2 ft. per second per second.

For braking purposes, a high-speed Westinghouse brake will be able to retard the train at the rate of 3 ft. per second per second, which will absorb 210 lbs. per ton weight of the car distributed over the four wheels, or 52½ lbs. per ton per wheel. This will stop the car in about 1380 yds. If, in addition to this, the motors are short-circuited, the remaining adhesion can be utilized on the two driving wheels, which amounts to another 52½ lbs. per ton per wheel, and is sufficient for an additional retardation of 1 ft. 6 in. per second per second. This will give a total retardation of 4 ft. 6 in. per second per second, and would stop the car in 768 yds. In this arrangement, the retardation produced by the motors will be at exactly the ratio of the average acceleration to attain the full speed. If the short-circuiting of the motors was used alone without the Westinghouse brake for stopping the train, there would be an available adhesion on the driving wheels of 215 lbs. per ton weight of the car, amply sufficient for a retardation of 3 ft. per second per second, and also for stopping the car in 1380 yds. Therefore, either of the brakes used alone will stop the car in that distance, whereas both combined will stop the car in 768 yds. This does not take into account the steep up grades at the stations.

The power required during acceleration is about 1100 hp, and during the run about 515 hp, or 129 hp per motor, there being four motors to a car.

The generating station is situated exactly half way, at Warrington. Three-phase currents will be generated at 15,000 volts and converted in five sub-stations placed along the line into continuous current at 650 volts. The motors are wound for 600 volts and weigh each about 2¼ tons. The system used is three-wire continuous current.

Each car will be fitted with four continuous current traction motors arranged in pairs. Each motor will have a normal capacity of 160 hp at the full speed of 720 revolutions per minute, but will be capable of giving at least 320 hp for short periods during acceleration. The driving wheels have a diameter of 4 ft. 4 in., the speed at 720 revolutions per minute corresponding to 110 miles an hour.

The whole line will be fenced with an unclimbable fence from end to end, preventing all possibility of trespassing, as there are no level crossings and no means of access of any kind.

By an arrangement on the axles of the guide wheels, which are freely suspended in slots fixed on the bogie or truck frames, the guide wheels on both sides of the car remain always horizontal and in fair contact with the guide rails, whatever may be the inclination of the bogie frames and the car itself, which can swing freely on the top or bearing rail under the influence of centrifugal force in the curves, or from any other causes. The main rail itself remains always perfectly horizontal, even on the sharpest curves. The result is that the pressure on the guide rails need never be increased or the inclination of the car, and this pressure can be limited in such a manner as to combine the greatest comfort of the passengers with the greatest economy in electrical energy through the diminution of friction.

THE BOOSTER MACHINE IN TRACTION SERVICE, AND ITS PROPER REGULATION.

BY PROF. DR. GUSTAV RASCH.

In power stations for electric railways, especially for those feeding a network having a small number of cars running at the same time, there is a demand for a device to steady the power-station service. The unsteady load and current consumption in such power-stations grows worse as fewer cars are running at the same time on the line. It is known that ammeters and voltmeters of small power-stations indicate fluctuations continually, while large power-stations show mostly a steady load with small variations only. The disadvantages of the unsteady service with regard to the efficiency and the life of the steam-engines and the generators of the power-stations are obvious. It is desirable also that the cars, especially those cars running on the outer ends of the line, be fed with a constant voltage, which, however, cannot be expected from a power-station having too heavily fluctuating a load. To steady the machine service, a buffer storage battery is often used; that is, a floating battery connected parallel with the power-station generators. It is indisputable that such batteries possess valuable features. For instance, they are of great importance in case of breakdown of the machine service and they give a chance to run some cars just before starting up and after shutting down the regular power-station service. They have a disadvantage, however, in that they do not react upon the fluctuations of the current, but only upon the voltage. Though an absolutely steady voltage on the bus cannot be assumed, it is evident that the battery does less work as a buffer battery the steadier the voltage. It is very likely, however, that even with nearly steady voltage the machine may be subject to heavy fluctuations.

The following discussion may explain these phenomena still more clearly. The generator at the railway power station is shunt-wound, and, to simplify the discussion, it may be assumed that the e.m.f.$= E$, may drop proportionally with rising current I_1 that is may follow the law $E = E_0 - I_1 c$ where E_0 is the electromotive force with no load, and c a constant. The constant c, may cover the influence of the armature reaction and the drop of speed of the machine with increasing current I_1. It has evidently the character of a resistance. The armature resistance of the machine is r (Fig. 1). The parallel connected buffer battery may have an electromotive force A and an internal resistance a. The heavy fluctuating current in the network (the actual line current) is I, while I_1 and I_2 are the currents of the machine and the storage battery.

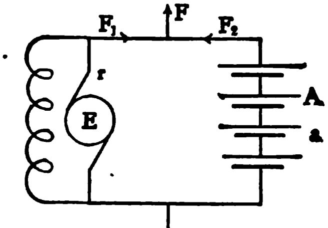

Fig. 1.

It is easy to derive the formula,

$$(1) \qquad I_1 = \frac{E_0 - A + aI}{a + c + r}$$

$$(2) \qquad I_2 = \frac{(c + r)\ I - (E_0 - A)}{a + c + r}.$$

At the average value I_m of the actual line current, the current of the storage battery must reach zero value, so that the battery may not be either overloaded or underloaded during daily service. That is, following equation (2):

$$o = (c + r)\ I_m - (E_0 - A), \text{ or,}$$
$$E_0 - A = (c + r)\ I_m.$$

That changes the equations (1) and (2) to

$$(3) \qquad I_1 = \frac{(c + r)\ I_m + aI}{a + c + r}$$

and,

$$(4) \qquad I_2 = \frac{(c + r)\ (I - I_m)}{a + c + r}.$$

It is necessary to make ample estimate of I_m.

The equation (3) shows that an absolute steadying of the machine current I_1 is impossible, because it is not independent of the heavy fluctuating actual current I. The larger the value of $c + r$, and smaller the value of a, the larger will be the dampening effect. The first means high internal resistance and large drop of voltage, features of the generators which cannot be called desirable ones. A small storage battery resistance a, means plates of large surface, that is expensive cells.

The buffer machine (booster) is another means of steadying the service. The value of such a machine, especially for hoisting installations, was thoroughly treated in a paper by Mr. Meyersberg,[1] read at the meeting of the Institution of German Electrical Engineers. It is indisputable, however, that these machines are also of great value for all railway central stations, and for all similar services with load fluctuations of short duration.

A large centrifugal mass is driven by an electric motor (under certain conditions two motors may suitably be used). The armature of the motor is in multiple with the network. The centrifugal mass naturally accumulates energy with decreasing network current and gives out energy in the network with increasing current consumption. Therefore the buffer machine works at one time as a motor, and at another time as a generator. For the moment we will not consider the character of the field excitation of this machine. It will be the object of this paper, however, to calculate the most favorable device for one special case.

It may be assumed that the actual current I, of a 600-volt power station for a small railway is the subject of regular fluctutations from 500 to 200 amperes inside of periods of 12 seconds. The condition regarding the regularity of the sequence of the fluctuations is of minor importance; it is important, however, that the utmost data be obtained regarding the fluctuation itself; that is, 500 and 200 amperes be not increased or decreased, because otherwise the buffer machine would be forced to run at a speed which would not agree with the speed which was assumed when designing the machine.

The curve $A\ B\ C\ D\ E$ (Fig. 2), shows the actual current fluctuation inside of one period. The average current of the generator ought not to be

$$\frac{200 + 500}{2} = 350 \text{ amperes,}$$

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[1] Meyersberg, *Elektrotechnische Zeitschrift*, 1903, page 261.

but somewhat higher, about 360 amperes, on account of the efficiency of the buffer machine, which is naturally below 100 per cent. With absolutely equalized service the generator would work continuously with this amount of current. One may be satisfied, however, in practice to limit the fluctuations to 10 per cent above and below this amount. We therefore assume that the generator current I_g must be dampened by means of the buffer machine to the limits of fluctuations between 400 and 320 amperes (see curve A_1 B_1 C_1 D_1 E_1 in Fig. 2). Now then, $I_g + I_p = I$, and it follows that the buffer current $I_p = I - I_g$. The curve A_2 B_2 C_2 D_2 E_2 Fig. 2, shows the work of the buffer current I_g. The positive values mean taking energy (charging), the negative values, giving out energy (discharging) by the buffer machine. For the moment, the e.m.f. may be assumed as constant, at 600 volts, the output of the buffer machine being a maximum during charging:

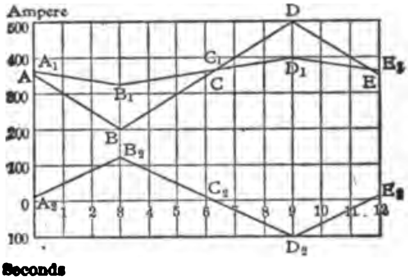

FIG. 2.—OUTPUT OF GENERATOR AND BUFFER.

$$600\ (320 - 200) = 72{,}000 \text{ watts.}$$

This value may be used as specific for the designing of the buffer machine, though naturally there is the intermittent service to be taken care of in addition.

The curve *A B C D E* (Fig. 3), shows the period of loading and unloading the buffer machine. This figure shows a time phase retardation against Fig. 2, inasmuch as the period starts with the beginning of the load. It shows that the loading has a duration of 6.54 seconds, and the unloading a period of duration of 5.46 seconds. The energy consumption is,

$$\frac{72{,}000}{2} \times 6.54 = 236{,}000 \text{ watt-seconds.}$$

The energy output is:

$$\frac{60{,}000}{2} \times 5.46 = 164{,}000 \text{ watt-seconds.}$$

The total efficiency is therefore assumed as

$$\frac{164{,}000}{236{,}000} = 0.695$$

corresponding to an efficiency of

$$\sqrt{.695} = .834$$

for the single conversion of electric energy to mechanical energy, or *vice-versa.* If a lower average current of the generator were to be assumed, the efficiency would be proportionately higher. It may be practical to reckon with more than 83.5 per cent efficiency; which was purposely not done, however, for the reason to be mentioned in the latter part of this paper.

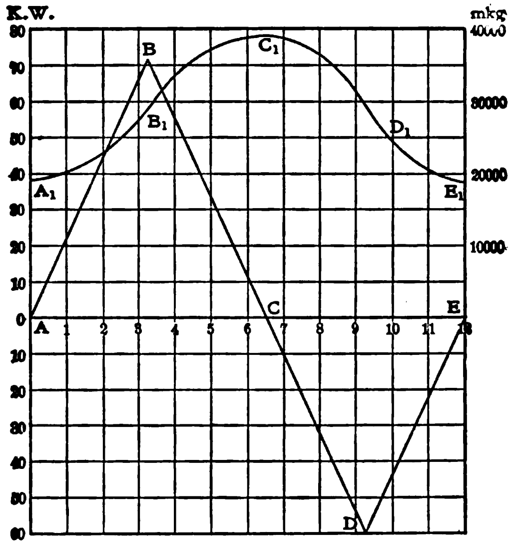

FIG. 3.—ENERGY AND POWER OF BUFFER.

We will not define how much of the energy stored in the centrifugal masses is to be used, but state only that at the end of an unloading period there has still to be stored an energy L_e + mkg

This energy storage will be

$$L = L_e + .834 \frac{236{,}000}{9.81}$$

That is,

(5) $L = L_e + 20{,}000$ mkg.

If U is the highest speed per minute, we have

(6) $L = c\ U^2$, c being a constant, the value of which is of no

interest at this place in the discussion. If $(1-s)\ U$ is the smallest allowable speed of the fly-wheel (s being the slip), we will have

(7) $$L_e = c\ (1-s)^2\ U^2$$

from (6) and (7) may be derived:

(8) $$\frac{L_e}{L} = (1-s)^2$$

and in connection with (5), we may write:

(9) $$L = \frac{20{,}000}{2s - s^2}$$

The amount of slip s is, therefore, of fundamental influence. Large values of s (for instance $s = .5$) allow the use of relatively small fly-wheels, the specification for which is determined by the value of L. On the other hand, however, the reserve of energy is very small with large slip. On the end of a normal unloading period, the vis-viva of the fly-wheel has diminished to:

$\frac{L_e}{L}\ 100 = 100\ (1-s)^2$ per cent of the starting value. This represents the reserve for exceptionally large unloading, decreasing with increasing slip, as shown by the following table:

$s =$	.2	.3	.4	.5
$100(1-s)^2 =$	64%	49%	36%	25%

Another reason against increasing the slip is, that the dimensions of the buffer machine increase with low speed. With large slip, however, the average speed will be lower than with small slip.

Remembering, therefore, that large slip calls for small centrifugal masses only, but for large buffer machines, and *vice-versa*, and that small slip calls for large centrifugal masses and small buffer machines, it is evident that the proper amount of slip to be chosen is one of the problems which come up often in engineering,— that is to find out the conditions under which the sum of the first cost of two parts of a machine is a minimum. This problem, however, is not to be solved generally, but can be solved only in each case, by approximation, giving due weight to all practical questions. We will not dwell upon this problem, but assume that we did find as most favorable value, $s = .3$. That would give us, following the equation (9), the maximum vis-viva

$$L = 39{,}200 \text{ mkg.}$$

Incidentally at this place may be answered the question why special buffer machines are used instead of using heavier centrifugal masses in connection with the generator itself. This question answers itself, if one observes the fact that in the latter case the slip would not be more than 5 per cent; for $s = .05$, however, it follows from equation (9) that

$$L = 205{,}000 \text{ mkg.}$$

Assuming the same peripheral speed of the fly-wheels, the weights of the fly-wheels are proportional to the vis-viva, and, to get the same effect, the fly-wheel connected to the generator would have to be made five times as heavy as that driven by the buffer machine.

Returning to Fig. 3 and choosing a scale for the vis-viva, we may draw on this scale the ordinate:

$$A\,A_1 = L_e = 39{,}200\ (1 - .3)^2 = 19{,}200 \text{ mkg.}$$

The loading time (AC Fig. 3) amounting to 6.54 seconds is to be divided in two parts of 3.27 seconds each. In the first part the energy put into the fly-wheel per unit of time is increasing, while in the second part it is decreasing. The effect transmitted to the buffer machine in the first part of the period at the time t is:

$$72{,}000 \frac{t}{3.27} \text{ watts.}$$

The amount of energy accumulated in the fly-wheel at this time t is:

$$L_t = 19{,}200 + \frac{.834}{9.81}\ \frac{72{,}000}{3.27} \int_0^t t\,dt = 19{,}200 + 935\ t^2 \text{ mkg.}$$

This gives us the means of calculating the several ordinates of the curve $A_1\ B_1$. Following the same formula, the vis-viva at the end of the first part of the loading time is found to be 29,200 mkg. For the second part, a similar simple calculation results in,

$$L_t = 29{,}200 + 935\ (t - 3.27)\ (9.81 - t)$$

where t is increasing from 3.27 to 6.54 seconds. The developing of the formula for the vis-viva with unloading fly-wheel may be derived in a similar way. It should be considered, however, that the efficiency of the buffer machine is to be regarded as the divisor of the expression. For the third interval:

$$6.54 \overline{\overline{<}}\ t\ \overline{\overline{<}}\ 9.27, \text{ we have}$$

$$L_t = 39{,}200 - \frac{1}{0.834 \times 9.81}\ \frac{60{,}000}{2.73} \int_{6.54}^{t-6.54} (t - 6.54)\ dt$$
$$= 39{,}200 - 1340\ (t - 6.54)^2.$$

This course is shown in curve $C_1\ D_1$. In the fourth interval there is,

$$9.27 \leq t \leq 12 \text{ and } L_t = 19{,}200 + 1340\ (12 - t)^2.$$

interval.

The curve $A_1\ B_1\ C_1\ D_1\ E_1$ Fig. 3, shows the course which the vis-viva has to follow if the buffer machine is to regulate in the way shown in Fig. 2.

The next question is: How is the speed to be changed in order to get this course of the vis-viva. We have to follow the earlier mentioned equation (6),

$$L = c\ U^2.$$

It refers to the maximum value of the vis-viva and speed, but may be used just as well for every other value. Thus substituting L_t and U_t, we obtain:

$$(10) \qquad L_t = c\ U_t^2.$$

From the equations (6) and (10),

$$\frac{L_t}{L} = \left(\frac{U_t}{U}\right)^2 \qquad \text{or}$$

$$(11) \qquad u \cdot \sqrt{\frac{L_t}{L}}\ .$$

One is not limited in the choice of maximum speed. The weight G (kg), the peripheral speed v $\left(\frac{\text{m}}{\text{second}}\right)$ and the vis-viva L, are (a plain cylindrical fly-wheel being assumed) in the relation,

$$L = \frac{v^2\ G}{4 \times 9.81}.$$

With a peripheral speed of 45 m. per sec., there is, therefore,

$$L = 39{,}200 \text{ and } G = 760 \text{ kg.}$$

In order to avoid too large fly-wheel weight, it is suitable to use a high peripheral speed. Speeds of 60 m. per second, and over, have been proposed for fly-wheels of suitable construction. There still remains the choice of speed. It is not necessary to determine now the exact number of revolutions. It is sufficient to assume as maximum value

$$U = 100$$

and to express the different values of speed in per cents of this maximum value. From the values found for the vis-viva the necessary number of revolutions are derived, shown in the curve $A\ B\ C\ D\ E$ in Fig. 4. The load of the buffer machine is transferred to this figure from Fig. 3. It is to be seen that the buffer machine has its highest load at a moderate number of revolutions, — (in our case 86.3 per cent).

It was assumed that the voltage on the busses was constant. Naturally this does not apply in practice; it will decrease with increasing current consumption, and *vice-versa.* Therefore, it will be higher when loading the buffer machine than with unloading. That is, the storing of energy while loading the buffer machine will be favored; the unloading on the other hand will interfere with the giving up of energy. Unsteady voltage will have the same influence as a resistance in the armature circuit of the buffer machine, resulting in a lower efficiency, which was chosen rather low for this reason. The question is now to decide upon the factors which could be used to improve the regulation:

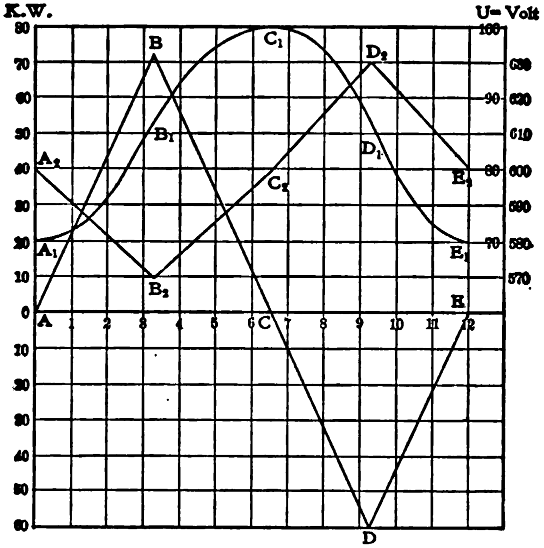

FIG. 4.— ENERGY AND POWER OF BUFFER.

These are,

(1) The voltage,

(2) Buffer current I_p,

(3) The actual line current I,

(4) The generator current I_g,

(5) The speed.

The same objections hold true for the voltage, which have been developed in the discussion of the buffer battery. If the buffer machine is simple shunt wound, it will be influenced by the voltage. This would not allow the regulation of such heavy fluctuations as defined in our above calculations, and the energy consumption and the restoration of energy by the fly-wheel would take place within much narrower limits.

Fig. 5 shows that the current of the buffer machine cannot be used for regulating purposes. Fig. 5 is derived from Fig. 4, using load and unloading current as abscissa, and the desired revolutions per minute as ordinates. The curve shows that to any value of the current there belong generally two different values of the speed, the difference of which is the greater as the current is lower. Obviously, this condition is not to be reached in practice. However, we may influence the regulation by the current, one value of it will always call for only one definite value of the speed. The same considerations regarding the buffer current holds true also for the actual line current and for the generator current. To Fig. 5 are added values of the actual and generator current, which prove in this case that a suitable regulation cannot be reached, since *one* of them, decreasing or increasing according to the network current load, cannot produce two different speeds of the buffer machine. It would be possible to influence the field of the buffer machine by the combined buffer current and line current, in addition to a special shunt winding fed from the bus, but even this would not give the correct result. We wish to transmit the fluctua-

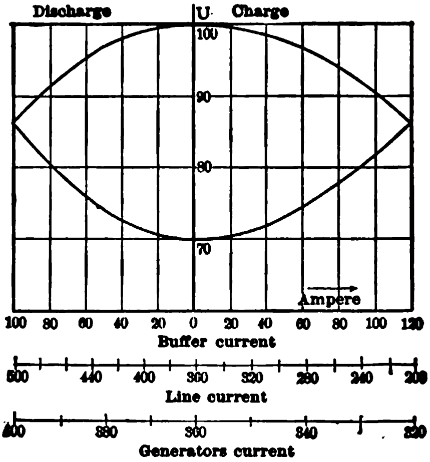

FIG. 5.

tions of the line current to the buffer current, which means that both of them must reach their highest values simultaneously, as shown in Fig. 2. The two currents working in two different windings on the magnet field of the buffer machine would, according to the way they were connected, work either with or against each other. In the first case they would not reach the desired result; in the second case, the result would be equal to that which could be reached with one of the currents alone, which is not suitable, as above mentioned.

The question of making use of a change in speed for regulating the buffer effect gives us two possibilities:

(1) Using a centrifugal regulator to adjust a rheostat placed in the field winding of the buffer machine.

(2) The use of a special exciter machine driven from the buffer machine, and having therefore a speed proportional to that of the buffer machine.[2]

The latter seems to be the most favorable, since this regulation is not applied step by step, but gradually.

We assume again a steady voltage on the bus, and assume furthermore that the e.m.f. of the buffer machine with maximum current varies from 5 per cent above to 5 per cent below this voltage; in this case the vibration of e.m.f. during the period of 12 seconds is shown in the curve A_2 B_2 C_2 D_2 E_2 (Fig. 4). The proportion of the ordinates of this curve, and of the curve A B C D E — that is

$$\frac{E}{U} = \frac{\text{E M.F.}}{\text{speed}}$$

are proportional to the lines of force which are necessary for the field of the buffer machine to produce the desired regulation. Fig. 6 shows a diagram, the abscissae of which are proportional to the value $\frac{E}{U}$, and the ordinates proportional to the speed. In this case there are also generally two ordinates for one abscissa, but the difference in the most unfavorable case is 8 per cent, while the regulation by means of the currents showed differences of 30 per cent (Fig. 5). If both branches of Fig. 6 could be combined — which would call for no armature resistance whatever in the buffer machine — the regulation would be a perfect one. We remark, therefore, that a low armature resistance is favorable.

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[2] Both kinds of regulation are the subject of the German patents No. 129,553, assigned to the German General Electric Co., Berlin.

The connections may be as follows (Fig. 7):

The buffer machine P is provided with two field windings M_1 and M_2. M_1 is excited from the busses; M_2 from a small generator e,

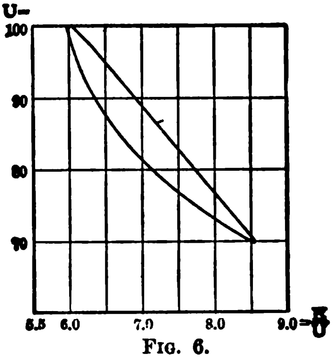

FIG. 6.

placed upon the axle of the buffer machine, and excited from the bus also. The windings M_1 and M_2 are differentially connected, so that with increasing current in M_2, the total field of the buffer machine will be weakened.

Another arrangement would be to use a part of the winding M

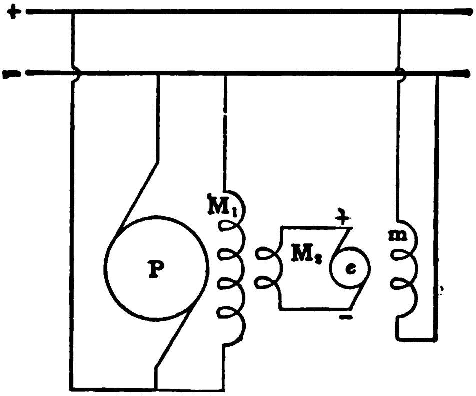

FIG. 7.

as the second winding M_2, as shown in Fig. 8. The latter arrangement has the advantage of a smaller winding space necessary for the buffer machine; it has the disadvantage, however, that the small machine e has eventually to be designed for rather high voltages, while with an arrangement according to Fig. 7, voltage and current of the small generator may be chosen at will.

The small generator may also be designed as motor, the armature of which is to be connected in series with the magnet winding *M* of the buffer machine (Fig. 9). In this case increasing the speed of the buffer machine will cause an increase of the e.m.f. of the small machine, and result in decreasing the exciter current of the buffer machine. In all arrangements, while working, there is a weakening of the field of the buffer machine, and, therefore, the dimensions of these machines must be made ample, in comparison with other machines of the same average load. We may mention that in all cases the maximum armature current of the buffer machine does not reach its highest value at the same time with the weakest field, but with an average strong field, which, of course, is favorable.

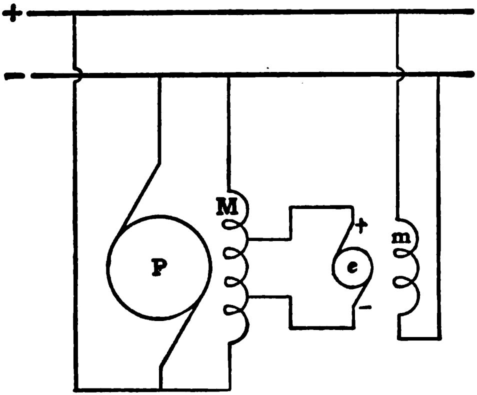

FIG. 8.

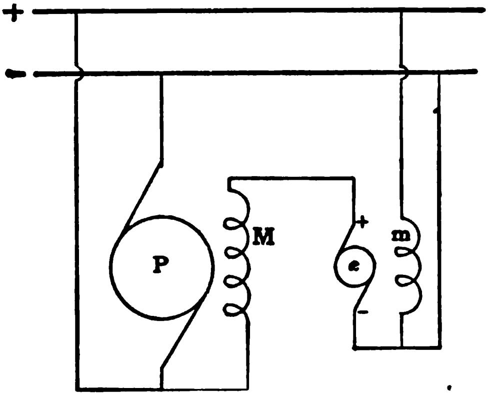

FIG. 9.

The discussion has shown that the most suitable regulation of the buffer machine is to be effected by means of speed regulation.

THE HISTORY AND DEVELOPMENT OF ELECTRIC RAILWAYS.

By FRANK J. SPRAGUE.

Although the earliest recorded experiments date back three-quarters of a century, the electric railway is essentially of modern development, for it achieved a recognized position less than twenty years ago, long after the telephone, the arc and incandescent lamp, and the stationary electric motor had been thoroughly established. This is but natural, for it is the logical outcome of the establishment of certain cardinal principles and practices in the kindred arts.

The first roads to carry passengers commercially were built in Europe, but the first railway experiments and the modern commercial impetus, as well as most of the essential and distinctive features of the art as it stands today, an example of almost unprecedented industrial development, are distinctively American.

Brandon, Vt., birthplace, and Thomas Davenport, blacksmith, father, are the names first on the genealogical tree of the electric railway, in the year 1834. A toy motor mounted on wheels, propelled on a few feet of circular railway by a primary battery, exhibited a year later at Springfield, and again at Boston, is the infant's photograph. This was only three years after Henry's invention of the motor, following Faraday's discovery ten years earlier that electricity could be used to produce continuous motion.

The records of Davenport's career, unearthed by the late Franklin Leonard Pope, show this early inventor a man of genius deserving a high place in the niche of fame, for in a period of six years he built more than a hundred operative electric motors of various

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NOTE.—The writer having been requested to prepare a paper on the subject of electric railways has done so with considerable reluctance because of his own connection with the art, and the difficulty under such circumstances in presenting events in a true perspective, unbiased by personal experiences. That such must be spoken of is, while embarassing, somewhat necessary, and due allowances should be made in his estimate of their importance.

designs, many of which were put into actual service, an achievement, taking into account the times, well nigh incredible.

For nearly two score years various inventors, handicapped with the limitations of the primary battery, and in utter ignorance of the principles of modern dynamo and motor construction, labored with small result. About 1838, a Scotchman, Robert Davidson of Aberdeen, began the construction of a locomotive driven by a motor similar to that used by Jacobi in his experiments on the river Neva, which was tried upon the Edinboro-Glasgow Railway, and attained a speed of about four miles an hour.

In an English patent issued to Henry Pinkus in 1840, the use of the rails for currents was indicated; also in a United States patent issued to Lilley and Colton of Pittsburg in 1847.

In 1847, Prof. Moses G. Farmer, late United States government electrician at the Newport Station, one of the most learned and able of the early electric experimenters, operated an experimental model car at Dover, N. H.; and about three years later one Thomas Hall exhibited in Boston an automatically reversing car mounted on rails through which current was supplied from a battery. These are said to be the first instances in which rails were actually used as carriers of the current, as well as the first time where there was a reduction by gear from the higher speed on the motor to the lower speed of the driven axle.

About the same time Prof. Page of the Smithsonian Institute, aided by a special grant from Congress, constructed a locomotive in which he used a double solenoid motor with reciprocating plunger and fly-wheel, as well as some other forms. This locomotive, driven by a battery of 100 Grove elements, was tried the 29th of April, 1851, upon a railroad running from Washington to Bladensburg, and attained a fair rate of speed.

Patents issued in 1855 to an Englishman named Swear and a Piemontais named Bessolo indicated the possibility of collecting current from a conductor suspended above the ground, and in 1864 a Frenchman named Cazal patented the application of an electric motor to the axle of the vehicle.

From the experiments of Farmer and Hall a decade elapsed before the invention by Pacinotti in 1861 of the continuous current dynamo, from which may properly be said to date all modern electric machines. These were developed in their earliest forms by Gramme and Siemens, Wheatstone and Varley, Farmer and Rowland, Hefner-Alteneck and others, and brought into existence the elements essential to any possible commercial success. Yet notwithstanding that the principle of the reversibility of the dynamo-electric machine, and the transmission of energy to a distance by the use of two similar machines, said to have been discovered and described by Pacinotti in 1867 — the same year in which Prof. Farmer described the principle of the modern dynamo in a letter to Henry Wilde — and demonstrated independently at the Vienna Exposition by Fontaine and Gramme in 1873, many years more passed before the importance and availability of this principle were generally recognized.

From 1850 to 1875, is a long period, relatively, and yet there seemed to have been practically an entire cessation of experimental electric railway work, until in the latter year George F. Greene, a poor mechanic of Kalamazoo, Mich., built a small model motor which was supplied from a battery through an overhead line, with track return, and three years later he constructed another model on a larger scale. Greene seemed to have realized that a dynamo was essential to success, but he did not know how to make one, and did not have the means to buy it.

Shortly afterward, in 1879, at the Berlin Exposition, Messrs. Siemens and Halske constructed a short line about a third of a mile in length, which was the beginning of much active work by this firm. The dynamo and motor were of the now well-known Siemens type, and the current was supplied through a central rail, with the running rails as a return, to a small locomotive on which the motor was carried longitudinally, motion being transmitted through spur and beveled gears to a central shaft from which connection was made to the wheels. The locomotive drew three small cars having a capacity of about 20 people, and attained the speed of about eight miles an hour.

In the same year important experiments were carried on by Messrs. Felix and Chretien at the little village of Sermaize in France to demonstrate the possibilities of the transmission of energy.

At Vienna in the following year, Egger exhibited a model of an electric railway, the current to be supplied through the running rails. About the same time Messrs. Bontemps and Desprez made a study of a scheme for replacing pneumatic transmission of dispatches by miniature electric locomotives in Paris.

The Siemens and Halske demonstration in Berlin was followed by others for exhibition purposes at Brussels, Dusseldorf and Frankfort, but no regular line was established until a short one with one motor car at Lichterfelde, near Berlin, the first in Europe, or in fact in the world. This road was 1 1/2 miles in length, used all rail conductors, and was opened for traffic in May, 1881.

The motor was carried on a frame underneath the car between the wheels, and current transmitted from the armature to drums on the axles by steel cables. The car was of fair size, having a capacity of 36 passengers, and attained a maximum speed of about 30 miles. The e.m.f. used was about 100 volts. This line was continued in regular service, but 12 years later the rail method of distribution was replaced by two conductors carried on top of poles, upon which ran a small carriage connected to the gear by a flexible cable.

Shortly afterward the same firm installed at the Paris Electrical Exposition of 1881, a small tramway about a third of a mile long, and used for the first time overhead distribution. In this case the conductors consisted of two tubes slotted on the under side, and supported by wooden insulators. In the tubes slid shoes which were held in good contact by an underrunning wheel pressed up by springs carried on a frame-work supported by the conductors, and connected to the car by flexible conductors. The motor was placed between the wheels, and the power was transmitted by a chain.

About the same time Siemens constructed an experimental road near Meran in the Tyrol with a view of demonstrating the possibilities of electric traction for the San Gothard tunnel, and later other small lines at Frankfort, Molding and elsewhere. These were followed by a comprehensive scheme for a combined elevated and underground road submitted to the city authorities at Vienna.

The invention about this time of accumulators directed attention to the possibilities of the self-contained car, and in 1880 a locomotive with accumulators was used at the establishment of Duchesne-Fournet at Breuil, and in the following year Raffard with a large battery of Faure accumulators made experiments on the tramway at Vincennes.

In 1881, Dr. John Hopkinson, in describing the application of motors to hoists, proposed both for them and for tramways the simple series-parallel control for speed, a principle which combined with resistance variation later became universal.

Meanwhile in the United States two inventors, Stephen D. Field and Thomas A. Edison, began electric experiments almost simultaneously. Edison was perhaps nearer than any other on the verge of great possibilities had it not been that he was intensely absorbed in the development of the electric light, for he had in the face of much adverse criticism developed the essentials of the low internal resistance dynamo with high-resistance field, and many of the essential features of the multiple arc system of distribution. In fact, in 1880 he built a small road at his laboratory at Menlo Park, on which he ran a car operated by one of his earliest dynamos from which the power was transmitted to the axle by a belt. One set of wheels was insulated, and the two rails were used for current. But beyond taking out a few patents, and for a while acting in conjunction with Field, Edison did little in this particular field, and soon ceased to be a factor.

Perhaps more than to any other the credit for the first serious proposal in the United States should be awarded to Field. Curiously enough, patent papers were filed by Field, Siemens and Edison, all within three months of each other in the spring and summer of 1880. Priority of invention was finally awarded to Field, he having filed a caveat a year before. He had been actively interested in electric telegraphs, and in an account of his work published some 20 years ago, it is stated that he early constructed two electric motors, and had in mind the operation of street cars in San Francisco, but had not been able to do anything in the matter because of a realization that a dynamo must be used instead of a battery. In 1877 while in Europe he saw some Gramme machines, and on his return two of them were ordered but not delivered. Later a dynamo was ordered from Siemens Brothers in London which was lost, and this was replaced by another which arrived in the fall of 1878. Meanwhile two Gramme machines were placed at his disposal, and shortly afterward an electric elevator was operated. In February, 1879, he made plans for an electric railway, the current to be delivered from a stationary source of power through a wire enclosed in a conduit, with rail return, and in 1880–81, he constructed and put in operation an experimental electric locomotive in Stockbridge, Mass.

Pending the settlement of patent interferences between Edison and Field (the Siemens application being late was rejected), the two interests were combined in a corporation known as "The Electric Railway Company of the United States," and the first work of the company was the operation of an electric locomotive at the Chicago Railway Exposition in 1883. This locomotive called "The Judge," after the late Chief Justice Field, ran around the gallery of the main exposition building on a track of about one-third of a mile in length. The motor used was a Weston dynamo mounted on the car and connected by beveled gear to a shaft from which power was transmitted by belts to one of the wheels. The current was taken from a center rail, with track return. A lever operated clutches on the driving shaft, and the speed was varied by resistance. The reversing mechanism consisted of two movable brushholder arms geared to a disk operated by a lever, each arm carrying a pair of brushes one of which only could be thown into circuit at a time, to give the proper direction of movement.

Meanwhile several other inventors were getting actively into the field of transmission of power and electric railways. In the summer of 1882, Dr. Joseph R. Finney operated in Allegheny, Pa., a car for which current was supplied through an overhead wire on which traveled a small trolley connected to the car with a flexible cable, and about the same time in England Dr. Fleming Jenkin, following a paper by Messrs. Ayrton and Perry before the Royal Institution on an automatic railway, proposed a scheme of telpherage which was developed by those gentlemen.

In the early part of the same year, the writer, then a midshipman in the United States Navy, who had in 1879 and 1880 begun the designing of motors, was ordered on duty at the Crystal Palace Electrical Exhibition, then being held at Sydenham, England. While in London he became impressed with a belief in the possibility of operating the underground railway electrically. He first considered the use of main and working conductors, the latter being carried between the tracks, with rail return, but noting the complication of switches on certain sections of the road, conceived the idea of a car moving between two planes, traveling on one and making upper pressure contact with the other, those planes being the terminals of a constant potential system. For practical application the lower of the two planes was to be replaced by the running track and all switches and sidings, and the upper plane by rigid conductors supported by the roof of the tunnel, and following the center lines of all tracks and switches, contact to be made therewith by a self-adjusting device carried on the car roof over the center of the truck and pressed upward by springs.

In 1882 he applied for a patent on the first idea, which was but a variation from that shown in other patents, but the second laid dormant for nearly three years because of central station work and the development of the application of stationary motors.

The storage battery still attracted attention, and in 1883 experiments were carried on at Kew Bridge, London. In the latter part of 1884 the Electrical Power & Storage Company of London, under the direction of Anthony Reckenzaun, began a number of trials. The same engineer repeated his work at Mill Wall, and later in Berlin. The car body in his last experiment was carried by two trucks, each of which was equipped with a motor driving one axle through a worm gear. Reversal was accomplished by using two sets of brushes, and speed was varied by using one or both motors, also by using the motors in series or parallel with a resistance to cut down sparking when making the change over.

Reckenzaun subsequently had charge of the experiments conducted by Wm. Wharton of Philadelphia, in which both a Reckenzaun and a Sprague motor were used in 1886. Here series parallel grouping of both batteries and motor circuits were used on the Sprague car, and a series parallel and resistance variation of motors on the car operated by Reckenzaun and Condict.

Meanwhile, in the United States, Charles J. Van Depoele, a Belgian by birth and a sculptor by original trade, and an indefatigable worker, had become interested in electric manufacturing, and soon energetically attacked the railway problem. His first railway was a small experimental line constructed in Chicago in the winter of 1882–83, the current being supplied from an overhead wire. In the fall of 1883, a car was also run at the Industrial Exposition at Chicago.

A year later a train pulled by a locomotive car, and taking current from an underground conduit, was successfully operated at the Toronto Exhibition to carry passengers from the street car system, and again in the year following Van Depoele operated another train at the same place, using on this occasion an overhead wire and a weighted arm pressing a contact up against it.

Experiments were also carried on by him on the South Bend Railway in the fall of 1885, where several cars were equipped with small motors, and also in Minneapolis, where an electric car took the place of a steam locomotive. Other equipments were operated at the New Orleans Exhibition, and at Montgomery, Ala., where the current was at first taken from a single-overhead wire which carried a traveling trolley connected to the car by a flexible conductor.

Other equipments were put in operation at Windsor, Ont., Detroit, Mich., Appleton, Wis., and Scranton, Pa.

In these several equipments the motors were placed on the front platforms of the cars, and connected to the wheels by belts or chains. The cars were headed in one direction, and operated from one end only.

In 1888, the Van Depoele Company was absorbed by the Thomson-Houston, which had recently entered the railway field, and Van Depoele continued in its active development until his death in 1892.

Among the early American workers of this period, none was for a time more prominent than Leo Daft, who after considerable development in motors for stationary work took up their application to electric railways, making the first experiments toward the close of 1883 at his company's works at Greenville, N. J., these being sufficiently successful to be repeated in November of that year on the Saratoga and Mt. McGregor road. The locomotive used there was called "The Ampere," and pulled a full sized car. The motor was mounted on a platform, and connected by belts to an intermediate shaft carried between the wheels, from which another set of belts lead to pulleys on the driving axles. A center rail and the running rails formed the working conductors. Variation of speed was accomplished by variation of field resistance, this being accentuated by the use of iron instead of copper in some of the coils.

In the following year Daft equipped a small car on one of the piers at a New York seaside resort, and a little later another one at the Mechanic's Fair in Boston, the motor for this last being subsequently put on duty at the New Orleans Exposition. In 1885 work was begun by the Daft Company on the Hampton Branch of the Baltimore Union Passenger Railway Company, where in August of that year operations were begun, at first with two and a year later with two more small electric locomotives which did not carry passengers themselves, but pulled regular street cars. A center and the running rail were used for the normal distribution, but at crossings an overhead conductor was installed, and connection made to it by an arm carried on the car and pressed up against it. The driving was by a pinion operating on an internal gear on one of the axles.

Daft's most ambitious work followed when a section of the Ninth Avenue Elevated Road was equipped for a distance of 2 miles, on which a series of experiments were carried on during the latter part of 1885, with a locomotive called "The Benjamin Franklin." The motor was mounted on a platform pivoted at one end, and motion was communicated from the armature to the driving wheel through grooved friction gears held in close contact partly by the weight of the machine and partly by an adjustable screw device. This locomotive, pulling a train of cars, made several trips, but the experiments were soon suspended. This work was followed by street railway equipments at Los Angeles and elsewhere, using double overhead wires carrying a trolley carriage.

Meanwhile Bentley and Knight, after some experiments in the yards of the Brush Electric Company at Cleveland in the fall of 1883, installed a conduit system in August, 1884, on the tracks of the East Cleveland Horse Railway Company. The equipped section of the road was 2 miles long, the conduits were of wood laid between the tracks, and two cars were employed which were each equipped with a motor carried under the car body and transmitting power to the axle by wire cables.

These equipments were operated with varying degrees of success during the winter of 1884–85, but were abandoned later. This work was followed by a double overhead trolley road at Woonsocket, the motors being supplied by the Thomson-Houston Company, and later by a combined double trolley and conduit road at Allegheny, Pa.

In 1884, Dr. Wellington Adams of St. Louis proposed a departure in motor mounting which recognized the necessity of removing the motor from the car body and directly gearing it to the axle. In his plan the field magnets were carried by the pedestals, and inclosed the axle on which the armature was to revolve, its motion to be transmitted by gearing. The method was impracticable, and found no application.

In 1884–85, J. C. Henry installed and operated in Kansas City a railway supplied by two overhead conductors on each of which traveled a small trolley connected to the car by a flexible cable. The motor was mounted on a frame supported on the car axle, and the power was transmitted through a clutch and a nest of gears giving five speeds. In the following year a portion of another road was equipped. A number of experiments seem to have been conducted there, and on some the rails were used as a return. The collectors were of different types, and it is said that among others there was one carried on the car. The final selection was a trolley having four wheels disposed in pairs in a horizontal plane, carried by and gripping the sides of the wires; this feature, but using one wire and rail return, characterized a road installed by Henry in San Diego, Cal., opened in November, 1887.

In the early part of 1885, Sidney H. Short began a series of experiments on a short piece of track in Denver which was followed by the construction, in conjunction with J. W. Nesmith, of a section of road for operation on the series system. These experiments were continued through 1885 and 1886, and were repeated at Columbus, but were doomed to ultimate failure because of the principle involved. Subsequently Short adopted the multiple system of distribution, and for a time essayed the use of gearless motors for tramway work, but reverted later to the geared type.

Meanwhile work had begun in Great Britain, where the first regular road to be put in operation was that known as the Portrush Electric Railway, in Ireland, installed in 1883 by Siemens Brothers of London. Power was generated by turbines, and the current was transmitted by a third rail supported on wooden posts alongside of the track, the running rails constituting the return. The pressure used was about 250 volts.

This was followed in the same year by a successful short road at Brighton, installed by Magnus Volk, the current being transmitted through the running rails. Then came the railway installed at Bessbrook, Newry, in 1885, under the direction of the Messrs. Hopkinson, and at Ryde, in 1886, in which latter year was also installed the Blackpool road by Holroyd Smith. In this latter case the conduit system was used with complete metallic circuit. The motor was carried underneath the car between the axles, and connected by chain gearing. Fixed brushes with end contact were used for both directions of running.

Reverting to work in the United States, Sprague again took up the electric railway problem, and in 1885, before the Society of Arts, Boston, advocated the equipment of the New York Elevated Railway with motors carried on the trucks of the regular cars, and work was actually begun on the construction of experimental motors. Shortly afterward a regular truck was equipped, and a long series of tests made on a private track in New York city. In May, 1886, an elevated car was equipped with these motors, and a series of tests begun on the Thirty-fourth Street branch of the road.

These motors may be considered the parent models of the modern railway motor. They were centered through the brackets on the driving axles, connected to them by single reduction gears, and the free end of the motor was carried by springs from the transom, the truck elliptics being interposed between this support and the car body. The truck had two motors, they were run open, had one set of brushes, and were used not only for propelling the car but for braking it. The motors were at first shunt wound, but later had a correcting coil in series with the armature at right angles to the normal field to prevent shifting of the neutral point. The car was operated from each end by similar switches, current at 600 volts were used, and increase of speed was effected by cutting out resistance in the armature circuit and then by reducing the field strength. This enabled energy to be returned to the line when decreasing from high speed. It being impossible to interest the railway management, the experiments were finally suspended. Soon afterward a locomotive designed by Field had a short trial on the same section of the Elevated.

Sprague then turned his attention to building a locomotive car of 300-hp capacity, each truck to be equipped with two motors, each having a pair of armatures geared to the axle, but this evidently being ahead of the times, and the possibilities of street tramway traction becoming evident, these equipments were abandoned, and he began the development of the type of motor finally used in Richmond, one crude form of which was first used in storage battery experiments in Philadelphia, and others in New York and Boston, in 1886. One of the Elevated motors was put into service at the East Boston Sugar Refinery, and continued so for sometime.

Reviewing the conditions at the beginning of 1887, statistics compiled by Mr. T. Commerford Martin show that, including every kind of equipment, even those a fraction of a mile long and operated in mines, there were but nine installations in Europe, aggregating about 20 miles of track, with a total equipment of 52 motors and motor cars, none operated with the present overhead line or conduit, and seven cars operated by storage batteries, while in the United States there were only ten installations, with an aggregate of less than 40 miles of track and 50 motors and motor cars, operated mostly from overhead lines with traveling trolleys flexibly connected to the cars. These were partly Daft, but principally Van Depoele roads. Almost every inventor who had taken part in active work was still alive. The roads, however, were limited in character, varied in equipment, and presented nothing sufficient to overcome the prejudices of those interested in transportation, and command the confidence of capital. The whole electric railway art may fairly be termed, and was in fact for sometime afterward, in an experimental condition, and some radical step was necessary to overcome the inertia which existed, and inaugurate that development which has been so remarkable.

This came in the spring of 1887, when the Sprague Electric Railway & Motor Company took contracts for roads at St. Joseph, Mo., and Richmond, Va., the latter covering a road not then built, and including a complete generating station, erection of overhead lines, and the equipment of 40 cars each with two 7 1/2-hp motors, on plans largely new and untried. The price, terms, and guarantees were such as to impose upon the company extreme hazards, both electrical and financial. The history of the Richmond road has been too often written to dwell upon it at any length here. Suffice it to say that after experimental runs in the latter part of 1887 it was put into commercial operation in the beginning of February, 1888, and for a year there followed an experimental period of development which taxed the technical and financial resources of the company to the limit. But it won out, and Richmond, by common consent of history, now stands as that pioneer road which more than any other was effective in the creation of the electric railway as it stands today.

The general features characterizing it may be briefly summarized as follows: A system of distribution by an overhead line carried over the center of the track, reinforced by a continuous main conductor, in turn supplied at central distributing points by feeders from a constant potential plant operated at about 450 volts, with reinforced track return. The current was taken from the overhead line at first by fixed upper pressure contracts, and subsequently by a wheel carried on a pole supported over the center of the car and having free up and down reversible movement, exposed motors, one to each, were centered on the axles, and geared to them at first by single, and then by double reduction gears, the outer ends being spring supported from the car body so that the motors were individually free to follow every variation of axle movement, and yet maintain at all times a yielding touch upon the gears an absolute parallelism. All the weight of the car was available for traction, and the cars could be operated in either direction from either end of the platform. The controlling system was at first by graded resistances affected by variation of the field coils from series to multiple relations, and series-parallel control of armatures by a separate switch. Motors were run in both directions with fixed brushes, at first laminated ones placed at an angle, and later solid metallic ones with radial bearing.

The well-nigh heart-breaking experiences and the alternation of good and bad performances are largely matters of personal history, but the results accomplished soon commanded the attention of those interested in the street transportation, most prominent among whom at that time was Henry M. Whitney, President of the West End Railway of Boston, who was considering the adoption of the cable. He consented to come to Richmond, and accompanied by his associates stopped also at Allegheny City to see the underground conduit of the Bentley-Knight Company. The demonstrations made for his benefit were conclusive, the cable was abandoned, and orders given for trial installations on both the overhead and underground systems to run from the Providence depot in Boston to the suburb of Allston. A winter's run resulted in the abandonment of the conduit and the adoption of the overhead trolley system, the principal orders for equipment going to the Thomson-Houston Company which, having absorbed the Van Depoele Company, was now pushing work energetically. Mr. Whitney's decision had a vital bearing upon the commercial development of electric railways, and from that time there followed a period of extraordinary activity, in which for a time two companies, the Sprague Electric Railway & Motor Company and the Thomson-Houston Electric Company, were the principle competitors. There was a continuous improvement and increase in the size of apparatus. Form wound armatures, proposed by Eickemeyer, replaced irregular windings, and metallic brushes gave way to carbon, this single change, initiated by Van Depoele in 1888–9, going a long way toward making the art a success. Cast and wrought iron yielded to steel, two-pole motors to four-pole, double reduction gears to single, and open motors to closed, protected only by their own casings. In 1892 combined series parallel and resistance control was adopted, when the Thomson magnet blow-out was successfully applied to controllers by Mr. Potter, and this was a most effective agent in reducing the troubles of operation.

The progress of the electric railway, however, was not unimpeded, for no sooner had the Richmond road started than there was emphasized a series of disturbances on the telephone lines which threatened the use of the rails for return, and brought on a conflict with the Bell Telephone Company, far reaching in its character and involving new legal questions. At that time it was almost universal practice for the telephone to be installed with single circuits and earth return. Already the service had become most unsatisfactory because of the multiplicity of electric installations of various kinds, with consequent leakages, troubles from induction and variations in earth potential. To the hissing and frying incident to the system as installed was now added the hum of the motor and exaggerated differences of potential at the ground connections.

The first attempt to meet this was made in Richmond by the superintendent of the exchange, who disconnected from the ground and joined all return wires to a common circuit. This obviated most leakage troubles, but did not get rid of the troubles of induction. Numerous law suits followed in nearly half the States of the Union, the telephone companies attempting to force the railways to use double overhead circuits, and the railway companies demanding their share of the heritage of the earth. The trolley contentions were in the main successful, and individual metallic circuits, vital to successful operation, and without which long distance telephone is impracticable, were adopted, for which condition of affairs the electric railway may be thanked.

The work accomplished at Richmond, the widespread advertising of the equipment and the rapid spread of electric railways in the United States commanded the attention of the Old World, and work was begun in Italy, Germany and elsewhere along the same lines, but it was not until a number of years later that there was any general adoption of the electric railway in the more conservative countries.

Meanwhile the Sprague Electric Railway & Motor Company was absorbed in 1890 by the Edison General Electric, which later combined with the Thomson-Houston Company and others in the General Electric.

For the next six years the record of the electric railway is that of industrial development, practically as indicated in the improvement of apparatus, the replacement of horse and cable power on existing lines, and the creation of new ones. Electric operation on tramways having become established, there naturally followed more ambitious attempts in limited applications of electricity to heavier work.

In November, 1890, a line on South London road, which was originally designed for cable, was opened, the trains being pulled by electric locomotives equipped with a pair of gearless motors having armatures mounted on the axles of the drivers.

In June, 1891, Sprague offered to install on the New York Elevated road a train to be operated by a locomotive car, and also one with motors distributed under the cars, and to make an express speed of 40 miles an hour. Two years later the Liverpool overhead railway was put in operation. Here the trains were composed of two-car units, each car having one motor, the two being operated by hand control.

In the spring of the same year, 1893, the Intramural Railway was constructed at the World's Fair, the equipment being supplied by the General Electric Company. Four motor cars with hand control were used to pull three trail cars, and a third-rail supply with running-rail return was adopted. Two years later the Metropolitan West Side Elevated road in the same city was equipped on the same general plan except using two motors instead of four.

In May, 1896, the Nantasket Beach road, a branch of the New York & New Haven Railway, was put in operation, and in September the Lake Street Elevated of Chicago began electrical operations. In November of the same year, electric service was instituted on the Brooklyn Bridge, the motor cars being used to handle the trains at first at the terminals but later across the bridge.

There were few attempts, however, to replace steam on regular roads, and only occasionally were electric locomotives adopted for special reasons. Among the earlier ones built were one of 1000 horsepower, 1892–94, designed by Sprague, Duncan and Hutchinson for Mr. Henry Villard for experimental operation on lines out of Chicago, which was never undertaken, and the still larger locomotives built by the General Electric Company, which began operation of the trains in the Baltimore & Ohio tunnel in 1895.

For a long time the conduit system, after its abandonment at Allegheny and Boston, remained quiescent, and all work was practically with the overhead trolley. In 1893 a short line was tried in Washington on the Love system, but it was not until the following year that work was begun in New York on the Lenox Avenue line, and carried to that successful conclusion which warranted its widespread adoption in that city, under the auspices of Wm. Whitney and Henry Vreeland, and in Washington under Connett, although a line had been in operation at Budapest for some time. All this of course was largely because of the necessary cost of the heavy construction, and because street railway managers would not and could not undertake any such investment except under most favorable traffic conditions, and then with the additional restriction of a prohibition of the use of overhead wires.

About this period there began that rapid introduction of interurban railways, soon aided by the developments in transformers by Stanley, in polyphase transmission by Tesla and Ferraris, and in rotary transformers by Bradley and others, which has had such an influence upon steam railway operation and been so instrumental in knitting together urban and rural communities.

The first practical proposal for a railway using high-tension alternating-current transmission, seems to have been made in 1896 by Bion J. Arnold in plans for a road to run from Chicago to the Lake region, and although this road was never built the general plans were utilized for a line actually put into operation about two years later, which was the forerunner of the standard practice of today by means of which the limitations of distance have been so effectively reduced.

In 1896 Sprague again sought the opportunity to make a demonstration on the Elevated Railway in the form of a proposition to the management to equip a section of the line, and operate a train of cars on a new principle, the "Multiple Unit."

Although the advantages of the system, such as higher schedules, reduced weights, variable train lengths, more frequent trains, distributive motive equipment and increased economy were presented, and supplemented by an offer to equip the whole system, no response whatever was made. A similar proposal repeated seven months later met with like fate, but in the spring of 1897 he made a contract with the South Side Elevated Railroad, in Chicago, to equip the line on this plan in lieu of the locomotive car plan then under consideration.

This system has now become so widely known that any detailed description of it is unnecessary. Generally speaking, however, it is essentially the control of controllers, by means of which cars equipped with motors and controllers for them are operated from master switches through a secondary line, with provision for so coupling up cars that from any master switch all cars can be operated irrespective of number, order or end relation, or whether all or only part of the cars are equipped with motors.

The first equipment was for 120 cars, and the first public demonstration was made in July, 1887, at Schenectady, on a full train of cars which had been sent from Chicago for that purpose. A regular train was put into operation before the close of the year, and within a few months steam operation was entirely replaced.

As originally equipped, the main controller consisted of a magnet-operated reverser and pilot-motor driven cylinder, operated semi-automatically and with throttle restraint through a secondary line and relays from master switches on the platforms. A number of variations have since been developed, such as operating the reverser and cylinder by air pistons electrically controlled, or breaking the main controller up into several magnetically operated parts, and all forms of equipment are now in operation. The essential principle of the system, however, has not been changed, and it has become standard wherever required to operate electric trains at high schedules. Equipments have grown from 100 horse-power per car to 2200 horse-power per locomotive, for in the largest work under way, that of the New York Central, the locomotives are to be controlled on this plan.

The necessities of tunnel traffic on the one hand and a grave accident on the other have curiously enough centered in New York the largest two electric transportation problems, namely, that of the operation of the Pennsylvania tunnel and terminals, and more extensive still, that of the New York & Hudson River Railroad for 35 miles out from its terminals. The general requirements are so exacting, and the installation of the latter under such difficult continuous working conditions that they will prove of historic interest, and be influential in determining the disposition of many terminal problems.

Up to comparatively recent times most of the electric railways, including those just mentioned, have been planned for operation with continuous current motors at moderate potentials, but this has often required the conversion of alternating current transmitted at high potential into continuous current at a lower one through the medium of transformers and rotary converters. While this bids fair to be the practice for some time, there are of course certain objections which are apparent, and the best energies of many of the ablest electrical engineers have for some time been bent upon solving the problem of operating directly with alternating currents. Among the most active and successful of these have been the Ganz Company, whose Valtellina line, equipped on the polyphase plan for Italian Government, is of special interest. Among noteworthy experimental installations is that conducted under the auspices of the German Government on the Zossen military line, where the highest record for speed of a car carrying passengers, about 126 miles per hour, has been made during the past year, the current being collected from the three overhead wires by sliding contacts.

The multiplicity of conductors, however, distinctly militates against this as any general solution of the larger railway problems, quite independently of other limitations affecting trunk-line transportation, and hence single-phase operation, using one overhead conductor with track return, is being energetically prosecuted. Among the workers who have sought solution and been active in invention along this line, as well as one of the earliest and most persistent advocates of single-phase railway operation, is Mr. Arnold, who has developed an electro-pneumatic plan in which is combined on a locomotive a constant speed single-phase alternating-current motor with reversible air pumps and a storage tank, by which starting and running can be controlled by compressed air with a more even demand upon the capacity of the station. Arnold's experiments, a long time delayed from various causes, are now being subjected to the actual tests which will demonstrate the practicability of this scheme. Meanwhile, becoming alive to the limitations of past practices and the increasing demands of the art, the engineers of the various manufacturing companies in the United States and Europe, among whom must be especially mentioned Finzi, Lamme, Latour, Winter, Eichberg and Steinmetz, are developing the single-phase alternating-current motor along two general lines. One is by using a series motor of special construction, plain or compensated current being supplied from the secondary of a transformer carried on the car and operated at moderate frequency. Another form is that originally proposed by Thomson, and known as the "repulsion" type, in which the field is supplied directly at high potential, and the armature is short-circuited upon itself and operates at low potential. An alternative of this form is that developed by European engineers, in which a variable potential is delivered to the armature from a transformer, the field being supplied direct from the line. One desideratum is of course to be able to operate both from alternating and continuous currents, and this has been done, but the best results may possibly be gotten by ignoring this limitation.

It is unnecessary to go into the many variations or details of these various schemes. Suffice it to say that all are being submitted to the crucial test of commercial operation, and the overcoming of difficulties of the early days of electric railroading warrant expectation that a great measure of success will likewise be attained on these new lines, and that another bar to the wider spread of electric railway operation may be speedily removed.

This paper will not be burdened with detail statistics, but to illustrate in a general way the growth of the electric railway it should be noted that three years after the inauguration of the Richmond road there were in operation or under contract in the United States, England, Germany, Italy and Japan, not less than 325 roads, representing an equipment of about 4000 cars and 7000 motors, with 2600 miles of track, on which there was made a daily mileage of not less than 400,000 miles, and three-quarters of a billion of passengers were carried annually.

By the end of 1903, in the United States alone, there was a total of over 29,000 miles equipped, 60,000 motors and 12,000 trail and service cars in service, and the passengers carried ran into billions.

What the electric railway has done may only briefly be referred to here, but the writer may be permitted to repeat the substance of remarks written some nine years ago, for it has become a most potent factor in our modern life, and left its imprint in the indelible stamp of commercial supremacy. It has given us better paved streets, greater cleanliness, more perfect tracks, and luxurious, well-lighted and well-ventilated cars. With the higher speeds it has made possible the extension of the taxable and habitable areas of towns and cities in a much greater ratio than is represented by the increase of speed.

It has released from drudgery tens of thousands of animals, and increased the morale of transportation employees. It has given employment to an army of men, and hundreds of millions of capital. It has improved and extended the telephone service by forcing the abandonment of ground circuits. It has built up communities, shortened the time between home and business, made neighbors of rural communities, and welded together cities and their suburbs.

Will it replace the steam locomotive?

Perhaps the best answer is that "its future is not in the wholesale destruction of existing great systems. It is in the development of a field of its own, with recognized limitations but of vast possibilities. It will fill that field to the practical exclusion of all other methods of transmitting energy; it will operate all street railway systems, and elevated and underground roads; it will prove a valuable auxiliary to trunk systems; but it has not yet sounded the death-knell of the locomotive any more than the dynamo has that of the stationary steam engine. Each has its own legitimate field."

NOTES ON EQUIPMENT OF THE WILKESBARRE & HAZELTON RAILWAY.

BY LEWIS B. STILLWELL.

The equipment of the Wilkesbarre & Hazleton Railway, which was completed in the spring of 1903, has been referred to in some detail in technical publications, but it is thought that a brief description of certain features, novel in whole or in part, particularly the covered third rail and the special form of collecting shoe employed, should be recorded in the proceedings of this Congress. The fact that this was the first railway of any considerable length in America to be equipped for commercial use with a protected third rail, and that for the last 18 months it has been in highly successful operation may make the following descriptive notes relative to construction and to performance of some value to engineers who may be called upon to deal with similar equipment problems.

The more important noteworthy features of this railway and its equipment are:

1). The use of a contact rail covered by a plank guard to protect it against snow and sleet, and to prevent accidental contact by people crossing the track or walking near it;

2). The elimination of all grade crossings;

3). The fact that it traverses a rugged and mountainous country, level stretches of roadbed being practically insignificant, while there are several stretches of 3 per cent grade not less than four miles in length;

4). The use of cars weighing 42 tons, net, without passenger load, and equipped with four motors of 125 horse-power (one hour rating) each;

5). Brake equipment so designed that no one accident to any part of the rigging can render all brakes inoperative;

6). The use of a portable converter station in the form of a car carrying transformers, converters and necessary switch gear;

7). The use of a soldered — not riveted — rail bond.


RANSOM
EXETER
PLYMOUTH
WILKESBARRE
HANOVER
SLOCUM
DORRANCE
HOLLENBACK
WRIGHT
BUTLER
SALEM
SUGAR LOAF
PENNSYLVANIA R.R.
Plymouth
Nanticoke
Pittston
White Haven
Upper Lehigh
Freeland
Jeddo
Drifton
Stockton
Wilkesbarre & Hazleton Railroad Co.

FIG. 1.

DESCRIPTION OF RAILWAY AND EQUIPMENT.

The railway is 26.2 miles long, has a single track and connects the cities of Wilkesbarre and Hazleton in northwestern Pennsylvania. It competes with two steam railways, the Lehigh Valley and a branch of the Pennsylvania, both of which were in operation long before their electrically equipped competitor was projected. The maximum grades used by the steam railways approximate 2 per cent, and the distance between their respective terminals in the two cities is 50.4 miles in the case of the Pennsylvania and 49.6 miles in the case of the Lehigh Valley. The country between Wilkesbarre & Hazleton is mountainous, the new railway being compelled to cross not less than three ranges, as shown in profile, Fig. 2. The routes of the three competing lines are shown in the map, Fig. 1. As will be seen by reference to Fig. 2 the terminus of the line in Hazleton is nearly 1200 feet above the Wilkesbarre terminus. One of the striking advantages of electric traction is illustrated by the fact that the adoption of a practically uniform gradient of 3 per cent has made it possible to locate and construct a line but 26.2 miles in length, connecting, through so exceptionally mountainous a country, termini which are 21 miles apart as the crow flies. In accomplishing this result, one tunnel is used; this pierces the Penobscot range, as shown on the profile, and is 2684 ft. in length.

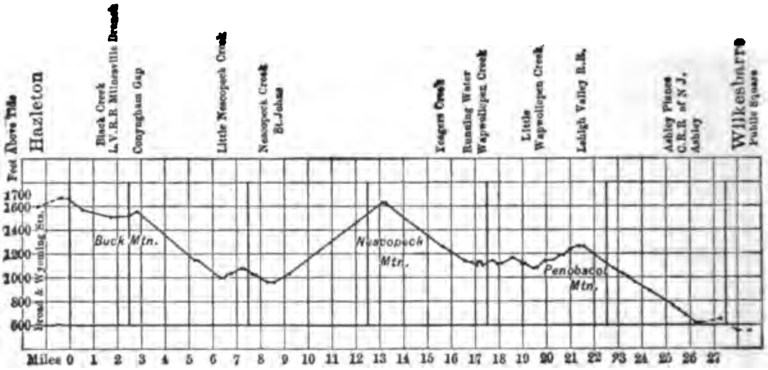


FIG. 2. — PROFILE OF PRELIMINARY LOCATION.

The passenger traffic of the road is chiefly through service, the country between the two cities being sparsely populated. A considerable freight business in delivery of supplies to the inhabitants of the intervening country and in hauling farm produce to market as well as a moderate express business has been developed since the service of this road was inaugurated.

The railway is constructed upon a private right of way 60 ft. wide, fenced on both sides throughout its entire length. Grade crossings are entirely eliminated, a feature of construction which may well be copied wherever and whenever possible, the resultant increase in speed compensating in large degree if not wholly for the increased cost of construction. There are 33 bridges crossing highways and streams; the majority of these structures have concrete abutments and steel girders. There is one three-arch bridge of granite masonry, and one bridge using steel girders supported upon high masonry piers. The track rail is a Boston & Albany section, weighing 95 lbs. to the yard and is supported upon 8-ft. ties spaced to 24-in. centers. Every fifth tie is 9 ft. long, the extended ends of these ties carrying the insulators which support the contact rail. The ties are laid upon a bed of anthracite coal cinders topped with a dressing of broken stone. All curves are carefully compounded, and the outer rail properly elevated with reference to high speed service.

The contact rails are 60 ft. in length and weigh 80 lbs. per yard. The specified composition of the contact rail is as follows:

Carbon not to exceed .10 per cent; manganese, .55 per cent; phosphorus, .08 per cent; sulphur, .10 per cent; silicon, .03 per cent. Its conductivity is equivalent to pure copper having about one-eighth its cross-section. The center line of the contact rail is 28 ins. from gauge line of the track, and its upper face is 5 ins. above the track rail, this location being selected to permit operation of steam locomotives over the track without disturbance of the contact rail or its guard. Fig. 3 shows relative position of the track rails, contact rail, the rail guard and collecting shoe.

Each 60-ft. length of the contract rail is anchored at its middle by a projection of the malleable iron casting at the top of the insulator, which projection engages with a slot in the base of the rail. To allow for expansion, adjacent rails are separated by a distance of 1/4-in. when temperature of the rail is 60 deg. F. To permit free expansion and contraction, the fish plates are left sufficiently loose. Contact rail and track rails are electrically connected throughout their respective lengths by copper bonds which are soldered to the rails. These bonds are fastened under the base of the rail. The rail guard is a 2-in. pine plank, 6 ins. in width, supported directly over the rail by oak posts at intervals of 8 ft., these posts in turn being supported by the contact rail to which they are attached by means of malleable iron castings and hook bolts, as shown in Fig. 3.

The schedule provided for in the equipment of the road contemplated an hourly express service and a local service upon headway of 90 minutes. The rolling stock equipment comprises six combination coaches, each having a passenger compartment, a baggage compartment and a toilet-room. The passenger compartment provides 38 seats of standard Pennsylvania passenger car size, i. e., 40 ins. long; while eight seats are provided in the baggage compartment, which is also used as a smoking compartment. The general dimensions of the car are: Length over end panels, 43 ft.; over platform, 51 ft.; width over outside sheathing, 9 ft. 6 ins.; height from bottom of sill over roof, 9 ft. 8-1/2 ins. Double sliding doors are used at the passenger end of the cars and single sliding doors at the opposite end. Loading steps are used at only one side of each platform, and the side of the platform opposite

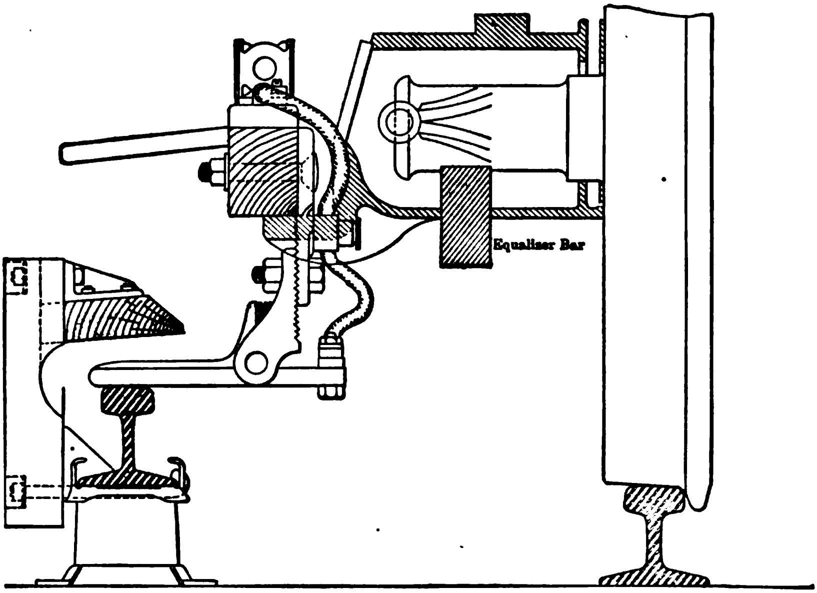


FIG. 3. — CONTACT SHOE AND GUARD-RAIL.

these steps is used for the motorman's cab. At each side of the baggage compartment is a sliding door 42 ins. wide; the vestibule side doors are hinged to the vestibule post next the car body, and when closed are locked by the trap door which is lowered to complete the floor of the vestibule and cover the steps when the door is closed.

The cars are equipped with M.C.B. couplers, Gould platforms and two-stem spring buffers. Automatic air sand boxes are used. "Cow-catchers" attached to the trucks are placed at each end of the car and are set back a sufficient distance to avoid interference with the couplings.

Brill No. 27-E-2 trucks are used; the wheel base is 7 ft. 6 ins., and the wheels are 36 ins. in diameter. A General Electric No. 66 motor is attached to each of the four axles. The control system is the Sprague multiple unit automatic control, using contactors instead of control cylinders. The total weight of the car equipped, without passengers, is 84,000 lbs. A railway using cars of this weight and operating over gradients of 3 per cent ranging from 3 to 5 miles in length, requires a reliable brake equipment. In the case described in this paper, both outside and inside brake shoes are provided, the outside brakes being operated by two independent means, viz., Westinghouse automatic air apparatus and a vertical hand wheel located in the motorman's cab. The inside brakes are operated by a vertical wheel in the vestibule through mechanical connection absolutely independent of that which operates the outside shoes. The failure of no one element in the brake equipment, therefore, can deprive the train crew of effective means for checking the speed of the car. In the arrangement of the inside brake equipment, provision is also made for the Newell magnetic track brake which, however, has not yet been developed for cars equipped with motors of so large a size as are used in this instance.

The Westinghouse air-brake apparatus is so arranged as to permit use of the "straight air system," and also of the automatic system. The former, by which air admitted by opening the engineer's valve operates directly upon the piston of the brake cylinder, is generally used for the reason that it readily permits graduated application of the brakes. At the same time, the automatic is available and is brought into service at any time by reduction of the train-line pressure.

The cars are arranged for operation singly or in trains, the multiple-unit control system being adopted with special reference to possible ultimate operation of trains comprising two or more cars each.

The construction of the contact or collecting shoe is shown in Fig. 4. This design is due to Mr. W. B. Potter, chief engineer of the railway department of the General Electric Company.

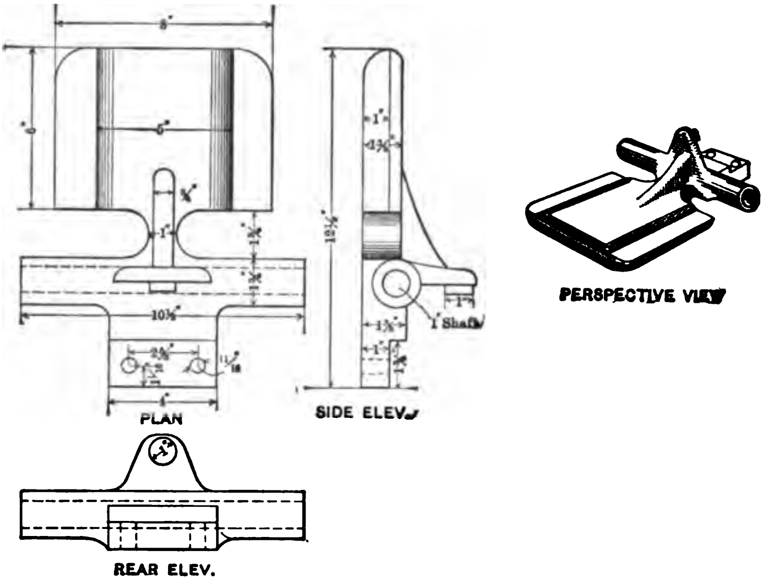


FIG. 4. — PLAN OF THIRD-RAIL SHOE.

The cars are equipped with trolley poles for use in passing over portions of the city traction systems, and the switch which controls the connection to trolley and shoe is arranged to permit change from trolley to third-rail supply or vice versa, without losing contact.

There are perhaps no special features of the power plant to justify a detailed description in this paper. It is located about 8.4 miles from the Hazleton end of the line upon Nescopeck creek. The dimensions of the building are 132 ft. x 84 ft.

The electrical equipment comprises three 400-kw three-phase alternators of the revolving-field type, direct-connected to three single-expansion twin engines, operating at 150 r.p.m. Each engine has two cylinders 18 ins. in diameter and 36 ins. stroke, the cranks being connected 90 deg. apart for the purpose of obtaining uniformity of rotation. Fly-wheels, 15 ft. in diameter and weighing 60,000 lbs. each, further facilitate parallel operation, and assist the engines in taking care of sudden variations of the load.

The alternators deliver tri-phase currents at 390 volts. A 400-kw converter, located in the power-house, receives alternating current from the generator bus bars, and delivers continuous current at about 625 volts to contact rail where the line passes the power-house.

Two groups, each comprising three transformers of 150 kw each, connected in delta, deliver to the transmission circuits energy at 15,000 volts potential. The transformers are of the oil-insulated self-cooling type. The equipment of switch gear and measuring instruments present nothing worthy of special description.

At a distance of 11 miles from the power-house, in the direction of Wilkesbarre, a sub-station with electrical equipment, comprising three step-down transformers and one 400-kw converter, is located. The contact rail, from this point to the Wilkesbarre terminus, is supplied from this sub-station, while between the sub-station and power-house it is supplied at each end from the converters located at these points. At the Hazleton end of the line, which is 8.4 miles from the power-house, the contact rail is supplied in part from the power-house of the Lehigh Traction Company, the direct-current compound-wound generators in the plant of that company operating in parallel with the rotary converter at the power-house of the Wilkesbarre & Hazleton Railway.

The alternating-current transmission from power-house to substation — and to a point several miles beyond the latter — employs a potential of 15,000 volts. The circuit comprises three bare copper wires, No. 4 B & S gauge, forming an equilateral triangle 30 ins. on each side. Double-petticoat glass insulators 7 ins. in diameter are used. The poles are spaced 100 ft. on curves and 125 ft. on tangents. Locust pins 7 ins. long and 2 ins. in diameter, where they enter the cross-arm, are used. Two of the pins are carried by the cross-arm, and the third is inserted in the top of the pole, which is clamped with 7-in. iron bands. The yellow-pine cross-arms are 6 ins. x 4½ ins. in section and 34 ins. long. They are secured to the pole by two 5/8 in. bolts. The transmission circuit is transposed twice, each transposition making one-third of a turn.

The transmission circuit is carried to a distance of 14 miles from the power-house in the direction of Wilkesbarre, i. e., about three miles beyond the fixed sub-station at Nuangola. This is done to permit the supply of alternating current to the portable sub-station, which is sometimes located at the end of the transmission circuit.

The portable sub-station comprises a car 36 ft. long and 9 ft. 6 ins. wide, carrying a complete sub-station equipment of electrical apparatus, comprising three 150-kw transformers, one 400-kw converter, and a complete outfit of alternating-current and continuous-current switching apparatus. It is also equipped with lightning arresters and reactance coils. Fig. 5 illustrates the arrangement of the apparatus inside the car. The total weight of the equipment is about 51,000 lbs. The car is not equipped with motors, but, when necessary, is attached to a regular passenger car and hauled to any part of the line where it may be needed. In the operation of the line it serves the double purpose of providing a reserve for the transforming and converting equipment of the power-house and sub-station, and of supplying an additional sub-station, which may be located near the top of the long grade at the Wilkesbarre end of the line when traffic on that part of the system is particularly heavy, as may happen in case of special excursions from the city.

Experience in Operation.

1). *The Contact Rail Guard.*

In operation of the road the guard has repeatedly demonstrated its value in protecting the contact rail against sleet and thereby preventing interruptions of service, which in the severe winter climate of these Pennsylvania mountains would otherwise have been comparatively frequent and serious. During the winter of 1903–04 cars were operated from 6 a. m. until midnight upon headway which at no time was less than one hour, and notwithstanding this infrequent service and the fact that no cars were running between midnight and 6 a. m. there were but two instances in which any serious delay occurred by reason of the formation of sleet on the contact rail. Upon one occasion a car was delayed one hour and 50 minutes, and at another time a car lost, during the round trip, 28 minutes. The trouble occurred on a stretch of track where the

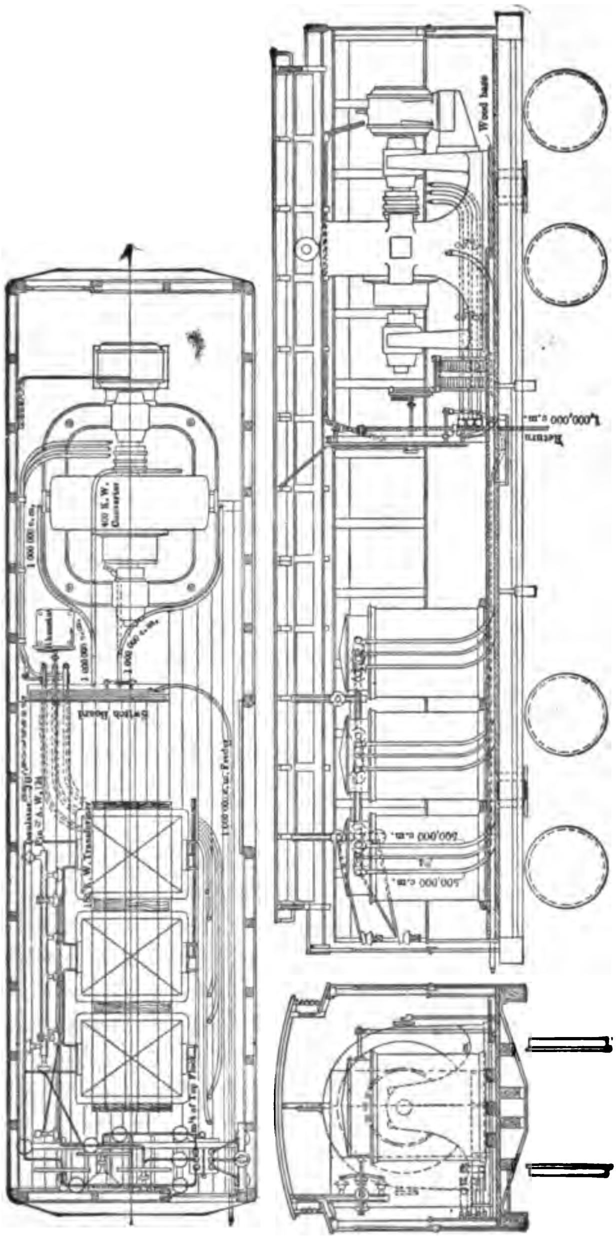


FIG. 5. — CONVERTER CAR.

line is particularly exposed to the sweep of the wind over the mountains. Partial formation of sleet on top of the contact rail which occurred in these cases would have been greatly reduced, if not eliminated, had the guard been even 2 ins. wider. In cases where it is not necessary to consider the possibility of occasional operation of steam rolling stock experience on this road seems to show that effective protection against sleet can be secured by employing a horizontal plank guard substantially as shown in Fig. 3, but extended in each direction, i. e., toward the track and away from it 1 in. farther than the guard adopted in this instance. Where possible operation of steam rolling stock will not permit such extension in the direction of the track, the guard should be widened at least 1 in. in the other direction, i. e., away from the track.

The addition of a vertical plank attached to the posts which carry the top guard would secure effective protection against sleet coming from that side of the track, but on the other hand it would tend to cause the accumulation of snow around and upon the contact rail. Mr. C. B. Houck, superintendent of motive power of the Wilkesbarre & Hazleton Railway, to whose courtesy I am indebted for many particulars regarding operation, attributes the success of the guard in large degree to the fact that it is open front and back, so permitting the wind to drive snow through the space between contact rail and the guard.

2). *The Collecting Shoe.*

The use of a horizontal guard above the contact rail implies necessarily the adoption of a collecting device differing from the familiar link type generally employed in connection with systems of third-rail supply. On the whole, experience in operation of the shoe illustrated in Fig. 3 has been very satisfactory, and in the opinion of the writer has demonstrated the essential superiority of a shoe of this type, particularly at high speeds. Some trouble in breaking shoes has resulted from failure to maintain accurate alignment of contact rail and track rails, as a consequence of which shoes have been broken by striking against the posts which support the guard, and in order to make sure that when the shoe strikes these posts the break shall occur at a predetermined point and not carry away the supporting casting as well as the shoe, it has been deemed advisable to reduce the section of the shoe casting at the weakest point to the dimensions shown in Fig. 4, which in this respect are considerably modified as compared with the original design. At high speeds the shoe has less tendency to jump than the link type shoe, the moving parts being comparatively light, and the spring pressure — about 15 lbs.— proving more effective than gravity in maintaining contact of shoe and rail. The design of this shoe can with advantage be materially modified in respect to details; in type, however, it is excellent and very satisfactory.

Its ability to collect heavy currents satisfactorily was well demonstrated by a test carried out for the purpose of determining the ability of the electrical equipment of the Wilkesbarre & Hazleton cars to draw a heavy trail car up the mountain grades. In this test a motor car was coupled to a standard Lehigh Valley passenger coach weighing 70,000 lbs. The total weight of the two-car train, including train crews and observers reading the measuring instruments, was 156,000 lbs. Simultaneous readings of current and e.m.f. were taken at 30-second intervals at the power-house and at the permanent sub-station, and similar readings were taken at 15-second intervals on the motor car. At times the speed was determined with a fair degree of accuracy by counting rail joints, although at the higher speeds the results thus obtained are hardly reliable.

The start was made at the Wilkesbarre terminal at 1 a. m., and the run to the Hazleton end of the line was accomplished in 68 minutes, the average speed being 22 miles per hour. During this run the current per motor cars in climbing the long 3 per cent grades exceeded 400 amperes per shoe. The only sparking noted occurred at irregular intervals, averaging perhaps distances of something over a quarter of a mile, and due doubtless to slight differences in elevation of adjacent rail ends. The night was dark and the slightest spark under the shoe was easily detected. At the end of the run the shoes were found to be in good order and not excessively heated.

3). *The Brake Equipment.*

That the brake equipment of some of our electrically operated urban, suburban and interurban lines is inadequate has been demonstrated in recent years by a number of fatal accidents; that similarly unsafe conditions exist in the equipment of many other lines is undoubtedly true. Electric traction is admirably adapted to operation over heavy grades. Obviously special precautions in respect to brake equipment should be observed where these grades are encountered. The general features of the equipment provided in this instance have been described. In operation they have proved very satisfactory. Where both inside and outside shoes are used it is found advantageous in descending heavy grades to apply one set or the other to the point of actual contact with the wheel, leave this set thus adjusted and use the other set for such additional braking as may be necessary. This method is particularly advantageous where axles and trucks are light in construction, or where from long usage or inadequate maintenance there may be lack of rigidity, and where, consequently, if but one set of brake shoes be applied the braking may become ineffective. The partial application of one set, e. g., the inside shoes, holds the wheel firmly in place, and increases the promptness and effectiveness of results attained in applying the other set of brakes. In the operation of the Wilkesbarre & Hazleton Railway, when a car reaches the top of one of the long grades the conductor takes his place in the vestibule and applies the inside brakes by hand, tightening them just sufficiently to take up the lost motion and bring the shoes into firm contact with the wheels. The motorman then holds the train, usually by applying the air-brake as may be necessary, and in case any part of the brake-rigging of the air-brake apparatus should fail the car can be held by using the inside brakes, which being already in contact with the wheels can be promptly applied.

4). *The Converter Car.*

The practical value of a movable sub-station has been demonstrated a number of times in service. It is a sufficiently effective reserve for the converters located respectively in the power-house and the permanent sub-station at Nuangola, and it has also been used with satisfactory results to increase the supply of continuous current on the long and steep grade which begins at the Wilkesbarre end of the railway.

The speed with which the powerful motor equipments carry up the long and heavy grades cars weighing, with their load, over 90,000 lbs. each is a striking illustration of the possibilities of electric traction in railway work. Upon the occasion of the test with trail car, which has been referred to, the speed of the train at a point midway between the power-houses at St. Johns and at Hazleton was 28 miles per hour, the grade being 3 per cent, and the weight of the train 156,000 lbs. At points nearer the power-house, the grade being the same, the speed attained was not less than 34 miles an hour.

FRIDAY MORNING SESSION, SEPTEMBER 16.

Chairman Duncan: The session this morning will consist of a discussion, or a continuation of the discussion on the application of alternate motors to railway work, and, if we have time, the reading of a paper by Mr. Parke on "Braking."

Discussion.

I will take the privilege of opening the discussion myself with some remarks on the general subject of the application of electricity to railroads. In the first place, the types of service that electricity has to perfect are tramway service, city-train service, interurban service and trunk-line service. Now, of those types the first three have fallen victims to electricity — tramways, city-train service and interurban service are now operated by electricity. The reason is, of course, that electricity affords better facilities and is cheaper.

Before the road at Richmond, Va., was started in 1887 and 1888, the practical success of electricity as a motive power had been shown. It had been shown that electricity could be applied to the propulsion of cars. It had not been shown that it was practical commercially. That experiment showed it was commercially practical, and from that time in tramways the motive power was rapidly changed to electricity.

What happened in the tramway service was this: A large number of small units were operated from one station; that means that the load factor at the station was good; that means that the load factor on the copper was good, and operated direct currents from one or more stations at a time. When the question of displacing cables came, the situation was more serious. Cable traction was successful; it was economical, and for crowded districts it was hard to see how electricity would replace it. However, the advance electricity made gradually ousted cables from tramway work.

For city-train service, again electricity ran against a harder proposition. The elevated roads were run by steam locomotives. The mechanical arrangements and the investments necessary to change to electric traction were enormous. It was not until the multiple system gave electricity a decided advantage over steam, that electricity was adopted over urban roads. In this city-train service we have the same condition of affairs. We have a large number of units in a small compass, as in the case of the tramway work, and a still larger number of units on one station, a comparatively good load factor for the station, a comparatively good load factor for the copper.

For interurban roads the advantages offered by electricity were very marked. It opened up a new type of service impossible to be operated by steam. It gave to country districts, the headway of the cars varying from twenty minutes to an hour, a service which it was impossible for steam to give, and the reason of its development was the fact that this service could be economically given. The reason of that, again, was the fact that by successive distribution a large number of units could be fed from one station. The load factor on the main station was good, although the load factor on the sub-stations and on the copper was bad. The load factor on the sub-stations and on the distributing part, the transmission part, on the copper, has been improved, of course, by the use of storage batteries in the sub-stations.

Now, in all of these cases the reasons for the success of electricity lies in the fact that the load factor on the generating station, where the losses are greatest, has been brought to a reasonable figure. The load factor on the sub-stations is not so important in its effects because losses in the sub-stations are not of great importance. The load factor on the copper is of importance, dependent upon the amount of copper used in the distribution of the service to the cars. The load factor on the copper is very bad, of course, but the expenditure for copper is not great.

Now, there is another point to be considered when you come into work like steam-railway service, and that is this: The load factor itself, as a figure, does not tell the whole story by any means. We may have in the same station the same load-factor for two days, and the power per hour may cost the second day twice as much as the first. In the ordinary load we have the load curve, which gives us the amount of power required at different times in the day, and we run our boilers and our generating units, turning them on as the power increases. In the type of load that would be given by railroad work, we do not have a curve that comes up and varies twice a day, but we have a curve that fluctuates greatly from time to time. So a large part of the capacity of the plant must be used all the time. Consequently, it is necessary to introduce another consideration, and that is the cost factor of power. With the same load-factor, the cost factor may differ very much. If we define the cost factor as the ratio of the actual cost per kilowatt-hour delivered to the cost per kilowatt-hour at full load, we will find with the same load factor that the cost factor will vary considerably, for if our boilers have to be operating and ready to give steam at any moment, losses would continually be greater than if the boilers are banked and fire spread only when we need power.

In the same way the cost-factor of our copper varies with the nature of the load factor. If we have a given amount of energy to distribute, and have enough copper to give it 10 per cent. loss, if it is distributed over twenty-four hours, then if we distribute the same amount of energy in twelve hours, the loss is twice as great. So in any situation we must have determined the cost factor in our copper, the cost factor in our sub-station, if we use one, and the cost factor in the main station; and those are figures that are more important than load factors, and dependent not only upon the load factor, but also upon the nature of the load factor.

When we come to trunk-line work, the matter has been discussed and will be discussed further. Taking for granted the possibilities of single-phase alternating motors, taking for granted voltages which make the copper investments comparatively small, we are in the same condition that we are in the other three types of service. That is, we can put on our generating station, where the losses are greatest, a fair load factor. The type of the load factor, however, will be different from the type of load factor in our ordinary service, and that must be taken into consideration in determining the cost of the power to be used. If we can use high voltages there is no doubt about it, that we can operate steam roads with overhead wires, the voltage being high enough to bring the current down to the quantity that can be collected. But the question is whether there is any great advantage in it.

We have had that fully discussed, and I hope we will have it further discussed, but it seems to me this: We can offer very little to the general railroad man, we can offer very little in the way of decreased expense. We can offer very little in the way of increased facility of operation. We do offer them this, though: We offer them the possibility of a great deal of trouble by using a high tension distributing system, by collecting from a high tension system to feed our road depending for its operation upon a few large units spaced at large distances; that is, at central stations, and then distributing through sub-stations.

It seems to me, so far as the general problem goes, outside of special problems that come up, that we still are not in a position to offer for general railroad work any particular advantage of electricity over steam. There are specific problems, as every one knows, in which electricity has tremendous advantages. Some years ago I investigated for the B. & O. the electrification of a section 100 miles in length, where the steam conditions had become practically impossible. The road was run up to its trackage limit and it curved so that the heaviest locomotives were limited, therefore the weight of the locomotive and therefore the size of the train. Dr. Hutchinson and myself went through that very carefully, and found electricity offered great advantages. There was one grade of seventeen miles of 2½ per cent. and another of fourteen at 2½ per cent. In a case of that kind there is no question of considering the loss in electricity, but by starting at one end and ending at the other there is great advantage in the traffic.

Another advantage Mr. Leonard pointed out is the fact that electricity allows us to increase the length of train with the steam draw-bar conditions. The size of the train is practically limited by draw-bar conditions, and with electricity the train can be very much increased.

I think Dr. Steinmetz took the ground that the reason for the larger train units was the increased economy of large locomotives. That, of course, is not exactly so. The reason for the larger train units is in the economy of the large locomotives and the increased *tractive effort*.

There is very little that electricians to-day, even with the single-phase alternating motor, can offer to railroad people, except assistance in special problems.

Mr. F. J. **Sprague**: Discussion on this subject seems to be assuming two phases,— first, how to use the alternating current in railway work, and, second, whether trunk lines can be operated by electricity.

This will extend the discussion into a pretty broad field. We can all learn something from the milestones we pass, and in view of the numerous claims which have been made for the alternating-current motor, more particularly of the single-phase type, I would recall some promises made a number of years ago when the continuous-current motor was to be promptly relegated to obscurity. You all remember the early phases of the development of the polyphase motor, and how the commutator was held to be the great bugbear of its rival. The commutatorless motor was to institute a revolution in railway work. Of course it has been applied to stationary purposes most successfully, and two companies in particular, the Ganz and Siemens, have made some effective demonstrations of its possibilities in railway work.

I cannot, however, but feel that the multiplicity of conductors is a practical bar toward any widespread application of this system. The position I take is not a new one. In 1888, when the question of equipment of the West End Railway of Boston was under consideration, and the Bell Telephone Company with all its power attempted to prevent the use of the rails for return circuits, the president of that road had to consider very seriously whether they would use two trolley wires. I objected to it as strongly as possible, and the modern trolley has been developed on the idea that one wire overhead is quite sufficient,—oftentimes too many, perhaps.

And so, I think, in the alternating-current development, we shall proceed on the basis that one conductor overhead is all that we can stand. If the experiments made demonstrate anything at all, it is the impracticability of operating general trunk lines on the polyphase system.

Now, after all these years and the various promises that have been made on behalf of the polyphase type of motor, we find in the series single-phase motor a reversal of practice, and the adoption of many of the features of continuous-current motors. The much-abused commutator has reappeared in a more unsatisfactory form, and the field windings are more complicated. I think I am safe in saying, that not only at present, but for all time to come,—prophecies are dangerous, but I think I will stand pat on this one—the continuous-current motor, measured by all qualities,—weight, efficiency, simplicity, reliability and cost of maintenance, can claim superiority over the alternating-current motor of the single-phase type.

Why, then, are we striving for the development of the latter machine? It is not because it is necessary in street-car service or in elevated railway or underground work, or for limited distances on interurban roads, but to reduce on long distances, and especially heavy traction the prime investment for line equipment, and the investment in the moving parts at the sub-stations.

Just here I may point out that people are apt to somewhat exaggerate the saving to be effected. Any road which extends over a considerable territory and operates from sub-stations may be considered merely as a series of connected railways operated from small central stations, each of which, instead of being steam-equipped, is run directly by a current transmitted from one central source. Increase the working potential and the distance between these small stations can of course be increased. The ordinary limit for continuous current work has been primarily determined by the limits of successful commutation for a single motor, but by operating two in series on four motor equipments the limit can be at once doubled,— to say nothing of other possibilities. When we put an alternating current directly upon the working conductor we run into certain possible difficulties. In the first place, the distance between the stations cannot be increased in that ratio which at first sight would appear. Whatever the maximum limit on the trolley wire, the average potential is of course much less, and the resistance of iron rails to the passage of an alternating current is much higher than for the continuous. It can be safely said that with any given size of trolley wire, and average load per unit distance, the distance between the sub-stations on an alternate-current proposition would not by any possibility increase in the same ratio as the increase of maximum potential, when compared with continuous-current equipment, nor even directly as the ratio of increase of its own potential, alternating-current propositions alone being considered.

In the operation of a single-phase alternating-current motor I fear that we have not passed through that period of time, or those conditions of service, which will develop certain conditions, some possibly dangerous and some irritable. In the earlier days of electric railroading probably most of us have at times noticed the possibility of shock,— and that with only 400 or 500 volts,— due to leakages on the car and a break between the metal of the car and the rails or the ground, when a passenger on moist ground made a contact in taking hold of the handrail. That experience leads to a possibility in high tension work which is not entirely agreeable to contemplate, and against which the utmost precaution must be taken.

We must, if we are going to have high-tension transmission on the trolley, bring that high tension into the car. It matters not whether we are going to use high tension direct on the motor circuit, or whether we are going to use a transformer and reduce it, the high tension must come in somewhere. This high-tension alternating circuit has a greater tendency to break down insulation, and it must of course be protected by an iron or lead shield which must be put in connection with the metal frame of the car. In time the gradual deterioration of the insulation may, in fact, it most likely will, lead to a partial or perhaps a complete break-down, bringing the whole metal frame into potential relation with the incoming current.

Fortunately, in most propositions for alternating-current work heavy cars are used which most of the time will make good rail contact, but we can easily see that at times on dirty or sleety tracks there may arise a condition in which there is a decided difference of potential between the frame of the car and the ground. That leads to possible dangerous conditions, and will require the utmost care on the part of engineers who are installing electric equipment on alternating-current circuits.

There is another condition to be considered. Fifty times a second the potential passes zero, and current ceases. When running with a continuous current, circuit can often be maintained even through bad rail contacts, but under this latter condition there seems a liability of a greater aggregate period of interruption of current in an alternating-current equipment than there is on the continuous current.

The question whether electricity should be used on trunk lines is such a big one that discussion would be almost endless. As the chairman has pointed out, there are special conditions, such as characterize sections of mountain roads and terminals,— where electricity should be seriously considered; and there are certain congested conditions on some railroads, and especially some of the foreign lines, where it is almost impossible to extend terminal facilities, which call for electric operation. But, as I stated at the general meeting of the Congress the other day, I think that a great deal of the money which may be available to a trunk-line system would be often spent in protecting its territory rather than changing equipment.

When the electric railroad was first introduced, of course everybody sought franchises. Many people got them, and, as usual in this country, at a very low cost. They have often pre-empted the territory parallel to steam railroads, have created a business of their own, and are in position to divert business from the steam roads. As such they are commercial propositions which can very easily be investigated, and no one should be better qualified to investigate these propositions than the steam railroad owners and managers. If I had a railway running between two points, with termini and roadbed well established, and somebody built a road alongside of me,— it matters not whether steam or electric,— and created a special business besides diverting my traffic, I would, if I could on fair terms, get control of it. I would not try to duplicate a special traffic on a system that was not fitted for it. And so I think that the policy which I see by the public press is being more or less adopted by the New York Central and some other railroads of buying up properties adjacent to them, which cannot be duplicated and which have already created business of their own, is one which, commercially speaking, is by long odds one of the best things the trunk line management can do.

In foreign countries, where there is not that freedom of granting franchises, and where the local conditions do not permit quite that interurban service that we have here, necessity dictated by competition is of course less, but the congestion of roads that terminate in cities like London is creating special conditions calling for a change of equipment.

A good many people, noting that the Pennsylvania and the New York Central systems are adopting electricity in New York, have jumped to the conclusion that this meant the end of steam on trunk lines. It distinctly does not. The Pennsylvania road had to get into the city of New York and connect through to New England and Long Island. There was no possible way save to go underground, and the only way they could then handle their trains successfully was by electricity, irrespective of cost — that was a matter of secondary consideration. It does not follow that the Pennsylvania is going to extend electricity on all its trunk lines, and it won't do it for a good many years.

The New York Central is somewhat similarly situated. It enters New York city through a tunnel. A terrible disaster in which a number of people lost their lives focussed upon the road an expression of public opinion which could not be answered except in one way — prompt assent to legislation that steam road power should be abandoned; and when the determination was made to abandon it, it could not be limited in territory to that required by law. To make this clear I will repeat details given at another session. Most of you know that Manhattan proper is bounded on the north by the Harlem river, only a few miles from the main terminal at Forty-second Street. Some distance above this the trains of the main and Harlem divisions, as well as the trains of the New York, New Haven & Hartford lines, converge, and come into the main station over the New York & Harlem Railroad. It was simply impossible to stop equipment on this stem. Furthermore, in adopting electricity it was also important to consider not only the requirements of the law but the effect upon suburban service, and also upon the general service in the same territory. The territory to be at present operated and the system to be adopted were matters of grave debate. The propositions made by the various companies, which included both continuous and alternating-current work, had to be carefully considered. The great expense of electrification beyond the actual legal requirement, at a time when all railway properties were at a low ebb in their finances, was a serious one, so we finally settled it something after this fashion: The law said: "You must abandon steam." The alternative of course was electricity. "You must go beyond the tunnel." Going beyond the tunnel took us to the neck of a bottle, and we had to get out of it. Suburban lines were being electrified, and outlying competition was ahead. Great elevated and underground railroads existed, and the possible relation of their traffic to that of the Central must be considered. So we decided that in the first place we would have to go above the Harlem river somewhere, and then came the question of location of terminals; and these had to be considered with relation to the balance of the traffic of the railroad — long distance as well as suburban traffic,— and also in connection with property and geographical conditions.

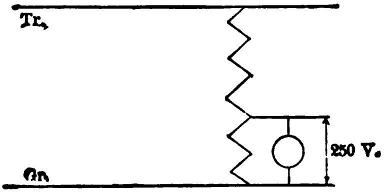
It was finally decided that all suburban service within a radius of an hour's run from New York, this, fortunately corresponding to the best terminal possibilities, should be made electric; and when that was decided it was only reasonable to abandon the idea of maintaining two services and three sets of terminals on the same tracks in the same territory, and logic required that all through trains within that district should be likewise handled in the same manner.

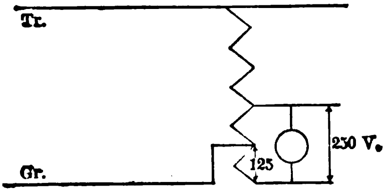
The two problems were somewhat different, of course. The result was finally an agreement that for a distance of about twenty-five miles on the Harlem division, and for about thirty-five miles on the main line, electricity should be used. And these decisions, let me say, gentlemen, have no bearing whatever upon what may be done beyond these points in the future; nor will anything that is done in the future, nor any development which takes place alter in my mind the wisdom of the decision which has already been made. In fact, no other decision was practicable at the time. There was not a company in the world prepared at that time to do anything else than supply continuous-current motors to perform the service which would be required by a road where 700 train movements a day must be maintained without excuse, delay, or explanation.

Secretary Armstrong: Mr. Sprague touched on one point to which I would like to call attention to, and that is the safety on an ordinary tram car having a potential on its trolley of 2000 volts or more, and I would ask Mr. Lamme or Mr. Lincoln if they have anything to say in connection with this point.

Mr. Lamme: There are several points brought up in Mr. Sprague's discussion of this subject on which I would like to speak further. He intimates that in a number of ways the direct-current motor will always be superior to the alternating-current motor. There is one point in which the alternating-current motor will be superior to the direct-current motor, and that is in the voltage which can be utilized directly on the motor. The direct-current railway motor will always necessarily be a high-voltage machine. We cannot use 200 or 250 volts advantageously on railway service with direct-current motors, but we can use it on the alternating motors, because with the alternating current we have a simple means of transforming the voltage from that supplied by the trolley to whatever is necessary for the motors. The high voltage on the direct-current railway motor is a source of weakness in practice, and in this particular point the alternating-current motor wound for low voltage will be superior.

"There is a second point of superiority in the use of such motors when operated from a transformer on the car, viz., by means of a certain arrangement of the taps on the transformer, we can reduce the maximum voltage from the motor to the ground to one-half that used on the motor. For example let us consider an arrangement of transformer and motor as illustrated in diagram No. 1. Connecting a 250-volt motor across the secondary of this transformer we get from motor to ground a maximum stress of 250 volts; but if the ground terminal of the transformer is tapped at a point midway between the two secondary terminals, as illustrated in the second diagram, then we get 125 volts maximum to the





ground. With this arrangement with two motors in series for 500 volts, we would get 250 volts to the ground instead of 500 as with direct current. This illustrates one of the advantages which can be obtained by the alternating-current motor over the direct-current, and it will serve to eliminate considerable trouble due to break-down of the insulation on the motor.

In regard to the difficulties which we will find in the development of the single-phase alternating-current system, I would say that we are not starting in under the same conditions as Mr. Sprague encountered in his Richmond line and his other early roads. At that time comparatively nothing was known about proper designs of railway apparatus and there was practically no experience to fall back upon. But the alternating motor now comes at a time when we have had many years of experience in electric railway work, and this is going to make a great difference in the development of the single-phase system. If, for example, in 1887 or 1888, we had undertaken the design of the large alternators of the Manhattan system of New York city, we would have had an undertaking which it would have been practically impossible to carry through at that date. But at the present time we are ready and willing to undertake generating machinery of much greater difficulty than the Manhattan generators. In the same way, the alternating-current motor now comes at a time when we have had all these years of experience on railway work, and we will be able to avoid a great many difficulties which developed in the direct-current railway system and which took years of experience to find out and eliminate.

As to the question of danger from high-tension trolley lines, I think it will be found to be true that there would be a greater possibility of open circuits and of shocks on a 250-volt direct-current railway circuit, for instance, than from a 500-volt circuit, because the higher voltage is more liable to break through from the car to the ground and thus ground the frame of the car. With 2000 or 3000 volts, I think it will be almost impossible to break the circuit between the frame of the car and the ground, because such voltages will spark through any ordinary separating or insulating medium on the track, and thus close the circuit. In other words, the higher the voltage from trolley to ground, the less liable is the circuit to be opened between the car and the ground.

There is one point which has not been brought out before in these discussions, which may have important bearing on the application of alternating-current motors to city work. A statement was made, in one of the discussions, that the cities would probably maintain direct current for their service, and that the field of the alternating-current motor would be in suburban service. If you look at only one part of the problem that might appear to be true, but there are certain conditions which may be of great future importance in deciding this question. One of these features, of which nothing has been said in these discussions, and which may have a great deal of influence some day, is the question of electrolysis. This question has come up in a number of cases and we know that railway people are thinking about it. It may be a serious question some day in the cities. We have made some elaborate tests to determine the electrolytic action of alternating currents, and while these tests have shown that the alternating current has a slight action, yet in general, with the same current it was found to be less than 1 per cent of that of the direct current. This feature may have a controlling influence in the adoption of alternating-current motors for city work. I know that in certain European cities this matter is coming forward rapidly and certain European engineers have told us that they will be obliged to adopt alternating current on their railway lines within a comparatively short time on account of difficulties from electrolysis with their direct-current systems.

It has been mentioned that the character of the load on an alternating-current railway system is different from that of the direct-current system. It is different in several ways. The proportion of load in the power-house will differ from that of the direct-current system, because in starting and accelerating, the load will be to a certain extent inductive, which represents no energy. This inductive element, while not representing energy, does represent torque. Therefore in starting and at low-speeds while accelerating, a considerable proportion of the current supplied to the car represents no energy and, therefore, represents no energy load on the power station. In this feature, the single-phase system resembles the present locomotive system in taking least power at start, with the amount of power increasing as the speed increases. If there were no losses in the motor itself and the control system, then the car would start with zero energy, and the energy consumed would rise proportional to the power actually consumed in accelerating and driving the car. This would be true only when potential control is used and all rheostats are omitted.

This inductive load taken by the motors at start will have very much the same effect on the alternating-current generators as if an energy load were carried, but represents an extremely small additional power required to drive the generator. This load also has an effect on the regulation of the generators. But experience has shown that this regulation can be taken care of very readily by means of voltage regulators in the generating plant. Such voltage regulators are very satisfactory for railway service and can operate sufficiently rapidly to hold an average constant potential, although it may not be exactly constant; but in general the regulator will maintain as good regulation at the generator as is obtained in direct-current railway service by means of the series coils.

On the question of polyphase motors for railway service, it has been brought out repeatedly before the American Institute of Electrical Engineers, that American engineers do not consider, and have not considered, the polyphase motor a satisfactory one for railway service, largely on account of the characteristics of the motor itself, and also on account of the two overhead conductors. A European engineer told me some time ago that he had made a careful investigation of the question of polyphase railways in Europe. He stated that in some of the railways where a single trolley was used with two wheels or rollers, the question of keeping the two overhead conductors exactly parallel to each other seemed to him to be an almost insurmountable difficulty, and that while it was being done in a number of instances, he did not consider it practical, and he would not have any arrangement that required as much careful adjustment as is required in these cases. This man was a mechanical engineer rather than electrical, and his criticisms were mostly on the mechanical construction. I have had no experience myself with such an arrangement, but it seems to me that with two overhead trolley wires it would be advisable to have two trolley poles with independent movement. I do not believe that the polyphase system will ever come into extensive use in this country, as the characteristics of the motors themselves will prohibit it.

In connection with the use of the single-phase alternating current on heavy railway service, I happen to know that in the case of some of the larger railways in this country, many of the engineers are fully convinced that they will be obliged to transform their roads to the electric system in a very few years' time, and many of them believe that an alternating system will be adopted. The Pennsylvania Railroad Company adopted direct current for their New York terminal, but a number of their engineers are not sure whether they have done the right thing in adopting direct current. They have adopted direct current for very much the same reason as given by Mr. Sprague in the case of the New York Central, viz., it was something which has been tried and proved to be operative. Nevertheless, a number of these engineers feel that by the time the direct-current system is completely installed on the New York terminus, they will find they should have adopted the alternating system. But they are in the same position as a number of the street railways many years ago in regard to the use of the cable system instead of the electric system; in some instances the cable system was adopted, as it was known to be an operative one, while at the same time the engineers felt that the cable system would have to be taken out in a very few years' time. It has been cited, in the adoption of direct current on the above-named steam roads, that as it proved an advisable method to install the cable system, even with the expectation of throwing it out later, so will it prove to be advisable to install direct current on the railway terminals with the expectation of changing later to the alternating. As stated before, many of the engineers are satisfied they will throw out the direct current before many years, and they recognize that a fundamental reason for making the change will appear when they begin to extend their system, and they see, before the terminal system is in entire operation, that the advisability for extension must be considered.

Mr. E. Kilburn Scott: I think that the question of working main lines and suburban lines we will have to settle from the standpoint of the ordinary mechanical locomotive engineer, and I cannot conceive of ten of those men being brought in front of a three-phase motor on the one hand and a single-phase motor on the other, with a commutator, or a direct motor, not seeing or think that the three-phase motor was the thing. That kind of man has more respect for the three-phase than we have. We have seen it grow from a crude apparatus to the perfect piece of work, but it seems to me it is very complicated, and I cannot conceive for a moment of the ordinary mechanical engineers considering the commutator machine. The thing that will decide them in England will be absolute simplicity of apparatus and safety of human life, and on the question of simplicity, the three-phase motor without any commutator it seems to me has the advantage.

On the question of human life, while we have got the three-wire system, it has come over to us with the commutator and we do not like it. We would rather have less efficiency and a more stable machine. Regarding the third rail, we have it as I say — what we call experimenting with it. That is about as far as we go, because I am sure if we kill off very many men on the Northwestern Road there will be such an outcry in the papers that we will have to give it up. Because we consider human life. In our country, we do not have what I see here and which it amazes me to see, we do not have railway lines running along streets with only level crossings. We do not have railway trains running over surface tramway lines. We do not have that; so we do not have that problem regarding the combination of single-phase and direct currents.

Now, take the three-phase motor again. I raised this point the other day and it was not answered. In a single-phase motor surely you have the current going to maximum and back to zero again and again to maximum. It seems to me if you had to take a fair test, say a locomotive equipped with the three-phase motor and one equipped with the single-phase and commutator, it seems to me, to draw a certain train of a certain weight, say ten tons, you would require a heavier locomotive in the case of the single-phase than you would in the three-phase. I have not that answer. Suppose it was five to one, the usual ratio, that is to say, ten would require a fifty-ton locomotive, a fifty-ton three-phase locomotive draws this. I think if it were equipped with a single-phase commutator it would have great difficulty.

Suppose you are on a steep grade, the brakes are down. You know when you start your steam locomotive you release your brake. Now, suppose the train was very heavy and suppose the train brakes did not come off, wouldn't this be the condition of the single-phase commutator motor? It would be standing still and would have full voltage and full current in the motor, the armature would be going as a static transformer, and the coils underneath the brushes being on short-circuit. Wouldn't you get breakages of the current through those brushes?

We used to make a single-phase commutator motor, and we struggled for nearly a year, but threw it out, because — we used to make it go all right, and then some person would tack it onto a very heavy machine that wouldn't start and try to get a short-circuit through those coils underneath those brushes, and the thing would burn out. And we couldn't go on like this, and we couldn't make a single-phase motor that would work, and don't make them for actual work.

In regard to variation of speed, we hear a great deal about variation of speed and control and arrest and all that. Now, if I want a machine, a motor to drive a Hoe printing press, where I want the machine to go very, very slowly, to get the thing in shape to start I go to Mr. Leonard, I buy one of his apparatus and I have a thing that will crawl, and under certain conditions run to speed. But we do not want a train to go slowly, and we are compelled to rely on the three-phase motor in the operation of trains.

Now, in regard to copper, this of course is a difficulty. We have the two arms as against the single wire, but if you take a high tension system like the Oerlikon, it uses three wires. There is one more wire in that, but isn't that a very condition where you have to give something in order to obtain results? Isn't this the case, that you have a certain amount of bare wire overhead, or a certain amount of insulated wire underground? Now then, if you have a system which calls for more wire overhead, certainly you are better off. You have much less wire underground and it is the insulated wire that runs away with the money.

Then looking at it from the point of the crossings, and that sort of thing. I know that you claim in the three-phase there is danger in the wires going over; but I think on nearly all of these surface systems we are talking about there are ways of protecting all these difficult crossings. If you want to give a speed of eighty or ninety miles an hour you cannot have curves. We cannot run on our present tracks eighty or ninety miles an hour. The inclination of the rails on some curves would be so great that if a train stopped on that particular point it would topple over. We shall have to straighten out our tracks and take away those difficult crossings before we can run that speed. Then you see all the objections to the three-phase disappear.

Anyway, there is this point in favor of the three-phase as against the single: That is, if you have a three-phase and one of them breaks down, you have a reserve in the system. If you have a single-phase and it breaks down it is gone, and if you have another single-phase you have got to switch it in or leave it in all the time, but as I say, if you have a three-phase system and one of them breaks down, the other two carry the load.

Regarding loss of time in shifting, owing to the fact that you are running with a three-phase motor with alternating currents, the traffic superintendent knows that that train is going to go along that track at a certain speed. It may have a greater speed going up an incline, but the fact he knows that that driver must run across the track. Being driven by a three-phase motor is an advantage I think in traffic work. Suppose the train got behind time, and to make that up of course the three-phase motor can make over-speed, and the traffic people I have spoken to about it — steam locomotive traffic people — don't see much trouble there.

At any rate, in this matter I really think that although there has been a great deal said here about single-phase, because the two big companies in this country decide on single-phase, it does not settle the question. There is a good deal to be said on the other side. Dr. Steinmetz said that our three-phase systems in Europe were on a level not far from perfection, and every company has received permission, or, rather, been asked by the government, to extend their lines. Do you think the Italian government would have asked the Ganz Company to extend that line unless it was a magnificent success? It is a magnificent success.

Mr. H. Ward Leonard: For thirteen years I have urged, and I wish to urge once more, an electric railway system having the features which characterize the system identified with my name: First, single-phase high-tension generation, transmission, and conduction by moving contact upon the train. Second, means on the train for deriving in a local, separate, insulated working circuit a current of lower voltage which is supplied to the propelling motors. Third, means on the train for varying from zero to the maximum, and without waste energy, the working electromotive force in the local circuit. I think I am safe in saying that nearly all modern single-phase systems have these essential features.

For passenger service, and for light freight and express service, the variable-speed single-phase alternating-current motor may be found sufficiently satisfactory, but for the heaviest freight service I am more confident than ever before that it will be necessary to transform upon the train the single-phase energy into continuous-current, variable-voltage energy and supply it to direct-current propelling motors, as I have urged continuously since 1891.

As a large number of engineers who are attending here have asked me as to the progress that I am making with this system of mine, I will mention some points in connection with it. I first publicly described this system in a patent in 1891, and I read a paper entitled "How Shall We Operate an Electric Railway Extending 100 Miles from the Power Station" in 1894 before the American Institute of Electrical Engineers. The first recognition of the system came from Col. Crompton, who in his presidential address before the Institution of Electrical Engineers of Great Britain, in 1895, I think, predicted that it had features which would give it great importance in electric traction work. Mr. Huber of the Oerlikon Company, in 1902, and Mr. Mordey of Great Britain in 1902, after analyzing the traction problem carefully, concluded that this system was the only one that had been proposed which gave commercial promise. The Oerlikon Company took a license under my patents in 1902, and proceeded to construct a locomotive which since then has been tested.

In 1902 the celebrated engineer of Sweden, Dahlander, as the head of a commission appointed by the Crown to investigate the question whether electric traction could supplant steam traction on 3,000 miles of railway owned by the government of Sweden, after giving careful consideration to the matter, first eliminated the continuous current for transmission; and second eliminated all but single-phase alternating current for transmission; and finally, after considering the systems that had been proposed to that date, reported in favor of my system. And after giving consideration to the cost of installation and of maintenance and of depreciation and operation, and after providing a sinking fund at the rate of 3 per cent per annum to retire the bonds which would be issued therefor, thus retiring the first cost of investment in thirty-three years, they concluded that my system would show a saving to the government of Sweden of $2,000,000 per annum over existing methods of operation by steam. This is the same system, I may say, that the General Electric Company had reported upon by three engineers twelve years ago, and each of the three engineers condemned the system, and each for a different reason.

The first engineer condemned it on the score that the transmission and utilization of single-phase alternating-current energy at any such voltage as I proposed — which was from 10,000 to 20,000 volts — was absurd and beyond consideration. The second engineer decided that I evidently had given no consideration to the question of sparking, and that it was utterly impossible to operate a system such as I proposed on account of the disastrous sparking. The third engineer reported that I evidently intended to use some very complex mechanism in restoration of energy into the line, and nothing but the use of very complex mechanism would enable me to restore the energy into the line, and, therefore, that this feature was without real value.

As to the application of this system which may have a bearing upon its possibilities for railways, I may say it has been operated successfully in a number of instances upon elevators since 1891 with the most striking freedom from depreciation and a most striking reliability in service, and a perfection of control in starting and making a landing, which is so important in elevator service.

In 1893, I think it was, the Heilman locomotives made use of this system of mine, and although the Heilman locomotive, on account of its enormous weight, proved a failure, it demonstrated that a locomotive of that size could be operated, and was operated, with perfectly satisfactory results as regards control and performance of the commutator for the large generator necessary for such a large locomotive.

About 1893, this system was first installed upon the turrets of the United States Navy, and to-day no other system is used for the operation of turrets in our navy. Great Britain has quite recently decided to try it; it has been recently installed upon a British battle-ship "The Terrible." Those turrets are, I think, quite comparable with the service which is to be expected in the handling of heavy freight trains. One of these turrets weighs 600 tons. It has to be accelerated, controlled, retarded and reversed, and that enormous mass is a thing which presents the greatest difficulty in handling, and the system has given perfect satisfaction and no other system has been employed.

The moving platform at the Paris Exposition probably represents the largest mass which has ever been accelerated and handled and controlled, under single control, by electricity, and that moving platform employed my system of control. It weighed about 3600 tons. It was practically equivalent to a freight train upon a level track with a very great number of curves. It had to be brought to full stop and run at full speed, and it was accelerated every day. Now, in the case of that moving platform, there was a clear demonstration of the fact that a freight train with my system, not only from theory, but from actual current and voltage readings, would be and could be in practice brought from rest to full speed with an amount of energy which under no conditions would be greater than the energy required at full speed. The watts during the period of acceleration were always less than the watts at full speed. I repeatedly took the readings at the installation and have those figures for anybody who is interested.

Other applications that have been made since then are automatic pumping, to maintain certain definite pressure — the rate of pumping being automatically governed by the work performed; electric automobiles, in which the source of power is a gasoline engine on board with my system for the transmission; electric trains such as are now being operated at England in which my system is employed for electric transmission from a gas engine on the train; and one of the finest, if not perhaps the finest building in New York city, the *Times Building*, is now about to start in operation with my system as applied to high-speed passenger elevators.

The Oerlikon locomotive, which was tested in May, 1904, this present year, of course represents the thing which is most pertinent. In that locomotive, the transmission line employs single-phase 14,000 volts; the entire control is by means of one lever, in starting, stopping, reversing, braking, etc. That locomotive was tested in the presence of a large number of engineers, and a great many engineers from this country received invitations to be present at the trial. The locomotive was tested to a point — and I don't know but further, but I do know it was tested as far as this — that the current in the secondary circuit was double the normal current of the rated horse-power. That is, that amount of current was available without any difficulty whatever as regards commutation.

In this connection, I wish to speak of the weight and cost of the motor generator by comparison with the weight and cost of the necessary motor generator for the sub-station. I wish to point out that in my system the motor generator has to provide only the power sufficient for the movement of the train upon which it is located. It is not necessary, as in the case of sub-stations, to provide, for emergency purposes, several times as much capacity in the converter as the average service would require.

Mr. Sprague incidentally mentioned in discussing another paper, the other day, the probable necessity in the case of the New York Central of installing storage batteries in order that he might get a fairly uniform load upon the sub-stations, as there was a probability at all times of there being four trains in a section to be supplied by a sub-station, and at other times no train. This I think will emphasize clearly the importance of having the energy transformer on the train, where it can be all the time loaded and operated at a good load-factor, and where the first cost will not have to be several times as much as that required by the average demand.

The well-known difficulty of controlling large motors by opening circuits carrying the energy of perhaps 1000 horse-power is going to increase very rapidly as the amount of the power increases. There is some difficulty in opening a circuit of 100 watts; it is worse at 1000 and much worse at 100,000, and it becomes more and more difficult as you go up. And I am not surprised to notice that the best engineers in the various countries are to-day attempting to avoid that difficulty and secure the speed control by voltage control rather than by opening circuits and adjustments of circuits and resistances.

Another point that is of great importance in this connection is the multiple control of a number of units; and here again we meet with great difficulty in attempting to open these circuits. We also meet with great difficulties due to the size of the conductors that must be carried along the train to carry a working current to the motors distributed through a long train. In the case of my system the size of the wires will be determined by the current which the field only has to carry.

There will be three wires that carry only field current, and there will be no automatic switches and no control of controllers.

The restoration of energy is a matter which is as old, almost, as the art, in discussions. So far as I am aware my system is the only one which does restore energy from the condition of full speed to the condition of rest. And I wish to emphasize the point that of course it becomes necessary that we have an energy transformation in order that we can take advantage of the energy of retardation, while it is falling from maximum to minimum, and continue to transform that energy into electric energy having a voltage sufficiently high to force energy into the line. A point of the greatest importance in all of these problems is the frequency. In order to make a commercial single-phase alternating-current motor, we are being driven step by step to lower and lower frequencies. We all know the disadvantages of low frequencies for lighting purposes. A comprehensive system generating a form of energy which can be used for all classes of light and power is of the greatest importance.

This Oerlikon locomotive is the first single-phase locomotive which has been designed for standard railway service, and the condition of the matter now stands in this way: It has been approved by the government of Switzerland, which has tested it, and authority has been given to the Oerlikon works to extend this system to the first section of the line which is to be equipped.

I appreciate fully the fact that a combination of patents and policy is always likely to make inertia in this country, and the General Electric and the Westinghouse companies, so far as concerns patents and as concerns electric railway policy, are practically in combination. It is the greatest difficulty for engineers of this country to receive any consideration for a railway system which is going to affect the existing policy as regards patents and business methods. And that is the reason, which no doubt many of the foreigners are very much surprised to note, that my system is considered favorably by leading engineers of Sweden, Switzerland, Great Britain, and France, and yet is not used in this country. The query is naturally made, if this system has any merit, why isn't it used in America? I think you have the answer in my remarks as to the inertia of a combination of patents and policy of such overwhelming size in any one country.

Of course, this is again an explanation of why the General Electric Company and the Westinghouse Company are so desirous of securing a motor, notwithstanding its immense disadvantages as to control, which has the one advantage that they can go to their former customers who have bought from them 500,000 kilowatts already installed, and say to them that their past assurances as to the permanency of the investment they have made can be realized. I can imagine that it would be rather embarrassing for a salesman to meet a gentleman whom last year and year before they had assured that if they bought the three-phase transmission and rotary with sub-station and series-parallel control of the series motor, that it was unalterable as far as they could see, absolutely permanent, and as good an investment as a gold dollar,— to have to go to these same investors two years later and say that system is all absolutely wrong, and that the real thing is the single-phase transmission, transformation to lower voltage in a local circuit on the car, and a voltage speed control instead of the series-parallel control.

Naturally this would be a very embarrassing situation from a commercial standpoint,— and they don't say that.

What they do say is "We have devised a system which will enable you to operate with either alternate or continuous current in the same motor and this has the advantage that you can use the 500,000 kilowatts capacity that you have already paid us for."

Now, that, of course, is very good business on the part of the General Electric and Westinghouse, and I am not criticising them in any way as to their business policy. I am merely indicating that the existing patent combination naturally interferes with the development and use of the best ideas. I need hardly say that had Mr. Huber been in the employ of either of the principal companies of this country, my system would not be installed now.

As to some remarks made by Mr. Sprague, I should like to touch on one or two points. Of course, I need hardly say I believe absolutely in the single-phase transmission. But I agree with Mr. Sprague that forever the direct-current motor will be superior to the alternating, and I represent both of these ideas in combination. Reliability, which he has emphasized, is, I agree with him, of the utmost importance; and in that connection I wish to point out that there probably is nothing electrically operated in the world in which reliability is of such great importance as the turrets on the battle-ships. No matter what the system might have in other regards in the way of advantages, if it were not absolutely reliable, or as nearly so as such things can be expected to be, it would have no chance whatever of being used. Reliability is the first factor in the control of those turrets.

Another point Mr. Sprague has commented on is one that I agree with him is of great importance, and that is the protection of the people in the train again the possibilities of danger from the high voltage, due to any kind of break-down or due to any leakage between the transmission circuit and the train circuit. And in that connection I wish to point out that the high-tension current on my system goes into the motor end of a motor-generator which is an entirely separate and distinct unit, that it is electrically and mechanically separate and insulated; and this is very different from a case in which the high-tension circuit is placed in as close proximity to the working circuit as the ordinary insulation of a static transformer would put it.

In the case of the Oerlikon Company installation, they employed a moving contact at the rail in addition to the overhead one, with the idea of insuring complete safety at that point in case any difficulty should arise as regards contact at the wheel, but the necessity of that may be open to debate. I am inclined to agree with Mr. Lamme,— that the higher the voltage the more certainty there will be that the contact will be preserved at the ground. Therefore, I think that the thing that needs to be protected most is the working circuit on the train, and that we ought to keep that as separate as we can keep it, and not get it as close as we can, with only a thin layer of insulation between it and the transmission circuit of high pressure.

On one point I am quite at variance in my opinion with Mr. Sprague. He said he did not think the Pennsylvania Railway would during the life of most of us extend electric traction on its line beyond the New York tunnel plant. In that I cannot agree with him. I have nothing more than my faith in the future of electric traction systems to justify my opinion — I don't know any Pennsylvania Railway engineer's opinion on the subject. I am merely banking on electric energy and electric engineering.

Mr. Lamme has emphazed the importance of low voltage in the motors, but he made the error of saying that we could not have direct-current motors for railway traction without having rather high-tension in the secondary circuit. Of course, in my system while securing the advantages of high-tension transmission the advantages of the low voltage in the motor circuit can be fully realized.

On the subject of electrolysis, I agree with Mr. Lamme. It is one of great importance and is going to cut a great figure in electric-railway work in the future, and of course in that regard my system has the advantages that are common to all alternating systems.

Referring to what Mr. Scott said about the crawling motor, and how if he wanted the motor to crawl he would use my system, but if he wanted full speed in addition to crawling he would use the three-phase motor. I want to say that the General Electric has three-phase currents and motors at their command and are no doubt as competent to handle them as are engineers abroad. In large central stations, in which one of the most important points is to have a *coal* hoist which will hoist the coal reliably night and day, they do not use the three-phase current, which could be used for such purposes, and which I should judge from Mr. Scott's remarks he would consider eminently suitable and superior to my system; but, on the contrary, with the three-phase currents right there, they do install a motor generator and my system for driving the hoist, because it does give superiority of control and reliability in service.

CHAIRMAN DUNCAN: May I ask that discussions be limited to ten minutes, please.

MR. B. J. ARNOLD: I am going to try and avoid saying anything about my own system this morning — not that I am ashamed of it, because I am very proud of what has been done with it as a pioneer in single-phase work, regardless of its merits. I do not know what my friend Sprague said before I came in, but I do not know that if it were not for the fact that he remains young so long in appearance I would say that his ideas of late years are quite what we might attribute to a gray-headed man — but he has not turned gray fast enough to justify it. But I do know that the atmosphere he has been in the last two or three years has put a certain conservatism into him which is very admirable, but we cannot get him away from the direct-current system quite as rapidly as I had hoped. However, he has maintained a consistent position on the matter and presents the merits of the single-phase as strongly as he feels they can now be advocated.

Mr. Lamme's point on the low voltage question I can see nothing in because I do not see but that we are getting along very well with 500 volts with direct motors, even 600 or 700 volts, and I have seen no difficulty in using alternate-current motors working at as high pressures. I think his position must be due to the fact that there is some other reason for using low voltage, due probably to the method of control or something else which he has not made clear. I am not able in the time at my disposal to bring out all the technical points involved, but I cannot see anything in the argument, and there is a certain disadvantage to it with the systems that are in use, because you must make and break this low voltage current, which is objectionable. There are certain elements both ways: You can make and break too high; you can make and break too low voltage.

I am going to call on Dr. Steinmetz to bring out some other points after I get through. The point made by Mr. Scott about the fact that it is a real advantage to the train despatcher to have railroad trains that run at a certain rate of speed and cannot run any faster, I think that is a very poor railroad, and if we had an association of train dispatchers here I think they could answer the argument much better than I can. It seems absurd to me to say that we do not want railroad trains to run high speeds, when we do want it because there are necessities for it.

Mr. Scott: You misunderstood me, sir.

Mr. Arnold: I do not mean to misrepresent you.

Mr. Scott: I said a certain railroad had its rolling stock equipped for certain speeds.

Mr. Arnold: That is what I said, and I do not misrepresent you. I understand you to say you thought it desirable to have a constant speed.

Mr. Scott: If there were people that wanted their rolling stock for certain speed, and wanted to run it higher of course they would not —

Mr. Arnold: In my judgment that is impractical railroading; however, I am only one individual.

I am a great believer in as much simplicity as you can yet, in spite of the fact that I have adopted complicated means to arrive at simplicity. But the system which will win is the most simple one and the one which costs the least money. And no matter what our present ideas are as to the merits of the various systems, that is the thing that will finally decide the question. And, therefore, I maintain that the two wires overhead and three-phase system are impractical for railroad work. We have got to have a single conductor, and if we could eliminate the conductor entirely we would be as nearly perfect as possible.

The other point is we have got to have pretty high voltage on our working conductor due to inductive loss in the rail. I have experimented with voltage as high as 6000 on the working conductor — and haven't killed any one yet, and hope not to. It has been tried by the parties I represent, as you know, as high as 15,000 volts, and I think it was tried in Mr. Leonard's locomotive, which so far as I can learn, has worked fairly successfully, and it seems to me the nearest approach to perfection of means for getting the energy on the train. Mr. Chairman, I am going to stop. I think I have used up my ten minutes.

Mr. **Henry Pikler**: Permit me to say a few words concerning this subject. I want to refer particularly to Mr. Steinmetz' discussion. Mr. Steinmetz gave us a very clear and concise description of the characteristics of the different alternating-current motor systems, and pointed out the advantages of one motor system above the other in the railroad service. The conclusions, however, which Mr. Steinmetz has arrived at I do not quite agree with. Mr. Steinmetz treated the polyphase induction motor rather step-motherly, and I think he called it an unsuccessful attempt. From this statement it appears that Mr. Steinmetz does not want to recognize the fact that such railroad systems are in a very satisfactory condition of operation. I refer especially to the Valtellina three-phase railroad, designed by the Ganz Company of Budapest, the experiments of the Siemens & Halske Company, and similar work of the Brown-Boveri Company. Of course, nobody will think of using polyphase induction motors for street-car service where stops are frequent. That disadvantage of the polyphase induction motor, that its torque decreases with the square of the proportional decrease of the impressed e.m.f., disappears when the central station and sub-stations are reasonably designed and equipped.

As to the variation in the speed for such railways, I think two variations — that is, the highest speed and the half speed — are entirely satisfactory. Half speed may be obtained either by concatenated operation of two motors or by changing the number of poles as has been done by the Brown-Boveri Company.

These, however, are general points in comparison with other motor systems, but if we would go into the details of design, performance and manufacture of the motors and the whole railroad equipment we find so many points in favor of the polyphase induction motor that it makes it much more desirable than any of the present systems for that purpose. The polyphase railway system of Valtellina Railway in Italy was so satisfactory in service that the Italian company accepted the entire equipment before the expiration of the test period. Discussion or hasty experiments will not prove the advantage or disadvantage of one system or the other, the future and long service in actual operation will effect the natural selection of the best system.

Mr. **A. H. Armstrong**: I want to give two or three historical facts connected with three-phase motor work in this country. The General Electric Company has had, from time to time, a large number of problems submitted to it in connection with railway work upon which they were supposed to pass their best judgment in regard to motive power. Some of those problems were so extensive and called for such peculiar treatment that the direct-current motor failed to serve the purpose in every case and some form of alternate motor was necessary. Up to within the last year or two, the three-phase induction motor was the only type that could be considered, and we have unsuccessfully tried tor the past ten years to adapt a constant-speed limited-output three-phase motor to railway conditions.

The chief objection to its use has been its constant speed characteristic, which would make the locomotive or car attempt to go up a ten per cent grade at the same speed at which it operated on a level,—the restricted output of the motors themselves, which, together with their poor power-factor, made the system expensive to install and operate.

Most of our suburban railways have a very irregular profile, ranging from a level track to 4 or 5 per cent grade, and in such cases the motive power must be designed to haul the car or train on the maximum grade, and still operate efficiently on level track. A 5 per cent grade will require a tractive effort of 110 lbs. per ton or more, while a level track will require twenty lbs. or more; thus the motor may be called upon to deliver five or six times its normal torque when operating on maximum grade. Furthermore, the torque of the induction motor varies as the square of the line potential, and must have sufficient margin to take care of the fluctuations in trolley potential which will occur in a commercial railway system. Giving due recognition to the fact, further, that the motor and distributing system all operate at a poor power-factor, it becomes necessary under the conditions of commercial operation to design the induction motor for such a large maximum torque that it will operate normally at a small percentage of its maximum output, with consequent poor constants.

The variable-speed motor, of which the commutator motor is the best type, is especially adapted to railway work, because it embodies most of the characteristics wherein the three-phase motor is deficient. It is a variable-speed motor, and follows the footsteps of the direct-current motor, which has proved itself well able to take care of general traction problems. Its output is unlimited, in a railway sense; that is, the motor can slip its wheels, which is all that is required; and its general speed characteristics, being of a variable-speed nature, are well adapted to the fundamental requirements, not only of suburban, but also of main-line high-speed railways.

I believe that the company which I represent have been justified in passing over the three-phase motor as not being adapted to general railway conditions, and were wise in waiting until a motor had been developed which embodied more of the good characteristics of the direct-current series motor.

Mr. B. G. **Lamme**: I wish to add something to Mr. Leonard's remarks in regard to the Swedish railway problem. Mr. Dahlander, the Swedish engineer mentioned by Mr. Leonard, made a report to the Swedish government on the question of electrification of the Swedish railways, and in this report, if my memory serves me right, the system which showed the least cost was the Westinghouse single-phase system, but it was considered to new and untried to be recommended. That was about two years ago. Since that time Mr. Dahlander visited this country, and among other places he visited the Westinghouse works at East Pittsburg and saw the Westinghouse system in operation. He evidently reported favorably on his return to Sweden, for since that time an electric locomotive has been ordered from the Westinghouse Company by the Swedish Government. This locomotive is to be equipped with single-phase motors of a frequency of twenty-five cycles per second, with a maximum voltage of 18,000 volts on the trolley line. The conditions are so arranged that different voltages can be tried on the trolley, with the maximum stated above. It is, therefore, evident that all of the European engineers do not favor the motor-generator locomotive system, as this order was placed after an investigation of all various systems proposed by the different companies. It may be noted that the Swedish Government has also placed orders with certain other companies for trial equipments, and in all cases these equipments comprise single-phase alternating-current commutator-type motors.

It has been suggested by Mr. Arnold that we did not adopt low voltage on the alternating-current motors in order to avoid danger of grounds, but that this voltage was used for other reasons. It was not my intention to give the impression that the voltages of 200 to 250 were chosen for this particular reason, but such voltages being fixed by features of design, there were compensating advantages. I intended to bring out that the motors being wound for 250 volts instead of 500 volts, our insulation stresses would necessarily be less than on the direct current.

Another point, which has not been brought out to any great extent, is the rail loss with alternating currents. In this country practically all rail work is being done at twenty-five cycles, and even at this low frequency, the rail loss is high. In some cases we have found it to be about four times as great as with corresponding direct current, while in other cases it was even higher. This means, of course, that relatively high alternating-current voltages are used on the trolley, or the alternating current should be fed into the track at more frequent intervals if high voltage is not used. Another way to reduce this loss will be by the adoption of lower frequency such as fifteen to twenty cycles per second, as is done on some of the European polyphase roads. This may be an important factor in fixing the frequency when it comes to equipping the large railroads electrically.

In connection with the European polyphase roads, I will mention that I visited a number of these some time ago, and the ones I saw were operated successfully in the sense that they were doing what they were planned to do. These roads did not possess the flexibility of operation that we are accustomed to in this country, and I was forced to the conclusion at the time that the reason they were considered successful was because there were no corresponding direct-current systems in the immediate neighborhood to furnish a comparison.

Mr. E. K. **Scott**: Two companies in Italy are running two lines.

Mr. **Lamme**: I did not see those lines.

Mr. E. K. **Scott**: The governments are preparing the statistics and have been doing so within the last year. They are within a few miles of each other.

Mr. **Lamme**: I did not see the Valtellina line. The data which we have prepared on the polyphase railway system in this country indicate that where polyphase motors are used for frequent starting and acceleration, they could not compare favorably with the direct-current system, even when arranged with the "tandem" or "concatenated" control. That fact was brought out I believe two or three years ago in a number of papers before the American Institute of Electrical Engineers.

Similar data has shown that the single-phase alternating-current system with frequent starting and acceleration is superior to the direct current in efficiency. The single-phase system is, therefore, superior to the direct-current system under the very conditions where the direct current is far superior to the polyphase system.

Mr. P. M. Lincoln: This matter of additional losses in the rails due to alternate currents has been cited as a very serious objection to the alternate-current system. I would like to say, however, in that connection I have figured over a good many different cases where alternate currents have been proposed, and compared the same with direct current. Under normal conditions, the alternate current with a thousand-volt trolley invariably gives a lesser loss in the rails than does the direct current at 500 volts,—due first to the considerably decreased current that the rail carries on account of the higher trolley voltage; and, second, to the closer supplying of sub-stations which can be allowed with alternate currents over direct.

A Member: You mean energy loss?

Mr. Lincoln: The energy loss is much less in the rail in the alternate current of 1000 volts than it is with 500 volts with the direct current.

Dr. Steinmetz: Gentlemen, the position which I take regarding the polyphase induction motor is not that such motors are not operative on railroads, but that the single-phase commutator motor is far superior, and the existence of polyphase railways shows that where you cannot use anything else, or believe you have nothing else, it can be made to work, after a fashion. It is not that we have not tried the polyphase induction railway motor in this country: since more than ten years we have been very energetically working on the polyphase induction railway motor, until we finally dropped it, only a couple of years ago, as hopelessly inferior for the general requirements of railroading, to the rotary-converter system with direct-current motors, and to the single-phase commutator motor. We have never built any induction motor railroad, though we have been hunting hard for a chance to do so, and were willing to build it without profit, but our engineers have really never been able to honestly recommend a customer to install induction motors, but even where conditions looked very favorable, closer investigation threw the balance decidedly in favor of the rotary converter system with direct-current motors.

Now, the rotary converter, which here in the States has been standard apparatus for ten years, is familiar to everybody, and known to be absolutely reliable, was practically unknown abroad until it was introduced from here, and is still viewed by some engineers abroad with some suspicion. Hence the necessity abroad, to make the induction motor go on railway cars, while here the converter permitted direct-current supply over unlimited distance, and, therefore, the question was not whether the induction motor can be used on railways, but whether it offers any advantage over the direct-current motor and converter system, and this question was answered decidedly in the negative.

The polyphase induction motor is a very beautiful apparatus when run at constant speed. But you cannot run it at more than one speed. It is possible to get half speed by concatenation, and, if anybody, I should be prejudiced in favor of this because I invented this method here in the United States. Mr. Görges simultaneously invented it abroad. Unfortunately, in concatenation the first motor carries the exciting current of both motors, and when using the very small air-gaps customary in induction motors, or the still smaller air-gaps our European friends use, the constants of the motor chain may still, if not good, at least not be hopelessly bad, especially at low frequency. But I have never been able to get a practical electric railway engineer even to consider such small air-gaps, and with the very smallest air-gaps mechanically permissible in railway motors, and the great limitations in space, especially in diameter, of railway motors, the constants of the motors in concatenation (or cascade connection) are usually hopelessly bad, so much so that two motors in concatenation may consume more current than both motors consume when giving the same torque in parallel connection. That cuts out this arrangement from further consideration.

The induction motor is well suited where you desire to go at a constant speed and load. This may be the case with a very high speed railway, where the torque required when running at full speed is of the magnitude of the starting torque. Then the question may be taken up again, but not under ordinary railway conditions.

Three-phase requires two wires, which is a nuisance and which is unendurable in a large railroad yard — where one wire or live rail is just one too many.

I desire to say one word regarding my friend Mr. Leonard. I can fully corroborate his statements on the beautiful control of speed and power given by his system. You are able thereby to start with powerful torque to run at any desired speed, run very slowly at constant speed, stop exactly where you desire to stop — in short, get a most beautiful control. And that is the reason why his system is used for the turrets of battle-ships, and to a certain extent in high-grade elevators.

But that is not the problem of the electric railway. What we want from the railway motor is to get away as quickly as possible, to run efficiently at high speed and at half speed. It is not necessary to run at any and every speed continuously. But what we want of the railway motor is to be as simple as possible; that is, to do the work with the least possible apparatus.

As regards efficiency of operation, if we look at the characteristics of the single-phase commutator motor, we will find that the whole range, from stand-still to full speed, is about one-quarter to one-sixteenth, in which, with rheostatic control, a resistance is used in the motor circuits, the rest is running on the motor curve; that is, at the highest possible efficiency, so that even in a service requiring very frequent starting, if we investigate the amount of power which could be saved by motor-generator control, it is so insignificant as not to warrant the complication. But from three-fourths to fifteen-sixteenths of the speed range, or during by far the greatest part of the time, Mr. Leonard's method must be decidedly inferior in efficiency, due to the constant losses in the motor-generator set (even if a very high-speed set), which a direct operation of the motor saves.

As regards the statement relating to the conservatism of large companies, I do not think I need to discuss that; but it is possible that a conference of impartial expert engineers does not always look at an invention quite as favorably as does the inventor himself.

To return to the railway induction motor, I had quite a considerable and variegated experience with it, and no doubt so did others. The first complete car equipment with two three-phase induction motors was in operation on the experimental track of the General Electric Company in 1894. It came to grief by our experimenting on a very short track which was used also by freight cars, in trying to show the powerful torque obtained by the motor brake, on reversing the motors. I believe my friend Armstrong was at the controller. Unfortunately one of the two trolleys came off, and the motor ran single-phase, without our knowing it (by the way, another early claim for single-phase railway operation), and a freight car happened to be a very short distance in front of our motor car — and you know what happens when an irresistible force meets an immovable body. Since then we have built several more equipments, but, as I stated before, we never have felt justified in recommending three-phase induction motors for railways.

Mr. F. J. **Sprague**: My friend Mr. Arnold — for whom no one has a higher affection than myself — would seemingly put me in the position of an opponent of the alternating-current motor, and suggests lack of virility for having enlisted too heatedly in the ranks of conservatism. As to this last, I am reminded that he has agreed with me on all the salient points of the New York Central equipment, and that we have a very harmonious board. The five gentlemen composing it have fought out their difficulties over the table, and come to a common conclusion, on which I, for one, am quite willing to stand.

So far as high potential is concerned, I am fully aware of all the economic facts achieved by its use, and I have been advocating it a good many years, starting with 600 volts in 1886. There is no one who has less antagonism than I to the development to perfection of the single-phase alternating-current motor, or any other. As engineers we hope to see it, and there are no men who will more completely welcome the perfect result after the diseases of the machine have been cured.

As to virility, it is possible that age, gray hairs and wrinkles are coming upon me, but if so they may tell of a good deal of hard work in the past twenty years, but I am still quite ready to assume any responsibility required by an engineer within the limits of technical risk and pocketbook. My gorge rose a bit when Mr. Leonard spoke of the multiple-unit system. For a long time I have been trying to hammer the definition of "multiple unit" into the electrical dictionary. It is not, as Mr. Leonard indicated, and as some of my other friends have described it, simply an assemblage of motors on different cars under common control. That is not necessarily a multiple-unit system — and I must beg to be allowed to speak authoritatively as to that, because, ungrammatical as the term is, I happened to be the one to coin it, and to use it for a specific purpose. It is simply intended to define a system of a plural control of a plurality of controllers by which a number of units can be assembled into a train, each unit being absolutely complete without any dependence upon or relation to any other except so far as relates to control of the several main controllers; the propelling motors, main controllers and collectors are all individual to the car on which they are situated. When the units are put together, and through a secondary system they are controlled and operated from one or more points, then and there only do we have multiple-unit control.

The distinction between the systems mentioned by Mr. Leonard and others and the multiple-unit system is that there are no heavy currents passing from car to car in the latter. The only currents passing, except where shoes are connected together for the purpose of preventing sparking on icy and sleety rails, are control currents, and these are of magnitude too small to consider. Mr. Lamme, since he refers to current transmission, must have missed my point when I said that the continuous-current motor was a better one than the alternate-current motor. I said that, considered only as a motor, in the matter of weight, efficiency, reliability, ease of construction, and reduction of liability to damage when working in the ordinary way, the continuous-current motor is the superior. The fact is the present effort is to make a series motor run on alternating-current circuits, and to utilize all the existing advantages, while getting rid of some inherent difficulties which crop up.

Again Mr. Lamme, or some one, took exception to the question of danger that might arise. I do not care to what potential you go, there is a period, fifty times a second, where you pass zero. If at that time the car is on a bad rail and making poor contact, and there is a leak on the high-tension connection, it may be possible for a person boarding the car from moist earth to get a severe shock.

To break through and make contact from wheel to rail there must certainly be a rise of tension from zero to some point which is necessarily sometimes higher than might exist with a rail arc when using continuous current. I do not wish to speak as an alarmist, or say that these difficulties will not be overcome, but it is folly to ignore them, and we must recognize the defects of any system which is being considered. My criticism is we are apt to brush aside what has been done in the past, and promise too much for a new departure, because it fulfills certain conditions, and that we ought not to do.

Dr. **Steinmetz**: What especially impresses me is that induction-motor railways have been run seven or eight years ago; the commutator motor has been brought out only within the very last year or two. But the amount of interest which the alternating commutator motor has raised, the great activity displayed in all countries, compared with the very low activity in the induction motor, give me the general impression that the commutator motor appeals to the railway engineers as greatly superior.

Chairman Duncan: Our time is exhausted, and as Mr. Arnold started the discussion I will ask him to close it.

Mr. Arnold: I think it is pretty thoroughly closed now. We have pretty well covered the theory. I am glad to see the sentiment in favor of the single-phase motor, regardless of what it has done in the past. I am bending my energies to it, and I think with what we may all do, we will have great results to report.

The following paper was then read by title: "Braking High-Speed Trains," by R. A. Parke.

The work of Section F being concluded, it was declared adjourned, *sine die.*

BRAKING HIGH-SPEED TRAINS.

BY R. A. PARKE.

During a hearing upon an application for a charter for the New York & Port Chester Railroad Company, before the New York Railroad Commission, some three and one-half years ago, the writer was called upon for expert testimony concerning the distance in which electric trains might be stopped, in regular service, from a speed of about 60 miles an hour. It was then that expression was first publicly given to the opinion that the special conditions under which the brakes are applied upon trains of such high speeds warrant a force and promptness of application which could be employed at low speeds only with serious shock and danger of train rupture. For years prior to that time, the uniform teaching and recommendation of The Westinghouse Air Brake Company, as given in instruction cars and by authorized representatives of the company, had been emphatically opposed to the use of what is commonly known as the "emergency application" of the quick-action air brake in ordinary train service, and a proposition which contemplated the use of the emergency application of the quick-action air brake, and particularly the more powerful high-speed form of air brake, appeared to the average railroad officer as nothing short of heresy. Members of the Railroad Commission promptly instituted a line of questioning which made it quite evident that they were similarly impressed.

One of the fundamental grounds upon which the New York & Port Chester Railroad sought to justify the granting of a charter for a railroad line paralleling a steam railroad already in operation, was the materially improved local express-train service which it was proposed to attain through the superior rate of acceleration acquired upon electric trains by the use of the system of multiple control of motors operating upon the axles throughout the train, and the higher rate of retardation to be obtained through the high efficiency of the emergency application of the air brake, in bringing such trains to a station stop.

In presenting the matter to the Railroad Commission, elaborately arranged curves, indicating the rates of acceleration and retardation, had been prepared by the able engineer, Mr. C. O. Mailloux, which appeared to justify the claims for the improved character of train services contemplated by the company. Although multiple-control systems of electrical train control were, at the time, in successful operation, it did not appear that the rate of retardation indicated by the stopping curves had been attained in regular service, and the high efficiency of the proposed train service was characterized as impracticable and chimerical by those opposed to the granting of the charter.

It is a notable fact that, while the effort to attain high acceleration in bringing electric trains to the required speed had involved costly extension of the application of motors to a number of cars throughout the train — being applied, in some cases, to the trucks of all the cars — practically no effort had previously been made to realize a higher rate of retardation, in regular service, than that which had been regularly employed in steam-railroad service, through the service application of the ordinary automatic air brake. Without attempting any discussion of the merits of multiple-control systems of electric locomotion, or the commercial limitation of the expense justified in extending the application of motors to a number of cars throughout the train, it may properly be suggested that commercial economy may not result from an indefinite extension of such systems. The inadequacy of a single motor car for the acceleration of a train of several cars easily justifies the application of motors to the trucks of one or more additional cars, depending upon the number of cars in the train; but it may also be readily understood that a point may be reached, in the increased acceleration due to multiplication of motors, beyond which the addition of other motors is accompanied by too small a measure of increased acceleration to justify the added expense of installation and maintenance.

An illustration may be found in the operation of city waterworks' systems. It is a well-understood fact that refinement of pumping machinery is justified up to the attainment of a practical duty of somewhere in the neighborhood of 90,000,000 gallons; beyond this, further refinement, whereby an increased duty is accomplished, is attended by an increased cost of plant and of repairs and necessitates a higher grade of skilled oversight and attendance which more than compensates for the fuel economy acquired. It is not fuel economy, but it is commercial economy of operation, which defines the limit of such refinement and establishes a duty which may not be exceeded with commercial advantage. Similarly, the extension of multiple-control systems to the application of motors to more than a certain limited proportion of the axles upon a train may easily be attained by an ultimate cost whereby economy of operation is impaired.

The pertinence of the foregoing observation lies merely in the fact that, while the application of multiple-control systems has, in some cases, apparently been pushed to extremes, in an effort to improve electrical train service, by attaining the very highest acceleration at the sacrifice of commercial economy, the absence of any effort to attain a fuller measure of the possible rate of retardation, in stopping, is the more noteworthy. That materially increased stopping efficiency may with propriety be employed in high-speed train service, it is the purpose of this paper to demonstrate; and, as every start, requiring high acceleration, is necessarily attended by a corresponding stop, in which a higher rate of retardation correspondingly improves the character of the train service, it is obvious that, if increased expense is justified in moderately increasing the rate of acceleration, materially increased stopping efficiency, at a comparatively small cost, is entitled to careful consideration.

To those who are familiar with the results of experiments with the friction of brake-shoes upon car-wheels and the difference in the conditions of brake application at high speed from those at low speed, the proposal to increase the force of application of the brake-shoes upon the wheels at high speeds will excite no comment.

The various trustworthy experiments upon brake-shoe friction have uniformly demonstrated a declining ratio of the friction to the pressure of the shoe upon the wheel at increased speeds. For the same brake-shoe pressure the friction excited at a speed of 60 miles an hour is but about one-half that which occurs when the speed is but 20 miles an hour. Other causes result in a reduction of the brake-shoe friction during continued application of the brakes; and this result combines with the increase of the friction through reduction of speed, during the retardation of the train, to maintain a comparatively uniform, though slightly increasing, rate of friction throughout the stop, until quite near its close. Thus, the average rate of retardation of the brakes, when applied to the wheels at a speed of 60 miles an hour, is about one-half of that acquired with the same brake-shoe pressure when the initial speed is but 20 miles an hour. It is evident, therefore, that the same rate of retardation — which may with entire propriety be employed at all speeds — can only be acquired by increased pressure of the brake-shoes upon the wheels, to correspond with the reduced rate of friction occurring at the higher speeds.

Moreover, an application of the brakes which will produce a given rate of retardation at one speed, without danger to the rolling-stock or discomfort to the passengers, may also be applied at any other speed with no more danger or discomfort. The high-speed brake was designed more particularly for use upon high-speed trains, and it employs a considerably greater brake-shoe pressure in emergency applications than that of the ordinary quick-action brake, to more nearly realize the rate of retardation obtained in the emergency application of the quick-action brake upon trains of lower speeds. At such a high speed as 60 miles an hour, however, even the emergency application does not develop greater brake-shoe friction than does a full service application of the quick-action brake at a speed of 20 miles an hour. It is true that the service application is attended by a comparatively gradual application of the brake-shoe pressure, while the emergency application develops the greater brake-shoe pressure very quickly; but experience and observation seemed fully to justify the conclusion that the reduced rate of friction at the higher speeds would permit the use of even the high-speed brake without noticeable shock or disagreeable sensation.

Though the conviction thus expressed three and one-half years ago was based upon observation, experience and knowledge of the results of experiments upon brake-shoe friction, it was, nevertheless, so far as practical employment in train service was concerned, a theoretical conclusion. Since that time experiments in the use of the high-speed brake upon passenger trains have amply confirmed the writer's views upon this subject and demonstrated the absence of disagreeable effect as well as the highly increased rate of retardation in employing the emergency application of the high-speed brake for stops in high-speed train service. The time and distance saved in such stops permit the employment of the maximum speed up to a comparatively short distance from the stopping point and cause the train to be brought to a quick, smooth stop in much less than half the time and distance required for an ordinary service stop.

That the shortened running time and increased efficiency of high-speed train service — particularly local express-train service — by the employment of such higher rate of retardation, may be attained at a small fraction of the expense at which a lesser improvement in such efficiency can be obtained through the increased acceleration resulting from extending the multiple-control system from the use of motors upon one-half the cars in the train to their application to all of them, seems hardly open to doubt. The neglect to take advantage of this higher rate of retardation would seem to be attributable chiefly to the long-established doctrine that emergency applications must not be employed for service stops, under far different conditions. It is to be understood that such a doctrine still applies, with all its force, to the operation of passenger trains at moderate speed, as well as to freight-train service. It is only under the special conditions of uniform operation at high speeds — not less than 50 miles an hour — that the recommendation of a most powerful application of a most powerful brake, in all stops, properly applies.

In addition to the advantage of effecting a reduction of from 50 to 75 per cent in the time and distance required by a service application of the brakes, a collateral advantage of material importance is the much greater accuracy of the stop. In a stop by a service application of the brakes, the application is affected by the personal judgment of the operator, whereby an element of uncertainty is introduced which almost invariably requires a subsequent release and a second application of the brakes, in order to bring the train to a stop within the range of the station platform. This frequently involves more or less "drifting" of the train, at greatly reduced speed, to avoid stopping short of the station and not infrequently involves backing of the train because of inaccurate judgment in the application of the brakes, whereby the train runs beyond the stopping point. In the use of the emergency application, not only is the individual application of every brake very much more prompt and powerful, but the rate of serial application from car to car is almost instantaneous and is automatically established to the exclusion of any influence of the operator's judgment. Grade and alignment of the roadway, of course, influence the stopping distance; but such influences are readily determined for each stopping point, and the point at which the motive power should be shut off and the emergency application of the brakes should occur, may be designated by a post or other permanent signal, whereby the train will be brought to a stop at the desired stopping point.

In comparison with the rate of acceleration, in starting steam-railroad trains, the rate of retardation in ordinary service stops has been so high that it is not unnatural that increased efficiency of train service has suggested higher rates of acceleration in starting, rather than improved retardation in stopping; but it should now be clear that a really efficient high-speed train service may be obtained only by also employing the maximum practical rate of retardation, by which so large a reduction of the time and distance of stopping is counted. Electric train service furnishes exceptional conditions for attaining the maximum retardation, as well as the maximum rate of acceleration — though for different reasons. Where trains are drawn by steam locomotives the conditions existing at the locomotive and the variable load carried in the tender involve limiting the braking power so that the retarding force is considerably inferior to that realized upon the cars. Where electricity is employed the motive power is applied directly to the cars themselves in such a manner that the maximum braking efficiency may be obtained as well upon motor as upon other cars, and the whole train is thus subject to the maximum rate of retardation.

While the special conditions of high-speed train service permit realization of the maximum obtainable retardation in ordinary station stops, it will be understood, of course, that all the ordinary means of general brake efficiency are contemplated in connection with the brake apparatus. In a paper presented to the American Institute of Electrical Engineers, and published in the January, 1903, volume of proceedings, the writer pointed out the more important features of the brake apparatus for attaining such high efficiency. They included efficient foundation brake-gear automatic slack adjuster, to maintain the minimum piston stroke in the brake cylinders, and brake beams hung between the wheels and adapted to regulate the brake-shoe pressure so as to compensate for the transfer of weight from the rear to the forward pair of wheels of each truck during the application of the brakes.

In addition to such general considerations an exceedingly important element of braking efficiency is the character of the brake-shoes applied to the wheels. Extensive experiments have demonstrated a very wide variation in the frictional quality of brake-shoes of different materials, and, further, a marked difference in the friction of the same brake-shoe upon wheels of different materials.

It is, in general, found that the maximum frictional resistance occurs in the application of soft cast-iron shoes to chilled cast-iron wheels, and the friction-producing quality generally declines as harder brake-shoe materials are employed. It should not be concluded, however, from this general relation of the hardness of the brake-shoe materials to the frictional quality, that soft material only should be employed in brake-shoes. Beside the cost of soft brake-shoes, which wear rapidly, the trouble and expense of replacement, together with the complications arising from rapid wear, are highly persuasive elements in favor of the use of harder materials. If the inferior frictional quality of the harder brake-shoes is compensated by correspondingly increased pressure of the brake-shoes upon the wheels, the operative objection to the hard brake-shoe practically disappears. The question is, to a large extent, a commercial one. Increased pressure upon the harder shoes involves, of course, somewhat increased wear; but when, in each case, the brake-shoe pressure is so adapted to its frictional quality that the maximum retarding friction is acquired, the practical question resolves itself into the relative cost of initial installation and of subsequent maintenance—to which must be added due consideration of trouble and annoyance arising from the necessity of frequent attention.

Within the past two or three years, two different series of experiments with the high-speed brake have furnished most interesting and important information bearing upon this subject. In one series, soft cast-iron brake-shoes were employed with chilled cast-iron wheels. In the other the "Diamond S" form of brake-shoe (of hard cast-iron, with steel inserts) was used with steel-tired wheels. Otherwise, the conditions were fairly comparable, the tests being conducted in the same general locality. In the case where soft cast-iron shoes were employed, the initial air-pressure in the brake-cylinder was about 85½ lbs., which became reduced, toward the end of the stop, to 60 lbs. In the tests with the Diamond S brake-shoe, the initial air-pressure on the brake-cylinder was also about 85½ lbs., which, by the use of special high-speed reducing valves, became reduced to a final minimum of from about 69 lbs., from a speed of 80 miles an hour, to about 78 lbs., in stopping a six-car train from a speed of 50 miles an hour. Moreover, in some instances, a brake-cylinder pressure of 75 lbs. or more occurred in applications of the brakes at speeds of 20 miles per hour (and even less), without producing wheel-sliding of an injurious character or exceeding that which occurred with the use of the soft cast-iron brake-shoe, when the final minimum air-pressure in the brake-cylinder was but 60 lbs. The stopping distances were phenomenally short in the tests with the Diamond S brake-shoe, averaging 602 ft. from a speed of 50 miles an hour, 982 ft. at 60 miles an hour, and 1334 ft. at 70 miles an hour — the shortest authentic stops on record.

It is true that these tests were made in dry weather, and that the rails were more or less affected by sand, in which the soil of the country abounded, and particles of which were carried about by wind. It is very doubtful whether such high terminal brake-cylinder pressure might be safely employed even with such hard brake-shoes, under the varying rail conditions of regular service — the corresponding total brake-shoe pressures, as customarily calculated, being from 104 to 117 per cent of the weight of the braked cars; but these experiments clearly illustrate both the fact that wide difference in the frictional qualities of brake-shoes should be given proper consideration in determining the brake-shoe pressure, and also the fact that, with a properly determined pressure, certain forms of hard brake-shoes may yield as good, or perhaps even better, average retarding influence than soft cast-iron brake-shoes. It is worthy of note that the material in the brake-shoes employed in these experiments was so hard that a number of the shoes were broken during the tests — but without apparently affecting their utility, inasmuch as the form of the shoes remained unchanged, the parts being held in place by a steel plate cast in the outer surface of the shoe.

The foregoing considerations assume the use of the automatic air brake. Inasmuch as high-speed *trains* have been under consideration, no other form than an automatic brake could properly be considered. In the case of a service employing single cars, the advantage of an automatic brake practically disappears and more simple forms of apparatus may be employed to advantage; but, where two or more cars are assembled in trains, and particularly in high-speed trains, the necessity of providing for the contingency of train partings permits but the one prudent and safe course of employing an automatic brake, and, thus far, the automatic air brake alone has become safely established as meeting all the requirements of service. The necessity of the most efficient high-speed train service requires, in addition, the most forcible application of the most efficient form of automatic air brake — the emergency application of the "high-speed" brake.

TRANSACTIONS

OF

SECTION G

Electric Communication

Honorary Chairmen, JOHN HESKETH, ESQ., and H. E. HARRISON, ESQ
Chairman, MR. FRANCIS W. JONES
Vice Presidents, M. FERRIE and J. C. SHIELDS, ESQ.
Secretary, MR. BANCROFT GHERARDI

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Total number of papers presented before Section G, 20.

Section G was called to order at 11:45 A. M., Monday, September 12, Mr. Francis W. Jones presiding.

CHAIRMAN JONES: I have much pleasure in introducing to you Mr. Jno. Hesketh, honorary chairman of this Section, and I will ask him to take a seat on the platform. We will proceed with the day's program, which includes a paper entitled "Telegraphy and Telephony in Japan," by Mr. Saitaro Oi.

TELEGRAPHY AND TELEPHONY IN JAPAN.

BY SAITARO OI.

Telegraphy, as in all other countries, is also the oldest and was the first practical application of electricity in Japan. It is generally believed that Commodore Perry of the United States, when he came over to Japan in 1854, brought two sets of telegraph instruments with him and presented them to the Shogun (at that time the Lieutenant General, or Governor General, of the Empire). The first telegraph line, however, was constructed between Tokyo and Yokohama in 1869, the instruments used being Bréguet's instruments, which were employed for some time until all were superseded by Morse inkwriters. There was not very much progress until 1877, when the civil war broke out in the southern districts; this naturally necessitated an increased use of the telegraph and the lines were extended to the important places of the Empire. These 36 years from 1869 to 1904, have wrought a remarkable change in our social conditions in general, and in the domain of means of communication for the public some progress has been made.

In order to show the progress made, during these thirty-six years, I give the following table:

STATISTICS OF JAPANESE TELEGRAPH AND CABLE LINES.

Year.	Miles of land lines.	Miles of wires.	Nautical miles of submarine cables.	Miles of aerial cables.	Number of telegraph stations.	Number of telegraph instruments in use.	Number of messages charged.	Expenditures in yen (1 yen=50 U. S. cents.)	Receipts in yen.
1869	20	20	......	......	2	......	....	....	....
1880	4,140	9,782	58	......	155	......	1,897,685	785,901	896,571
1890	5,890	19,800	121	......	408	734	4.089,319	1,386,381	1,256,555
1900	14,785	66,884	2,081	......	1,654	2,817	14,280,280	5,778,482	6,072,990
1903	16,600	80,213	2,178	10	2,178	4,216	16,987,760	6,234,738	6,567,487

It may be remarked here that about 3,000 miles more of wires are to be added to the existing lines this year so as to meet the increase of traffic.

The above table refers to those only which are used for the public traffic, excepting that of Formosa. There are, in addition, a good many private telegraph and telephone lines worked exclusively for railway and for various other industrial purposes which, according to the latest report, amount to the remarkable figures shown below:

	Miles of wire.	Number of instruments.
Telegraph	10,892	1,340
Telephone	10,635	5,381

The first telegraph line in this country was constructed by some English engineers and linemen in the service of the Japanese government. The chief engineer was Mr. E. Gilbert, who had been connected with a railway company in Scotland before he came to Japan, and as may be imagined, the method of surveying, construction and maintenance of the land lines laid out by him was naturally after the English practice, and is continued, with more or less changes, down to the present day. The lines are built in a solid manner, so that they can withstand the attacks of storms, which are almost certain to come once or twice in autumn every year.

As to the telephone lines in towns, the method of construction may be said to follow American rather than English practice, and in some places where no cables are employed, as many as 100 to 150 wires are run upon a pole planted along the side of the streets. In large towns, however, these crowded overhead wires are generally being taken down and laid underground, and as will be seen from the table I give later on, there are at present some miles of underground lines.

Poles are generally of cedar, which grows in abundant quantity in different parts of the country. The number of main poles used varies, of course, with the number of wires put up, the nature of the route through which the lines pass, etc.; but in the open country there are, as a rule, from 38 to 26 per mile; and where there are too many wires for one pole to carry, trussed poles — often H poles — are employed. Ordinary main poles are of 22 to 24 feet. Taking the average, 64% of the main poles are stayed, while 14% are strutted. Boucherizing is a common practice as a means of preservation of the poles, but lately creosoting is being tried, though on a small scale.

Fig. 1.— Telegraph line.

Fig. 2.— Telephone line.

Boucherized poles last about 18 years on an average, whilst untreated poles begin to decay within 5 or 6 years; and owing to the fact that the price of timber, which was fabulously cheap in the earlier days of telegraphy, has become somewhat expensive with the recent progress of engineering work in general, various compounds and methods of preserving wood have naturally had the attention of the engineers concerned. Considering, however, the different conditions of this country, the most suitable one for telegraph and telephone purposes seems, so far, to be the boucherizing process. 46% of the poles are boucherized, the remaining untreated.

Arms with double-cup porcelain insulators are exclusively used and are always fixed on that side of the pole facing the so-called up-station. For telegraph lines, two-wire arms of 24" and 34" are generally used except where many wires are to be run. They are secured to the poles a foot apart, and alternately in case more than two wires have to be put up.

Telephone wires are run on 4, 6 or 8-wire arms most commonly, and long-distance lines on braced 6-wire arms. The distance between the centers of the arms is 1 foot 6 inches, the minimum distance allowed from the ground to the lowest arm being 16 ft. The span of the long-distance lines is usually 48 yards, the minimum transposition being done at every twentieth pole.

No. 8 S.W.G. iron wire is the standard for the telegraph lines, though No. 11 iron wire is sometimes used for short lines. The long circuits for fast automatic or quadruplex working are of No. 12 S.W.G. copper wire. As a rule, an earth wire is attached to each pole.

For telephone lines in towns where there is not much snow we use No. 17 S.W.G. hard drawn copper wire, and silicon bronze wires, but in the northern districts where snowfall is abundant during the winter, No. 14 iron wire is run for subscribers' lines. For the interurban telephone service three gauges of copper wires — No. 8 S.W.G., No. 12 S.W.G. and No. 14 S.W.G. — are employed.

For long spans such as river crossings, steel is almost always used in the case of telegraph lines, and bimetallic wire for telephone circuits of long distance. We had many long spans when railways were few, but at present we have our telegraph lines at river crossings, attached to railway bridges, or cables are laid on the girders in a trough. The longest air span now in existence is 800 yards with steel wire, and 320 yards with bimetallic wires, each of 170 lbs. per mile. Figs. 1 and 2 are respectively a general view of a telegraph line, and a telephone line in a town.

Underground construction for the telegraph lines is rather limited at present, it being confined to a part of Tokyo only; but the increase of telegraph wires from year to year, in addition to those for telephony, electric light and power, etc., shows the necessity of laying more wires underground in the large towns, and it is very likely that in the course of a few years the telegraph lines in the busy part of the large towns will be put underground. The greater part of the telephone lines, however, in large cities such as Tokyo, Osaka, Kyoto, Yokohama, etc., is already laid underground.

When the first underground construction was undertaken in Tokyo in 1896, we adopted 3 in. cast-iron pipes and the same system was employed, to a considerable extent, in the other towns also; but my visit to the United States in 1898 gave me a favorable impression as to vitrified clay conduit, and immediately after my return home, I advised the authorities to adopt it where we have more than three ducts. Since then the single-duct vitrified clay conduit has become the standard of underground working, as our manufacturers can make it excellently and cheaply.

Underground cable used for telegraph purposes has prepared fibre insulation and is covered with lead pipe. The telephone cable for underground work is of the dry-core paper insulation, and in large towns apparatus for sending compressed dry air from 3 to 4 atmospheres into the cable are provided for. This proves very useful in Japan as the cables are all imported, and in case cables should get low in insulation we can easily repair them. 100-pair cable was used when the underground work was commenced, but now, 200-pair cable is very common, No. 20 S.W.G. being the size of the conductors. Smaller wire cable has been suggested for some uses, but it has not yet come into actual use. Most of the lines in towns being overhead, we have naturally a great many aerial cables, both of India rubber and dry-core type, put up on poles to avoid too many telephone wires crowded together, or to cross electric light and power conductors, which are also carried along the streets like the telegraph and the telephone lines.

The laying of submarine cable was considered the most difficult work, and except in a narrow strait or in a river the work was almost always executed by the Great Northern Telegraph Co.'s steamer. The features of the country, however, called for a number of submarine cables in various parts, and in order to establish new communications and to maintain efficient working, it became necessary to do the work with our own staff. Sometimes we equipped a steamer with rough machinery to lay a new cable or to repair a broken one, and although not without inconveniences in most cases, still we accomplished our object and in this way our engineers and workmen have obtained some useful experience in this branch of telegraph engineering.

When Formosa was annexed to Japan in 1895 it became an urgent necessity to put the new possession in direct communication with Japan, and consequently measures were at once taken to lay cables connecting the Islands of Kiushu, Liuchu and Formosa. A cable steamer was built and fitted out at Glasgow for the purpose of laying and repairing cables and was brought out to Japan in June, 1896. The "Okinawa Maru," our cable ship, is a twin-screw steel steamer, having a double bottom. The gross tonnage is 2,212, the length between perpendiculars being 290 feet, the breadth extreme 40 feet, and the depth of hold 24 feet. She is equipped with triple-expansion engines, double-ended boilers, and has three cable tanks of 15,952 cubic feet, 8,389 cubic feet, and 6,945 cubic feet capacity, respectively.

It remained still a question with us whether our engineers could manage to lay cables in very deep waters, as their experience had been previously limited to comparatively shallow waters, and it was strongly suggested to engage some experienced foreign engineers for the work. We wanted, however, to gain all possible experience and so we took up the work ourselves. The cables were successfully laid though not without some difficulties; they have been working well during the past eight years, being worked duplex with direct siphon recorders.

As mentioned elsewhere, Bréguet instruments were the first instruments used for the transmission of public messages, while Wheatstone needle instruments were used for the railway service. The complication of the mechanism of the former and the consequent liability to get out of order made its extensive use unsuitable, and very soon the Morse inkwriter replaced it.

Of about 1,100 telegraph circuits now working, 850 are fitted up with Morse instruments and the remaining 250 circuits are fitted with telephones. Out of 850 circuits, 90 are worked duplex, 9 quadruplex, 4 automatic, and the remainder simplex. The sounders were first introduced in Japan in 1895, and have been working in comparatively large offices only. At present about 40% of the total instruments are sounders. Duplex telegraphy was tried in 1879 but its practical success dates from 1889; as to quadruplex working, it was only from 1893 that we could put it into actual use on important circuits. The Wheatstone's automatic is limited to a few circuits in ordinary circumstances; but violent storms occur among the Islands, particularly in autumn, and often cause an extensive breakdown of the important lines; on such occasions the automatic working is found valuable to dispose of the accumulation of messages. Repeater boards are employed in important centers to the best advantage of working. Telegraph exchanges are confined to circuits in towns or to very short and less important lines only.

The Morse signals used in telegrams written in the Japanese characters are 50 in number in addition to those representing figures, and the signs of punctuation, etc. These signals are partly composed of those representing the Morse Alphabet, and partly of additional combinations of dots and dashes.

Telegraphically speaking, about 3.65 Japanese letters are equivalent to one word in English, which, on an average, consists of 4.67 Morse letters, and therefore one Japanese Morse signal corresponds to 1.28 international Morse signal. It may be perhaps interesting here to note how Japan is related telegraphically to foreign countries. Of the whole number of foreign messages forwarded or received, and which amount to some 800,000 a year at present, about 40% are credited to Korea, 28% to China, 9% to England, 7% to the United States, 4% to India, 3% to Germany, 2% to France, 2% to Russia and 4% to all other countries.

Testing lines is carried out in 24 different offices located in the important centers of the country. Conductivity and insulation resistances of the lines are regularly measured once a month, while the condition of the lines is ascertained every day by observing the current strengths received from the distant stations.

The lines are all worked open circuit with Daniell cells, except in Tokyo and Osaka, where storage batteries have been in use since year before last. The change from primary batteries to secondary in these two large offices brought about a considerable reduction in the expense of maintaining batteries therein, and changes in the other large stations are now being planned.

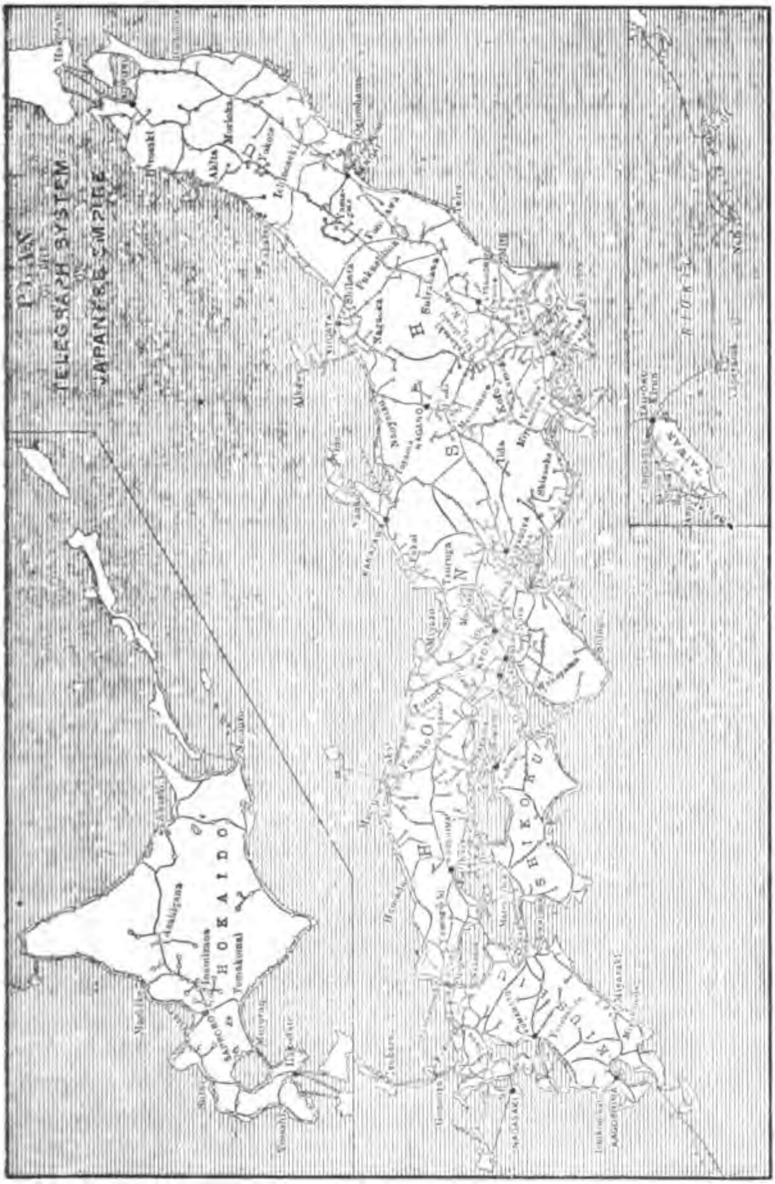
PLAN OF THE
TELEGRAPH SYSTEM
IN
JAPANESE EMPIRE
H O K K A I D O
SAPPORO
Hakodate
H O N S H U
NIIGATA
NAGANO
S H I K O K U
K I U S H I U
NAGASAKI
KAGOSHIMA
TAIWAN

FIG. 8.

The charge for inland telegrams in Japanese letters is 20 sen (1 sen = ½ U. S. cent) per message of fifteen letters or less of text, the address of the receiver being free in this case; and for every five letters or less exceeding the first fifteen the additional charge is 5 sen. Inland messages in Roman letters are charged 25 sen per message of five words or less, the additional charge being 5 sen per word. For telegrams within the limits of a town, 10 sen per message in Japanese and 15 sen per message in Roman letters are charged; for additional letters or words exceeding the numbers allowed for one message 3 sen are charged per five letters or one word.

Fig 3 is a chart of the telegraph system of the Empire in 1904.

The telephone was first brought to Japan in 1877 by a mechanic returning home from America, and was a magneto telephone encased in a box. Soon after its introduction, the telephone was put into practical use as an auxiliary to the police service in Osaka and vicinity, a considerable length of lines being built for that purpose. Some of the circuits then constructed were more than 30 miles in length and as many as ten such magneto instruments were connected in series on a single circuit of iron wire. As can be readily understood, conversation was no easy task unless by those who had experience in using the instrument. After the introduction of the carbon microphone the application of the telephone for industrial and commercial purposes began to increase remarkably, and it was in 1883 that the idea of starting telephone exchanges first occurred to the authorities. A company was promoted for carrying on the business and a petition was forwarded to the Government asking for a license to start an exchange and carry on the telephone business in Tokyo. That was in 1884. The question whether it should be carried out as a Government undertaking or entrusted to a private capital remained unsettled until 1889, when it was decided, after deliberation, to undertake the work as a state monopoly.

While the matter was still in consideration by the Administration, it was thought necessary that our engineers should get more detailed information for the successful working of telephone exchanges. The writer was appointed to make a tour to Europe and America to study telephone matters. My stay in Europe and America lasted a year and a half, and it was in December, 1889, that I returned home from my first trip abroad. At that time an ap-

FIG. 4.— INTERIOR OF TOKYO EXCHANGE.

propriation for the telephone undertaking had already been made, and the work was to be started as soon as possible in Tokyo and Yokohama. The executive office was opened in Tokyo, and letters and circulars were sent out to business men, to the nobility, to Government officials, to manufacturers and, in fact, to any person in the city of more or less prominence. We advertised in the popular papers the opening of telephone exchanges and invited subscriptions from the general public. We did not confine ourselves to letters and circulars or to the newspapers alone, in introducing the telephone to the public, but, in addition, we put up a switchboard and telephones in the building of the Tokyo Chamber of Commerce, and in the Rice and in the Stock Exchanges, and invited people of various occupations to try the instruments in order to be convinced of the practical utility of the telephone. In Yokohama the writer gave a popular lecture to convey to the public an idea of the commercial and social uses of the telephone. In fact, we spared no pains to secure a satisfactory result in the new enterprise, but notwithstanding such efforts on our part, we got only about 70 contracts in Tokyo and 20 in Yokohama when we commenced the construction of the lines. The service was started in Tokyo and Yokohama in December of 1890, the number of subscribers at that time being about 200 in Tokyo and 40 in Yokohama. However, the actual opening of the exchanges and establishment of communication between the subscribers spoke far more eloquently to the public than any letters, newspapers or lectures, and before long our facilities were far behind the demand. The growth of the telephone exchange business since 1890 may be seen from the following table:

GROWTH OF TELEPHONE SERVICE.

Year.	Number of telephone exchanges.	Number of telephone substations.	Miles of subscribers' lines (pole).	Miles of wires.	Miles of overhead cables.	Miles of underground cables.	Nautical miles of submarine cables.	Miles of toll lines.	Miles of toll wires.
1890	2	359	100	669	......	......	....	22	139
1895	4	2,918	888	4,826	1	......	....	46	410
1900	25	19,208	1,332	29,287	117	78	4	598	5,309
1903	46	36,700	1,669	40,598	198	178	4	901	

The increase of traffic necessitated putting up more toll circuits, and some 100 miles of new line with about 1,600 miles more wire are now under construction. On completion of the line, Tokyo and Nagasaki, which cities are 800 miles apart, will probably be put in direct communication.

When the exchanges were started in Tokyo and Yokohama, single circuits of No. 18 S.W.G. hard-drawn copper wire were arranged for subscribers' lines, the 100-wire standard switchboards of the Western Electric type and a modified form of the Gower-Bell telephone set with a battery for calling, were employed, the toll lines between the two towns being metallic circuits of No. 12 S.W.G. copper wires. No. 18 copper wires were afterwards changed to No. 17, which is now the standard size of wire for subscribers' lines, except in the northern snowy districts; and the modified Gower-Bell set with calling battery, has been changed to the solid back or Delville set with a magneto.

Small exchanges not having upwards of 600 subscribers are operated with the 100-wire standard switchboard, and for exchanges where more than 600 subscribers are to be connected, multiple switchboards are generally used. At present Tokyo has five exchanges, the largest of which contains 4,000 subscribers and the smallest 1,500, and each exchange is equipped with bridging multiple switchboards. In Osaka there are two exchanges, both of which are also fitted with bridging magneto multiples, having an ultimate capacity of 6,300. Reverse trunking is used between different exchanges in a town and also on short toll lines. Yokohama, Kobe and Nagasaki are also worked with bridging magneto multiples, these towns having only one exchange in each. Kyoto, our ancient capital, was worked with the old series-multiple switchboards, but an alteration to the relay switchboards, manufactured by the Western Electric Co., was effected in May last year, and since then the system is working satisfactorily. Kyoto has no branch exchanges; it has an ultimate capacity of 6,300 and the present equipment 3,000. The series-multiple switchboards are still in use at Nagoya. All other exchanges are being operated with the 100-wire standard switchboards, but some of them experience inconvenience at times in working, due to increase of subscribers, and we anticipate supplying them with multiple switchboards. Fig. 4 shows the interior of the exchange in Tokyo, and Fig. 5 the interior of the Kyoto exchange.

FIG. 5.— INTERIOR OF KYOTO EXCHANGE.

FIG. 6.— STREET CALL BOX.

In order to give an idea of the present situation of our telephone exchanges, I give the following figures for the seven towns where the exchanges are worked with multiple switchboards:

MULTIPLE SWITCHBOARD EXCHANGES.

Name of town.	Number of subscribers.	Number of subscribers not yet connected.	Public call offices.		Population.
			Ordinary.	Automatic.	
Tokyo	14,192	8,019	46	68	1,640,000
Osaka	6,481	3,608	28	10	930,000
Kyoto	2,413	3,308	13	9	380,000
Yokohama	1,464	517	22	14	300,000
Kobe	1,487	1,152	16	9	260,000
Nagoya	1,327	1,023	7	6	270,000
Nagasaki	742	259	4	1	140,000

A subscriber's set is furnished with either the solid-back or the Delville transmitter and always equipped with an arrester. A desk set, artistically designed, is liked by some people and supplied, if required, upon an extra payment of 6 yen per annum. Where the C. B. system is employed, the same type as the post-office wall set is in use, the transmitter being the solid back. Fuller's bichromate battery for the solid back, and the Leclanché for the Delville are generally used.

The automatic telephone, which has come into use since 1899 is somewhat like the Grey instrument, and so constructed that the operator is enabled to distinguish the kinds of coin put into the slot by hearing different sounds made by the coin in its sliding down along each chute. Fig. 6 shows a view of an automatic call box in the street of Tokyo.

No party lines are in existence at present, except a few telephone call office circuits in small villages. This system, however, has been often considered, with a view to meeting the pressing demand of the public for the telephone, but so far it has not come into use.

The actual number of toll line circuits amounts to about 100. In addition to that number 22 telephone circuits are formed by utilizing the telegraph lines for simultaneous transmission, and 20 by duplex telephony or virtual circuit. Simultaneous transmission of telegraph and telephone was first experimented in 1884 after the Van Rysselberghe system between Tokyo and Yokohama, but the experiment was not made with sufficient care and it ended in failure. The second experiment was conducted rather more carefully in 1886 by using the telegraph wires crossed and it resulted in a success.

When the telephone exchanges were started in Tokyo and Yokohama in 1890, all the lines connecting the two towns were specially constructed with copper wire transposed at intervals as a precaution against disturbance from external causes, and there did not exist much necessity to have recourse to the telegraph lines. In 1894 duplex telephone circuits were tried between Osaka and Kobe, which are 23 miles apart, and were worked quite successfully. In order to actuate the indicators on the duplex circuit, the neutral points of the repeating coils were earthed, and by using the circuit so formed by earthing, direct signal current was sent so as not to cause disturbance to the conversation. The telephone lines between Tokyo and Osaka were opened to the public use in 1896. Combining these lines, which are 377 miles in length, duplex telephony was successfully applied.

In course of time telephone exchanges were gradually opened in various provincial towns, which has enhanced the popularity of the telephone to a great extent and petitions for telephone facilities came in to the hands of the authorities from various quarters. This brought up the necessity of opening telephone call offices first in those places which did not possess telephones, and to save money, existing telegraph lines were used. At present some 1,000 miles of telegraph wires are worked simultaneously for the telephone. Fig. 7 shows the toll line system in Japan at the present moment.

The flat rate system is adopted in all towns. The charges are as follows:—

Tokyo and Osaka	66 yen per annum.
Yokohama, Kobe, Kyoto, and Nagoya..	54 yen per annum.
Other smaller towns	48 yen per annum.

These are for subscribers located within the town limits. Those living in the vicinity beyond the town limits, but within a certain telephone area specified by the government, can be connected to the exchange by a payment of 10 yen per 120 yards or under, for construction of a line beyond the city limits; and a payment of 2 yen per annum per 120 yards or under beyond the city limits as additional subscription.


MAP OF THE ROUTES
OF
TELEPHONE TOLL LINES
IN JAPAN
CONVENTIONAL.
Exchange Office.
Toll Line Pay Station.
Telephone Line.
Toll line under construction.
Telegraph and Telephone Simultaneous Line.
SAPPORO
OTARU
HAKODATE
SENDAI
NIIGATA
TOKYO
YOKOHAMA
NAGOYA
KIOTO
OSAKA
KOBE
HIROSHIMA
SHIMONOSEKI
MOJI
KUMAMOTO
NAGASAKI
APRIL 1904

FIG. 7.

Interurban lines are charged for according to the distance and for a conversation not exceeding 5 minutes. The basis of the toll rate is approximately as follows:—

Up to 5 ri (one ri is nearly 2.5 miles)	20 sen.
Up to 25 ri	25 sen.
For each ri beyond 25 ri	1 sen.

In a small provincial town or in a village specified by the government, and which is connected by a toll line to any other town having an exchange, people can be connected at their own expense to the post-office of the specified town or village in order to make use of the toll line from their house.

Small switchboards are provided and worked in such post-offices by the Government, and the subscribers have to pay to the Government 24 yen per annum for the service in addition to the charges for the maintenance of the line, the instrument, etc., which by the agreement must be entrusted to the Government. Seventeen such special exchanges are now working.

The financial condition of the telephone undertaking is a satisfactory one as shown by the following table:

TELEPHONE FINANCIAL STATISTICS.

Year.	Expenditures in yen.	Receipts in yen.	Capital in yen.
1895	91.548	142,616	....
1900	964.899	1,583.417	....
1903	1,280,592	2,670,631	12,618,658

The work is partly suspended for the present, owing to outbreak of the war, but when the peace is restored and commercial activity is resumed, it will, no doubt, be continued to meet the public requirements.

DISCUSSION.

CHAIRMAN JONES: In opening the discussion of this paper, it is not that I feel at all qualified to break the ice, but I am glad to take up a paper like this, so replete with valuable information and statistics relative to the work which is being done in Japan. I think many would be surprised, if shown the map, at the extent of the wires stretched from the northern to

the southern bounds of Japan. The work is very methodical and complete, when we think that only a few years ago telephony, even in England and this country, was an experiment. We find this paper by Mr. Oi is not only creditable to him, but I think reflects a great deal of credit upon electrical engineers in general, because it is through them that the people of Japan have largely been inspired.

If there are no further remarks to be made upon the paper of Mr. Oi, we will pass on to the paper of Mr. Joseph Hollos, which is now presented to you for discussion.

SIMULTANEOUS TELEGRAPHY AND TELEPHONY.

BY JOSEPH HOLLOS.

The question of simultaneous telegraphy and telephony is not of recent date. While, however, in some places, good results have been obtained, in others the advantages reached by this combined using of telephonic circuits are hardly worth mentioning, and in view of the difficulties experienced in the service, it was thought preferable to abandon the scheme.

If we look closer at the question, we can at once observe that wherever the telegraph and telephone services are under the supervision of one and the same interested person, the results obtained are excellent. Where, however, the two systems are in different hands the result is unsatisfactory. Thus, in America, where the financial interest of the telephone companies is involved, because of the desire to increase income by leasing lines for simultaneous telegraphy, and where, for this reason, these two operations are under the control of one technical staff, the result is excellent. The results are also fair in the European services, if the same technical officer supervises both telegraphy and telephony, and one service is co-ordinated with the other. The result is, on the contrary, very poor in all cases if the telegraph and the telephone services are in different hands.

This is evident if we consider how greatly the one system interferes with the other; that is, that careless handling of the one interferes at once with the proper functioning of the other, the two systems thus being brought into mutual opposition.

For this reason the service must be arranged in such a manner that the two systems cannot interfere with each other, and in as far as troubles are unavoidable, they must be reduced to a minimum. If they should exceed a certain limit, arrangements must be provided to suspend the less important service without delay.

In this direction the Hungarian telegraph and telephone service can show good results by comparison with similar installations, and, therefore, it will not be without interest to outline the principles which were followed in the formation of the system.

Above all, the simultaneous installation must be the simplest possible, because only thus and with the fewest possible instruments may undisturbed working be obtained. For this reason the method of simultaneous working, founded on the Wheatstone bridge principle, was made the basis of procedure.

The telephone circuit is closed through two inductive branches. At their point of intersection the battery branch is led off to the group of telegraph apparatus, while the telephone apparatus is placed in the so-called galvanometer branch.

It is thus evident that the connecting-in of the telephone apparatus — namely the leading of the telephone circuit through the switchboard — requires some care, because if there is a ground in the switchboard connections, the telegraph working is disturbed. Even if one telephone circuit is directly connected to another, and there be simultaneous working on the latter, the two telegraph simultaneous systems are brought into contact, which again causes marked disturbance. This may also be caused by the operators ringing simultaneously on several circuits from the same common source of ringing current.

Even if only one of the circuits fed from the common ringing source is connected for simultaneous telegraphy, such working will still be slow, because, in ringing on the simultaneous conductor, we ring also on five or six other conductors. However well insulated these circuits may be individually, the insulation of the simultaneous telegraph circuit will be so far reduced by the connection that it will hardly be possible to maintain continuous telegraph working.

It is true that we can remove all these difficulties at one stroke, by connecting the incoming telephone circuit, before leading it to the switchboard, to a repeating coil and working then only on the other half of the repeating coil. But by this plan the difficulty is only transferred to the other side — the telephone side. Above all, we have a loss of energy in the repeating coil to which are added losses inevitably occurring in the signaling apparatus, and it may happen that with such an arrangement the telephone subscriber does not get as much as 50 per cent of the incoming speaking energy into his receiver. We must strive, therefore, that along with the undisturbed working of the telegraph, the telephone working be kept at the same relative level that would exist in the absence of simultaneous working. Moreover, the repeating coil not only weakens the speaking current but also the calling current, and we must, therefore, take precautions in this direction.

Under these conditions it is inadvisable to connect the circuit first to the repeating coil. As long as the circuit is on the calling apparatus there is no danger of disturbing the simultaneous working. The disturbance arises only at the moment of connecting. For this reason it would be sufficient to place the repeating coil in the connecting cord; but in the same path there is also the clearing-out signal, and a great loss of energy might thus be incurred. This we may, however, remedy if the repeating coil is constructed in such a manner as to serve at the same time as the clearing-out signal.

The clearing-out signal is, as a rule, connected in the bridge between the two branches of the circuit, and its duty is by its great self-induction to prevent the wasting of any considerable part of the speaking current. How far it is able to satisfy this demand might be readily ascertained by inserting a receiver in the shunt path. In spite of thus increasing the impedance of the bridge, we still obtain intelligible speaking even with a clearing-out signal of 2000 ohms resistance, if the latter is entirely embedded in iron. These currents do not so rigidly follow the rules which apply to strong currents and, therefore, inferences drawn from such rules do not apply in this case, as may be shown by a simple experiment. With such a clearing-out indicator 30 per cent of the energy is lost on the average, and 70 per cent only is available, as I have been able to ascertain myself.

With a well-constructed repeating coil, if arranged as a clearing-out signal, the loss is not greater. Consequently if we insert such a repeating coil into the connecting cord simultaneous working without affecting the telephone is secured.

The repeating coil transformed into a clearing-out drop naturally possesses a closed iron circuit. In European practice this plan is avoided and an open-circuit repeating coil is generally preferred. The question whether the repeating coil has an open or closed magnetic circuit does not affect the high frequency involved, and for weak currents this is of much less importance than the other losses that arise in an open-circuit repeating coil.

For relatively strong signaling currents the closed iron circuit is of decided advantage, because with open-circuit repeating coils it is only exceptionally possible to ring through with alternating current, while it is always certain when there is a closed iron circuit.

From the point of view of simultaneous working it only remains to separate the ringing currents.

This may be accomplished if alternators are used, by branching the ringing current at each operator's position on a separate repeating coil. Where batteries are used, which are today exceptional, each operator's position must be given its separate battery. This is a matter for the technical department.

As for the operating department it is only desirable that the telephone and telegraph operators should be able to communicate with each other quickly, so that they can co-operate in case of trouble.

In the simultaneous working apparatus itself, the branching coil is of the highest importance. It is most important that the inductance on the two sides should be equal. This is more important than the exact equality of their ohmic resistance. This, however, determines not only the resistance of the coil but also the size of copper wire to be used.

From the point of view of choking, it is desirable to use long coils; such coils, however, by reason of the phenomena of dispersion, prevent the complete neutralization of the telegraph currents, and, therefore, it is necessary to select short coils. With such an arrangement the operation of the telegraph apparatus is not perceptible on well-balanced telephone circuits.

In the Hungarian Telephone System the results hitherto obtained with simultaneous telegraphy and telephony, in the manner above described, have been excellent.

DISCUSSION.

Mr. John Hesketh: This paper appears to deal simply with the application of simultaneous telegraphy and telephony on a complete metallic telephone circuit. As such, it is interesting, but it would be more interesting if we knew what their efforts in the other direction had been. My criticism is not so much on the application of the system to metallic telephone circuits. That question is not of such immediate importance to us in Australia as that of telegraphy and telephony with a single wire and earth return. It might be of interest to say that a system somewhat similar to that described has been used in various parts of Australia with considerable success — it is also used for making up phantom telephone lines; that is to say three metallic circuit telephone lines out of what would otherwise be two such lines. In my opinion, where you have four such wires the value of the lines is greater when used for phantom telephone lines than when used for simultaneous telegraphy and telephony.

Col. **Samuel Reber**: It has been the practice of the Signal Corps in our service to use the telephone on telegraph circuits, and this combination has proved extremely valuable, especially in the Philippines. This combination has been used in our service since 1894. In 1896, we had a very interesting experiment in Texas, in which we superimposed a telephone circuit on the quad working between San Antonio and Dallas where, after considerable experimental difficulty and adjustment, it worked successfully. The system used was simply a modification of the Van Rysselberghe method.

Mr. **Hesketh**: Do you weaken your receiver by shunting it, and increase your microphone battery to compensate?

Major **Reber**: You mean in the telephone?

Mr. **Hesketh**: Not particularly. All we have is the Van Rysselberghe system, with, of course, the Morse instrument shunt. We have a kind of cut in — we can go out anywhere on a telegraph line and work either with the telegraph stations or beyond them.

Mr. **Bancroft Gherardi**: I believe I can give some information in answer to Mr. Hesketh's question, as to what has been done in telephone working over ground-circuit telegraph lines. The American Telephone & Telegraph Company has developed a system known as its "Railway Composite System" which permits of the simultaneous working of telephone instruments on single-wire telegraph circuits. This system has been installed on a large number of railways in the United States and is, I am told, operating very satisfactorily. The principle upon which this system works is that the power of the microphone transmitter is increased as much as practicable, while at the same time the sensitiveness of the receiver is diminished. By diminishing the sensitiveness of the receiver, the effects of the telegraph current and outside disturbances are minimized, while by increasing the power of the transmitter, sufficient energy is received in the telephone to enable communication to be carried on. The stations are connected to the line by legging them to ground, the telegraph instruments being of course at the same time shunted by suitable condensers.

Mr. **Hesketh**: Do you use the A. T. & T. Co.'s shunt arrangement?

Col. **Reber**: The standard Western Union.

Mr. **Hesketh**: There is such a telephone system, worked superimposed upon a quadruplex line, between Launceston and Hobart, Tasmania, a distance of about 100 miles. On this line the quadruplex is a non-reversal system, designed by Mr. Hallam of the Postmaster-General's department. Very fair telephone service is given between the stations.

Col. **Reber**: I do not mean to say that ours was more than an experimental trial. The Van Rysselberghe system was used and the method of the A. T. & T. not tried. We worked this system for two years, and with success. I did not know at the time whether it had been done by other people or not.

Mr. Hesketh: The method of superimposing telephones upon Morse lines, as adopted by some railway companies in the states, appears to me to promise the best results. The main principle is to shunt the telephone receiver with an inductive shunt, making it less sensitive to Morse signals, but not correspondingly less sensitive to telephone currents, and increasing the microphone current to counterbalance any reduced efficiency of the receiver.

Col. Reber: I suppose the method of the A. T. & T. is preferable to the old one; but I never had any practical experience with it.

Joseph Hollos (communicated): At present we have twenty "simultaneous telegraph and telephone" circuits, representing a total length of 6576 kilometers. The shortest circuit has a length of fifty-two kilometers, and the longest 999 kilometers. Seven circuits are worked by Morse ink-writers, connected directly, without relay in the circuit. Thirteen are worked by Hughes printing apparatus; two of these, the 999 kilometers Budapest-Berlin, and the 606 kilometers Budapest-Fiume, are worked with Hughes duplex. Morse ink-writers are used only on wires, when the traffic is not heavier in the most busy hours than sixty words; if the traffic is heavier, we go to the Hughes, up to 300 words, when we use the Hughes in duplex.

Upon motion the Section adjourned.

TUESDAY MORNING SESSION, SEPTEMBER 13.

The Section was called to order promptly at half-past nine o'clock by Chairman Francis W. Jones.

Chairman Jones: The first paper upon the program this morning is "High-Frequency Telephone-Circuit Tests," by Dr. A. E. Kennelly, of Harvard University. Dr. Kennelly will now present his paper.

HIGH-FREQUENCY TELEPHONE CIRCUIT TESTS.

BY DR. A. E. KENNELLY, *Harvard University.*

In land-line telegraphy, it has for many years been a custom to test the circuits periodically by applying a steady assigned voltage to their sending ends, and measuring the strengths of current received to ground at their distant ends, through a milliammeter or equivalent apparatus.[1] Fig. 1 shows this well-known arrangement. An e.m.f. E volts is applied to the end A of a line L miles or kilometers in length, and the current-strength i is observed at B, passing to ground through the instrument of resistance R_r ohms.

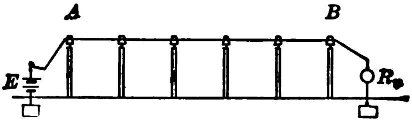

FIG. 1.—TELEGRAPH CIRCUIT TEST.

It is known that for a uniform line of conductor-resistance r ohms per mile or kilometer, and of leakage conductance g mhos

$$i_r = \frac{E}{R_0 \sinh (La) + R_r \cosh (La)} = \frac{E}{R_1} \text{ amperes} \ldots\ldots (1)$$

where[2]

$$R_0 = \sqrt{\frac{r}{g}} \ldots\ldots \text{ohms} \quad (2)$$

$$\text{and } a = \sqrt{rg} \ldots\ldots \text{per mile or kilometre} \quad (3)$$

The resistance R_1, represented by the denominator of the fraction in formula (1), may be called the "receiving-end-resistance" of

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[1] "On Testing by Received Currents" by H. R. Kempe. *Journal* Soc. of Tel. Engrs. Vol. IX, pp. 222–231 (1880).

[2] "On Electric Conducting Lines of Uniform Conductor and Insulation Resistance in the Steady State" by A. E. Kennelly. *Harvard Engineering Journal,* May, 1903.

the circuit; because it is the resistance which the circuit apparently offers to the applied e.m.f. E, as judged by an observer at the receiving end. If the maximum available e.m.f. at the sending end is, say, 200 volts, and the minimum received current-strength at the receiving end of the line which will operate the signalling relay is, say, 1 milliampere; then the "receiving-end-resistance" of the line must not exceed 200,000 ohms in order that the received current in the steady state may suffice to produce a signal. During the variable states of rapid signalling, the effective "receiving-end-resistance" of the circuit may differ appreciably from that of the steady state. Nevertheless, the steady receiving-end-resistance furnishes a useful and reliable criterion as to the workable condition of the circuit. When the steady receiving-end-resistance of any such circuit exceeds some particular limit, the circuit becomes unworkable and requires the lineman's attention.

As an example of formula (1) the case may be considered of a uniform telegraph line, 345 kilometers long, having a conductor resistance of 15 ohms per kilometer, and an insulation leakance of 1 micromho per kilometer (corresponding to an insulation resistance of 1 megohm-kilometer). An e.m.f. of 80 volts is applied at A. What current-strength will flow to ground B: (a) when grounded directly, (b) when grounded through a measuring instrument of 32 ohms resistance? Here $L = 340$; $r = 15$; $g = 10^{-6}$; $E = 80$; $R_r = 0$ in (a) and 32 in (b).

By (2) $R_0 = \sqrt{\frac{15}{10^{-6}}} = 3873$ ohms, the sending-end-resistance for an indefinitely long line.

By (3) $a = \sqrt{15 \times 10^{-6}} = 0.003873$

$La = 340 \times 0.003873 = 1.317$; sinh $La = 1.7321$; cosh $La =$ 2.007.

$$\therefore \text{by (1) } i_r = \frac{80}{3873 \times 1.7321} = \frac{80}{6708} = 0.01193 \ldots \text{amperes in(a)}$$

$$\text{and } i_r = \frac{80}{3873 \times 1.7321 + 32 \times 2.007} = \frac{80}{6772} = 0.0118 \text{ amperes(b)}$$

The receiving-end-resistance of the line would be 6708 ohms in case (a) and 6772 ohms in case (b).

In the case of a telephone circuit, precisely similar formulæ apply.[8] The conditions are, however, rendered more complex, because instead of a steady current system (frequency = zero) we have a multi-frequency alternating-current system. Each frequency of alternating current obeys the formula:

$$i_r = \frac{E}{Z_0 \sinh (La) + Z_r \cosh (La)} = \frac{E}{Z_1} \text{ amperes} \qquad (4)$$

where

$$Z_0 = \sqrt{\frac{r + j\,l\omega}{g + j\,c\omega}} \text{ ohms, the sending-end-impedance} \qquad (5)$$

$$a = \sqrt{(r + j\,l\omega)\,(g + j\,c\omega)} \;\ldots\ldots\ldots\ldots\ldots\ldots \qquad (6)$$

n = frequency cycles per second.
ω = angular-velocity = $2\pi n$ radians per second.
r = conductor-resistance ohms per loop mile or kilometer.
l = conductor-inductance henrys per loop mile or kilometer.
g = dielectric-conductance mhos per loop mile or kilometer.
c = dielectric-capacity farads per loop mile or kilometer.
$j = \sqrt{-1}$
E = effective harmonic e.m.f. at A, or maximum $/\sqrt{2}$ volts.
i_r = effective harmonic current at B, or maximum $/\sqrt{2}$ amperes $\angle$
Z_1 = receiving-end-impedance, or maximum ohms $\angle$
Z_r = impedance of receiving apparatus, ohms $\angle$

In order, therefore, to test a telephone circuit for effectiveness, it is only necessary to apply a known effective sinusoidal e.m.f at A, and to measure the corresponding current strength received at B. The ratio of these quantities will be the "receiving-end-impedance" of the circuit at that frequency. If this impedance exceeds a certain value, assignable for each particular circuit, the circuit will be defective or even inoperative, and will require to be overhauled. It is, moreover, highly probable that the limiting length of circuit over which telephony is commercially possible is that which has a certain definite receiving-end-impedance at a certain standard sinusoidal frequency, whether the circuit is overhead, or underground, mixed, loaded, or natural, and after variations in sending-end-impedance have been taken into account.

It is not, of course, necessary that the measurements shall be

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3. "A Contribution to the Theory of Telephony" by A. E. Kennelly. *Electrical World*, Vol. XXIII, No. 27, p. 208, February, 1894. *The Electrician*, Vol. XXXIII, No. 841, p. 232, June 29, 1894.

made with a simple harmonic, or sinusoidal e.m.f. A mixed frequency or complex harmonic e.m.f. may be used. In that case, however, although the results will be comparable with each other, and with a certain empirical standard, they will cease to be interpretable or checkable by formula (4).

The object of this paper is to describe certain apparatus constructed for the purpose of measuring the alternating-current strength, at telephonic frequencies, received at the distant end of a telephone circuit, with a definite e.m.f. impressed on the sending end. The apparatus, therefore, is one which enables the receiving-end-impedance of a circuit to be measured for a given frequency, or enables that routine test to be made for telephone circuits which has so long been well known for telegraph circuits.

The receiving instrument in such a test should either have negligible impedance, or an impedance of magnitude similar to that of an ordinary receiving apparatus. There is no difficulty in producing an electrodynamometer of sufficient sensibility to enable a telephonic current-strength to be measured under laboratory conditions, but such an apparatus has relatively large inductance, and at a frequency of 1000~, such inductance develops 6283 ohms reactance per henry, while formula (4) shows that this impedance is multiplied by the hyperbolic cosine of the attenuated-length $L\alpha$ in producing its effective share in the receiving-end-impedance of the circuit.

The device selected for the purpose (with Prof. Fessenden's permission) was the "solid barretter" used in the Fessenden system of wireless telegraphy. This consists of a minute loop of very fine platinum wire or filament. Out of several sizes of platinum filament tried, the size which gave the best results has a diameter of about 1.7 microns ($1.7\,\mu = 0.001{,}7$ mm $= 0.000{,}067''$) and a length of about 1.5 mm (0.06″). The resistance of this filament is about 40 ohms per millimetre, or 1000 ohms per inch, at room temperatures. Such a filament has a cross-section of 2.27×10^{-8} sq. cms (3.5×10^{-9} sq. in.), and a volume of 3.4×10^{-9} cc. With the specific gravity of 17.5 for platinum, the mass of the filament would be 6×10^{-8} gramme, and with the specific heat of 0.032,3 for platinum, one erg of heat, accumulated in such a filament, would suffice to raise its temperature 12.3 deg. C.

To produce a platinum filament of such dimensions, the Fessenden device is seen in Fig. 2. *A* and *B* are two brass strips (25 mm × 6 mm × 0.7 mm) pinned, side by side, to a hard-rubber supporting-block *rr*. Copper connecting wires *c, c,* are soldered on above. A short v-loop of silver wire *b* is soldered as a bridge at the lower ends. This silver wire has a diameter of about 0.075 mm (3 mils), and has a central filament of platinum running through it, like the wick within a candle. The point of the silver v is dipped below the surface of strong nitric acid for a few minutes, and with the aid of a current of some milliamperes from a voltaic cell, the silver is rapidly dissolved away, leaving the platinum filament intact. The process is watched under a microscope, and stopped when the estimated right length of platinum filament has been exposed. The barretter is then protected from injury by being enclosed in a short glass test-tube containing air at the ordinary atmospheric pressure.

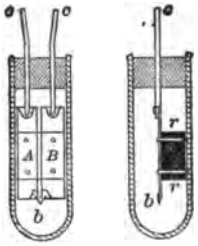

FIG. 2.— FRONT AND SIDE ELEVATION OF BARRETTER.

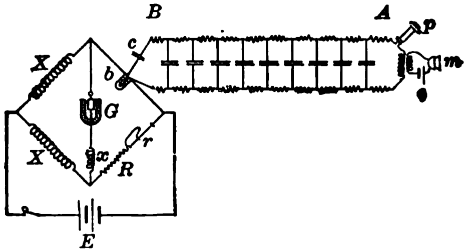

FIG. 3.— CONNECTIONS OF LABORATORY BARRETTER TESTS.

In one of the Fessenden systems of wireless telegraphy, a barretter of this kind is connected between the receiving air-wire and the ground. The passage of the feeble electromagnetic waves through the apparatus generates in the filament a small amount of joulean heat, and the sudden small change in the temperature of the filament produces a correspondingly sudden small change in its resistance. By means of a telephone connected in a local circuit through the barretter, the sudden fluctuations of resistance due to the passage of electromagnetic waves produce audible signals.

In adapting the Fessenden barretter to the telephonic circuit test, the arrangement of Fig. 3 was employed. Here the barretter b is made one arm of an *inductive* Wheatstone bridge. $X, X,$ are two similar coils of low temperature-coefficient resistance wire, wound upon closed magnetic circuits of steel wire, so as to have each 500 ohms resistance, and a relatively large reactance. A smaller reactance-coil x, of low resistance, of copper-wire winding, was included in the galvanometer branch. The galvanometer G is a wall-pattern d'Arsonval reflecting galvanometer of 620 ohms resistance, with a telescope and a scale at about half-meter distance from the mirror. No attempts were made to secure extraordinary sensitiveness, and 1 mm of deflection in the telescope represented approximately 10^{-8} ampere. The testing battery consisted of two storage cells (4.0 volts total e.m.f.). The platinum filament in the barretter had a length of about 5 mm, a diameter of $3\,\mu$, and a resistance of about 125 ohms at ordinary temperatures. Under these conditions a steady battery current of about 6 milliamperes passed through the barretter, raising its temperature some 25 deg. C. A balance at R, aided by a slide-wire r, was secured at about 135 ohms.

If feeble alternating currents are sent through the barretter, superposed upon the steady testing current, they are practically confined to the arm b of the bridge by the reactances X, X, x, and heat the filament above the temperature due to the testing current. It is shown in Appendix I, that for *small* alternating currents, the change in the resistance of the barretter is proportional to the square of the strength of the superposed alternating current.

As shown in Fig. 3, the barretter b was connected at the receiving end of an artificial telephone cable lent by the American Telephone and Telegraph Company. This artificial cable has a conductor-resistance of 2820 ohms, and a capacity of 1.92 microfarads at 15 deg. C. Its CR time-constant was, therefore, 0.0054 second. The cable represents 32 loop-miles of standard underground cable of No. 19 B & S copper wire (88 ohms and 0.060 mfd. per loop-mile). The electrical length of this artificial cable could be adjusted to even miles. With the condenser c short-circuited, and a balance in R of 130 ohms, loud singing into the transmitter at A, operated by 1 storage cell, or 2 volts, produced a distinct deflection on the galvanometer G, representing a received current-strength of nearly 100 microamperes, over the 32 miles of cable. This length represents the limit of "easy commercial" telephonic conversation. As the length of artificial cable in circuit was reduced, the strength of the received current increased, roughly as the inverse square of the length.

It was found practically impossible to obtain steady readings of the current-strength received through the barretter either over different lengths, or even over one and the same length, of the artificial cable, owing to variations in the transmitting apparatus, including the singer. The galvanometer showed that the intensity of the note delivered by the singer could not be steadily sustained for even a few seconds. Moreover, the difference in the effective current at the receiver due to variation in the distance between the lips and the transmitter was very remarkable. The current received, when the lips of the singer were only a few centimeters from the transmitter, was only a small fraction of that received when the lips almost touched the transmitter cone. It was evident, therefore, that the conditions of sound-production at the transmitter would have to be standardized, if consistent and reproducible measurements were to be secured.

A short standard organ-pipe was lent for this purpose by Prof. W. C. Sabine of the Jefferson Physical Laboratory. This pipe sang a fairly pure note of $C'' = 512 \sim$. It was connected by an electromagnetically controlled valve to a small air-holder, which, descending under a constant imposed weight, maintained a nearly constant amplitude of sound at the lips for half a minute at a time. By setting this pipe immediately facing the transmitter, and at a carefully maintained distance therefrom, fairly consistent measurements of alternating-current strength were obtained, with different lengths of cable in circuit. The results are indicated in the curve sheet of Fig. 4. It will be seen that the received-current strengths are roughly proportional to the inverse squares of the lengths of the cable, the inductance of which was negligible. The received current varied from 0.13 milliampere at 32 miles, to 1.16 milliamperes at 13 miles. The dotted line follows the values calculated from equation (4), taking $E = 1.74$ volts. It will be seen that there is a rough agreement between the observed and computed current-strengths. The sources of the discrepancy between them were not, however, investigated.

It is evident that the sensibility of the test depends upon the smallness of the filament's diameter, so that it may become heated by a feebler alternating current, and also upon the minimum increase in resistance that can be accurately determined by the Wheatstone bridge. With 3-micron wire this was about 1/700 of 1 per cent. This represented the effect of a telephonic current strength of 23 microamperes. With 1.7-micro wire in air, the limit was reduced to about 7 microamperes, and with the same 1.7-micron wire *in vacuo,* to 3 or 4 microamperes.

Although such degrees of sensitiveness are attainable under laboratory conditions, and might suffice for measuring telephonic conversation currents at the receiving end of long circuits, yet the reflecting galvanometer is quite unsuited for routine tests at the switchboard. Any galvanometer that can at present be used under switchboard conditions is much more limited in sensibility. If, however, the limit of resistance change to be detected is increased from 1/700 of 1 per cent to 1/10 of 1 per cent, the minimum measurable telephonic current-strength becames about 1/2 milliampere, with 1.7-micron wire in air. This current strength can be supplied over the longest commercial telephone circuits if an effective

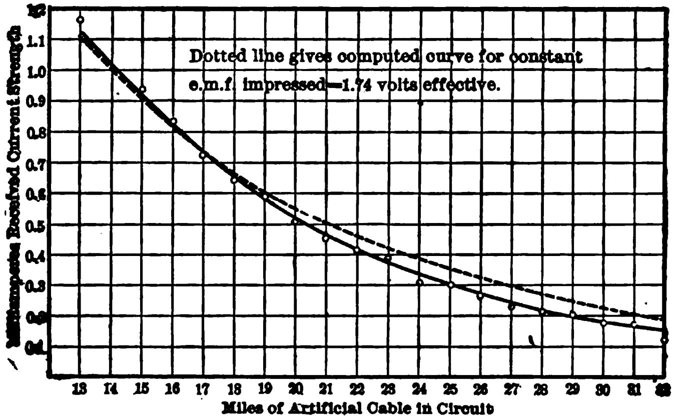

FIG. 4.—CURVE SHOWING RECEIVED CURRENT STRENGTHS AT EACH SUCCESSIVE MILE LENGTH OF ARTIFICIAL CABLE BETWEEN 13 AND 32 MILES.

impressed alternating e.m.f. of about 25 volts be substituted, at the sending end, for the transmitter. That is to say, routine tests using switchboard instruments become quite practicable if a standard 25-volt alternator of telephonic frequency can be applied at the sending end of each circuit to be tested.

In order to adapt the apparatus in this manner for switchboard use, a Weston milliammeter, in series with the barretter, was substituted for the reflecting galvanometer and Wheatstone bridge.

The connections of the switchboard apparatus are indicated in Fig. 5, where *b* is the barretter, with a 2-microfarad condenser in its circuit, to stop the testing current, supplied by the dry cell *e*, from flowing around the telephone circuit; *x* is a reactance coil to stop the telephone current from being diverted through the Weston milliammeter *m*, which gives a full-scale reading of 10 milliamperes over 100 divisions of 1/10 milliampere each. The dry cell *e* has an e.m.f. of 1.45 volts, and an internal resistance of less than 1 ohm. The resistance of the local circuit is adjusted, with the aid of the rheostat *r*, until the full deflection of 10 milliamperes is obtained. This requires 145 ohms in the circuit, of which about 120 are in the barretter, at working temperature, 8.5 in the reactance-coil *x*, 4 in the milliammeter and the remainder, or 12.5, in the dry-cell and rheostat, *r*.

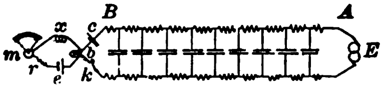

FIG. 5.—BARRETTER AND MILLIAMMETER AT RECEIVING END OF CIRCUIT OPERATED BY ALTERNATOR.

Pressing the key *k* allows alternating current from the source *E* to pass through the barretter, thereby heating it, increasing its resistance, and temporarily reducing the current in the local circuit. Each division of the milliammeter scale represents 1 per cent of the testing current, and 1/10 of a division or 0.1 per cent can be readily estimated. A convenient strength of alternating current is one which will reduce the testing current 1 per cent, or one scale division. The action is very prompt and dead-beat, so that the needle's deviation follows at once upon the movement of the key. It is shown in Appendix II, that the strength of the received alternating current is equal to the square root of the needle's deviation in scale divisions, on pressing the key, multiplied by an instrument-constant, depending on the barretter. Thus in the actual instrument, one division of deviation from the full scale reading represents 1.4 milliamperes of superposed alternating current, with shunt multiplier of unity.

The source of standard alternating e.m.f. *E* employed with the switchboard testing-set was a small 12-pole inductor alternator, weighing about 2 kilogrammes, and originally designed for a very different purpose. When belt driven, this little machine could readily deliver a few milliamperes at a frequency of 1200 ~, and, when directly connected to a small motor, 600 ~ The rotor consisted of a laminated inductor cylinder with grooves and polar projections. Owing to the peculiar magnetic actions set up during operation, the frequency delivered was very impure. Thus, when running at a speed corresponding to the principal frequency of 1200 ~, there was a prominent undertone frequency of 600 ~, in addition to overtones of 1800, 2400, and higher orders. Moreover, the pressure regulation of this little alternator was very defective, the voltage at terminals varying greatly with the nature and impedance of the circuit to which it was applied. Consequently, although this was the only convenient source of telephonic-frequency e.m.f. available, yet it left much room for improvement. An ideal source of alternating current for these tests should be simple, reliable, consume little power, having constant frequency and terminal e.m.f. with a pure sine-wave.

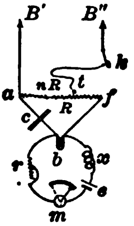

FIG 6.—CONNECTIONS OF BARRETTER HIGH-FREQUENCY MILLIAMMETER FOR TELEPHONE CIRCUITS.

Since the 1.7-micron wire melts at approximately 14 milliamperes in air at ordinary pressure (about 2.5 milliamperes *in vacuo*), and the steady testing current is 10 milliamperes, the barretter should fuse when the measured superposed alternating current reaches 10 milliamperes (10 + j 10 = 14.14). Consequently, the barretter must be protected from alternating currents of more than 3 or 4 milliamperes. The theory of Appendix I also shows that beyond 2 or 3 milliamperes of measured alternating current, the readings diminish in accuracy unless the formula of the measurement is complicated by the introduction of a correction. It becomes desirable, therefore, to protect the barretter by an adjustable shunt, as shown in Fig. 6. Here *R* is a resistance of 2000 ohms, permanently bridged across the barretter *b* and 2-microfarad condenser *c*. By shifting the contact *t*, to points distant *nR* ohms

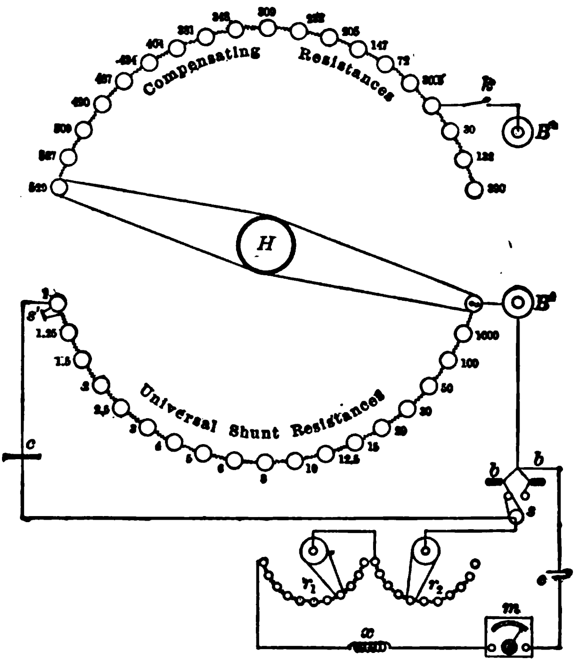

FIG. 7.—DETAIL CONNECTIONS OF BARRETTER MILLIAMMETER FOR TELEPHONE CIRCUITS.

from *a*, where $n = 1, \frac{1}{2}, \frac{1}{3}, \frac{1}{4}, \frac{1}{5}$, etc., successively, the multiplying power of the shunt is made 1, 2, 3, 4, 5, etc., on the principle of the Ayrton universal shunt, as shown in Appendix II, for all frequencies of alternating current.

The actual connections employed differ only from those of Fig. 6, by the insertion of compensating resistances in the wire *kt*, so as to keep the impedance of the apparatus constant under

Fig. 8.

all conditions, and about equal to that of an ordinary telephone receiving apparatus at the testing frequency. In the case considered, the frequency selected was 600 $\sim$, and the constant impedance, including barretter, condenser and universal shunt, 529 ohms. The full connections are given in Fig. 7.

B′ B″ are the line terminals, connected to the telephone circuit under test, at its receiving end. *H* is a double-ended ratchet-switch, bridging diametrically across the two semicircular rows of contacts. The upper contacts are separated by the compensating resistances. The lower contacts belong to the universal shunt. In the position shown, the barretter *b* and condenser *c* are entirely short-circuited, or shunted with a multiplying-power ∞; while the impedance of the apparatus, between line binding-posts, is 529 ohms, when the key *k* is depressed. On turning the handle *H* clockwise from this initial position, the multiplying power of the shunt is gradually reduced to 1, in 18 steps. By this means the instrument has a theoretical range of measurement from 0.5 milliampere to 4000 milliamperes.

Two barretters *b b* are installed, under the control of the switch *s*, one for working, and the other for reserve, in case of accidental fusing. The adjustable rheostats r_1 r_2 of 1/2-ohm and 5-ohm steps respectively, enable the testing current from the dry cell *e* to be kept constant at 10 milliamperes, except at such moments when the key *k* is depressed.

A view of the actual form of barretter receiving apparatus, as constructed by the International Instrument Company of Cambridge for the Engineering Department of the American Telephone and Telegraph Company, is seen in Fig. 8.

The process of testing a circuit with this apparatus consists in applying the required voltage and frequency of alternating e.m.f. at the sending end of the circuit, connecting the receiving ends to the line terminals *B′ B″*, adjusting the steady testing current to the precise value of 10 milliamperes, pressing the testing key with the left hand, and turning the handle of the universal switch with the right hand from point to point by ratchet, until a suitable small deviation of the needle is observed with the magnifying glass on the milliammeter scale. The square root of this deflection times the shunt multiplying-power, times the instrument constant, gives the effective alternating current in milliamperes received through the 529 ohms impedance in the instrument. From this current, and the applied effective e.m.f., the receiving-end impedance follows at once by Ohm's law. If the impressed e.m.f. is pure, or simply harmonic, this observed receiving-end impedance can be compared with its computed value, for the frequency employed. If the e.m.f. is a complex harmonic, the observed receiving-end impedance can be compared with that similarly observed on varying lengths of artificial standard underground cable. The comparison will show whether the circuit under test is in satisfactory telephonic condition.

The curves of Fig. 9 show the current-strengths received with

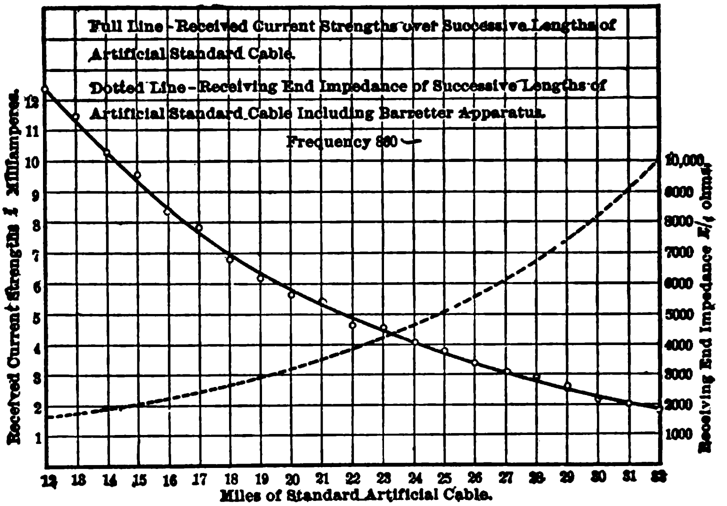

FIG. 9.

the apparatus of Fig. 8 through successive lengths of the artificial standard underground cable above described, and also the corresponding receiving-end-impedance. In this case the e.m.f. E had a magnitude of from 18 to 20 volts, varying with the length of the circuit, and the frequency was 860 ~ with components of 430 ~ and upper harmonics. It will be seen that the received current-strength increased from 1.85 milliamperes at 32 miles to 12.35 milliamperes at 12 miles, and the receiving-end-impedance from 1650 ohms at 12 miles to 10,000 ohms at 32 miles, with the particular frequencies used. With lower frequencies these impedances would ordinarily be less, and with higher frequencies greater.

The following table gives a few measurements made with the apparatus over various looped circuits, the inductor alternator and the barretter receiving apparatus being in the same room, near the switchboard. The frequency was 600 ~ (with 300 ~ and harmonics):

Length of circuit loop. Miles.	Wires. Gauge.	Applied e. m f. E. volts.	Received current.			Receiving end impedance. ohms.
			Deflection divs.	Shunt.	i. Milli. amp.	
470	8 B. W. G.	5.9	0.5	1	0.99	5,960
470	8 B. W. G.	25	1	3	4.20	5,950
470 + 1 mile art cable.	8 B. W. G.	26	0.8	3	3.75	6,925
" " " "	– –	–	1.2	2.5	3.84	6,760
235 +235 } 470	8 B. W. G. 12 N. B. S. G.	24	1.0	1	1.4	17,150
235 +235 } 470	12 N. B. S. G. 8 B. W. G.	30	1.2	1	1.58	19,600
470	12 N. B. S. G.	30	0.1	1	0.442	67,800
25	Art. cable.	28	0.8	3	3.75	7,470
26	Art. cable.	28	0.65	3	3.378	8,280

The experimental research described in this paper was undertaken with the assistance of Messrs. Moses King, Jr., and E. A. Stevens, Jr., senior students in the Department of Electrical Engineering at Harvard, in consultation with the Engineering Department of the American Telephone & Telegraph Company, as represented by Dr. Hammond V. Hayes, Mr. H. S. Warren, Dr. George A. Campbell and Mr. G. W. Pickard. We owe to these gentlemen not only the loan of special apparatus for the prosecution of the work, but also aid and suggestions at every stage; so that whatever has been usefully accomplished is virtually the joint result of both departments.

We also desire to express our indebtedness to Prof. R. A. Fessenden, who assisted us with apparatus, barretters and valued suggestions, as well as to Prof. W. C. Sabine for his apparatus and aid.

APPENDIX I.

THEORY OF THE METHOD OF MEASURING ALTERNATING-CURRENT STRENGTHS BY THE CHANGE OF BARRETTER-RESISTANCE TO DIRECT CURRENT.

Using the c.g.s. system for simplicity, and the connections of Fig. 6.

Let r = the resistance of the barretter b, when heated by the steady testing current (absohms).

Δr = the small increase in the resistance r due to the superposition of the feeble alternating current.

I = the strength of the steady direct testing current (absamperes).

i = the effective or square-root-mean-square strength of the superposed alternating current (absamperes).

p = the power dissipated by the barretter b when traversed by the steady testing current (abswatts).

Δp = the small increase in power dissipated when the alternating current is superposed.

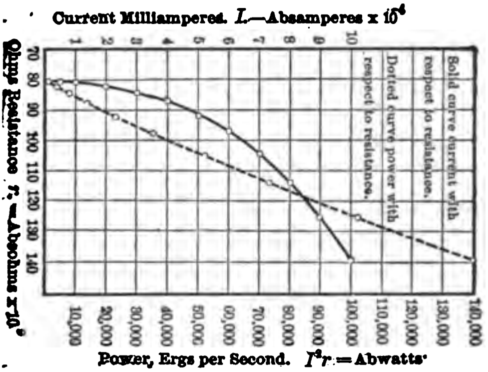

FIG. 10.—CURVES SHOWING RELATION BETWEEN THE RESISTANCE r, OF A PARTICULAR 1.7 μ BARRETTER, THE CURRENT STRENGTH, I, STEADILY FLOWING THROUGH THE BARRETTER; AND THE POWER I^2r DISSIPATED IN THE BARRETTER.

Then $p = I^2 r$ abwatts.

$$p + \Delta p = (I^2 + i^2)(r + \Delta r) \qquad \text{''}$$

$$= (I^2 + i^2)\left(r + \frac{\Delta r}{\Delta p}\,\Delta p\right) \qquad \text{''}$$

$$= (I^2 + i^2)\left(r + \frac{dr}{dp}\,\Delta p\right) \text{ when } \Delta r \text{ is very small} \qquad \text{''}$$

$$\therefore\ \Delta p = (I^2 + i^2)\frac{dr}{dp}\,\Delta p + i^2 r \qquad \text{''}$$

$$\therefore\ \Delta p \left\{ 1 - (I^2 + i^2)\frac{dr}{dp} \right\} = i^2 r \qquad \text{''}$$

$$\text{But } \Delta p = \frac{dp}{dr}\,\Delta r \qquad \text{''} \qquad \text{''} \qquad \text{''}$$

$$\therefore\ \frac{dp}{dr}\left\{ 1 - (I^2 + i^2)\frac{dr}{dp} \right\} \Delta r = i^2 r \qquad \text{''}$$

$$\left\{ \frac{dp}{dr} - (I^2 + i^2) \right\} \Delta r = i^2 r \qquad \text{''}$$

$$i^2 = \frac{\Delta r}{r}\left\{ \frac{dp}{dr} - (I^2 + i^2) \right\} \qquad (\text{absampere})^2$$

By actual measurement it is found that in all cases p follows nearly a straight line with respect to r, see Fig. 10, and, at least within the range of r considered, $\frac{dp}{dr}$ becomes a constant for each particular barretter. Thus in Fig. 10, and near 10 milliamperes or $I = 10^{-3}$, $\frac{dp}{dr} = 2700$ ergs per ohm $= 2.7 \times 10^{-6}$ abwatts per absohm.

Let $\frac{dp}{dr} = b$ an approximate constant, which may be called the dissipation-resistance constant.

Then $$i^2 = \frac{\Delta r}{r} \left\{ b - (I^2 + i^2) \right\}$$

and $$i = \sqrt{\frac{\Delta r}{r}} \sqrt{b - (I^2 + i^2)}$$ absamperes.

Thus in the case of Fig. 10 for $i < 2$ milliamperes,

$$\begin{aligned} i &= \sqrt{\frac{\Delta r}{r}} \sqrt{2.7 \times 10^{-6} - 10^{-6}} \\ &= \sqrt{\frac{\Delta r}{r}} \sqrt{1.7 \times 10^{-6}} \\ &= \sqrt{\frac{\Delta r}{r}} \quad 1.304 \times 10^{-3} \end{aligned}$$

For $\frac{\Delta r}{r} = 0.01$ or 1 per cent, $\sqrt{\frac{\Delta r}{r}} = 10^{-1}$

$i = 1.304 \times 10^{-4}$ absamperes.

$= 1.304$ milliamperes.

Thus if $\sqrt{b - I^2} = c$ the barretter-constant,

then $i = \sqrt{\frac{\Delta r}{r}} \times c$ absamperes

$= \sqrt{\frac{\Delta r}{r}} \times c^1$ milliamperes

where $c^1 = c \times 10^4$

Or the alternating-current strength in milliamperes will be a constant times the square root of the proportionate increase in barretter resistance due thereto.

The sensibility of the method, or the minimum current which can be measured, depends upon the minimum proportionate increase in resistance $\Delta r/r$ that can be determined, and upon the magnitude of $b = \frac{dp}{dr}$ the dissipation per unit increase of resistance; also, in lesser degree, upon the strength I of the testing current.

When the barretter of Fig. 10 was sealed within an exhausted glass vessel, the testing current I was reduced to 1.5 milliamperes, or 1.5×10^{-4} absamperes and b to 90 ergs per ohm $= 9 \times 10^{-8}$ abwatts per absohm. From these values $c = 2.6 \times 10^{-4}$

$$i = \sqrt{\frac{\Delta r}{r}} \times 2.6 \times 10^{-4} \qquad \text{absamperes.}$$

If the least determinable change in resistance is 1/7000 of 1 per cent;

then $$i = \sqrt{\frac{1}{700{,}000}} \times 2.6 \times 10^{-4} = 3.1 \times 10^{-7} \qquad \text{absampere}$$
$$= 3.1 \qquad \text{microamperes.}$$

APPENDIX II.

THEORY OF DETERMINING THE PROPORTIONATE INCREASE IN RESISTANCE OF A BARRETTER (AND HENCE THE ALTERNATING-CURRENT-STRENGTH) BY A MILLIAMMETER IN DIRECT SERIES CIRCUIT AS IN FIG. 5.

Let $r =$ the res: of the barretter under steady test (absohms).
$R =$ the res: of the barretter circuit steady test (absohms).
$e =$ the e.m.f. of the dry cell (abvolts).
$I =$ the steady testing current (absamperes).

Then $$I = \frac{e}{R}$$

$$\frac{dI}{dr} = -\frac{e}{R^2} = -\frac{I}{R}$$

$$\therefore \frac{dI}{I} = -\frac{dr}{R}$$

$$\therefore \frac{\Delta I}{I} = -\frac{\Delta r}{R} \text{ when } \Delta r \text{ and } \Delta I \text{ are small}$$

$$\text{or } -\frac{\Delta I}{I} = \frac{\Delta r}{r} \times \frac{r}{R}.$$

The proportionate change in current as indicated by the milliammeter will be less than the proportionate charge in barretter by resistance in the ratio r/R

$$\text{or } \frac{\Delta r}{r} = -\frac{\Delta I}{I} \times \frac{R}{r}.$$

In order to make the minimum $\frac{\Delta r}{r}$ observable, the resistance of the barretter should be as large a proportion as possible of the resistance of the circuit.

If $\frac{R}{r} = d$ a constant of the circuit

$$\frac{\Delta r}{r} = -\frac{\Delta I}{I} \times d.$$

By observing the proportionate diminution of current $-\frac{\Delta I}{I}$, the proportionate increase in resistance is thus deducible.

Theory of the Universal Shunt with Alternating Currents.

Referring to Fig. 6, let R be a constant non-inductive resistance constantly connected to the barretter b and condenser c. Let z be the vector impedance of the condenser at the particular frequency or association of frequencies employed, absohms, $\angle$. Then the multiplying power of the shunt R permanently applied is

$$N = \frac{R+z+r}{R} \qquad \text{(vector).}$$

If now the contact t is shifted from f along R to some position distant electrically nR from a; then

$$N^1 = \frac{R+z+r}{nR}$$

$$= \frac{N}{n}.$$

If n be taken as $^1/_2$, $^1/_3$, $^1/_4$ etc.,

$$N^1 = 2\,N,\ 3\,N,\ 4\,N, \text{ etc.}$$

Consequently it is unnecessary to know the impedance z offered by the condenser. It is sufficient to maintain the resistance R constantly connected, to calibrate the apparatus under this condition, and then obtain a desired shunt by bringing out a contact-position at the corresponding point of the resistance R. The only drawback is the permanent reduction in sensitiveness of the apparatus by the constant shunting of the resistance R, even when the contact t is connected at f. If, however, $R = 2000$; while $(z+r) = 200 \;\diagdown\!\overline{53^\circ}$

$$N = \frac{2126 \;\diagdown\!\overline{4^\circ.19'}}{2000} = 1.063 \;\diagdown\!\overline{4^\circ.19'}$$

so that the permanent loss of sensibility is only 6.3 per cent.

With the universal shunt applied, the formula for the instrument becomes

$$i = n N d c^1 \sqrt{\frac{\Delta I}{I}} \qquad \text{milliamperes}$$

$$= nK \sqrt{\Delta I} \qquad \text{milliamperes}$$

where n is the multiplying power of the universal shunt, K is the constant of the instrument with the full shunt R applied and the testing current I; while ΔI is the small diminution in testing current-strength (as read off in scale-divisions) due to the action of the alternating current.

APPENDIX III.

SERIES OF PRACTICAL TESTS WITH THE APPARATUS.

Since the paper was written, the engineering department of the American Telephone & Telegraph Company has made a series of tests with the apparatus from day to day, on a loop of open-wire circuit from Boston to Bedford, N. Y., and return, with a view to ascertaining the variations which might occur in repeating the received-current test on the same circuit day after day under conditions kept as nearly the same as possible. Owing to the fact that no high-frequency alternator has been available of sufficiently good regulation to afford a constant impressed voltage from day to day, the impressed voltage at the sending end had to be observed simultaneously with the current at the receiving end. The observations are tabulated below. It will be seen that the receiving-end impedance varied from 10,600 ohms to 13,000 ohms, being affected apparently by the insulation of the circuit.

TABLE I.

Date.		Impressed voltage.	Barreter number.	Insulation of circuit megohm-miles.	Shunt multiplier.	Deflection.	Receiving end impedance ohms.
July	22.......	33.85	7	6.67	1.25	2.0	12,800
	22.......	33.85	9	6.67	1.25	1.9	13,100
	26.......	30.78	7	9.85	1.25	1.8	12,200
	26.......	30.78	9	9.85	1.25	1.6	13,000
	27.......	30.78	7	8.53	1.25	1.9	11,900
	27.......	30.78	9	8.53	1.25	1.7	12,600
	28.......	30.78	7	5.14	1.25	1.8	12,200
	28.......	30.78	9	5.14	1.25	1.7	12,600
	29.......	30.78	7	13.26	1.25	1.8	12,200
	29.......	30.78	9	13.26	1.25	1.7	12,600
August	5.......	30.16	7	8.98	1.25	1.7	12,800
	5.......	30.16	9	8.98	1.25	1.8	12,000
	8.......	29.54	7	5.43	1.25	1.7	12,100
	8.......	29.54	9	5.43	1.25	1.7	12,100
	10.......	30.78	7	2.35	1.25	1.8	12,200
	10.......	30.78	9	2.35	1.25	1.7	12,600
	11.......	30.16	7	8.53	1.25	2.0	11,400
	11.......	30.16	9	8.53	1.25	1.7	12,300
	12.......	30.78	7	6.98	1.25	2.0	11,600
	12.......	30.78	9	6.98	1.25	1.9	11,900
	14.......	30.78	7	0.63	1.25	2.4	10,600
	14.......	30.78	9	0.63	1.25	2.1	11,300
	17.......	33.24	7	12.08	1.25	2.1	12,200
	17.......	33.24	9	12.08	1.25	2.0	12,500

Circuit tests of loop of 384 miles of two No. 12 N. B. S. G. copper overhead wires (plus underground wires in Boston city limits). Resistance per loop mile, 10.5 ohms. Capacity per loop mile, 0.008 microfarad. Inductance per loop mile, 3.66 millihenrys. Insulation as above. Frequency about 300.

DISCUSSION.

CHAIRMAN JONES: Of all the papers that will be presented to this Section and pass into our records, I think for importance the paper of Dr. Kennelly will not be the least. I would like to hear from any gentlemen present having any suggestions to offer.

MR. W. C. YEATMAN: I would like to ask if you made any experiments with the liquid barretter?

DR. KENNELLY: No, sir; not in connection with this research.

MR. C. B. COATES: Did you make any experiments with a loaded line of any kind?

DR. KENNELLY: One of the experiments detailed in the paper was with a loaded line. I do not remember which it was, but the results obtained checked the practical work of the telephone department, and means that a very short loaded line is worse than an unloaded line. There is no necessity for loading a short line, unless the circuit is going to be looped up with some other and longer line.

MR. BANCROFT GHERARDI: I have listened with the greatest interest to the paper which Dr. Kennelly has just presented to us. In my judgment, his paper represents not only a very fine research, but is also work which in time will be of great use along a number of different lines in telephony. Somewhere in his paper Dr. Kennelly refers to his work as being particularly useful in making routine or daily tests of lines. I should expect that some such method as the one that he has described will be very useful for that purpose, but I think that there is another application of such methods which may be even more important and valuable. I refer to the possibility of using some such method as the one described, in making special researches with reference to the efficiency of lines of various kinds and apparatus of various descriptions. Such investigations are at the present time conducted, in general, by using the ear as a measuring device. It is well known to us all that the ear is a very crude measuring device, and that large percentage changes must take place in the energy at the received end of the circuit before there is a perceptible difference in the sound observed in a telephone. I think such a method as outlined by Dr. Kennelly is going to enable us to make very precise measurements and tests of the character referred to above, and that this phase of his work is quite as important, if not more important, than the matter of making routine tests.

Mr. John Hesketh: I wish to add my thanks to Mr. Gherardi's for what I feel sure will prove to be a most valuable and practical method of testing telephone lines. In common with all telephone engineers, I have felt the need of a reliable and comparatively easy method of testing telephone lines under practical working conditions, and I am sure this method will give us a great deal of assistance in our work.

Dr. Frank B. Jewett (communicated): In using the barretter set in which the measurements are made by means of the change in the reading of a milliammeter, the limiting deflection for which the simple barretter formula is applicable is so small that any error in estimating the position of the needle causes a large variation in the calculated current, thus making the method unreliable. The needle and the rulings on the scale are so wide that, except when the setting is well between two marks, the accurate estimation of one-tenth of a division is extremely hard, especially for one unaccustomed to this method of reading. This way of measuring the alternating current also introduces another chance for error by bringing in the *total* resistance of the local battery circuit as a factor in the determination of the percentage change in barretter resistance.

$$\frac{\Delta r}{\ } = -\frac{\Delta I}{I} \times \frac{R}{r} \qquad (1)$$

Thus any accidental change in *R*, such, for example, as a loose contact, would destroy at once the original calibration of the instrument, even supposing the new resistance to remain constant.

The precision with which the ammeter needle may be set on any given mark being much higher than any possible estimation of small deflections, the desirability of modifying the formula to conform either to no deflection or to a constant deflection seems quite obvious if the barretter is to be an effective instrument in the hands of persons not especially trained in the use of delicate physical apparatus.

In order to keep the current in the local circuit constant, it is only necessary to alter the resistance by an amount depending upon the value of the superimposed alternating current; the value of which may be at once determined if the change in resistance is known. Under these conditions and following the same line of reasoning used by Dr. Kennelly, the formula for the alternating current is easily found to be

$$i^2 = \frac{\Delta R}{r}\left(\frac{dp}{d\Delta i} - \frac{dr}{dR}(I^2 + i^2)\right) \qquad (2)$$

or

$$= \frac{\Delta R}{r}\left(\frac{dp}{dR} - \frac{dr}{dR}I^2\right)$$

when I is large — e. g., 10 milliamperes — as compared with i. R is the resistance of the external circuit, r that of the barretter when current I is flowing and p is the power dissipated in the barretter. (ΔR is the *real* change in R irrespective of sign; it always represents a decrease.) Collecting the constant parts of the above expression,

$$i = \sqrt{\frac{C}{r}}\sqrt{\Delta R} = C_1\sqrt{\Delta R} \qquad (3)$$

where C_1 is a constant depending upon the barretter and the electromotive force of the battery; for barretters made of 1.7μ wire, and having a resistance of about 120 ohms under a current of 10 milliamperes, using a single cell of electromotive force 1.48 volts, gave $C_1 = 8.20 \times 10^{-4}$, approximately, for R in ohms and i in milliamperes. Since the above formula involves only *changes* in the external resistance, it is evident that no especial care need be taken to determine the resistance of the part of the circuit outside the adjustable rheostat, nor is there any need of making it small in order to insure sensitiveness — a condition imposed by equation (1).

In order to determine the amount of care required in constructing the barretters, a number were made up from 1.7μ wire with resistances varying from 107 ohms to 126 ohms at 10 milliamperes. Using a cell of electromotive force 1.48 volts, the values of C_1 varied from 8.08×10^{-4} to 8.37×10^{-4} with an average of 8.22×10^{-4} — the maximum difference is less than 3.6 per cent, and for those barretters whose resistance differed from 120 ohms by 1 ohm or less, the variation in the constant was only 1.2 per cent.

To show that the constant is independent of the external resistance and dependent on the electromotive force, two barretters were tested with, (1) a single cell, (2) two cells in parallel and (3) three cells in series; of the two, barretter "M" had a resistance of 125 ohms at 10 milliamperes and barretter "P" a resistance of 117.5 ohms.

	(1)	(2)	(3)
M	$8.08+ \cdot 10^{-4}$	$8.04 \cdot 10^{-4}$	$5.36 \cdot 10^{-4}$
P	$8.37 \cdot 10^{-4}$	$8.33 \cdot 10^{-4}$	$5.52 \cdot 10^{-4}$

These constants were determined by means of the adjustable resistances furnished with the set and consequently may not have been quite accurate.

Assuming 0.1 ohm as the smallest measurable change in *R* and also that 0.1 scale division can be read with absolute accuracy, the smallest measurable current with shunt multiplier unity is 0.460 milliampere for the deflection, and 0.245 for the constant *I*, methods. The following table shows the value of the current in milliamperes through various lengths of artificial cable, as determined by the two methods. Column I is from constant current and column II from deflection. The motor driving the 800-cycle alternator was run on the lighting mains and consequently the speed varied somewhat from time to time. That the values in column II range slightly higher than those in column I is probably due to the fact that, with the barretter used, the constant for the deflection method was carefully determined by bridge readings, while that for the constant current was done on the regular box.

	Multiplying	Current.	
Miles Cable.	Factor.	I	II
8	10	14.61	14.5
	6	13.85	14.3
12	5	9.19	9.45
	4	9.12	9.53
16	4	6.01	6.08
	3	6.01	6.32
	2.5	5.95	6.17
20	3	3.72	4.25
	2	3.73	3.89
25	1	2.07	2.17
	1.5	2.15	2.12
30	1	1.25	1.25
32	1	0.90	0.92

Summing up, the apparent advantages of the constant current method for regular instrument work are:

(1) Greater accuracy of reading. (2) Less need of care in the construction of barretters, where separate calibration is not feasible; as shown above the maximum observed variation in the constant was less than 3.6 per cent over a wide range of resistances, while for two barretters as carefully constructed as possible, the constants for the deflection method were 1.4 and 1.5 respectively — over 7 per cent variation. (3) Possibility of using a cheap portable galvanometer instead of an expensive milliammeter. (4) Readings found in a way more familiar to the ordinary wire chief than estimating deflections.

Dr. Kennelly (communicated): Dr. Jewett's amendment of the method of using the barretter testing apparatus seems to be both interesting and valuable. Instead of observing the diminution of current ΔI produced in the milliammeter by the alternating current received over the tested circuit, he compensates for this diminution by cutting out resistance in the local dry-cell circuit and so restores the current to its original value. The observed quantity is then a diminution in resistance at constant current instead of a diminution of current at constant resistance. As Dr. Jewett points out, it is easier to read a change of ohms required to keep a deflected needle precisely over a scale mark than to read a small change in the needle's deflection.

Chairman Jones: I am pleased to now present to you our honorary chairman, John Hesketh, Esq., electrical engineer for the State of Queensland, Postmaster-General's Department, Commonwealth of Australia, who will present a paper upon the subject, "A New Danger to Lead-Covered Aerial Cables."

A NEW DANGER TO LEAD-COVERED AERIAL CABLES.

BY JOHN HESKETH, *Electrical Engineer for the State of Queensland, Postmaster-General's Department, Commonwealth of Australia.*

In 1896 the attention of the writer was directed to perforations which had, in a few instances, been discovered in the sheathing of aerial lead-covered telephone cables in the Brisbane district. The perforations were not sufficiently frequent to make the question one of great moment at the time, but with the adoption of similar cables for use in other towns throughout Queensland the trouble increased and became of importance.

The cables in which the defects were found were of various kinds, the following being the chief types:

(1) Copper conductors, fibrous insulation, anti-induction lead-foil serving, lead-sheathed, and served with tarred tape.

(2) The same, but served with lead-painted tape.

(3) The same as in (1) but with the sheath composed of two layers of lead, a serving of Stockholm tar being placed between them.

(4) Paper-insulated conductors, plain lead-covered.

These cables were all suspended in approximately similar manner from metal hangers on steel bearing-wires; the bearing-wires and sheath of the cables being connected with earth at each pole.

The holes found in the cable sheathing were of various sizes from 1 mm up to 6 mm diameter. They did not uniformly penetrate the lead, in some instances only entering to a depth of 1 or 2 mm while in others the perforations were complete. There did not appear to be any general damage to the adjoining portions of the cable; that is to say, the damage was confined to well-defined holes either partly or completely piercing the sheathing. A general gnawing of the cable was obtained only when the beetles were in confinement. Fig. 6 shows clearly the difference between the general damage to the small lead-covered conductors by the beetle in confinement and the clear-cut hole in the larger lead sheath of the cable.

Fig. 1.— Borings (perforations) by "grub" or larva of beetle Ecelonerus sp. Charters Towers.

View from within and from without, with grub in action. Only the light-spot represents scales of lead. About two-thirds natural size.

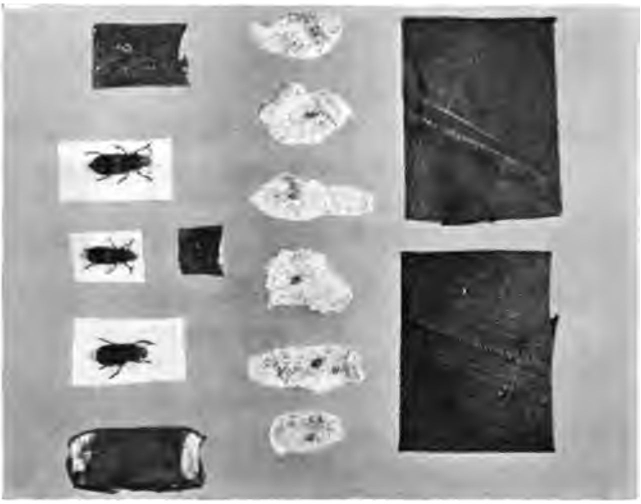

Fig. 2.— Ecelonerus beetle.

Three specimens. Larva case on, and perforations in, tarred parcelling; larva case on white-leaded parcelling; perforations in lead. About seven-tenths natural size.

The small holes mentioned were found in the taped cables only, while the larger holes were found in all types. No cables so far used in Queensland have been immune, and the damage has occurred in Brisbane, Gympie, Toowoomba, Rockhampton, Charters Towers and Townsville. So far, however, plain lead-covered cables have been less subject to damage from insects than have the taped cables.

The trouble was as a rule made evident at the beginning of the rainy season in each year, say about November or December, and was commonly associated with the heavy thunderstorms which prevail about that time. The air then being saturated with moisture, the insulation of the cable fell until the lines were often unworkable until the defects had been located and removed. The holes being so numerous this was often a matter of considerable trouble and time.

The disinclination to believe that an insect could cause the trouble delayed the solution of the question somewhat. Even in October, 1903, nearly two years after instructions had been issued for insects to be searched for, the belief was still held by some officers of the department that the smaller holes were caused by lightning.

The first direct evidence that insects were the cause of the trouble was found at Townsville in 1903, when the black Jesuit beetle was found in holes in the cable there. Very shortly afterward, very complete investigations carried out by Mr. F. Roseneder, telephone officer at Charters Towers, produced the evidence which is embodied herein.

The remedy usually applied when a fault developed in any cable was to have the cable dried out, either naturally or artificially, when the rain ceased, and then close the holes with solder. A remedy for the trouble as a whole has not yet been found.

As the question became one of importance it was referred to the Entomologist for the Queensland Department of Agriculture, Mr. H. Tryon, who wrote a most exhaustive supplementary paper upon it. This supplementary paper being deemed, however, too specially entomological for inclusion as a whole in these transactions, I have extracted fully from it and desire here to acknowledge my indebtedness to Mr. Tryon for his most valuable assistance in so special a subject.

Figs. 1 and 2 show the beetle Ecelonerus (order *Coleoptera*, family *Anthribidæ*) which had been provisionally associated with the beetle larva that undoubtedly traverses lead by gnawing a passage as it proceeds.

Fig. 3 is a drawing made by Mr. H. Tryon from completely dried-up samples of larvæ submitted to him.

The larvæ, at least when quite young, occur ensconsed separately within oval egg-like objects that are attached to the surface of the substance within which they feed. These egg-like objects are outwardly rough and are almost identical in color with their immediate environment (e. g., blackish on tarred tape and gray on white-painted tape). They measure nearly 2 mm in length and 1 mm in breadth, their depth slightly exceeding their breadth. On the upper surface near one end of many of these objects is commonly present a small opening with jagged outline, though in some of the objects the opening is not present.

Fig. 3.— Ecelonerus beetle.

The face by which the object or shell is adherent is almost wholly removed or wanting, being eventually occupied by an oval opening corresponding in size and outline to that leading to a perforation in the cable.

The lead-boring habit of these larvæ was brought to light by Mr. F. Roseneder, Charters Towers, the original discoverer of the above-mentioned objects and of the grubs or larvæ associated with them. Mr. Roseneder not only found these grubs in the perforations whilst still in process of being made, but he transferred the grubs and their dwellings still attached to the tarred tape, to sections of lead sheathing which he could keep under observation, and he had the good fortune to witness in one instance the act of perforation being pursued by the grub and the method in lead tunneling that it adopted. The specimen so obtained is shown in the center of Fig. 1, where the "mullock-heap" of lead made by the grub can be clearly seen. The specimen from which the photos were taken is also exhibited.

The lead sheath that was perforated by these grubs was 2 mm in thickness. That attacked was invariably covered with tape that had been originally tarred or painted. Externally on this the cases were attached and the perforations were continuous through the tape into the lead sheath. The perforations were perpendicular in direction and extended in some cases partly, and in others wholly, through the lead sheathing. They were oval in section, the entrance and exits measuring about 2 mm in length and 1 mm in breadth. Where the perforations were incomplete, the bottoms of the holes exhibited fine linear gougings parallel and adjacent to each other. These gougings were in the direction of the longer axis of the oval cross-section of the tunneling, and plainly revealed the nature of the implements, the insects' mandibles, used in their production.

The usual habits of this grub are quite unknown. Mr. Roseneder used every effort to find the "cases" or shells associated with either trees or timber, but without avail.

Similar "cases" containing beetle grubs identical with those described have also been secured from Rockhampton, where they had been attached to the white-lead painted parceling of a cable. It is not, however, in evidence that the grubs proceeding from these cases had penetrated the subjacent cable. Indeed, the specimens suggest that they succumbed — possibly through taking the lead salt into their system — prior to being able to bore into the lead sheath.

Mr. Tryon has discussed very carefully the question of the parentage of the grub under consideration, and in his paper already referred to gives the reasons leading him to associate the larva with an Anthribid beetle, and with Ecelonerus.

The perforations made by this grub are very numerous, as many as 14 holes having occurred in 16 ins. Being so small and being further covered by the "case" of the insect, they are difficult to find, and this may be regarded as the most serious part of the trouble.

The following table will give some idea as to the extent of the damage to the cables at Charters Towers. It shows the numbers of holes through the cable sheath in each span of each cable in February, 1904. The spans were about three chains long:

CABLES DAMAGED.

	Cable number.														
	31	A31	42	37	13	10	5	29	A29	S60	W60	S66	N66	74	70
Span 1...	0	0	3	12	1	43	2	4	5	6	2	17	6	10	0
" 2...	0	0	4	10	0	84	5	2	5	16	0	10	1	14	0
" 3...	6	0	3	15	4	10	9	3	4	20	0	......	......	7	0
" 4...	3	0	22	16	14	31	....	1	2	2	0	......	......	0	0
" 5...	0	0	0	8	1	8	....	1	1	7	1	......	......	4	1
" 6...	9	0	4	15	12	3	....	....	......	......	......	......	......	1	..
" 7...	0	0	32	12	2	21	....	....	......	......	......	......	......	6	..
" 8...	11	0	19	6	3	13	....	....	......	......	......	......	......	0	..
" 9...	1	0	7	2	0	....	....	....	......	......	......	......	......	0	..
" 10...	1	0	0	0	1	....	....	....	......	......	......	......	......	0	..
" 11...	0	0	2	0	0	....	....	....	......	......	......	......	......	....	..
" 12...	0	0	0	1	....	....	....	....	......	......	......	......	......	....	..
" 13...	0	......	....	....	....	....	....	....	......	......	......	......	......	....	..
" 14...	12	......	....	....	....	....	....	....	......	......	......	......	......	....	..
" 15...	0	......	....	....	....	....	....	....	......	......	......	......	......	....	..
" 16...	1	......	....	....	....	....	....	....	......	......	......	......	......	....	..
" 17...	5	......	....	....	....	....	....	....	......	......	......	......	......	....	..
" 18...	1	......	....	....	....	....	....	....	......	......	......	......	......	....	..
" 19...	0	......	....	....	....	....	....	....	......	......	......	......	......	....	..
" 21...	2	......	....	....	....	....	....	....	......	......	......	......	......	....	..
" 22...	1	......	....	....	....	....	....	....	......	......	......	......	......	....	..
" 23...	5	......	....	....	....	....	....	....	......	......	......	......	......	....	..
" 24 to	1	......	....	....	....	....	....	....	......	......	......	......	......	....	..
" 31...	0	......	....	....	....	....	....	....	......	......	......	......	......	....	..
Totals per cable...	59	0	96	97	38	213	16	11	17	51	3	27	7	42	1

NOTE.—The above represent the complete perforations. There were at least an equal number of holes which did not do more than just enter the sheathing.

Fig. 4 shows the beetle Xylopertha (order *Coleoptera,* family *Bostrychidæ*), of which four dead specimens were, in October, 1903, found in as many perforations met with amongst numerous others that occurred in a lead-sheathed aerial telephone cable at Townsville. Mr. E. A. Towell, telephone officer at Townsville, collected these specimens and also observed a living specimen emerge from one such hole, proceed along the cable for about a foot and then return on its course. Forty such holes were found in one cable at Townsville. Of these six were examined and found to possess the following characteristics: The lead was 2 mm in thickness; the holes had sharp edges on both inner and outer surfaces of the sheathing, the holes being somewhat larger on the inner surfaces. Almost invariably they were shortly oval in outline and not circular, and the major axis of the figure on the outer surface of the lead was usually transverse in direction to that on the inner, the former usually corresponding to the line of the cable.

FIG. 4.— XYLOPERTHA BEETLES.

Perforations in lead; 1. 3, and 5, perforations viewed from outside; 2 and 4, from within sheathing. One-half natural size.

FIG. 5.— BOSTRYCHUS JESUITA. FABR. JESUIT BEETLE.

Perforations shown passing successively through tarred tape parcelling, lead sheathing, untarred tape surrounding conductors, and metal foil covering of individual copper wire. About one-half natural size.

FIG. 6.— ORTHORRHINUS CYLINDRIROSTRIS. FABR.

A lead-gnawing beetle; males and females. Lead-covered conductors, illustrating its gnawing habits. Lead sheathing with perforations probably made by it. *Belus Sp.* (2) Found to gnaw in confinement. About one-half natural size.

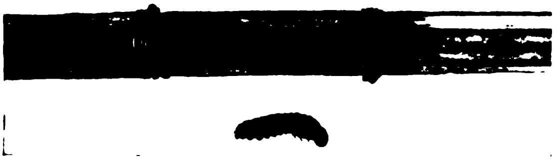

FIG. 7.— XYLEUTES BOISDUVALI. ROTSCH. (ORDER LEPIDOPTERA.)

Partially grown caterpillar, and hole through conjoined lead-covered conductors made by it in effecting exit from telegraph pole. About one-half natural size.

In five cases the holes were almost perpendicular to the surface, in a sixth oblique. The openings to the five perforations presented the following measurements:

1. 2 mm x 2.2 mm and 2 mm x 2.5 mm
2. 2 mm x 2 mm and 2 mm x 2.5 mm
3. 2 mm x 2.5 mm and 3.5 mm x 3.5 mm (circular)
4. 1.2 mm x 1.5 mm and 1.7 mm x 2.5 mm
5. 1.7 mm x 2.7 mm and 3.5 mm x 4. mm nearly.

The walls of the perforations presented linear gougings such as might be produced by the mandibles of the insect under notice.

This species of Xylopertha is common and widely distributed in Queensland, having been found as far west as Clermont and as far south as Brisbane. It feeds on wood (*Eucalyptus*) and bores into the hardest of Queensland hardwoods. At the time the damage was done to the cables in Townsville, the beetle was very numerous there and dozens of holes that had been made by it were found in telephone poles.

It has been found that wood painted with tar, and to a less extent with ordinary paint, escapes the attack of this insect. Mr. Towell reports that in the case of damage to a cable served with two sheathings of lead, separated by a layer of Stockholm tar, the perforations did not extend through both. Instances have, however, since occurred where the perforations have extended through both lead sheaths and the intervening coating of Stockholm tar in such a cable, but whether the perforations were caused by the insect under notice or by another I cannot say.

Fig. 5 shows the beetle Bostrichus Jesuita, Fabr. (order *Coleoptera,* family *Bostrychidæ*) or Jesuit beetle, which is very common in Queensland.

The evidence pointing to the causal connection between this beetle and the perforation in the metal shown on the same photo is of a circumstantial character. The perforation corresponds in size to that required for the passage of the insect, and in this and other respects to bores habitually made in wood by the same beetle. Moreover, of five insects found by Mr. Roseneder within a day or so of each other, all were captured at the time (November, 1903) that the injury was remarked, and amongst the lead-covered leads at the place where the injury occurred. Further, not only was no other beetle found there and then to which the work of forming the perforation could be attributed, but there was an entire absence of beetles other than individuals of the kind under notice.

Further, the writer, on confining living examples of the Jesuit beetle without food, found that they had most clearly marked with their mandibles a piece of lead that was accessible to them. The perforation in this instance (which is the only one so far under special observation) passed through the tarred tape, lead sheath, inner tape, lead foil and paper insulation of the conductor, but no damage was done to the conductor.

On the outside of the lead the perforation measured 8 mm x 7 mm, but on the inside it was nearly circular with a diameter of 7 mm. The walls of the perforation show very plainly gougings corresponding in character to those due to the action of cutting insect mandibles. The margins of the perforations were sharp and irregularly jagged.

This insect is found both in New South Wales and Queensland, in the latter State being distributed widely from the western border right through to the eastern seaboard. It is met with boring in or out of various kinds of trees, principally those belonging to the genus Eucalyptus.

Fig. 6 shows the Elephant beetle (*Orthorrhinus Cylindri-rostris* Fabr; order *Coleopetra,* family *Circulionidæ*) and the damage caused by it. When in confinement this beetle has gnawed the lead from covered wires as shown in the illustration. Mr. Roseneder has also remarked clear-cut holes in the lead sheathing of the telephone cables not corresponding to those made by any other insect that at Charters Towers similarly attacks this substance.

A specimen examined shows a perforation which is found to bear the same relation in size to the average width of the proboscis of the female insect, as is borne by holes in wood that have been made by it when placing its egg therein.

The lead sheath was 3 mm in thickness and the perforation circular of a diameter of 1.5 mm. The walls of the perforation exhibited gougings which were for the most part circumferentially directed.

The insect when it gnaws away the bark of trees only injures the wood by piercing it with its proboscis, and then only for the purpose of placing its egg there, and of ascertaining the suitability of the wood for that purpose.

Fig. 7 represents the only instance of the damage to lead-covered wires by this caterpillar (*Xyleutes, Boisduvali,* Rotsch; order *Lepidoptera,* family, *Cassidæ*) that has so far come under notice.

This instance was brought under the notice of the writer by Mr. Curtin, an officer of the engineering branch of the Queensland telegraph service, as having occurred at Toowoomba. The work was effected by the partially grown caterpillar which, finding the wood in which it dwelt becoming dry, proceeded to gnaw its way out in order that it might acquire more congenial quarters. In doing so it was impeded by two lead-covered conductors (placed up the pole to connect a cable with the aerial lines on the pole) and gnawed a hole nearly a quarter of an inch in diameter through the lead, but was discovered prior to effecting its escape.

Such an incident must be regarded as a highly-exceptional occurrence and not likely to recur.

Since the above paper was written the attention of the writer has been directed to an article which appeared in the *Electrical World and Engineer* of July 16, 1904, in which mention is made of somewhat similar damage which has been found at Shanghai, and which is reported to be caused by wasps. As no description of the wasp is given, it is impossible to make any comparison between it and the insects described herein. The damage to the cable in Shanghai does not, however, bear any marked resemblance to that which is the subject of this paper, but appears to be somewhat similar to the damage effected by the Elephant beetle when in confinement. (See Fig. 6.)

DISCUSSION.

M. A. L. STADERMAN: Do I understand that all the cables, whether taped or not, were attacked alike?

MR. HESKETH: The taped cables were attacked in just the same manner. No cable used in Queensland has been immune. However, cables that were not taped were less frequently attacked.

A MEMBER: We have had some experience along this line with insects. The particular insect with which we have had trouble gets under the bark of the southern pine and after a while develops into a fly. There were no less than a hundred cases in one southern city where the insect had bored out of the pine pole and into the lead sheet of the cable. Accidently, in coming out of the hole, he struck the cable, and cut through the lead sheet, sometimes leaving his teeth marks on the wire inside of the lead sheath. The trouble was traced to the insect, but it was found that only near pine poles did the trouble occur, and, therefore, no particular notice was taken except that the pine poles were taken out and replaced by cedar poles. I think this was in 1894. The insect is the common white worm of the southern states; it is a grub about an inch and a half long. We sent to the engineering department pieces of that sheet of lead and some of the insects. Another case in Savannah, Georgia, was that of an insect which made his hole in the ends of the tubes that are used to protect the wires at the cable terminus. He would get in and destroy the lead filling, open a circuit, and, when we sent out for the location of the trouble, the insect would be found imbedded in the end of the tube. The insect never attacked the cable in the spans, but only on the poles.

Mr. GREEN: We have had cases of rats eating into our cables, where we brought our aerial cables in between floors and ceilings, and we had one case reported in which a gray squirrel, in a park, was found busily engaged in drilling into one of our aerial cables. The squirrel was shot before he showed what he was going to do, and the man that killed the squirrel was arrested for doing so. I would like to ask if Mr. Hesketh has any suggestion to offer to prevent this trouble — an anti-bug device?

Mr. HESKETH: As yet we do not know what to do to cure it or prevent it.

Mr. BANCROFT GHERARDI: The paper which Mr. Hesketh has just presented to the Congress is I think a most interesting and valuable addition to our knowledge. This idea that insects may eat small holes in the sheaths of lead-covered aerial cables is a new one to me. When I return to my office, I shall examine with much interest our records and samples of damaged cable sheaths, to see whether we have had any trouble of this nature ourselves in the company that I am connected with. I am satisfied that in our case this trouble, if any at all exists, must be very small in quantity. All cases of damage to cables where the cause is not perfectly evident are referred to my department for investigation. Had our cables suffered to any extent I should have seen large numbers of samples which I should now know were due to some bug. Going back in my mind over the samples which I have seen in the last three or four years, I do not recollect any which might be due to this cause. I think, therefore, I am warranted in saying that in the vicinity of New York, at any rate, this trouble is very small, if present at all. Substantially our whole aerial cable system is of lead-covered untaped cables.

Mr. W. C. YEATMAN: In what State is the same insect found in this country?

Mr. HESKETH: The samples shown to me of cables had in the holes the same gougings as these samples which I have. I examined them as closely as I possibly could. They were particularly numerous in one of the warmer Southern States, where the damage is more likely to occur, and I am convinced that the trouble which was attributed to lighning in these instances was really due to an insect closely allied, at any rate in habits, to the one I have been describing.

CHAIRMAN JONES: The telegraph companies employing aerial cables throughout this country frequently have reports of damage done to such cables and find on investigation that the lead sheath has been perforated by small, round holes, which have been attributed to sportsmen making marks of the cables, as they frequently do of the insulators. It may be that while a great many of our linemen are not entomologists, they may be attributing these perforations to birdshot or something like that, when they have been caused by voracious insects. I think this matter will bear closer investigation.

CHAIRMAN JONES: The next paper on our program is one by Major Samuel Reber, of the United States Army.

Major Reber presented his paper, as follows:

THE TELEGRAPH, TELEPHONE AND CABLE IN WAR.

By MAJ. SAMUEL REBER, U. S. A., *Delegate of the United States War Department.*

"War," says Von Moltke, "is the only science that lays under tribute all the other sciences." The great discoveries and advances in science made during the past century have been utilized in the art of war, and none, with the possible exception of steam, has produced a greater change in the application of its principles than the use of electrical means of communication. The saving of time, and consequently money, by the use of the telegraph, the telephone and the cable in the affairs of daily life has been beyond calculation. The use of electrical means of communication is now absolutely necessary to success in war, not only in the grand strategical combinations of a campaign, but also in the varying tactical situations on the field of battle.

The element of time is one of the dominating factors in modern warfare involving enormous expense incident to the equipment, maintenance, supply and movement of large fleets and armies. The longer the duration of a war, the greater the strain on the physical and financial resources of the nations involved. The ultimate result of a war may depend on the financial capacity of a nation to pay, feed and supply a victorious army. War disturbs not only the normal internal conditions of belligerent nations, unsettles and frequently paralyzes their trade, industrial and agricultural prosperity, but also produces a far-reaching result on the commerce of the world.

Nations are now so intimately connected by business and fiscal ties that the effects of a war are quickly felt in the markets of the world. Although business may be stimulated for a while by a war, the ultimate effect must be one of depression. The exhaustion of the resources of one of the family of nations, caused by a protracted war, is felt to a greater or less degree by all the others. Anything which tends to shorten the duration and limit the sphere of a war is a decided gain, not only to the belligerents involved, but to the world at large. Electricity with its space and time-annihilating properties has proved an ideal agent in shortening the duration of wars.

Napoleon in one of his maxims of war has said: "Le secret de la guerre est dans le secret des communications." It is absolutely necessary for the commander of an army to have rapid and positive means of communication for the transmission of orders, instructions and information from his extreme outposts in contact with the enemy back to his base in the rear of his army, and with all independent commands engaged in the theater of operations.

The development of the use of the telegraph, telephone and cable in war has been along lines similar to those of commercial practice. The engineering principles are the same, but the operative conditions are, of necessity, more exacting and difficult. Efficiency and certainty of operation under all conditions are the fundamental principles governing design. Cost of installation and economy of operation are of less importance than absolute continuity of service. It is not to be understood, however, that due regard should not be paid to cost of installation and maintenance, but commercial methods fail under the stress of war conditions. A large number of ingenious methods and apparatus have failed on account of delicacy of operation or complication of design. Any apparatus that cannot stand lack of attention and skilled supervision, exposure to weather, rough handling in transportation, and the effect of the blast of heavy guns, cannot be relied on at the critical moment of its use in actual battle. Portability, simplicity and mechanical strength are essential requisites of all the apparatus used in the service of field communication. The demands of a fortress system of communication are not as exacting, while the installation and operation of military cables follows the commercial practice of the nations using them.

It is impossible in the scope of a single paper to give the characteristic features of the systems and apparatus employed by the various nations for military purposes, or the organizations of their special technical troops. With the exception of the United States, all the great military powers of the world control the service of electrical communication in time of peace as part of their civil establishments. Experience has proved that in time of war and especially in the field of active operations, this service must be part of the military establishment. All the great nations have special technically trained troops to operate their military systems. The operation of a system by joint civil and military control has proved a failure in the past, and the experiment will probably never be repeated.

The service of communication is, in general, separated into field and fortress work. The fortress system consists of the permanent lines, usually underground, connecting the various works in the line of circumvallation around fortified positions, and in seacoast works, the system of fire control and direction for the laying and training of the heavy batteries, rapid-fire guns protecting the mine fields, and the searchlights. The details of such systems are zealously preserved as governmental secrets for obvious military reasons. For armies operating in the field a complete chain of communication should exist from the outposts in touch with the enemy back to the capital of the nation, or the main base of operations, which is connected to the seat of government by permanent lines. In case of over-sea operations the base is connected by cable.

Depending on the construction used, the chain of communication is usually divided into three parts — permanent, semi-permanent and temporary, or flying lines. Permanent lines are usually those existing in the country or are built after the army has advanced. They are ordinarily outside of the zone of active operations, their construction following the usual engineering methods. When taken possession of and operated by the army the methods used are those of established commercial practice. Semi-permanent lines are used to connect the principal bases or depots of supplies on the edge of the zone of operations with the field bases within it, and the general headquarters. Field or flying lines are used in the zone of active operations and connect the general headquarters with all the principal subdivisions, even to the extreme outposts. In this service expedients of rapid construction of every nature are employed, and the telephone is fully utilized. It is possible to construct a line, using lances of ash or bamboo to support the wire, at the rate of from one to three miles an hour, depending on the character of the ground. By the use of light field cable and bare wire a detached cavalry column, or even a reconnoitering party, can be connected during its movement with the main body. At night each brigade and division headquarters can be connected by a field telephone system with the corps headquarters and the supply points, while the extreme outposts can instantly report any movements on the front. On the field of battle the commanding general can be connected telephonically with his corps commanders, and they in turn with their division and brigade commanders.

Major Von Etzel, of the Prussian army, first suggested in 1839 to the War Department the possibility of employing the electrical telegraph, but it was not until 1844 that a board of officers was convened to consider this subject, and not for several years subsequent to that date was the necessary material obtained and a line built. There is no record of the result of this experiment.

In 1853, during the maneuvers of the Austrian army at Olmütz, a movable telegraph line was constructed by stationing men at intervals to hold light lances to support the wire. Naturally the result was not considered successful.

The first practical application of the telegraph was during the siege of Sevastopol by the allied armies in 1855, where the searchlight was also first tried, the current for the arc being supplied by primary batteries. The dynamo was not used in searchlight work until the siege of Paris in 1871, where it was employed by the Germans, the French using primary batteries for the arc. During the siege of Sevastopol the lines were of permanent character and were not used for tactical purposes.

From 1854 to 1856 the Prussians again took up the telegraph for war purposes, but limited its scope to permanent lines. They did not contemplate its use in following the movement of troops, or on the field of battle, where it was first used by the Federal forces at the battle of Fredericksburg in 1863.

During the great Indian mutiny, field telegraph lines were constructed connecting the column in the field with the seat of government in Calcutta. Uninsulated iron wire circuits, suspended from trees, bamboo lances, or even laid on the ground, were worked for a distance of 100 miles, although in the rainy season communication was frequently entirely interrupted.

In 1857, during the French operations in Algiers, the telegraph line was operated by civilians, the wire being suspended from trees. During the same year a school of instruction for military telegraphers was established by the English at Chatham.

Spain in 1859 organized and maintained in the Morocco war the first properly equipped and efficiently manned field telegraph train, using insulated wire coiled on reels and arranged for pack transportation, the instruments employed being Morse printing registers.

During the Franco-Austrian war in 1859 in Italy, the civilian employees of the State telegraph service operated the military system, which was maintained by peasant labor requisitioned from the inhabitants living in the zone of operations. This method of operation proved decidedly unsatisfactory, and the necessity for a military personnel and improved material was first recognized. During this campaign we find the first example of communication with the home government from the field of operations by telegraph, and the transmission of orders from the commanding general to both the front and flanks of the French army.

The Italian army in 1861 gave the first example of the value of continuous communication between parallel moving columns separated by a mountain range. The two army corps starting from different points marched to concentrate at Ancona, and although separated by the Appennine mountains, were in constant communication with each other by lines that were built by and kept pace with the troops. Copper wire suspended by insulators on light poles were used. In front of Ancona the fleet, the front and flanks of the army, and the general headquarters were connected together by a system of field telegraph and semaphores.

In the Civil War in the United States in 1861–65, the telegraph was considered indispensable, and was employed on a greater scale than ever before attempted or since reached. The results obtained awakened anew the interest of the great military powers in the development and equipment of their field organizations. For a while in the beginning of the war, magneto instruments were employed but they were soon replaced by Morse sounders. Over 15,000 miles of line — land, submarine and field — were constructed. For the first time in the history of war the telegraph was used on the field of battle in the several encounters in the peninsular campaign and at Fredericksburg. General Grant, from his headquarters on the Rappahannock and at City Point, controlled and directed the movements of over 600,000 men in 18 separate armies maneuvering in a theater of operations that contained 800,000 square miles of territory.

It has been said that strategy is a fixed science and that wars during all ages have been conducted on the same strategical principles. The factors in the problems of strategy have been greatly influenced by improved methods of communication, and while the abstract principles have remained the same, the means of employing them have been greatly improved. Strategical combinations which were impossible at the beginning of the nineteenth century are now of frequent occurrence. Sherman's march to the sea compared with Napoleon's campaign of 1812 exemplifies this change. Napoleon early in 1812 made up his mind to invade Russia, but owing to the poor means of communication was unable to concentrate a force of 500,000 men and enter Russia from Poland until the last part of June. After 84 days and a very costly battle he entered Moscow. The country having been laid waste, the Russians retreated to St. Petersburg after having burnt Moscow, and a severe winter coming on, he retreated, losing 450,000 men. His downfall dates from this disastrous campaign. In 1864 Sherman began his advance into Georgia with 100,000 men in the early part of May. After continuous fighting for three months he entered Atlanta. His enemy had not been destroyed but fell back and began very active operations against his communications. He immediately communicated with the commanding general, some 1500 miles away, by wire, and arranged with him to march to the sea where supplies should be provided. Having reached the sea, he proceeded northward against the line of retreat of the main army of the enemy in Virginia. After having made a march of about 1000 miles through the enemy's country, he materially aided in the final destruction of the Southern armies. These are the two longest marches in the campaigns of recent time, the one disastrous, the other highly successful. The failure in the one case was due to the lack of communications, the success of the other to their existence and utilization. "What was false strategy — because impossible — in 1812 was good strategy in 1864."

In the five years' war between Brazil and Paraguay in 1864–69, the telegraph was of great value not only in connecting the permanent works, but also detachments from the main armies and outposts. It was successfully used at the siege of Humaita.

During the six weeks' war in Bohemia the telegraph was only utilized to a limited extent owing to the contracted front of the theater of operations and the undeveloped stage of apparatus and material. No lines constructed were of greater length than 10 miles, as the permanent telegraph systems of the country could always be reached within that distance. Light field cables of the Siemens type were first used in this campaign, during which the headquarters of the three Prussian armies were connected by wire with the general headquarters of the King and the capital at Berlin. The working of the organization was not very satisfactory for strategical purposes. The personnel and material were unsuited for tactical use.

France did not, until 1868, establish any definite military system, although a number of experiments had been made for a series of years, when a military telegraph organization was adopted. This organization does not appear to have worked in a satisfactory manner during the Franco-Prussian war and fell into the hands of the Germans at the capitulation of Metz. The Germans employed the telegraph extensively during the war, its use contributing in a marked degree to their success. Their three armies were connected to their bases and the home government. At Strassburg the telegraph line was carried to the third parallel, and was of great assistance in directing the artillery fire. The siege of Paris would probably not have been successful without the use of the telegraph, for the lines of investment were 46 miles in length with about 4000 men per mile, the besiegers being less numerous than the besieged. During the three days' fight on the Lisaine where Von Worder, who was covering the siege of Belfort, was attacked by Bourbaki, it was due to the thorough telegraphic communication which had been established by the Germans that the timely arrival of the reserves from the extreme right was effected, as was their subsequent return there at a critical moment. At the close of the war the Prussians had in operation 6730 miles of field wire with 407 stations.

The military system of Spain which had been developed during the Morocco war had been improved. At the battle of Alcoba, the Spanish commander was in constant communication with Madrid, and the field telegraph was an indispensable aid to General Prim in putting down the Republican and Carlist insurrections. During the Civil War in 1873 the field telegraph was in constant use, and in the defense of Bilboa the weak garrison was enabled to hold the extensive works by concentration ordered by telegraph at the threatened points.

During the Turko-Russian war the Turks had no special field telegraph corps, although some permanent lines were built for military purposes. The Russians, however, used field and outpost telegraphs extensively, constructing 1344 versts of line in the Balkan Peninsula and 1034 versts during the Asiatic campaign. The following incident in the Asiatic campaign is an example of its value to the Russians: In the operations in the Kurukdere mountains against Mukhtar Pasha, General Lazereff was ordered to march around the Turkish right, passing along its rear and cutting Mukhtar's force off from Kars and placing him between the two Russian forces. After severe fighting Lazereff obtained possession of Mount Oghur, a strongly fortified point which connected the Pasha with Kars. From this point Lazereff telegraphed the Grand Duke over the field line, which had kept pace with his movements, that he was confronted by a superior force and a simultaneous attack by the Grand Duke's and his own troops was needed to extricate him from his critical position. The despatch reached the Grand Duke in such time that the simultaneous attack the following morning led to the total destruction of the Turkish army.

The development of the military telegraph system of the English army appears to have progressed quite slowly at first, as its importance does not seem to have been recognized by the authorities. When the Ashantee war of 1873 broke out no field telegraph material existed in the army, and none reached the troops in the field until they were well into the interior. When the supplies were received they were both insufficient and unsuitable, but assisted in hastening the termination of the war. Again in the Zulu war in 1879, no provision seems to have been made at the beginning of the campaign. Better use of the telegraph was made in the Afghan campaign of that same year in the face of great difficulties of operation caused by the constant cutting of the lines by the enemy.

In 1881, Major Cardew introduced the telephone as a receiver for telegraph purposes, using a buzzing note produced by an interrupted current for transmitting Morse characters. This system has been modified and extensively used with great success in our own service. The buzzer, as it is called, is simply a coil of low resistance and high self-induction in circuit with a telegraph key, an interrupter and a few cells of dry battery. On opening the circuit the discharge from the coil goes to the line, and owing to the high self-induction and consequent comparatively high e.m.f., enough current reaches the other end of the line to give audible signals. By the use of the buzzer, leaky and broken lines which would be absolutely grounded for ordinary Morse working can be operated. Major Cardew's system was first used in the Egyptian campaign of 1882. The telegram announcing the result of Tel-el-

Kebir was sent from the battlefield by this system. Profiting by their previous experiences, about which an English writer of high authority in 1894 naively said: "Some ill-luck seems to have attended our telegraph arrangements on service," the British had a completely equipped and supplied telegraph organization in the field during the recent Boer war in South Africa. Some 220 separate field cable-lines of 3749 miles in length, and 2191 miles of aerial line were constructed by them, the traffic on some of their main trunks being so heavy that they used Wheatstone automatic instruments. The telephone was also extensively used. The defense of Ladysmith was conducted entirely by telephone, and it was said that the telephone system saved the place when the Boers attacked Wagon Hill and Cæsar's Camp on January 6, 1900. To protect their long line of communication against the raids of the Boers, blockhouses were built at intervals of about 1000 yards and every second or third one supplied with a telephone connected with centers for the dissemination of information and for the obtaining of succor. Certain of the blockhouses were supplied with telegraph instruments in addition to the telephone. "The blockhouses together with the systematic 'drives' organized by the Commander-in-Chief finished the war, as the Boers themselves confess."

In the Spanish-American war, though of short duration, the telegraph, telephone and cable played a most important part, both strategically and tactically. In the operations in front of Santiago the telephone was used to connect the trenches along the 13 miles of front. The bombardment of Santiago was directed by telephoning from the front to the shore, where range and direction were flagged to the fleet. The operations are summed up in the following extract from the official report of the chief signal officer for 1898:

"The major-general commanding the Fifth Army Corps reached by telephone points on the right, center, and left of his line within 400 yards of the enemy, and communication with his subordinate commanders was not only possible at all times, but was continuously maintained, as these lines worked twenty-four hours in the day. On the other hand, the major-general commanding the Fifth Corps was able to communicate directly with the admiral commanding the fleet through the telephonic station near Aguadores. In addition, the War Department, with all its bureaus and the supply depots of a great nation, were within 20 minutes of the general commanding, so that any deficiencies of equipment could be asked for or re-enforcements requested; and further, he was able to keep in touch with the President, the Secretary of War, and the Commanding-General of the Army, so as to receive at critical moments such advice, encouragement, or assistance as might advance the interests of the campaign."

In the Porto Rican campaign every part of the widely distributed invading army was connected by telegraph and telephone from the first day of landing at Guanica to the termination of the war. The telegraphic and telephonic service was such that within 33 minutes after the receipt of the cablegram announcing the armistice which suspended hostilities the commanders of three separate divisions of the army operating in different parts of the island miles apart were ordered to suspend operations. In the case of two of the commands the message arrived just in time to prevent actual contact as the troops were in position for action, and at Guayama held the lanyards stretched on the guns to open the artillery duel. In the Philippine campaign and the subsequent insurrection, the telegraph and telephone were of great value, so much so, that the Commanding-General remarked in 1901: "It is not too much to say that in the absence of this efficient service it would be impossible to hold this archipelago with less than 150,000 men, which is now well and efficiently held by 60,000." During the insurrection some 4851 miles of aerial line were constructed and 500 miles of submarine cable laid.

In the present war between Russia and Japan it can be inferred from the meager published reports of the operations that both sides are using electrical means of communication to their full extent. It is known that the Japanese armies are connected together by a system of field lines, their outposts by telephone and their bases with Chemulpo and Japan by cable. On the day before the battle of the Yalu, the fire of the Japanese howitzer batteries was controlled and directed by telephone, and on the day of the battle during the movement of the XII Division its commander was continuously connected by telephone with the Commanding-General of the Japanese forces. The value of wireless telegraphy to the Japanese navy in its operations in the China seas, and to the Russians by allowing the commander of a beleaguered place to communicate with his home government, is too obvious for comment. It seems at the present state of the art that wireless telegraphy will not play as important a part in land communications as the telegraph or telephone until the present methods of its operation have been greatly improved upon.

The part played by the cable in the history of recent years has completely proved that its rôle is scarcely inferior to the military and naval forces themselves. All the colonial powers of the world have so arranged their means of cable communication that the cables are under their immediate control and touch only the shores of their own possessions or those of countries that are allied to them by treaty and community of interest. The control of the seas, one of the material elements contributing to the power and prosperity of a nation, is influenced largely by cable communications, and in a war in the future between two naval powers the result will depend largely on coal and cables.

DISCUSSION.

Lieut.-Comdr. J. L. **JAYNE**, U. S. N.: I notice that Col. Reber does not lay much stress upon the use of wireless telegraphy for war purposes. I would like to ask what difficulties he has encountered, because we in the Navy have thought of using such apparatus of portable character for landing purposes.

Col. **REBER**: I think that Commander Jayne has possibly misunderstood my paper if he draws that conclusion. I said in the paper that the operation of wireless over long distances on land has not as yet proved successful for military purposes. For short distances we have apparatus that has been successfully used up to about thirty-five miles overland. We are working on that problem now and as soon as definite results are obtained I shall be glad to communicate them to the Navy. The difficulty with the present Hartman-Braun system is that instead of using a telephonic receiver a coherer with a relay and printer is employed, which is difficult to operate successfully in field work.

Mr. **JOHN HESKETH**: In the British military service, there is a great prejudice in favor of maintaining a complete record, and that prejudice is transmitted to the Colonies in cases. Therefore, we are sometimes required to use tape recording instruments there. For my own part, I think that the use of tapes leads to more errors than it prevents. I should like to ask what your experience is in the States. Whether you have any tapes at all or whether you rely altogether on the record taken from the sound? With regard to the cable lines, it will be interesting to know the construction of your field cables. Are they made of stranded steel or copper, or are they combinations of both? Also what lengths do you usually carry on one field telegraph wagon? Another point of much interest is: — What have you found has been the practical limit of signaling by the vibrator from point to point over bare wires laid on the ground?

Col. Reber: We rely, in our service, on sound receiving, having abandoned the tape recorder years ago. We use several types of field cable. The first one which is called the outpost cable, consists of an insulated seven-strand conductor of six copper wires laid spirally over a steel center. We have successfully used bare copper wire for emergency work and field communication, this bare wire being laid on the ground. We are trying, in the manœuvers of this year, a new type of cable which consists of two copper and one steel conductor No. 24, covered with a jute or cotton wrapping and weighing about seven pounds per mile. This wire is recovered if possible, if not, it is simply thrown away. It is comparatively inexpensive. By giving a field party twenty-five or thirty miles of it, we can keep in communication with moving columns. The longest strip of bare wire laid on the ground was used in the advance to the North from Manila by General Lawton, where in spite of the wet tropical undergrowth, a distance of forty miles was successfully worked through.

Chairman Jones: I have pleasure in presenting to you Mr. Patrick B. Delany, who will present his paper on "Rapid Telegraphy," which I know will be a valuable one.

Mr. Delany presented his paper, as follows:

RAPID TELEGRAPHY.

BY PATRICK B. DELANY.

Rapid Telegraphy is the designation by usage given to systems requiring composition of the message on a tape as a preliminary to transmission by mechanical means over the wire, and recording of the message in Morse characters on a tape at the receiving station, requiring transcription before delivery.

Bain and Wheatstone.

Two kinds of rapid telegraphy have now been worked out, the ink-recording system of Wheatstone, so long the standard, and, just recently, the chemical recording method begun by Alexander Bain nearly sixty years ago. He was the first to propose a perforated tape as a stencil for transmission of signals, but he had no efficient machine for making it. His chemical system was much faster than the Wheatstone ink-recording system which came along a little later with a good perforator. Bain's speed was ahead of the necessity of the times, nor had he, being a runaway apprentice from Scotland, the backing for successful competition with his powerful English rival.

Wheatstone's perforator may be said to have anchored his comparatively slow system in the English service. When the Government took over the telegraph lines,.the best efforts of the brightest men were directed to the improvement of the system generally, until, under the administration of Chief Engineer Sir William Henry Preece, a speed of 400 words per minute was reached in a trial between London and Newcastle, a distance of 278 miles.

This was about equal to the highest chemical recording up to that time, fifteen years ago, and required approximately 200 movements of the armature of a polarized relay per second.

Experimental and Working Speeds.

In all kinds of telegraphy, however, manual and machine, the gap between the practical or average working speed and the experimental maximum is very wide. Morse operators have sent 51 words in a minute by key, but the average rate is 15 words a minute.

The Wheatstone speed between London and the cable stations in Ireland, about 400 miles, is from 70 to 80 words per minute. These circuits, however, comprise considerable underground and under water cables.

In this country it is claimed that 75 words per minute each way is obtainable by Wheatstone over a duplexed wire between New York and Chicago through a repeater.

Limitations of Electromagnetic Working.

The obstacles in the way of higher speed and reliability for the Wheatstone system are both mechanical and electric. The transmitting tape will not bear any greater strain or impact by the contact controlling rods, and the electro-magnet of the receiver will not respond reliably at a rate of over 40 impulses a second and leave any margin for change in the circuit. With the best designed instruments and the most approved expedients for improving the definition of impulses, the responsiveness of the electromagnet falls at least ten times below the recording speed of the latest chemical telegraph, and for reliability of operation the electromagnet is not to be compared to the chemical system.

The higher the speed the smaller the margin of stability of magnetic working. This rule applies to all electro-magnetic systems, so that an important drop from the occasional possible rate is necessary for continuity of operation.

Notwithstanding that the highest development of electro-magnetic telegraphy leaves about nine-tenths of the signalling capacity of the wire unused, *the electro-magnet is the foundation of all the telegraphs in use today. The Morse, single, duplex and quadruplex, synchronous multiplex Morse, and all printing systems are based upon it.*

Amplifications of the Morse and Synchronous Systems.

Amplifications of the Morse beyond single transmission are, as is well understood, due to combinations of polarity and potential increase, enabling the different circuits to be operated at actually the same time. Synchronous multiplex Morse is based upon the rotative distribution of the time of the line among four or six operators. The transfer is made so quickly from one pair of operators to another pair, and so on progressively until its return to each, that no break in the continuity of connection is manifested by the receiving relay. The line being given to each corresponding sender and receiver in its entirety about 40 times per second, it is impossible for the sending operator to miss connection, even though he should work his key at the rate of 14 or 15 excursions per second, the limit of hand manipulation. Thus, although all the keys are worked simultaneously the line is only connected to one at a time. With this system, circuits may be operated all in one direction, or divided into opposite directions like separate wire circuits.

Printing Systems.

Synchronous multiplex printing circuits are apportioned among different operators in the same way, but instead of the circuits being smooth and apparently continuous for each operator, as in the Morse multiplex, they are worked on selective or step-by-step principles, or combinations of both. Thus like the Morse, all printing telegraphs are based upon the electro-magnet, and although there is wide difference in their methods of operation, in all of them the receiving electro-magnet must respond to every impulse transmitted over the line.

Taking into consideration the constantly changing electrical conditions of the circuit, the exceedingly small margin of adjustment permitted by differential balancing for quadruplex Morse, and the high rate actuation of the relay armature in the Wheatstone and printing telegraphs, the instability of such systems, outside of single transmission, or at best polar duplex Morse, constitutes a most precarious dependence.

Disturbing Elements for Electro-Magnetic Telegraphy.

Up to about ten years ago atmospheric change was the main cause of disturbance in telegraphy, but at present the stray currents from power transmission are much more demoralizing, so that taking these effects together, it has become most difficult to maintain balances and adjustments. Indeed the Morse quadruplex is already regarded as having had its day. Fluctuation between 10 and 70 volts are not uncommon on many routes, and as the tendency of power transmission is strongly in the direction of higher voltage, the outlook for ground-return telegraph circuits is very menacing to electro-magnetic systems. The only safe refuge for these will be in metallic circuits which will bring the most perfect quadruplex down to the present duplex rank, while printing systems using combinations of single, double and increase currents, and depending on emphatic delivery of every impulse have certainly no better prospect ahead.

Polar Duplex and Typewriters Best Printing Telegraph.

The results reached by the exceedingly ingenious printing systems devised by clever inventors during the past few years have not altered the opinion held by the writer for a long time, that the best printing telegraph, and the most efficient and economical development of Morse working, is a polar duplex, manned by four first class operators and using typewriting machines for receiving.

The superiority of this plan is just now being more strongly emphasized than ever before by the introduction of the keyboard transmitter. Here the intelligent operator with his simple sounder obviates all the electrical and mechanical complications of the printing telegraph machine, and wastes no time. He can space, paragraph, rub out, change blanks, and do all that the sender tells him,— and much more if necessary, without being told. The organization is mobile, practically noiseless and takes up little space. It is always ready, requires no expert supervision, and with an average speed of 20 words per minute for each circuit yields, all things considered, the best output of any electro-magnetic system — Morse or printing.

Best Results Obtainable with Present Systems.

Notwithstanding the high speeds claimed for various printing systems, and taking the officially published results of 80 words per minute for a quadruplex over an ideal circuit with picked operators, and premium pay for each message handled over a certain number, and with permission to abbreviate and use arbitrary code signals for shortening the key work, *as its extreme achievement;* it is safe to say that the best facility derivable from a telegraph wire, with Morse, or printing system, day in and day out, and for all the minutes of the day, will not exceed an average of 60 full words per minute. Even this output is. for the reasons stated,— increasing leakage from power wires, and frailty of adjustments,— sure to drop to the duplex standard of 40 words per minute. At times the advantage of the quadruplex over the duplex reaches 30 words per minute, but at an expense of four expert operators.

More Wires or Faster Method of Operation.

It must be obvious therefore that these limitations for systems which up to the present time have carried all the telegraph business leave but two alternatives for meeting growth of traffic or for *permitting it to grow,* viz.,— increase of wires, or further utilization of the carrying capacity of the present wires by rapid automatic methods of operation.

Preferred and Ordinary Business.

The great volume of what is known as "Broker" business, amounting, it is said, to about 40 per cent of the whole, and the incomparable fitness of the Morse sounder for this work is, doubtless, largely responsible for the lack of broadness, shown by telegraph companies in dealing with the problem of electrical correspondence generally. For this reason the decision has always been in favor of "more wires," relying for justification wholly upon the record for efficient handling of that portion of the traffic originating with interests having the power to enforce good service. It should be remembered, however, that promptness in handling this preferred business has been at the expense of that large portion belonging to the diversified community lacking the concentrative pressure necessary to secure equal treatment at the same cost.

This is why exchange traffic has so rapidly increased while ordinary mercantile and social telegraphy has almost stood still.

That it is possible to keep on adding new wires and carrying messages by Morse, no one will deny; but so long as the profits will arise still from inadequate facilities for more than one-half of the business, no important expansion of telegraphy may be looked for.

To bring the ordinary telegram time within reasonable range of the "Broker" message would require such an increase of wires as would quickly force higher utilization of the carrying facilities of existing ones.

Exchange Business Will always be Quickest.

It may be conceded that it is too much to expect that general telegraphy will ever be conducted as quickly as the exchange business, but many are of opinion that the time has come for an improvement in ordinary telegram transmission speed, a decrease of cost, and, as a natural consequence of both these factors, a development of telegraphy to many times its present volume.

Commercial Side of Telegraphy.

Figures explanatory of the commercial side of the telegraph business, covering a period of about twenty years back, seem to show, that as at present conducted, the rate cannot be lowered, and leave fair dividends for stockholders on the capitalization basis adopted by the companies. It would seem, therefore, that owing to the engineering difficulties in the way of duplication of lines, and in view of demonstrable improvements in rapid transmission, an important departure in the method of carrying the bulk of electrical correspondence must soon be inaugurated.

The limit of electro-magnetic quickness having been reached,— not considering the speed due to super-sensitiveness and most favorable conditions, but the positive actuation which must be insensible to outside effects,— the result makes it plain that telegraphy can only reach its full growth and occupy the extensive scope legitimately belonging to it by the use of machine transmission, which will operate up to the physical capacity of the wire, instead of making the nimbleness of the operator's fingers or the movement of a relay armature the limit.

Supersensitive Systems Impracticable.

Many inventors have labored under the erroneous belief that high speed working was to be reached by devising apparatus of great delicacy, only to find that beyond a certain point this characteristic was, on land lines at least, a positive drawback, as the highly sensitive apparatus proved, to a fatal degree, amenable to stray currents and inductive effects abroad in the earth and the air.

The telegraph of the future must be a comparatively roughshod affair, oblivious to foreign influences, and capable of high rate actuation by the margin of current over-riding.

The Chemical System.

In the chemical system alone can these conditions be obtained. The receiving tape can be made irresponsive to all outside effects, and, at the same time, susceptible to a stronger signalling current, up to the limit of impulse definition over the line.

The chemical system is unaffected by ordinary fluctuation in the working current. Changes which would cause signals to drop out of any electro-magnetic system, and call for readjustment of apparatus, have no effect on the chemical system, beyond production of a lighter or heavier record in the tape. No dots or dashes are missed. The record is all there, a true reproduction of the characters on the perforated tape.

Objections against Automatic Telegraphy.

The main objections raised against automatic telegraphy, by the uncompromising adherents of the primitive method, have been the necessity for perforating messages for transmission, and transcribing them before delivery, it being claimed that these processes cause delay. But those who argue from this standpoint lose sight of the fact that, with a sufficient number of perforators and transcribers, the delay need not exceed four or five minutes at most, and that if it averaged 15 minutes it would then be about ten minutes quicker than the average Morse time, for while a single message may be sent off by key in a minute, messages do not come to the operator's table one at a time. There may be a dozen at once, and this accumulation entails a delay on all that come after.

Average Delay.

The average delay throughout the United States for messages between the time of reaching the operator's table for transmission, and passing from the receiving operator's hand, is probably close to half an hour, more than half of which is due to limiting the messages load of a wire to the expertness of the sending and receiving operators. Such a course may be likened to the restriction of a railroad's track facilities to its gate accommodations at the terminals, and building another track and establishing another gate when travel increases, instead of adding another gate and running trains faster.

To provide each pair of operators with a circuit, when one wire may be made to keep forty pairs employed at regular speed, seems wasteful. Surely the greater the number of operators kept busy by a wire the greater the economy. Long wires and their maintenance require large outlay, and companies cannot much longer afford to neglect their carrying capacity.

Relative Accuracy of Morse and Automatic.

The other objection put forth against automatic working forces the conclusion that it is prompted by prejudice solely, since it has no foundation whatever. It is, that more errors are made by the recording system.

As nearly everybody knows, messages over ocean cables are the most difficult known in telegraphy. The majority of them are in code words having neither context nor meaning to guide the operator. These messages are nearly all perforated on tapes, and sent by machine, not only on account of some increase in speed, but mainly because of the greater accuracy of the automatic over hand working.

No better evidence of superiority in this most important regard could be cited than the fact that every cable message transmitted over land lines by sounder Morse must, under the rules of the Company, be *repeated back* by the receiving operator, so that the sending operator may be certain that the receiving operator read it correctly. No such verification is practiced over the cable. No Atlantic Cable Co. would work by sound if it were electrically practicable to do so. They require the automatic system because of its correct record. Anyone acquainted with the subject knows well that the cable tapes with their wavy lines are far and away more difficult to read than the simple dots and dashes of the Morse code, which can be learned in a few hours.

The exact degree of accuracy in telegraphy is difficult to fix, but it is well known that the land line sounder errors with messages made up of plain English, are ten time more numerous than cable errors with words without meaning. Indeed, a land line message without some error is exceptional. Usually the receiver can construe the meaning intended, and the error is passed over.

About four-fifths of all the messages transmitted on the continent of Europe are read from tapes, the balance being carried by printing systems. There is no reading by sound, and yet, no one has claimed that more errors are made over there than on this side of the water.

Quality of Morse Working within Hearing.

Anyone well trained in sound reading tarrying within hearing of the average Morse wire, in hotels, office buildings, or railway stations must marvel at the quality of the service upon which the telegraph business of the country depends. Here he has an insight, not only into the capacity of the branch office operator, but also of the operator at the main office, with whom he is working. The experience leaves no escape from the conviction that telegraphy, the most important of all means of communication, is conducted in a strikingly inefficient and stinted way, which, if persisted in, must render any improvement in the utilization of the telegraph by the public impossible.

Keyboard Transmitter.

That the inadequacy of the Morse key is at last being recognized is proven by the introduction of keyboard transmitters, by which a single depression of a key causes all the dots and dashes of a letter to be sent in a perfectly correct way. This, it is to be hoped, marks the first step in the direction of automatic telegraphy.

Gap between Extremes of Speed.

As already stated there is, and always will be, a large amount of business demanding transmission as near the instantaneous as it is possible to get. This is the speculative business between exchanges, and for this work Morse working has no equal, not necessarily key transmission, but transmission by some practically direct means and reception by sound.

Before referring to the developments in high speed transmission and chemical recording which reach the limit of telegraphy, there are important modifications which fill the abrupt and wide gap between the slow Morse and this extreme capacity, and which, combined with the simple Morse circuits, and the high speed automatic method, form an organization complete for all needs and conditions included in the most comprehensive conduct of electrical correspondence.

Morse Working Hampered by the Key.

It is well known that in these days Morse working is hampered one-half by the key. In the old days the keyman could send a fast as the reader by sound could put the words down with a pen, but for 15 years past the typewriting machine has enabled the receiver to take things very easy with the fastest sender. It is fair to estimate that the receiver could average 40 words per minute, but he is held down to the Morse key rate of 15 words.

Important Modification of Rapid Telegraphy.

The modification of the rapid system adapted to this intermediate stage, between the extremes of speed, consists of a *perforator machine which may be operated by the ordinary Morse key* at the highest speed of the most expert operator. With two such machines an automatic transmitter may be fed with perforated tapes and messages sent over the line at a rate up to the highest ability of the typewritist receiver. In this way one receiving operator will take as much as two key senders can put on the tapes, thus doubling the facilities of a circuit, with one operator less, for the same amount of work. The messages coming from the key perforator may be automatically alternated through the transmitting machine, so that whenever there is more than one message on hand they are divided between perforators, and being sent off at double speed, the delay will be less, on an average, than at present, with an average accumulation of four or five messages on each operator's table during the busy hours, even when the wires are all working.

Improved Signals and Double Speed.

The automatic Morse transmitter delivers much better signals than could possibly be sent by key direct, for no matter how light or heavy the operator's manipulation may be, the holes in the tape are all of the same size, and consequently all the impulses sent over the line are of the same value.

As the tape runs continuously through the perforator, spaces and dash lengths correspond to those made by the operator, but the impulses of which the dots and dashes are formed are absolutely uniform, so that they carry much better over the line than the uneven impulses usually made by the key.

With two perforating operators working at 20 words per minute, the automatic transmitter will deliver the 40 words in a minute in greatly improved Morse to the receiving operator, who, if an expert, can maintain that speed. The receiver can break or stop the automatic transmitter which can easily be attended by the perforating operators, all the apparatus being on the same table.

In this way the Morse capacity of a circuit may be at least doubled, so that a duplex becomes equal to quadruplex in output, with six operators against eight, and a quadruplexed wire may be made to carry double the number of messages with 12 men doing the work of 16.

Automatic Morse Transmitter Determines Grade of Receiving Operator.

The automatic transmitter at once determines the grade of the receiving operator, and can be regulated to his ability instantly, whether he be a ten or a forty word per minute man.

Perforating from a Distance.

Another important feature of the perforating machine is that it can be operated from any distance, or over any circuit where it is possible to work a relay; thus branch, suburban, or way offices can, by the Morse key, perforate their messages at the central office for high speed transmission over trunk lines.

Reproduction of Tape instead of Repeaters.

For transmission over long circuits where automatic repeaters are now necessary, a perforated tape put into the transmitter in New York will reproduce itself in perforations at Buffalo, and this tape may be started in another circuit to Chicago, and so on to San Francisco, each reproduction serving for retransmission to the end, where the message may be taken by sound at 40 words a minute, a speed easily maintained over the different sections, which are worked independently, thus avoiding the cumulative effects of interdependence between repeaters, which lowers the speed to about 12 words per minute, New York to San Francisco.

High Speed Automatic Telegraphy.

In the high speed automatic transmission and chemical recording system as now perfected, is realized the best practical and theoretical results for telegraphic traffic of large volume.

Its speed is limited only by the impulse conveying efficiency of the wires — or the delivery of impulses of sufficient power to make a mark on the chemical tape by electro-chemical action on the iron recording wire, and with plainness permitting of ready transcription.

Heretofore, chemical telegraphs have used sending tapes having regular dots and dashes cut into them, and sending short and long impulses of one polarity. With a line of any considerable length, or electro-static capacity, these characters, when sent at anything approaching high speed, were run together by the discharge from the line, known in telegraphy as "tailing", so that transcription was difficult and unsafe. Recent improvements have entirely overcome this most serious drawback, and removed the main obstacle in the way of reaching the full carrying capacity of a line.

The perforated message is made up entirely of dots. No dashes are perforated or transmitted. All impulses have the same time value, and each succeeding one is of opposite polarity to the one before it. The time elapsing between a positive, marking, impulse and the negative, cutting off or spacing impulse, determines whether the character is a dot or a dash.

In preparing the perforated tape with Morse key, when the operator presses his key down, a hole for a positive impulse is made in the tape, and though the key be held down indefinitely, but this one hole is made, and the tape continues to run. When the key is let up, a hole for a negative impulse is made. Thus the holes for dots just clear each other from the vertical, while the holes for dashes are at an angle corresponding to the time the key was held down.

Utilization of Static Discharge.

Through these holes positive and negative impulses, or marking and spacing currents, are sent. A negative immediately following a positive permits only a short mark on the receiving tape, but when the negative impulse is delayed a dash is produced. The impulse for the dash is the same as for the dot, but as it is not followed by the reversal for some time, the discharge current running out of the line, after the circuit is broken at the transmitting end, completes the dash. The length of mark made by this prolonged current depends upon static capacity of the line, the rate at which the tape is running, and the delay of the negative impulse.

Should the normal capacity of the line be insufficient for the longest dash in the Morse code, the necessary amount is easily made up by placing a condenser between line and earth, either at the sending or receiving end, or elsewhere.

"Capacity" an Aid to Signalling.

About 300 miles of average pole line affords ample discharge for dashes at a speed of 1000 words per minute. Short cables in the line, instead of being a hindrance, as in the case of the electro-magnetic system, contribute to perfect signalling.

Added artificial capacity need not be altered to compensate for changes of weather — the margin being wide.

Disturbing Currents Ignored.

Speed depends upon voltage, and character of the line. A certain amount of current for a certain period is necessary at the recording finger of the receiver to make a plain record, and here it may be again remarked that in these days the conditions abroad in the land do not warrant the use of the most delicate instruments, or supersensitive solutions for telegraphic recording. On the contrary, the receiving tape should be sufficiently unconscious of stray currents and inductive effects to ignore them in the record,— responding only to the impulses from the transmitting station. With this safe margin the Rapid System is immune to interferences fatal to high speed or finely balanced electro-magnetic systems.

Atmospheric changes requiring constant adjustment and balancing of the latter apparatus have no effect on the automatic, except to change the density of the mark. *No signal can be dropped out or mutilated.*

The longest lines can be worked direct, without repeaters, at a speed proportioned to the distance.

Perforation by Morse key needs no special staff of operators.

Keyboard Perforator.

The latest improvement, and one of far reaching importance, consists of a perforator worked by a keyboard transmitter, so that any typewritist can perforate without even knowing the Morse code, and owing to its perfect uniformity of action, the record from this machine perforation can be transcribed almost as rapidly as copying from print.

8000 *Words a Minute.*

Mechanically, the rapid transmitter apparatus may be run at any speed up to 10,000 words a minute, 8000 words, or 2500 impulses a second have been recorded over an artificial circuit.

As the sending contacts are made by wire brushes pressing toward each other above and below the tape, there is no injurious sparking, since the arc is brushed out by the tape and the contact kept clean by the edges of the holes.

Automatic Control of Apparatus.

The receiving machine is entirely under control of the transmitting operator, and can be stopped at any stage. Likewise, the transmitter can be stopped by the receiving operator, and contact with outside wires will stop both machines. All tapes, sending and receiving, are automatically wound on reels as they pass through the machines. There are no loose and fluffy bundles of tape in evidence. The receiving tape is only slightly damp. It is not handled by anybody, being drawn in short installments in front of the typewritist transcriber by a mechanical contrivance controlled by the foot.

Effect of Rapid Telegraphy on Installations.

With Rapid Telegraphy there will be fewer wires, greater stability in construction, and a full utilization of their carrying capacity.

System Superimposed on Telephone Circuits.

The System can be operated over a telephone circuit without interference with conversation.

Great Field for Development of Traffic.

Rapid Telegraphy foreshadows great changes in correspondence. Outside of the present telegraph business there is a vast and profitable field for development of an electrical correspondence for which the trains are too slow, and the present telegraph and telephone too expensive and inadequate.

Telephone Cannot Compete.

The telephone cannot compete with the telegraph for long distance communication. Its average is not more than 60 intelligible words per minute, or 30 words per wire, which is twenty to thirty words below the present telegraph wire speed, and only about one-fortieth of the number of words that can be recorded by rapid telegraphy. Long distance telephony is commercially possible now only through the rental of superimposed Morse telegraph circuits, two of which are obtained from the metallic circuit of the telephone.

Difference in Minimum Charge Assures Supremacy of Telegraph.

The difference in the minimum rate of the telegraph and the telephone must always sustain the supremacy of the telegraph for distances of over 50 miles. Forty cents for a ten word telegram, and five dollars as a minimum for three minutes talk, New York to Chicago, leaves the telegraph practically without a competitor; and when, by the Rapid System, availment of all that a wire can carry is had, delivering to the customer a typewritten letter of 180 words, or the telephone five dollars' worth, for say seventy-five cents, the permanent prevalence of the telegraph as the great medium of communication and correspondence will be indubitably demonstrated.

Telephone and Post Office Collection and Distribution for Rapid Telegraphy.

Millions of local telephones will collect and distribute telegrams for high speed work over trunk lines.

The post office will also be used for collection and delivery of telegraphed letters.

Between cities separated by any considerable distance all correspondence of any urgency will be telegraphed at a cost so moderate that the wire will supplant the train as a mail carrier and the relation between miles and time will be practically set aside.

DISCUSSION.

Mr. **JOHN HESKETH**: This is a subject upon which Mr. Delany has for many years been considered to be so well qualified to speak with authority that I hesitate to do more than just comment upon his paper. The speed of 400 words per minute with the Wheatstone apparatus is not the maximum speed obtained, as he states. I myself saw a speed of 600 words per minute before I left the British Post-Office Service in 1888, and I do not think the speed has gone down since then. It is too common in the

United States, where the conditions are altogether different, to think that the automatic system, as used in England, does not do what it set out to do, and for the speed of seventy or eighty words a minute to be taken as the average Wheatstone speed over the lines of the little island, would be altogether misleading. The average working speed would not be considered satisfactory if it were not over 200 words. I think that in his enthusiasm Mr. Delany has also been inclined to take the average of Morse working a trifle too low. I will admit, if you average all the lines and all the operators, that you do not exceed an average of fifteen words per minute; but all the instruments and all the operators are not going to be replaced by automatics. If you take the average of those conditions under which the automatic might be used, then the average speed of working is above twenty-five; I wouldn't say it was *much* above twenty-five; I think that twenty-five would be a fair rate at which to put it.

I am very pleased indeed that in one particular portion of his paper, Mr. Delany recognizes that there is and always will be a large amount of business demanding transmission as nearly instantaneous as it is possible to get, and that for this work, Morse operation and reception by sound is unequalled. I am pleased indeed to have Mr. Delany's opinion on that point, because a phase of the question which is concerning us somewhat in Australia is the extent to which hand operating or receiving by sound is to be replaced by automatic working. In my opinion, by far the greater bulk of business must be received by sound, transmitted possibly by a keyboard transmitter of the kind Mr. Delany has indicated. I have seen the keyboard transmitter at work at a rate of over forty words a minute. The sending operator was comfortably seated, leaning back in his chair, with his feet on another; he was taking things very easy, and was keeping the receiving operator busy at a comfortable speed receiving by sound and transcribing on the typewriter. That kind of transmission and receiving will, in my opinion, handle far the greater portion of telegraph business for many years to come; but for unavoidable congestion — cases where lines have been interrupted and where there is a big rush of business — I am looking forward with a great deal of interest to the adoption of some such system as is outlined by Mr. Delany.

Chairman Jones: Of course, you are aware that this paper has a different bearing in this country from what it will have in European countries, where the telegraphs are entirely in the hands of the government. In this country, the telegraphs are conducted by private enterprise. In foreign countries, if you send a telegram, and some very serious error is made by the telegrapher in the message, causing a serious loss, after several months of red-tape correspondence you are sent an official letter, stating that if you will have your claim presented at such a time, at such an office, they will hand you an order on the Treasury of the Nation for the amount of the tolls you paid. In America if you should sustain a loss of three or four thousand dollars, your attorney immediately files your claim before the court, and we know pretty well what the result will be — at least the telegraph companies do. Those are two important features. Another feature seems to be one that concerns the telegraph management in this country and one in which they have a very vital interest. The public has, of course, a great interest, as outlined by Mr. Delany, who, I think, covers every phase of the subject. We are very much indebted to him for this clear and concise statement of the situation, which I think refers more particularly to the United States than to foreign countries.

It gives me very much pleasure to introduce to you now Dr. Louis M. Potts, of Johns Hopkins University, Baltimore, who has prepared a paper upon the subject of "Printing Telegraphy."

Dr. Potts presented his paper, as follows:

PRINTING TELEGRAPHY.

BY DR. LOUIS M. POTTS.

Ever since the original invention of the electromagnetic telegraph, inventors have been striving for a system of telegraphy which would print in Roman characters, and at the same time be rapid, and have as far as possible the simplicity of the Morse system. As far as practice is concerned, this result up to the present time has not been accomplished, but several systems are now being exploited which bid fair to overcome most of the disadvantages of former systems of printing telegraphy, for use in fields where, up to the present time, it has not been found practical to employ them. It is not the purpose of the present paper to give a treatment of the many printing telegraphs which have been proposed at various times, but rather to treat of the various essential principles involved in those systems which have been shown to be of value by their adoption in actual practice, or systems of recent invention which, although not in general use, involve essentially new and promising features. In all printing telegraphs there are four points which above all others require primary consideration. Of primary importance is the method employed to obtain a number of operations at a terminal station under the control of an operator at the distant station. Next in importance are the form of telegraphic current employed, the method of sending the signals, and the method of their reception in print.

SYNCHRONISM.

In practically all of the printing telegraphs which have ever been proposed, the control of a number of operations over one wire has been accomplished by the employment of synchronism in one form or another, and a good and stable form of synchronism is a necessary foundation for its successful operation.

The simplest form of synchronism employed was that used by Royal E. House in his printing telegraph invented in 1846. This is the so-called step-by-step method. In this system at the receiving station a toothed wheel is driven by a motor. As this wheel rotates, the current sent over the line is made and broken as each tooth passes under a contact. At the receiving station, the apparatus is likewise driven by a motor. A toothed wheel is here employed similar to the one at the sending station, but in this case it is an escapement wheel. This escapement oscillates under the control of an electromagnet operated by the pulses of current received. As the sending toothed wheel rotates one tooth, the current is made and broken once, and the receiving toothed wheel is allowed to advance one tooth by a to-and-fro motion of an escapement. A key is provided by means of which it is easy to first set the wheels when the machines are first put in operation. The printing is always preceded by the operation of this key. As each succeeding key is depressed, the toothed wheel of the sending machine is allowed to rotate to the letter to be printed, and, in so doing, makes and breaks the current a number of times, corresponding to the number of teeth intervening, and these impulses at the receiving end allow the corresponding ratchet wheel to move the same number of teeth. This method of synchronism has the advantage of simplicity; but as it is often necessary to rotate the wheel nearly a whole revolution between succeeding letters, and as the mechanical parts must needs have considerable inertia, a limit is set to the speed at which the machine may be operated.

To the class of step-by-step synchronous motions also belongs the Buckingham. However, this method represents a great improvement over the method previously mentioned, particularly in regard to speed. The necessary number of steps has here been reduced to six for any character and always the same number. Each complete signal results in the advance of the receiving mechanism six steps in every case, the difference in the signals being merely different combinations of long and short impulses. And, further, the synchronism is rendered more positive by being reset after each character by the so-called release impulse. This will be clear from Fig. 1.

Another phase of the development of the principle of synchronism is exemplified in the Hughes machine. Here we have the method of first regulating two machines; so that they naturally tend to run at as nearly the same speed as possible, and then, at frequent intervals, correcting the rate of one or both by the amount they have deviated the one from the other. This idea has been extensively used, and variously modified since. Even the Hughes machine itself has employed several different methods at different times. In one form, the approximate synchronous motion of the sending and receiving machine is obtained by the use of two vibrating reeds or pendulums. These reeds or pendulums, by means of a ratchet wheel and escapement, regulate the speed of rotation of the type wheels. The rate of vibration of this pendulum can be regulated in the same manner as a clock-pendulum, by sliding a weight nearer to or farther away from the point of support. In another form, the approximate synchronism is obtained by a conical pendulum. This arrangement is similar to the ordinary engine governor. A heavy weight at the extremity of a long rod, pivoted at the extreme end, is rotated around its long axis. As it rotates, the weight is thrown out by centrifugal force and describes a circle of continually increasing radius. When this radius has reached a certain value, by means of a set of levers acted on by the weight, friction is applied to some part of the mechanism, and the speed prevented from going above a certain value. By regulating the position of the weight, quite a delicate regulation of the speed may be obtained. However, no matter how nicely such a mechanism may be regulated, they will continue in synchronism only for comparatively short intervals, so that it is necessary to have some means of accelerating, or retarding, the motion of one or both machines at frequent intervals. In the Hughes machine, this correction is obtained each time a character is printed. The type wheel is carried loosely, by friction on the rotating shaft, and rigidly to a so-called correction wheel, which has a number of notches equal to the number of characters on the type wheel. Each time a character is printed, a cam

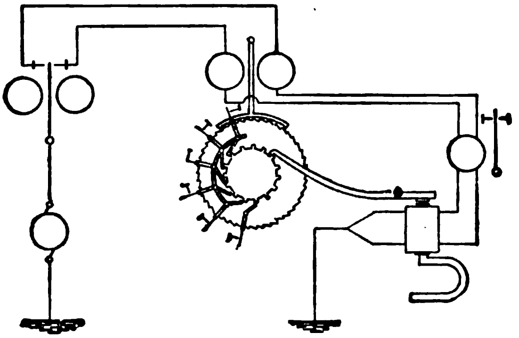

FIG. 1.

rigidly fastened to the printing mechanism engages the tooth corresponding to the letter to be printed, and turns the type wheel backward or forward, as may be required, to bring it accurately to the printing position. Each time a character is printed this correction is applied. If the interval between the printing of two characters is too great, and the two machines get apart as much as one character, the wrong character will be printed and the machine will have to again be brought into unison.

In the Baudot Multiplex system we have a system of synchronism very similar to the Hughes. But here we have a distinct improvement on the Hughes method, in that the synchronism is not corrected by the signals for the characters, but a separate impulse is transmitted over the line for the purpose of correcting the synchronism. The machine is kept in continuous motion by a weight or a motor. The speed is locally kept very close to a definite speed, as in the Hughes, by a centrifugal governor, which, as the speed increases, causes the motor to do more work against friction, and thus keep its speed within a certain limit. The apparatus at one end is set to run slightly faster than at the other. Once in each revolution, or more frequently, the correcting impulse is sent out at the receiving station, by means of a commutator and rotating brush arm, which connects the line to the battery at frequent intervals. (See Fig. 2.) As will be seen on a part of the commutator (C_2), at the other terminal of the line, slightly in advance of that which sends out the correcting impulses, is a segment connected to the ground through an electromagnet. Assuming the brush B_2 to travel faster than B_1, it will arrive on the segment S_3 before B_1 leaves S_1, and the magnet E will be energized. The magnet E operates a mechanical arrangement, which has for effect to set back the brush B_2 a small amount, so that it again starts out in phase with

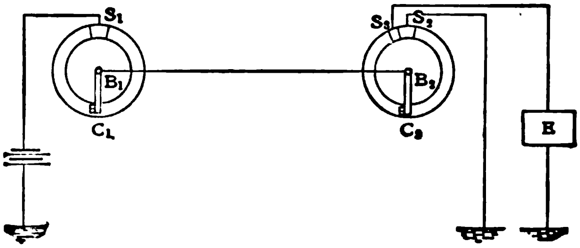

FIG. 2.

B_1, and thus, at each revolution, the magnet E corrects the rotation by the slight amount it has shifted during the previous revolution. We thus have two systems in synchronous operation within certain limits of variation.

We now pass to a somewhat different type of synchronous motion in which, when in proper adjustment, the two tend to run at synchronous speed, and, if disturbed from this position, will tend to return, i. e., they are in dynamic equilibrium. In the Murray Page Printing Telegraph we have an example of this form. As in the correcting systems, we have here at each station a vibrating reed, whose rates are made nearly equal by weights sliding along their length. These reeds vibrate against what are known as resilient stops, that is, stops which are not rigid but have a certain amount of elasticity. The effect of these stops is to allow a considerable variation in the period of the reed according as it is actuated by a weak or strong periodic force. This periodic force is produced by an electromagnet operating on the reed as an armature. In series with the electromagnet are two sets of contacts; one set is operated by the reed itself, the other set is on a relay operated by the line relay. This line relay has both front and back contacts so connected that the circuit of the reed magnet is broken each time that the line current is made or broken. If the breaks at both contacts occur at the same time, the reed magnet will receive its maximum current.

If, however, the two breaks occur at different times, the reed magnet will receive less current, and due to the effect of the resilient stops, as before mentioned, it will decrease its rate of vibration. If now the reed tends to go faster or slower, it will receive a less or greater amount of current, and will assume such a position that there is a balance between its tendency to go faster, and its tendency to receive less current due to its increasing rate.

The most perfect type of synchronism that has yet been devised is that used in the Rowland System of Telegraphy. This is of the same general type as the Murray, but differs more particularly, in that the Murray is merely a synchronism of vibration, while here we have the synchronous rotation of machines of considerable inertia and consequently a much more stable system, and one subject to disturbances to a correspondingly less extent. A number of different methods have been used in this system, all having the same fundamental principles, but differing considerably in the methods of their attainment. In the first place, a means is provided whereby two motors, when rotating in synchronism, are in dynamic equilibrium, and secondly, a means of producing a frictional force when they are disturbed from this relation. This can be best understood by reference in detail to a particular form.

The simplest form, and that used on the latest type of the Rowland machine, is that in which the principle is applied to two direct-current motors. One motor drives a mechanism by means of which an alternating telegraphic current is produced, in this case an alternating current of something over one-hundred complete periods per second. The second motor drives a commutator for synchronising. Referring to Fig. 3, we have the polarized relay *R*, which is kept in continuous vibration by the alternating current, produced by the mechanism driven by the motor at the originating station. The commutator *C* is kept in continuous rotation by the motor whose field and armature are shown. In series with the armature is a permanent resistance *R*, and a speed regulating dial. The commutator *C* is an ordinary crown commutator, having its alternate segments connected to the contacts of the relay. When the tongue *T*, and the brush *B*, are at the same time on the contact C_1. and segment S_1, which are connected, the resistance *R* is cut out of the armature circuit, and it receives its maximum current. When they are at the same time on contact C_1, and segment S_2, which are not connected, the armature receives its minimum current. If now the relay *R* is so vibrated, and the commutator *C* so rotated, that as the tongue passes from C_1 to C_2 the brush *B* passes from S_1 to S_2 and as *T* passes from C_2 to C_1 the brush *B* passes from S_2 to S_1 and so on continuously, the resistance *R* will be permanently cut out of circuit. If, however, the brush is shifted the distance of one segment ahead of this position, the resistance *R* will be permanently in circuit. For any relation between these two extremes, the arma-

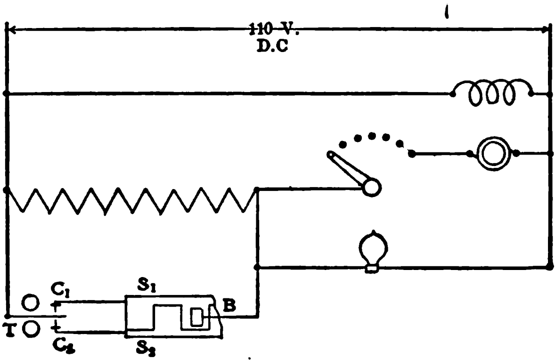

FIG. 3.

ture will receive at rapidly recurring intervals a larger and smaller amount of current.

The relation of the rotating brush and the vibrating tongue will determine the relative length of the interval of large current and of small current, and the integral effect will determine the speed of the motor, which, it will be seen, can have quite a large range. When the brush and tongue have such a relation that there are intervals both of large and small current, a tendency of the motor to increase its speed will call into action a tendency of the commutator to allow more or less current to flow through the armature, and the motor will assume a state of equilibrium where these two tendencies exactly balance. And, if the rate of this tongue increases, there is a corresponding increase in the current through the armature, until a state of equilibrium is reached and conversely. Such a system will remain in synchronism continuously for all ordinary variations, since such a state is a state of equilibrium, and, if disturbed from this state, it is acted upon by a force tending to return it. However, any freely moving system if disturbed from a state of equilibrium, will not return directly to that state, but, when allowed to return, will go beyond this point, and possibly make a number of oscillations about it.

Under ordinary circumstances, due to various causes, such a system is almost certain to be subject to many such disturbances, and may even continuously oscillate about its position of equilibrium. In order that such oscillations may be removed, it is necessary that some frictional force shall be called into action whenever such oscillations arise, i. e., the system must be made aperiodic, or nearly so. In this case, this result is very easily and quite effectively accomplished by having mounted on the motor-shaft a light but strong fly-wheel, having a large hollow rim filled with mercury. When the motor rotates steadily, this acts practically as a solid fly-wheel. However, when the speed changes the mercury drags or pulls on the outer wheel, and thus creates the frictional force necessary to dampen the oscillations when any disturbances occur. This also has the further effect to make the inertia of the system quite large, so that its period is so much slower than the alternations of the current, that the separate pulses, or even a considerable number, have no separate distinguishable effect on the speed, but only the integral of a large number, so that the modifications of the current caused by the signals have no effect on the synchronism, except as they may effect differently large blocks of waves. Practically, it is found that about half the waves require to be altered to have any serious effect on the stability.

CURRENT.

The basis of all electric telegraph systems is a succession of electric impulses sent to the point with which communication is desired. The character of these impulses has a most important bearing on the speed attainable by any system. In general, it is true that the speed will be determined by the number of impulses required for each signal, using as a unit the shortest signal, and counting each large unit in terms of the shortest. This is, however, very materially modified by other characteristics of the current. The principle effective consideration is the so-called trailing of the signals. This effect is not only produced by the electrical properties of the line, but is quite materially increased by the terminal main-line instruments. This effect is the duration of the action of a signal for a longer time than the length of the signal at the originating station. The line acting as a condenser, the other plate being the earth, takes up a certain charge, which, depending on its amount, prolongs the signal. This effect is still further increased, by the fact that the iron core of the receiving relay holds its magnetism after the magnetising force has been removed. This phenomenon exerts itself to a greater or less extent depending upon the duration of the signal. A long impulse charges the line more fully, and also magnetizes the core of the receiving relay to a greater extent, so that a very short impulse will have a less effective value at the distant station when following a long impulse, than when it follows a short impulse. These facts very greatly modify the speeds of different systems, having apparently the same number of unit impulses per signal, but which have different limits to the upper and lower length of the impulses employed.

In the simple step-by-step systems, the current consists simply of a succession of impulses of equal length which may alternate in direction or not. One long impulse for printing the signals is used; or the sending current is interrupted altogether, and the printing mechanism operated by purely local means. In this system we have a considerable number of impulses per signal, it being frequently necessary to rotate the wheel nearly a whole revolution. In addition, there is the length of time required for the actual printing, which, in many cases, requires even more time than the actual sending of the signal itself, since it requires the stopping and starting of parts having more or less inertia. For these reasons, any system acting on such a principle is limited in speed by the rapidity with which the mechanical parts can move.

In the Buckingham system, a decided step in advance has been made, and we have here a step-by-step system of remarkable speed. The speed has been increased by an extremely ingenious arrangement, by means of which six impulses are sufficient for any character. However, three of these impulses are short and three prolonged, so that the gain from this reduction in the number of impulses is not as great as might at first appear. The length of the long impulses being equal to three short ones, we have in reality from eleven to sixteen impulses for each letter, but, on account of the reversed polarity, and also on account of the fact that the longest impulses are equal to only three short ones, the current is well adapted for long-distance transmission. The speed limit has also been very ingeniously and materially increased, by the small inertia of the moving parts.

In the Hughes system, the current is extremely simple, being one impulse for each letter sent. However, a long interval ensues during which no impulse is sent over the line. We have here the fact that the wheel must in many cases be rotated nearly a complete revolution between successive letters, although, in certain cases, more than one character may be printed in one revolution. The speed of operation which has been possible with this machine, however, has not been such that the transmission of the line current enters seriously into consideration.

In the Baudot system, we have a much greater speed than that presented by the systems previously mentioned. The speed here has been greatly increased, due to the fact that the time element which enters into the step-by-step system, necessary for the actuating of the printing mechanism, has been entirely removed. The current at receiving station has merely to operate the light tongue of a relay. The printing is controlled by five relays and actuated by mechanical means, so that the time required to operate heavy mechanical parts is not added to the time necessary to transmit the signals, but takes place simultaneously and independent of them. However, a part of the time of the line is taken up to maintain synchronism, which must be subtracted from the effective use of the line for actual signals. The Baudot signals are made up of units of five short impulses, which may be all in one direction, or any combination of six impulses in opposite directions. On account of this feature, it is possible to have very long impulses followed by very short ones in the opposite direction, thus bringing in the trailing effect mentioned above. We have two features which limit the speed of this system: the trailing of the waves, and the limit of the speed at which it is possible to maintain sufficiently stable synchronism.

In the Murray system, we have an alphabet practically the same as the Baudot, except that current only in one direction is used, the alphabet being made by the use of the various possible combinations of any number of impulses up to five, the remaining impulses simply being omitted. The same troubles enter into the transmission of this current as in the case of the Baudot. However, we have no added time interval for the purpose of maintaining synchronism. This is accomplished by the signals themselves. A limit is here set upon the speed by the operation of the punching magnet. Although it is possible to make such a mechanism operate with great rapidity, yet it is most likely that the limit of speed in this system will be found to be limited by this operation, and not by the failure of the signals.

The basic current in the Rowland system is an alternating current, the ideal current for long distance transmission. To transmit signals, it is necessary that the alternating current be modified. This is accomplished as follows: For each signal the base is a block of the alternating current, consisting of eleven half waves; these eleven half waves are modified by the reversal of any two. By this means, the alternating current is modified to the smaller extent than if more waves are reversed. There is an extremely limited amount of trailing if signals here, due to greater equality in the duration of succeeding impulses. As in the Baudot, the time element of the local printing mechanism is completely removed, it being purely local and controlled by eleven relays. As in the Murray, the synchronism is maintained by the signals themselves, and no deduction is made for the effective value of the line for the maintenance of synchronism. The speed at which it is possible to send by the Rowland system is only limited by the frequency of alternating current it is possible to use, and still receive sufficient current at the receiving station to actuate the main line relay positively, as no difficulty has been encountered in maintaining stable synchronism.

METHODS OF SENDING.

In the earliest printing telegraphs, also on the Hughes and Rowland, the messages are sent directly by a keyboard having a key for each character sent, and in the Baudot directly from a keyboard, but in this case having only five keys, and on this account requiring great skill for its operation. In many other systems, including the Murray and Buckingham, a punched paper strip, the invention of Bain, is employed. In both the Murray and Buckingham systems, the preparation of the punched tape has been very much simplified by the use of a keyboard perforator, having a separate key for each character, the operation of which is very similar to the operation of an ordinary typewriter. This tape is prepared by one or more operators. The tape is then passed through a transmitter very similar to the Wheatstone. This method of transmitting presents the advantage of using the line to its fullest capacity.

In the Baudot and Rowland systems, the fact that one sending operator cannot send as fast as a line is capable of transmitting, is met by having several operators use the line at rapidly recurring intervals. In the Baudot there are two or three operators at each end, while in the Rowland there are four. The great skill required for the Baudot is not required in the Rowland due to the use of a keyboard having a key for each character. These keys are locked and unlocked so that the operator can depress a key only at the proper intervals. The signals are transmitted at the proper interval by a commutator and rotating brush in connection with a transmitting relay. The keyboard simply completes the circuit through the proper segments of the commutator for the signal to be sent.

Reception of Signals.

In the matter of the reception of the signals there is as great diversity as in the sending. In the simple step-by-step system, the Hughes and Buckingham, the printing is accomplished by a prolonged impulse, which by means of a relay sensitive only to long impulses, either sets in action a mechanical printing hammer, or operates an electrical one. In the Murray system, we have at the receiving station, as well as at the sending station, a punched tape, which, after it has been prepared by the receiving apparatus, is passed through an attachment to an ordinary typewriter, which, by means of a set of ten levers, controlled by the holes in the receiving tape, allows, by means of a combination of slots, the keys of the typewriter to be depressed by a series of cams actuated by a motor drive.

In considering the practical value of any system of printing telegraphy, there are many points which enter into the question. Of course in the first place it is necessary that the system, both mechanically and electrically, shall be sufficiently stable and certain in its operation to be operated continuously under the conditions of commercial work. It must also, for the greater and most important class of telegraphic business, be capable of sending the messages in such a manner that there shall be the shortest interval of time possible between the actual receipt of the message in the sending office, and the delivery of the message at the receiving station. No matter how great advantages any system may have, if these conditions are not fulfilled, the system cannot be even considered for the greater part of the telegraphic business handled to-day, although an exceedingly rapid system, which did not fulfill the second consideration, might be employed for a certain class of business which is to-day conducted by the mails. (There are a number of printing telegraphs which have recently been invented that show extreme rapidity but are not adapted to much of the present telegraphic business but fill a new field notably the Pollak-Viràg and Siemens and Halske rapid systems.)

Aside from the two above necessary considerations, the usefulness of a system is dependent on the amount of business that can be transacted over one wire, and also upon the amount of business that can be transacted per operator, modified as may be necessary by the skill of the operator required. A very great point in favor of any system of telegraphy is simplicity, although this is not a necessity, provided that certain other conditions are fulfilled. If any system is shown to be reliable in its operation when supervised properly, the only point which really determines its usefulness is whether the cost of transmitting the message is reduced, as the determination of this cost per message should take into consideration any skilled employees who may be necessary to insure the continuous operation of the apparatus.

By considering the various printing telegraphs, with the above points in view, an idea of their comparative value may be obtained. The step-by-step telegraphs and the Hughes machine cannot seriously be considered for the transaction of any heavy business over long distances, since both the speed per operator and speed per wire are low..

In the Baudot machine we have a moderately high speed per wire, but not an exceptionally high speed per operator. The most serious objections to the Baudot are the great skill required for the operation of its keyboard, and the comparative difficulty of keeping it in stable and continuous operation, especially over many of the longer circuits.

The Murray system presents a high rate per operator, and also a comparatively high rate per wire. We have here, however, a serious objection from the fact that both the sending and receiving stations employ a perforated tape. It has been found in actual practice that a considerable delay is necessarily incident to the use of tape for this purpose, as it is necessary to perforate a considerable amount of tape before it can be actually used, this is likely to cause a delay of some minutes at both terminals. The greatest difficulty, however, is presented in the case of errors or damaged tape, in such cases it is always necessary to go back some little distance in the tape, and considerable delay is experienced in finding the error or disputed point on tape and to transmit it again over the wire.

In the Buckingham system we have also a high speed per operator, and a comparatively high speed per wire, although probably not as great as in the case of the Murray. However, the Buckingham system presents a decided advantage over the Murray from the fact that the punched tape has been dispensed with at the receiving station, and is used only at the sending station. The use of tape at the sending station causes considerable delay, but not as much as in the case of its use at both stations, as the errors are detected much sooner. The Buckingham system would also in actual practice probably gain somewhat on the Murray, due to the fact that its operation would be more stable, as there are no reeds to tune at the terminals of the line. but the motion is a positive step-by-step action.

In the Rowland system, there is a large speed per operator, possibly not as great as could actually be obtained on some other systems, such as the Murray and Buckingham, but it is to be expected that in practical work the sustained rate of the Rowland operator would be practically the same as that of the Murray or the Buckingham. The speed per wire is much greater than that of any other printing telegraph system, and is greater that that of most other automatic systems, if we except the chemical. In the Rowland system, both sending and receiving are direct, and neither requires the services of a skilled operator. The time of delivery of the message has here been reduced to the minimum possible with an automatic system, and, by the aid of the several special contrivances, the correction of errors or inquiries in regard to messages has been reduced to the minimum. It is possible in this system to stop an operator in the middle of a message, and have the message duplicated, without the sending of a service message. The objections which have always been made to the printing telegraphs employing synchronous motion have been almost completely removed by the employment of stable synchronism, and also the furnishing of a means whereby synchronism can be established in less than one minute. On account of the direct method of operating the Rowland system, and also on account of its large capacity, a larger amount of mechanism is required than in the case of systems of smaller capacity. This feature has resulted not so much in great complication as in the multiplicity of parts.

The subject of printing telegraphy presents so many phases, and the demands of the telegraphic business are so varied, that no one system is likely to be adaptable to all needs. It would appear evident from the good showing of the several recently invented printing telegraphs, that the adoption of printing telegraphs for general telegraphic business in America is imminent, and that the same machines will be used side by side with the printing telegraphs already employed in Europe and will in many cases completely replace them.

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TABLE OF SPEEDS.

	Messages of 20 words each per hour. Theoretical speed.	Maximum theoretical speed. Words per minute.	Practical speed (telegrams, 30 words) per hour.
Morse quadruplex	....	....	188.8[8]
Hughes simplex	72[1]	21	40[7]
Hughes duplex	144[1]	42	80[7]
Baudot simplex	112[1]	85[3]	40[7]
Baudot duplex	224[1]	70[3]	80[7]
Baudot quadruplex	....	140[3]	160[7]
Baudot sextuplex	....	210[3]	240[7]
Wheatstone simplex	240[1]	....	....
Wheatstone duplex	480[1]	....	....
Murray simplex	....	96[4]	120[4]
Murray duplex	....	192[4]	240[4]
Buckingham simplex	....	100[5]	100[5]
Buckingham duplex	....	200[5]	200[5]
Rowland single	162[2]	47	60[6]
Rowland octopolex	1,296[2]	876	480[6]

NOTE.—In the preparation of the above table, the author has encountered serious difficulties in getting the speeds of the various systems under comparable conditions. It is believed, however, that the table gives as nearly the comparative values of the various systems as it is possible to obtain, until more data has been furnished by a more extended practical use of certain ones included in the list.

1. See "Valore Comparativo dei Sistemi Telegrafici usati in Italia," by Z. Ferranti. Roma, 1893.

2. These calculations have been made by the author based on same assumptions as above and for messages received on a continuous band, as in the case with Hughes and Baudot.

3. These figures are based on the maximum speed 192 revolutions.

4. See "A New Page-printing Telegraph" by W. B. Vansize. *Transactions* of American Institute of Electrical Engineers, Vol. XVIII.

5. See *Telegraph Age*, Vol. XIX No. 17. "The Buckingham Long-Distance Page Printing Telegraph" by Wm. Maver, Jr.

6. These figures are actual performances over real lines under commerical conditions personally observed by the author. The messages were received on telegraph blanks ready for delivery.

7. These figures are the result of information collected by the author from various reliable sources and are intended to represent as nearly as possible the comparative values of the systems under actual conditions. In each considerably greater speeds are actually attained but are not maintained.

8. Mr. F. W. Jones in Vol. 39, *The Electrical World and Engineer.* This

is highest average claimed for the Morse Quadruplex for a full day's work on the line of the Postal Telegraph-Cable Company between Boston and New York.

DISCUSSION.

Mr. J. S. STONE: To what extent has the Squiers receiver ever been used?

Dr. POTTS: I am not prepared to answer that question. I think the system has been used, but I cannot say positively.

Mr. JOHN HESKETH: In your comparison of the Buckingham system with the Murray, is it intended to suggest that there is necessity for synchronism between the sending and the receiving ends in the latter system? I do not believe that to be so. If you have synchronism between the parts of the receiving station only, I think there is no necessity for synchronism between the sending and receiving ends.

Dr. POTTS: It depends very largely upon what is meant by the term "synchronism." I have taken a rather broad view of that term. In the narrow sense of the term, it probably would not be considered real synchronism.

CHAIRMAN JONES: The next paper upon the programme is by Prof. Ferdinando Lori, of the University of Padua, who is not present with us.

Upon motion, the paper was read by title.

HARMONIC TELEGRAPH.

BY PROF. FERDINANDO LORI, *University of Padua.*

The interesting phenomena of electromagnetic and electromechanical resonance in alternating-current circuits are well-known. These phenomena, which chiefly depend upon frequency, take place when this factor reaches a certain value; and, therefore, this gives us a method of measuring frequency. If the e.m.f. acting on the circuit has a complex form resulting from the algebraic sum of several harmonics, each of them having a sinusoidal form, a method can be derived for ascertaining the existence of any given harmonic.

Let us assume a complex e.m.f. resulting from several harmonics, each of which can at will be included or excluded from a circuit at fixed time intervals. Then the resonance phenomena may be employed to determine when each harmonic is acting; and, if these time intervals follow a fixed law (like that of the Morse alphabet), we will be able to transmit simultaneously on the same line as many telegrams as we have harmonics at our disposal.

A multiple transmission system based on this principle has been devised and tried by the author. The results of the experiments I have thus far made in order to ascertain the practicability of the system have been so satisfactory as to induce me to beg the honor of briefly calling your attention to the matter.

The transmitting station includes several transformers, whose secondary circuits are all connected in series with each other and with the line, while the primaries are separately supplied with alternating e.m.f., as nearly as possible of sinusoidal form, quite independent of each other and of different frequencies. The currents can be generated by means of special alternators or by means of microphones excited by playing before their mouthpieces organ pipes of proper length. In the circuit of every e.m.f. a switch is inserted to be manipulated as an ordinary Morse key, to send the signals corresponding to that frequency. The receiving apparatus is also connected in series with each other and with the line in the receiving station.

Each receiving apparatus includes a wire stretched between the poles of a permanent magnet, the tension of which wire can be varied by means of a micrometer screw and regulated so as to make the vibrational period of the wire coincide with the frequency of one of the generators. Under such conditions, and when the e.m.f. of the generator is acting on the circuit, the wire vibrates; and if it is small enough, no sensible disturbance by phenomena from inertia takes place, the vibrations practically begining with and being simultaneous with the action of the e.m.f.

Perpendicularly to the vibrating wire is placed a thin and rigid rod (for instance a small glass tube); one extremity of the rod is fixed and a point of it is connected with the vibrating wire. Consequently, when the wire vibrates the rod also comes into vibration, and the free extremity can be employed to write its own oscillations on a recording cylinder, after the manner of a recording tuning fork. The receiving apparatus is sensitive to very small currents, under 1/20,000 of an ampere. The vibrating wire is of phosphor bronze, about 20 cm in length, with a diameter of about 1/20 mm.

Chairman Jones: I am pleased to present to you Mr. Franz I. Dommerque, who will present a paper on the subject of "Telephone Problems in Large Cities."

THE TELEPHONE PROBLEM IN LARGE CITIES.

BY F. J. DOMMERQUE.

The present hour confronts the telephone engineer with the problem to find adequate and economical ways and means to provide proper telephone service for many large cities, where the number of telephone users has increased enormously in late years, caused by a better appreciation of the usefulness and convenience of the telephone and the decreased cost of telephone service. In the last decade the population itself has shifted under the expansion of rapid transit; on the one hand the business men congregating in huge office buildings, on the other hand the residential districts radiating far out into the country. These altered conditions must be taken into consideration in the arrangement of new switching apparatus, to replace old equipment, now inadequate, obsolete and worn out.

When speaking of large cities, it would be drawing the limits too close to consider only New York and Chicago and the capitals of the old world. All cities with more than 100,000 inhabitants should be included, and in fact all that will be said for cities of 100,000 pertains equally well to cities of smaller population, as long as they can be termed cities at all.

Telephone service must be reliable in all cases; it also must be quick and not involve any operation on the part of the subscriber. The cost of service must be reasonable; the business man can and will pay a greater amount for good service than the residence subscriber, but there should be no difficulty in arranging rates satisfactory to the latter by a judicious use of party lines and measured service.

It has been the general rule up to the present time to divide a large city into a number of districts; to locate a central office in each district and to connect these offices by trunk lines. When economy only is taken into consideration, this method of handling the telephone business is probably correct, as in large cities the actual minimum of annual expenditure will be obtained with more than one office district, because the expense for the wire plant, which is the principal item of annual expense, decreases with increasing number of office districts, while the other items that contribute to the annual expense increase up to a certain point where the sum of all items gives a true minimum.

Paying, however, due respect to the quality of service, it is a plain fact that with the introduction of trunking the service must become less efficient, because, to begin with, it takes more time to put through a trunk call than a local call. As all trunk calls must be handled by at least two operators, a greater liability to human errors is introduced; trunking also increases the apparatus and cable in the office, tending thereby to deteriorate the quality of transmission; and, finally, no matter how good the discipline of the operating-room may be, it generally happens that in the busiest hours of the day when the service should be most rapid, all the trunk lines are in use and subscribers are forced to wait for connections. The trunking troubles are still more aggravated by the necessary evil of order wires. It is a wonder how in large cities where the percentage of trunking is very high, the operators are at all able in the busy hour to distinguish between orders. Any one who ever listened in on an order-wire circuit in a busy exchange will be convinced of the difficulties in that respect.

If, therefore, money was no object, the ideal way of giving telephone service would be to bring all subscriber's lines into one switchboard. Looking at the problem from a physical standpoint, there is a limit to the size of the switchboard. To begin with, it may be conceded that as a result of many years' experience the multiple form of switchboard has shown itself as most adapted to satisfactory service. As a multiple board demands all subscribers to be in reach of every operator, it is absolutely necessary to decrease the size of the multiple jacks with increasing number of subscribers. The greatest number of lines that can be accommodated in a multiple section with the smallest jacks at present in commercial service (jacks with 3/10-in. centers) is 20,000 in an *A* section (a section upon which only local and outgoing trunk work is done), and 25,000 in a *B* section (a section used for incoming trunk work only). The capacity of a *B* section is greater on account of the gain in space by the absence of the answering jacks and signals and outgoing trunk jacks. However, 20,000 lines do not necessarily mean 20,000 subscribers, since by the aid of party lines and private branch exchanges the number of subscribers may be greatly increased. Party lines being mostly used in residence districts, where the lines are of considerable length, effect a great saving in line expense and consequently permit of lower rates, which circumstance increases the number of residence subscribers; party-line service naturally tends to increase the size of an office district.

Assuming that the use of telephones would become so general that one telephone would be required for every five people, and assuming furthermore that one-half of the telephone equipment would be used for a single-line service, and the other half for party lines and private branch exchanges; and that the party-line and private branch exchange subscribers would require only one-third as many lines as the other subscribers — in other words that three times as many party-line and private branch exchange subscribers could be accommodated as there is line equipment in the switchboard — then with a board having a capacity of 20,000 multiple jacks, 10,000 single-line subscribers and 30,000 party-line and private branch exchange subscribers or a total of 40,000 subscribers could be given service without necessitating the use of more than one office. According to the above assumption, this would correspond to cities with not more than 200,000 inhabitants, or better expressed, all cities that will not increase to more than 200,000 inhabitants during the life of the switchboard.

There exists the possibility of extending the use of a single office to a larger city than of 200,000 population by the aid of so-called "division systems," sometimes termed group systems. Such systems subdivide a multiple board into two or more divisions so that only one-half or one-third or one-fourth the number of lines (according to the number of divisions) are multipled in each division, while each division contains answering jacks and signals for all the lines. A two-division board thus would contain 20,000 multiple jacks of the 3/10-in. type in each section of each division, giving a total of 40,000 lines. There would have to be a total of 80,000 answering jacks and signals, as each line would have to appear in each of the two divisions. This doubling of answering jacks and signals, however, does not mean doubling of space, as in a two-division system the answering jacks can be spaced close together (20 per strip), while in a straight multiple board they are spaced 10 per strip for good service; because in a two-division board there are twice as many jacks for the same number of originating calls as in a straight multiple system.

Seven years' experience with division boards has established the fact that more than two divisions will not give both good and economical service; four divisions can give *good* service, but the service is not *economical,* principally on account of the practical impossibility of using an intermediate distributing board, since the cross-connecting wires become unwieldy; hence, the possibility of distributing the load evenly over the operators or rather the possibility of loading each and every operator to the limit is excluded. With two divisions, the use of an intermediate distributing board is practical as not more than a three-pair cross-connecting wire is required. Therefore, with a two-division system, 20,000 single line and 60,000 party line and private branch exchange subscribers can be accommodated on 40,000 lines in the switchboard, whence the use of a single exchange may be extended to cities with a population of 400,000.

Many telephone engineers are unfavorably disposed toward anything that involves labor on the part of the subscriber, and in a two-division system the subscriber would have to press one of two buttons upon his instrument, according to the division upon which the desired subscriber is located; and this operation, though involving only a minimum of attention on the part of the subscriber, is not quite as simple as just lifting the receiver off the hook to signal the operator. Where a two-division system would not find favor, the city must be divided into districts and trunk lines must be used. In such a case the number of districts should be kept small in order to keep the trunking in narrow limits. In fact, the trunking should be kept below 50 per cent — in other words, of all the originating calls, not more than one-half should be trunked. This can best be accomplished by establishing one office with a 20,000-line board in the center of the densest telephone population, then selecting clusters of less dense telephone population and providing each of them with an office and trunk between them. In this arrangement all boards would be multiple-boards, as there would be sufficient local business to require a multiple on the *A* sections. As soon as the district of *dense* telephone population becomes too great for one office, and must, therefore, be subdivided into more districts, the percentage of trunking will naturally rise; and from experience it is known that in New York and Chicago, for instance, the percentage of trunking exceeds 60 per cent and has been considerably higher at the time when the offices, or rather the switchboards, were smaller. When the percentage of trunking is high, the multiple in the *A* boards is not used much, and the question is raised if it would not be better under the circumstances to trunk all the calls so that the *A* board would be a receiving board only, while the *B* board would contain a large multiple. Doing this should offer an opportunity to simplify operation, as the *A* operator's circuit could be made very simple. Time also should be saved in the average duration of a call on account of simpler and more uniform manipulations; in other words, when all calls are trunked, it should take less time to put up a connection on a trunk line than where only part of the calls are trunked.

From the above considerations it follows that in an exchange without trunking, the best service can be rendered, and that the quality of service deteriorates with increasing percentage of trunking. It also is a fact that with large office districts the annual expense is greater than with small office districts. The question arises, which of the two, better service with greater expense or inferior service with minimum of expense, should be selected; or is there a compromise?

Where competition exists, as is now the case in all large cities of the United States with the exception of New York and a very few others, that company which gives the best service is most apt to find the greatest favor with the public. Where the telephone service is in the hands of the government as in all principal European countries, the government certainly desires to give the best service. It seems, therefore, reasonable to say that the best service should be made the rule, and that every effort should be made to render this best service with the least expenditure.

The principal item of expense entering into this problem is the line expense. Any reduction therein will be in favor of larger office districts, the term "district" being here relative, meaning a district containing a great number of subscribers and not necessarily covering a large area, though the larger the area the more marked the difference in expense will appear.

With large office districts more lines can be concentrated into heavy underground runs, which will reduce the relative cost of the conduit system. Larger cables can be used and larger cables are cheaper per conductor than small ones. The demand for larger cables has prompted the cable manufacturer to build cables with 400 and more pairs. Of course, the conductors in these cables have to be of a finer gauge than had previously been the custom; but the development in transmitter design kept pace with the progress in cable manufacture, so that these cables with finer wire do not deteriorate the transmission so long as the capacity is kept within reasonable limits. All these briefly mentioned items are in favor of large as against small office districts.

The introduction of party-line service in the residence district has made the proposition of large offices still more favorable. With small office districts the management often was doubtful whether party lines would really be money savers, because the parties as a rule were located so far apart that the common line from the exchange to the point or points of connection with the party lines, plus these party lines, did not cost much more than individual lines direct from the exchange to each of the parties; the saving in the line expense in that case did not seem to be in accordance with the decreased revenue per party line. With large office districts the common line from the exchange to the connecting points is most likely long in comparison to the party lines and, therefore, a real saving results.

On the other hand, improvements have been and are constantly made in the design of trunk circuits, the principal step in advance being the introduction of automatic features like automatic or machine ringing, which secure simpler operation and reduction of time, but necessarily involve complication in the apparatus.

In the Strowger automatic telephone system, now so largely exploited, trunking is carried on entirely automatically, the subscriber being made to perform the operating. This is a case of going to the other extreme where all calls, as far as large exchanges are concerned, involve trunking, and where all the trunking is done automatically in the exchange with, at present, very complicated apparatus. It is not the purpose of this paper to enter into a discussion of automatic v. manual exchanges; it may only be assumed that the automatic exchange can be made practical and it may further be expressed as a personal opinion that the vertical and rotating movement as applied in the Strowger switch is the keynote of automatic working. With this in mind, the exchange problem in large cities becomes entirely different. The trunking no more affects the service and, therefore, the choice between large and small offices or office districts resolves itself into a problem of economy pure and simple. In this case the engineer must find the true minimum of annual expense and be guided thereby in the selection of the number and location of the offices.

The sum total of automatic apparatus will be the same whether all concentrated in one building or scattered over many. The length of the trunk lines, however, varies, being shortest with all the switches in one building and increases with the increasing number of and distances between offices. The reverse is the case with the subscribers' lines, and there can be found a balance where, ceteris paribus, the expenditure on trunk lines plus the expenditure on subscribers' lines gives a minimum.

So far the term "service" has been used to designate the more or less satisfactory arrangement and working of the apparatus either by operators or automatically. Another phase of service is represented by the quality of the transmission of speech. Not much need be said in relation to this, as there are obtainable the most efficient transmitters and receivers, and it is only a matter of dollars and cents to obtain them; it is furthermore simply a question of finances to build the lines so that they will present sufficiently high insulation, low enough resistance and balanced induction and capacity.

Stress is here laid upon a good talking circuit for the reason that with the introduction of automatic exchanges this most essential requirement in any telephone enterprise has been sadly neglected. The advent of the Strowger automatic exchange has also caused a return to the local battery at the subscriber's station for talking, which is contrary to the trend of the present moment toward centralization in all manually operated exchanges. Moreover the necessity of a ground connection at the subscriber's premises for signaling purposes is against modern practice.

After having disposed of the local exchange requirements for large cities, a few words may be added with regard to the toll and long-distance facilities that should be provided. Both the toll business and the long-distance business being of the same nature and closely allied, one switchboard seems to be preferable for both kinds of service. The switching apparatus for this purpose should be so located that either no cable at all or only a minimum amount would enter between the toll and long-distance lines and the point where the same are switched to the local subscriber's lines.

As the toll and long-distance lines are very costly, they ought to be loaded to the fullest extent. To do this effectively the operator should be enabled to keep the lines busy all the time, and, therefore, only a few lines should be assigned to one operator (in Germany they assign only two lines to one operator) while provision should be made to make the connections with the utmost speed. For outgoing calls for such subscribers as frequently use the toll and long-distance lines, provision can be made to call the toll board direct without going first through the local board, by providing a double signaling device; one being the regular signal upon the local board, operated by the subscriber taking the receiver off the hook, and the other a second signal terminating in a distributing operator's section of the toll boards, this signal being arranged similar to the second signal in a two-division signaling system previously alluded to and operated by the subscriber's pressing a button.

For incoming toll and long-distance work the same subscribers may have their lines multipled through the toll board so that every operator can connect to them direct.

All toll boards in large cities should be provided with ticket carriers somewhat along the line of the cash system in large department stores which are operated by compressed air or belts.

By the use of composite circuits much time can be saved, as the calls may be ordered up by telegraph, leaving the lines ready for actual conversations.

DISCUSSION.

Mr. J. S. STONE: I should gather from what has been said about the automatic trunking, that you would advocate a combination of the manual and automatic, the automatic being used for the trunking and the manual for the other work. Is that the suggestion that you implied?

Mr. DOMMERQUE: To some extent. I do not advocate the use of the automatic trunking system to do away entirely with the manual.

Mr. JOHN HESKETH: I take it that between the one-office system, to which the leaning in the first portion of the paper seemed to be, and the multiple, to which the latter portion might be taken to incline, there is a mean which is to be determined by the local conditions in each case. There is one question I want to ask as to the use of call buttons on divided exchanges, where the subscriber selects the part of the board to which he makes his call. We all know that when we leave any portion of the operating to the subscriber, errors creep in. These errors, when they are once made, it is very difficult to get the subscriber to correct. The correction has to be made at the exchange. I should like to know what percentage of the calls are wrong calls, and when wrong calls are made, what steps are taken in the exchange to correct the mistake?

Mr. **Dommerque**: In the four-division work, the mistakes are great. I should say the percentage of transfers to all switchboard troubles is forty. The mistakes are corrected in this way: As soon as a wrong call comes in, or a call on the wrong board, the operator transfers it to the transfer table, and the transfer table puts it to the right operator. Very frequently it is the case that a subscriber pushes the right button, but, not getting a response as quick as he thinks he should, he pushes the second or third or fourth button, thus calling two or three operators at the same time. This is a serious trouble we have to contend with.

Mr. **Hesketh**: I was only anxious, if possible, to bring out some information as to the fallibility of the subscriber as against the fallibility of the operator. I myself do not believe that the average telephone user is capable of doing anything more than take off the receiver and talk — in fact, he very seldom does even that correctly. As soon as you give him anything else to do, you have a complicated system. I wanted to know whether the experience so far obtained in St. Louis furnishes any reliable data as to the fallibility of the operator on the system now in use.

Mr. **Dommerque**: I believe there has been a distribution of the percentage of mistakes that are made, but I am not able to give the data. It is true that a subscriber will push two or three or even four buttons, thinking that if he does not get a prompt response from the first button, he may from the second or third; while on the single line, if he does not get the quick response he wants, he hasn't anything else to do but wait. Each subscriber has a line that leads to four divisions, therefore, if he does not get A when he touches the A button, he pushes the B button and gets the B operator.

Mr. P. H. **Patton**: In the ordinary common-battery system, we expect our subscribers to call by number, and they occasionally will insist on calling by name. We handle these calls through a chief operator or monitor, which is such a slow manner, that the subscriber naturally prefers to call by number and get the quick service. I thought possibly some such slow-down of the trunks might have been tried on the divided system and not produce any results.

Mr. **Bancroft Gherardi**: May I ask whether the calls by name are handled by a slow method of operation to discourage the subscribers from making calls in that form, or whether that is the only practicable way to handle them and that incidentally, from the nature of the call, it must be slow?

Mr. **Patton**: I think both elements enter into the proposition, but the result is naturally the same.

Mr. H. **Linton Reber**: I will state, briefly, in answer to the question by Mr. Hesketh, that the number of originating calls transferred from division to division of the switchboard, amounts to about one-half of 1 per cent of the total incoming calls. This one-half of 1 per cent is classified as follows:

About 88 per cent of the transfers are due to subscribers calling the wrong division of the board, either through carelessness or ignorance of the proper method of operation. About 2 per cent of the transfers results in trouble due to depolarization of the drops, and the remaining transfer trouble, namely 10 per cent, is due to drop armature failures; improper adjustment of the armatures; bending and sticking of shutters, etc. In other words, about 88 per cent of the transfers are due to subscribers' operation of the equipment, and the 12 per cent due to equipment faults.

The transferred calls are handled as follows:

Every operator's position in each of the divisions is provided with signaling and talking circuits with the corresponding sections of the other three divisions. In each position there are three brass buttons set in the face of the board, immediately above the drops which correspond to the drops with associated jacks in each of the corresponding positions of the three divisions.

When "A" operator receives a signal which is intended for a different division, the proper division is secured by tapping the brass plug mentioned, signaling the proper operator, who in turn answers the signal as if it was an originating call. The "A," or originating operator, notifies the second operator the nature of the call by saying, "transfer second letter 1459," the second, or "B" operator, then handles the connection as if the subscriber originally signalled the proper division, and the connection is quickly made and little delay resulting. It then devolves upon the operator receiving the transferred call to at once make proper report, when inspection and examination is made and trouble corrected.

Careful records are kept and the trouble diagnosed so that we have definite information as to the number of transfers and their causes.

CHAIRMAN JONES: The next paper on our programme is by Mr. J. C. Barclay, assistant general manager and electrical engineer of the Western Union Telegraph Company, who is unavoidably absent.

MODERN HIGH SPEED PRINTING TELEGRAPH SYSTEMS

BY J. C. BARCLAY.

Machine telegraphy is undoubtedly destined to play, if not a dominant, at least a highly conspicuous part in the telegraphy of the future. For the present, and probably for a long time to come, the Morse system will continue to be the standard system employed in this country. It is doubtful indeed, if the Morse apparatus — representing as it does the very acme of simplicity — will ever be wholly superseded, but new and improved, as well as more economical methods of working, will, slowly perhaps, but nevertheless surely, limit its field of operations.

The advances made in recent years in the direction of developing and perfecting a printing telegraph system, adapted to meet all the requirements of a modern telegraph service, have been of such a practical and progressive character as to leave no room for doubt that the successful advent of such systems into the domain of commercial telegraphy will soon be, if it is not indeed already, an accomplished fact.

Ever since the birth of telegraphy, the subject of printing telegraph systems has more or less engaged the serious attention of electrical inventors, and as a result of their efforts quite a number of such systems have been devised and put into operation; but until quite recently their usefulness has, with few exceptions, been restricted to stock and market reporting or other enterprises of a more or less private and local character.

For the general telegraphic work of the country these systems are entirely too slow; they can only be successfully operated over limited distances, and their records are, as a rule, made upon a strip of paper which is regarded with anything but favor by the telegraphing public of today.

In the elements of weakness above mentioned lie the stumbling blocks to success, but of this the majority of printing-telegraph inventors appear to be entirely unconscious, judging from the way their energies are misdirected in continued efforts to develop and perfect a type of machine for which there is absolutely no demand in the great commercial departments of the telegraphic industry.

Many of the more recent inventions are based upon the principles embodied in the ordinary commercial typewriter, whose peculiar adaptability to the requirements of a telegraph printer was soon recognized, and whose advent into the art may be said to have marked the beginning of the new era of modern high-speed type-printing telegraph systems.

It may be said of the majority of printing-telegraph contrivances based on the typewriter principle that they are "fearfully and wonderfully made," but a few comparatively simple ones are to be found that can be operated at speeds higher than those attainable by any of the ticker systems, while at the same time making their records in page form instead of upon the objectionable paper tape. The maximum speed at which they can be worked, and the distances over which they can be satisfactorily operated, are, however, so far below the requirements of the present telegraph service, that until they have become more highly developed along the lines indicated, their sphere of usefulness will be limited to enterprises outside the field of commercial telegraphy.

One principal source of weakness in connection with these moderately-fast short-distance machines consists in the character of the signaling currents employed, which, as a rule, lack the necessary quality for overcoming the retarding and attenuating effects of the main line. Very short signaling impulses that differ greatly in strength with occasional changes in direction — as employed by some inventors — is not a current arrangement adapted to long-distance transmission. Nor is a combination of electrical impulses of one polarity and of uniform strength much better calculated to increase the signaling distance over lines of considerable inductive capacity, the tendency of which is to retard and absorb such impulses.

A much better plan to secure effective signaling is to incorporate into the system a method of reversing or alternating the line currents, and until inventors more fully realize the importance of some such arrangement, their chances for success in the direction of long-distance working will be highly problematical.

The superiority of the alternating-current method for printing telegraph purposes has already been pretty well demonstrated, and this fact opens up the interesting question as to what particular extent such currents might be utilized with advantage in the working of ordinary telegraph circuits. It is well understood that the successful operation of these circuits is seriously handicapped by certain line-disturbing elements that are more likely to increase than to diminish in magnitude and intensity as the years roll by.

The leakage interference from the ubiquitous trolley lines constitutes, for instance, one of the growing evils that beset the telegraph engineer, while more or less trouble is to be apprehended from the development and extension of high-pressure transmission lines with their immense capacity for creating inductive or other disquieting influences. It is possible to exclude the former, and to modify the effects of the latter's interference by the use of condensers directly inserted in the main line, which arrangement would also wholly or partly rid the circuit of all ground currents and leakage currents from neighboring wires, as well as minimize the deleterious results arising from defective insulation, variations of resistance, capacity, etc. Such an arrangement, however, would be utterly impracticable with the ordinary battery currents, but as the alternating signaling impulses can be easily transmitted through condensers, a combination of the character mentioned would seem to lend itself in a manner quite feasible to the practical exclusion of most of the disturbing influences to which all telegraph lines are more or less subjected.

Whether or not this principle will ever find a general application in ordinary telegraph working, it is certain that the subject is receiving considerable attention at the hands of telegraph inventors, several of whom have already succeeded in making practical applications of such a character as to suggest possibilities of the utmost importance in this new and promising field of telegraphic development.

Harking back to the subject of printing telegraphs, it may be remarked that no matter what kind of transmitting current may be employed in connection therewith, a satisfactory system at the present time calls for page printing, at a high rate of speed, over considerable distances, and some few of the latest inventions pertaining to this particular art take note of these essential requirements.

The most highly developed specimens and best known examples of this modern class of machine are those invented by Murray, Rowland and Buckingham.

In the Murray system the messages are both transmitted and recorded mechanically through the medium of a typewriter. A perforated paper tape is first prepared by means of a keyboard mechanism, and is then run through a Wheatstone transmitter which automatically, and at a high rate of speed, sends out the signaling currents to the distant receiving station. These currents are utilized, not to actuate the printing mechanism direct as is the case with all other printing telegraph systems, but to reproduce another perforated tape, the particular function of which is to mechanically control the working of a typewriter in a manner analogous to that by which a mechanical piano may be operated by a perforated band of paper. This is a highly novel and ingenious application, since the actual printing is accomplished locally, and wthout regard to the signaling currents coming over the line; but the use of the perforated tape at both the transmitting and receiving stations introduces an element of delay that is more or less objectionable despite the rapidity with which the signaling currents may be flashed over the main wire.

In Rowland's printing arrangement there is no such objectionable feature, the transmitting apparatus having been designed to work directly into the line, and to operate the receiving mechanism in a manner equally direct. Direct transmission and reception is, in fact, one of the most desirable features in connection with the operation of any telegraph system, but when this is accompanied by a very large increase in the carrying capacity of the wire over which such system is worked, the latter may not unjustly be regarded as one coming well within the range of being an ideal method of working. Such, at least, are the views expressed by the advocates of Professor Rowland's Octuplex System, and these views might be readily accepted if to the other admirable features of this "Telegraphic Wonder of the Age" the great merit of simplicity could only be added.

The system is operated on the multiplex principle, and requires that between certain corresponding parts of the rotating mechanism at each end of the line perfect synchronism be maintained. Success in this direction heretofore has only been practically accomplished over very short distances with transmissions as numerous as those involved in the Rowland printing arrangement. It is claimed, however, that the difficulties previously encountered in the way of maintaining unison over considerable stretches of line have now been fully overcome by the use primarily of an alternating current continually flowing to line, which current not only provides for the necessary synchronizing impulses, but for the signaling impulses as well. The sending of the signals, it may be remarked, is actually accomplished not by supplying the line with current at the moment the signal is being transmitted, as in the ordinary telegraphic methods, but by cutting out certain of the alternating-current waves, the arrangement being such that one or more of these signals can be made to consist of a combination of suppressed half-waves, the signals so produced being then automatically translated into printed characters. In this way, and by grouping the waves in a manner admitting of entirely different and independent signals being sent from four Remington keyboards, each of the four transmitting operators employed can cut out four different wave combinations, and send as many different signals over the line in a single second. Forty words per minute is said to be an ordinary rate of speed for a practiced operator using this system, or, since the system can be duplexed, eight times that number, making 320 words in all, may be sent and printed over a telegraph wire in the course of a minute. This, if practicable under the regular conditions of working, would make the Rowland system the fastest of all printing systems, or, what amounts to the same thing, it would be capable of more fully utilizing the electrical conductivity, or transmitting properties of a wire than any other system of similar character.

That the Rowland machine has been very highly developed on the most modern and approved scientific principles is undoubtedly true, but it remains to be more fully demonstrated that an extremely complex system, necessitating the maintenance of the most perfect synchronism, and employing as many impulses as those required for the formation of each of the letters or characters, is one practically adapted to the working of other than circuits of moderate length.

To Mr. C. L. Buckingham belongs the credit of having invented the first really rapid, long-distance, page-printing mechanism that was ever successfully employed for the transaction of ordinary telegraph business. Many years had been spent by the inventor in an endeavor to devise and perfect a printing telegraph machine that could be operated over practically unlimited distances, but it was not until the happy idea was conceived of utilizing the Wheatstone automatic system as a basis that success appeared in sight. Through the medium of the Wheatstone terminal and repeating apparatus, it at once became possible to transmit and receive the necessary signaling pulses over the longest telegraph lines, the pulses in this case differing from those of the Wheatstone or Morse in being quite definite in the number requisite to form the various characters, for each of which six electrical impulses alternating in direction are essential.

The distinguishing features of the invention consist of the perforating apparatus for preparing the slip for transmission, and the printer, which is placed in a local circuit arrangement at the receiving end of the line.

The operation of punching differs from that employed in the Wheatstone in that it involves the use of a typewriting machine, by means of which any one may manufacture the slip without the slightest knowledge on the part of the manipulator as to the particular code employed, and at a rate of speed considerably greater than that possible by the use of the Wheatstone perforator.

The slip thus prepared is then run through the Wheatstone transmitter, which automatically forwards the signals to the distant terminal station where they are received upon a Wheatstone relay and thence repeated into the local-circuit arrangement. In this circuit is a variety of relays and electromagnets, which call into action a number of novel and ingenious contrivances of both a mechanical and electrical character. Under the control of the electrical impulses received over the line these devices perform their various functions with a regularity, precision and harmonious working of parts that is simply amazing.

One of these devices is a modified form of "sunflower" or current-distributing apparatus of very peculiar construction. It was especially designed to secure a rapid transmission or switching of certain line pulses through one or other of a series of relays connected to the sunflower. Five of these relays known as "selectors" are employed for the purpose of actuating a corresponding number of electromagnetic "adjusters," which control the movements of the type-wheel. Short pulses do not affect the selecting relays, but when the pulses are sufficiently prolonged, the motion of the sunflower or distributor — which is normally one of rotation — becomes temporarily checked or arrested by means of an electromagnetic escapement, thereby permitting any such pulse to actuate the particular relay whose circuit is at that moment completed through contact arms on the sunflower.

At least one of the series of the six line pulses required to form a character must be prolonged, and the particular relay or number of relays that shall be affected within the time required to transmit the entire series of pulses is determined by the regular order in which such pulses are transmitted to line. If, for instance, the first pulse be a prolonged one, the first in the series of relays with its corresponding "adjuster" will respond, and no other. Similarly, if the second pulse be lengthened, the second only in the group of relays will respond thereto, and so on. One or all of the selector relays may be involved in the operation of bringing any letter or character into the required position for printing, the impression itself being invariably accomplished through the medium of the sixth pulse. This pulse, the last in the series, is always a prolonged one of a certain definite polarity, and is not only utilized for the purpose stated, but also to start the feed mechanism, as well as to operate a dogging device which holds the type-wheel firmly in position while the impression is being made. It contrives, furthermore, to actuate the synchronizer, and thereafter to reset or restore to their normal positions such of the selecting and adjusting instruments as were brought into activity by the one series of line pulses, and to thus put them in a condition of readiness for the next cycle of operations.

The type-wheel is suitably mounted upon a shaft of such construction as to permit the wheel to move axially, or circumferentially, or in both directions simultaneously. Instead of a comparatively large wheel having the entire number of characters on its periphery and rotating all the way round, the inventor employs a small wheel bearing four rings or rows of type which only rotate through a half revolution in either direction. The regulation of the type-wheel is effected through the action of the adjuster magnets whose armature levers are connected with certain impelling or driving devices, some of which impart a rotary, and others a longitudinal motion, or a combination of both movements to the type-wheel. The axial, or longitudinal movements of the wheel bring any desired ring or row of type into line with the press pad, while the rotary movements shift the different type of a row or ring into the proper position for printing.

It is by such movements, either singly or in combination, that any type of the several rings may be brought to position on the completion of the requisite number of pulses.

The blanks upon which the messages are printed are the regular message forms whose edges have been pasted together so as to give the blanks a tubular shape or appearance. When the printing of a message is about to begin a tube is placed in position beneath the type-wheel by sliding it edgewise upon a brass tube which serves as a support, and in which there is an opening to admit of the necessary operations and impressions taking place. The blank when printed is quickly slipped to one side and a fresh one takes its place, after which the first blank is removed from the support by opening it on the line where its edges are joined, and so on. These latter operations are performed by hand, and they constitute about the only ones so far as the printer is concerned that are not entirely automatic in character.

The Buckingham system may well be regarded as the most unique and original one in existence, and it will deservedly take high rank among the list of marvelous and useful telegraph inventions of the times. It has been in practical operation over the Western Union lines between New York and Chicago, and New York and Buffalo, for the past six years, and has a maximum working capacity of about 200 messages per hour operated as a duplex. It does not, as will be noticed, utilize the transmitting properties of a wire to the same extent as that theoretically possible with the Rowland multiplex system, but it is successfully operative over distances that would not at all be practicable with any synchronous multiplex system as yet invented.

The Buckingham system possesses the disadvantage of requiring a perforated strip for transmitting purposes, but, as in the case of the Rowland, the received record is a direct one instead of having to be translated as in the Murray system. If the perforated tape could be entirely abolished, and a rate of speed obtained by direct manual transmission approximately equal to that obtained in actual practice by automatic working, a grave objection to the Buckingham system would be overcome, and the author is strongly of opinion that such a change is not only desirable, but entirely feasible, and is, in point of fact, well under way.

One other defect of the Buckingham system consists in the fact that the number of characters that can be printed by means of his type-wheel is limited to 32, admitting only of the letters of the alphabet and certain punctuation marks being recorded. To print all of the characters desirable for commercial telegraph purposes would involve some radical changes in the apparatus and greatly increase the already complicated character of the system. By substituting for the present recording arrangement a modified form of electrical typewriter of great sensibility and rapidity in action, a comparatively simple printing mechanism can be devised that will more fully meet the service requirements along the lines indicated, and at the same time increase the legibility, and improve the general appearance of the printed message. This is what the author has set out to accomplish, and his experiments so far demonstrate that a speed of at least 100 words per minute can be readily secured thereby. The particular changes necessary to bring this about involve the use of as many small printing magnets as are requisite for the desired number of mechanical operations. As this particular arrangement is the subject of patent proceedings, nothing can be said further than to intimate that the printing magnets are actuated by local currents properly directed through the medium of certain electromagnetic selecting devices, whose particular function is to distribute the different signaling impulses among the various printing and auxiliary magnets in a manner appropriate to the requirements in the case.

In looking over its past history, one cannot but be struck with the fact, and take pardonable pride in the knowledge, that the printing telegraph art constitutes an industry, the origin, growth and development of which may be credited almost exclusively to American inventors, whose persistent efforts in the face of many difficulties and discouragements have at last brought about an extension of its sphere of usefulness into the commercial branch of practical telegraphy. It may be reasonably assumed as a consequence thereof, that the technical and industrial development of this particular art will be much more rapid in the future than it has been in the past; but much remains to be done in the way of simplifying and more nearly perfecting the working apparatus in order to thoroughly complete the task of those early experimenters who, some 50 years ago, first undertook to solve the problem of devising a practical, useful, as well as economical printing telegraph system.

CHAIRMAN JONES: In the absence of the author, the paper by Mr. Kempster B. Miller, entitled "Automatic vs. Manual Telephone Exchange," will be read by title.

THE AUTOMATIC v. THE MANUAL TELEPHONE EXCHANGE.

BY KEMPSTER B. MILLER.

There are two general methods of giving telephone service to a community:

1). By what is commonly called the "Manual" system, because of the fact that the switchboards employed at the central office require manual operation.

2). By the so-called "Automatic" system, wherein the central office operator is dispensed with, switches being so arranged that they will, without the aid of human hands, perform the necessary act of connecting lines for conversation, and afterward disconnecting them at the will of the subscribers.

In the manual system in its highest development, the telephone user has only to place his receiver to his ear and make his wants known, the desired connection being made at the central office by operators. This system may be assumed to be highly developed, as it has been almost universally used since the advent of telephony, a period of nearly 30 years. The manual system, in its present form, represents the consecutive work of a large number of men in a field of the most intense and constantly increasing activity, all these men striving for the best possible means of accomplishing a desired result.

In the automatic system, the central office switches are governed in their movements by the actions of the subscribers or users who desire connections and subsequent disconnections. The subscriber does his own work, manipulating the apparatus before him in such way as to cause the switches at the central office to select, connect with, and afterward disconnect from, the line of the subscriber desired.

Unlike the manual system, the automatic cannot be assumed at the present time to have reached a relatively high development. While the automatic switchboard has been in the minds of inventors since the year 1879, it is not true that it has been put into considerable use until very recently. Instead, therefore, of its development being paramount in the minds of a large number of practical telephone workers, it has been fostered till lately by but few men, some of whom were unfamiliar broadly with the details of the telephone business. With a courage that must excite the admiration of all, a very few of these men have persisted, and as a result, the telephone engineer, the operator of telephone companies, and last but most important, the general public, are confronted with what I think is the greatest problem that has been recently before the telephone world: The problem of the automatic v. the manual switchboard.

It is not the purpose of this paper to attempt to solve this problem. The unequal degree of development of the two systems makes impossible a final satisfactory solution at the present time. It is rather to state some of its phases as they appear to me; and to make comment on them wherever my study of the situation has led to more or less positive convictions, that this paper is offered.

A fundamental question affecting the entire problem is this: Is it possible to make a machine serve to effect the electrical connection of any line, in a large or small group, with any other line in the group, for the purpose of telephonic communication, and afterward to affect a disconnection when required? There can be, even at the present early stage of development, but one answer to this question. That it is. The automatic switchboard at Grand Rapids, Mich., recently selected for me 100 different lines chosen at random from among approximately 5000 lines centering in that office. Some of the subscribers called did not respond, which will occur in any system; and some of the lines were automatically reported busy, which is to be expected; but in no single case was the wrong line chosen, and in but one case was the disconnection improperly effected. The verdict of a large number of the subscribers interviewed by me in that city is practically unanimous to the effect that they uniformly secure their connections and disconnections promptly, accurately and satisfactorily.

I conclude, then, in view of present achievement, and of that future progress which this must stimulate men to make, that it is possible for the automatic switch to perform these functions satisfactorily.

If, then, the automatic switchboard may be made to accomplish the commonplace connection and disconnection of lines, which forms the great bulk of the work in a telephone exchange, is not the system so inflexible in its method of operation as to preclude the possibility of its performing the great multitude of special duties which, while not constituting the main bulk of the work, are nevertheless of constant occurrence and of hardly less importance? I refer to such matters as toll connections, private branch exchange work, and to a number of subordinate but necessary classes of service.

A prominent telephone engineer has recently remarked to the effect that if some of the people enthusiastic on the subject of automatic switching in telephone exchanges were to visit the school for telephone operators maintained by the New York Telephone Company, they would be discouraged in their efforts, as no machine could ever be made to perform the many and varied functions that it was necessary to teach these young ladies before they became proficient telephone operators. This seems to be a statement that has very little to do with the real automatic problem. It should never be required that the machine shall do the same work that is demanded of the girl, nor do it in the same way. That is manifestly impossible, for no machine can ever be endowed with intelligence. (It may be that some will say that there are some telephone girls similarly affected.) Since the very reason for the existence of the automatic exchange is to do away largely with the operator, it follows logically that whatever intelligence is to be applied to the making of the ordinary connection between two lines shall be that with which the subscriber desiring to make the connection is endowed. Here is a fundamental difference between the two systems which must always lead to different modes of operation.

The real functions that the automatic switchboard should be required to do automatically are those relating to the ordinary routine work of connecting and disconnecting subscribers' lines under the control of the calling subscriber. When some act needing intelligence at the central office is required, then let an operator supplement the work of the machine. To condemn the automatic switch because it will not perform all of the special requirements without the aid of human intelligence is just as unfair as to condemn a linotype machine because it cannot digest one of Steinmetz' equations. My mind has gradually changed upon this point until the doubt now exists as to whether the automatic system, wisely supplemented by operators, is not even more flexible than the manual. It is the ease with which the personality of the operator may be introduced into the automatic system, and also the ease with which certain of the purely automatic functions may be varied by mere changes in the circuit, or in the mechanical relation of the parts, that make this doubt exist.

Of course, there are many problems concerning traffic and service that are yet to be worked out for the automatic system, but apparently the longer one studies the automatic problem the more nearly he becomes convinced that the automatic system is sufficiently flexible, with the interjection of human intelligence when necessary, to make possible the solution of practically all of the problems of service.

So far as I am aware, selective signal party line working has never been accomplished commercially with automatic systems. I believe that the reason for this is solely the fact that automatic telephony is yet new. I have recently seen a plan whereby any ordinary number of stations can be selectively operated on a party line with practically no other added complication either at the central office or at the subscribers' stations, than that which is added to the apparatus of an individual line manual system, to adapt it to the same class of party line work. I can say, therefore, that while the automatic party line is not yet developed to the extent of being actually introduced into commercial use, it is entirely feasible and will not be one of the controlling factors in the solution of the problem: automatic v. manual.

I have looked into the subject enough to believe that the same thing that is true of the party line problem is true of the common battery problem, and also of the measured service problem, whether the measuring of the service is accomplished by collecting coins or tokens at the subscribers' stations, or by operating counting devices either at the sub-stations or at the central office. There is undoubtedly a vast amount of work yet necessary before these features are commercially incorporated in working apparatus in a satisfactory manner. I merely say that my study has shown me that no insurmountable obstacles exist that would prevent the successful establishment of party line, common battery and measured service working.

These statements do not greatly help the man who is today casting about in making a choice between the automatic or the manual system for present use. It is not, however, with the present alone that we are concerned. We must plan and build for the future; and the remarks just made are given merely as little bits of contributory evidence as to what developments may be expected in the future.

Having seen that the thing is possible, that it seems from a technical standpoint to be able to do what is wanted, another question is: Do the subscribers like it?

The evidence all seems to point in one direction. They do. At Grand Rapids, Mich., 95 per cent of a large number of subscribers interviewed by me liked it better than common battery manual service; 4 per cent did not care much one way or the other, and 1 per cent liked the manual system better. At Fall River, Mass., where the system has been in use for a much longer period, the verdict was quite the same in effect. Evidence from other cities where automatic service is being tried seems to agree. It must be said in fairness, however, that at Grand Rapids, the mass of subscribers is leavened by the presence of a large number of stockholders in the local company. Again, there is in that city much civic pride in the system. Telephone people come from all parts of the country to inspect the plant. Still again, the delight of the subscribers may be similar to that of a child with a new toy, but this can hardly be true, because of the fact that the exchange at Grand Rapids has been in service for a period of nearly nine months, and is carrying a very large business load, so that if the people were not actually getting satisfaction, they would probably know it. The new toy idea is also apparently disproven by the condition at Fall River and New Bedford, where the service has been maintained for several years, and seems to be much liked.

The question also naturally arises: Is not the automatic switchboard and necessary subscribers' mechanism too complex to be maintained in proper working order without undue cost? It is perhaps too early to decide this question. There is not enough evidence one way or the other. Judging from the past, however, the tendency of industrial achievement seems to be to do things automatically. As examples, take the arts of printing, of weaving, and the use of machine tools.

Summing up, therefore, the statements already made, the automatic system is not only a possibility, but is actually here. With the interjection of human intelligence to supplement it in performing certain functions, it seems to be as flexible as the manual. Party line, common battery, and measured service working, while not yet achieved commercially, so far as I am aware, seem to be well within the grasp of those who are doing the development work. The public seems to like it, and we do not know whether it is too complex or not.

It will be noted from the foregoing that the idea of having the central office apparatus perform *all* the phases of telephone service is certainly not tenable. Many of those who have advocated it in the past have abandoned it, and are introducing human aid in the performance of some of the functions. This being true, a certain number of operators will be, and are, needed in automatic exchanges. This tends to destroy in some degree the primary object of the automatic system — the doing away with operators. We have seen many papers bearing on each side of this question, to the effect that the salaries of the operators were or were not to be eliminated; that retiring-rooms, matrons, operators' luncheons, etc., were or were not to be done away with. These items of expense will probably exist to some degree in all large automatic exchanges. That they will be greatly reduced is without question, but whether or not they are reduced to such an extent as to offset other sources of expense introduced by the employment of automatic apparatus is a problem yet to be solved.

What are some of these sources of expense that tend to offset the reduction in operators' salaries and expenses coincident therewith? Taking the system as a whole, we find that the present automatic system is considerably higher in first cost than the manual system, and assuming that interest and depreciation are at the same rate in each case, this shows to considerable disadvantage for the automatic system in the annual charges due to these items alone.

For an exchange of 5000 lines served by one office, the cost of automatic equipment including telephones may be taken at $35.00 for each individual line. In manually operated exchanges the corresponding cost is not far from $25.00 per line. The difference becomes greater, that is, more in favor of manual, for smaller offices, and smaller or less favorable to the manual in larger offices.

Whether or not the depreciation on automatic apparatus should be taken at a higher rate than that on the manual is a question that we have not at present sufficient data or information to determine. It is true that in the automatic switchboard the flexible cord nuisance found in all present forms of manual switchboard apparatus is largely eliminated. It is also true that the automatic apparatus is more complicated, and requires greater care in its maintenance; but whether, if both systems are maintained with reasonable care, the automatic will show a much greater rate of depreciation than the manual, I am not at all certain. Much of the depreciation in manual telephone apparatus is due, not to the fact that the apparatus wears out, but rather to the fact that the apparatus is rendered obsolete by new inventions. That the same will be true in the case of automatic apparatus cannot be doubted, but it is a good point to bear in mind that if telephonic development should point toward automatic apparatus to the exclusion of manual, and should prove the superiority of automatic, then the highest developed and newest manual apparatus will depreciate greatly in value by that fact alone. It does not seem unreasonable, therefore, to place the rate of depreciation on both manual and automatic apparatus at about the same figure.

In point of maintenance the advantage must be conceded to the manual. This is certainly true at present with regard to both the central office and the subscriber's station apparatus. No good reason is apparent why it should not always be true. Automatic apparatus is especially at a disadvantage at the subscribers' stations and it is really at this point that the automatic system seems to involve a poor engineering feature. The tendency of telephone development in regard to sub-station apparatus has been until lately along what seemed to be unquestionably good engineering lines. The sub-station apparatus has been gradually simplified, the battery has been removed, as has also the magneto generator, and the instrument has been reduced to the simplest fundamental parts.

Automatic telephony as at present developed for large work takes a step backward by reintroducing the local battery. That this is disadvantageous no one can deny, but on the other hand it must be pointed out that the disadvantage is by no means as great as it would have been several years ago because of the fact that dry batteries have recently come into almost universal use for this kind of work and are far superior, all things considered, to anything heretofore available.

The disadvantage of local batteries, while mitigated, is still present, and is real; but, taking the automatic system as we have reason to believe it will exist in the future with no local batteries, it will still possess, as far as we are able to see, a more or less complicated impulse transmitting device, by means of which the subscriber will be able to direct the movements of the switches at the central office. Complexity not only of mechanism, but of function, is thus introduced at the subscriber's instrument, and this seems to be an inherent disadvantage to all present schemes of automatic exchange working. This, of course, is another factor that must be weighed in considering the relative economies of the two proposed methods.

There is a point that I have not yet seen mentioned in print, which under certain cases seems to be of great importance. This is the matter of trunking between two or more automatic offices in such cities or communities as naturally demand, by the distribution of their subscribers, more than one office. It is true that the present automatic switchboard seems to be capable of properly handling this condition if the requisite number of trunk lines between the two offices are provided. At first thought it seems that the number of trunks required between offices for a given amount of traffic might be somewhat less in the case of the automatic than in the case of the manual system, on account of the immediate disconnection and release of the trunks, in the automatic, upon the hanging up of the receiver of the calling subscriber. Further consideration, however, will show that there is very little difference in the time the trunk is held busy in the two systems, the length of actual conversation being assumed to be the same in each case. The reason for this is that, while the automatic gains in this respect in the release, it loses something in the making of the connection, because in the case of the automatic the trunk is selected with the first movement of the dial by the subscriber, and the length of time that the trunk is held busy, therefore, must in the case of the automatic include the time during which the subscriber is setting up his own connection; whereas, in manual boards a trunk line begins to be busy at the time when the *B* operator picks up the incoming trunk plug and designates its number to the *A* operator.

So far there seems to be little difference between the systems in this respect.

The bearing on the trunking problems of the relative efficiencies of different sized groups of trunks between offices does not, however, seem to have been weighed by many in considering the question of automatic v. manual exchanges. When sufficient trunks are provided between offices to handle business on the so-called "no delay" basis, it is known that a large group of trunks will handle very much more business per trunk line than a small group. For instance, when there are only 10 trunks in a group between offices, it is a well-established fact that slightly less than 80 calls per trunk per day may be handled. If, however, the group is increased to 100 trunks, as many as 145 calls per trunk per day may be handled. This is an increase of considerably over 80 per cent in actual trunk efficiency. In the present automatic system, group the trunks as you may, it is inherently true that the efficiency of the trunks is reduced to that of a group of 10. I do not mean by this that it is not possible to place as many trunks as desired between any two offices, but that any subscriber has access to 10 trunks only in order to secure a connection to any other office. It is true that some other subscriber may have access to another 10, or to the same 10, but no one subscriber can reach more than 10. This seems to be a grave objection to the use of automatic systems as at present developed, in those communities where several offices must be employed and where traffic is such as to demand a large number of trunks between offices. The remedy to this is obviously that of giving the subscriber the chance to select his trunks from larger groups. This, I take it, is one of the problems that need serious consideration in adapting the automatic system to very large communities. It does not enter seriously in single office work.

In all that I have said I have attempted to take the very practical view of the engineer, and fundamentally that view must always compare systems with the intent of selecting a means of doing what is required well enough for the smallest price. From the strictly engineering view one does not take into account relative popularities of mere ways of accomplishing results. But this is necessary in such a case as this, for there are features of the automatic system which may make it so popular as to force upon the owners or prospective owners of telephone industries a serious consideration of the doctrine of expediency. This is by no means the least of the important things to consider.

I expect to be criticized because I have not solved the problem. It cannot now be solved any more than the question of alternating v. direct-current transmission could be decided when we first were brought to realize that there was an alternating v. direct-current transmission problem. My object has been to state the problem as I see it, and I hope that in doing this, something may have been accomplished toward clarifying it.

Upon motion, the Section adjourned until nine o'clock Thursday morning, September 15, 1904.

DISCUSSION.

(The following discussion on the paper by Mr. Kempster B. Miller took place during the session of Friday:

CHAIRMAN JONES: At the Tuesday meeting we received a paper from Mr. Kempster B. Miller. He was not present at the time and the paper was laid over for discussion. Mr. Miller is now present, and I will call upon him to open the discussion upon his paper.

MR. MILLER: At a meeting of about eight prominent telephone men in Chicago, I asked them what they considered the most live question before the telephone engineer to-day. The verdict was unanimously "Automatic versus Manual," and those gentlemen are really responsible for the paper which I presented. In preparing the paper, I realized fully that the time for the ultimate solution of this problem has not yet arrived. Therefore, I made the paper in the form of personal notes as to my impressions of the situation as it exists to-day. Mr. Hesketh pointed out yesterday that he thought I had been a little unfair to the manual by comparing the manual system as it exists to-day with the automatic system as it may possibly exist in the future. I think it is better in such cases as this to be unfair to the side in which we have all been brought up, but I don't think it is quite as unfair as he thought at first, because we people who have been in the manual business so long have succeeded in developing a system, the common-battery multiple system, which for the past few years has shown no radical changes. I think it is fair to assume that we have done our best, have reached somewhere near the limit along the line on which we started. Now a different group of people come into the field, and they have not had time yet to reach their limit. Moreover, certain of the improvements which I suggested as being probable in the future are, perhaps, nearer realization than some of us present realize.

MR. F. J. DOMMERQUE: I am connected with the manufacture of manual boards, and it may look at the outset that I am prejudiced against automatic boards. I am probably more interested in finding out whether it would be best for the manual manufacturers to go into the manufacture of automatic boards. In the last four years, I have observed everything going on in the field of automatic telephony. I have visited the principal exchanges that have been built with the automatic system, and had also the good fortune to visit repeatedly in an experimental exchange in Berlin, which was put in by the German engineers for the sole purpose of finding out whether automatic systems were advisable. I have found that the principal difficulties exist in the subscriber's station. The apparatus put into the hands of a subscriber is too complicated at the present time to give a satisfactory service for any length of time, and I anticipate there the first dissatisfaction. All the subscribers, at the present time, in all the exchanges like the automatic system. I have inquired of 500 automatic subscribers and unanimously they say there can be no better service than the automatic service. I asked why, and the principal reason given to me was that the "automatic telephone does not talk back." I believe that there is a difficulty on the operating end of the manual board wherein the automatic board excels at the present time. If the operating end could be made so that the connection might be had without the operator talking back to the subscriber, then I do not see why any difference should come in, so far as the subscribers are concerned. In the automatic system, he has to perform certain acts, and in the present form it is new to the subscriber and he takes an interest in it and likes it; but I believe in large cities, where the business man is very busy, he will not be satisfied for any length of time with the manipulation of a dial. Maintenance will be one of the great disadvantages in all automatic systems of exchanges on account of the complicated apparatus. It has been said that I am mistaken on that ground, because in any automatic exchange everything moves automatically and moves regularly, while in a manual exchange the operator is the destructive feature, working all kinds of manipulation that are harmful. However this may be, the abandonment of automatic switchboards in a great number of exchanges seems to show that there is something dissatisfying in that respect. I believe in large exchanges, like Chicago and New York, it would be practically impossible to equal the brain work that is necessary to give perfect service. For instance, take New York, outside of the local service or the long distance service, and there is what is called short-haul service between Manhattan and other neighborhood places. I went to New York to see what ideas I could get from the operation of those exchanges. I examined a great many sub-stations and made calls to Jersey City, and also from Manhattan to Brooklyn, and return calls from the private exchange there to Manhattan Island, and I was surprised at the very short time in which I got connections. In all the connections there was not one which exceeded thirty-one seconds.

I do not believe this is a time to enter into the use of automatic telephone systems. I do not believe the manual system has reached its limit. In fact, I believe we will see great advances in the manual systems in the coming year — perhaps see a combination of the manual and automatic to some extent.

Mr. Miller: I think we must go deeper than Mr. Dommerque has gone. I do not think there is any grave difficulty to be found in the problem of connecting the automatic with the manual exchange; because what thought I have put on the subject, and thought I know other competent men have put on it, seems to show that that can be done with a reasonable degree of efficiency. Just how it will be done, and what will be the final solution, I do not know. I do not think that here in America, regardless of the conditions existing in Europe, we can assume that, because Europe is equipped with manual apparatus, and the cost would be too great to change, that any such condition as that is going to hold a meritorious thing out of public use. In other words, I believe that if the automatic system finally proves itself to be the system, it will come, regardless of the present one now in business. I think one of the chief troubles that must be remedied is complexity at the subscriber's station. In the present automatic system, we have spread a complex apparatus, which is hard to maintain, all over a large territory, instead of having it centralized at the central office. I do not think that the central office complication, in view of improvements we are naturally expecting, is of a very serious nature; but a complex apparatus at the subscriber's station will be the serious difficulty to overcome.

Mr. **Bancroft Gherardi**: I read with great interest Mr. Miller's paper on this topic and think we are all indebted to him. Since reading Mr. Miller's paper, there have been a good many points upon which new thoughts have come to me, but I will take your time only with reference to one or two of the principal points in regard to which I have made a few notes. The first point is in regard to automatic machinery. No one has a greater honor or respect than I have for the great work of our American inventors, with reference to the development of automatic machinery; but this service which these inventors have done to the country has grown out of the fact, not that the machinery was automatic, but that it was labor-saving, and our appreciation of the work of the American inventors should not blind us to the fact that the automatic feature, *per se*, is not necessarily a desideratum, and that unless the automatic machine is in each specific case really a labor-saving machine, it has failed of its principal function. The real test of whether any machine is labor-saving or not is to compare the annual charges of the machine with the annual charges without the machine. If the annual charges of the machine method are equal to or greater than the manual method, the machine has not been a labor-saving one. It has simply been a labor-transferring machine, taking a certain amount of money from the pay-roll of an operating company, and transferring it to the pay-roll of manufacturing concerns, to the iron works and to the coal mine. Unfortunately, when we try to make this comparison, which is the only sound one from an economical standpoint, we are confronted with an absence of reliable data. In one of the most talked-of instances, the published figures, while perfectly true in themselves, are grossly misleading when comparisons are made, for the reason that the cost of the most efficient automatic machinery was compared with the cost of the most antiquated manual machine. The manual machinery has been thoroughly tried out by world-wide experience and has been found to attain a remarkable degree of efficiency and economy. I might say that the records of the maintenance department in New York city show that on an average each line is out of order once in a period of two years, and that for a time of forty-five minutes, on an average. These records include out-of-order troubles of all classes and descriptions. It includes anything which puts the line out of order and comes to the knowledge of the telephone company. This was not a result attained by any peculiar and narrow definition of the term "out of order."

The efficiencies and economies of the automatic machine have yet to be demonstrated. While we all gladly welcome every improvement of this nature, we should at the same time avoid being carried away with that natural enthusiasm which we all feel toward the results of American inventive genius. Even with the automatic board, operators and attendants are required at the central office, and even with the manual board, you will be surprised to learn to what an extraordinary extent it is automatic. The work of telephone engineers for the last fifteen years has been steadily directed toward two ends: First, to make the telephone service reliable, for without reliability no telephone service can survive; cheapness will not save it. Second, the endeavors have been to cheapen the service. Great strides have been made in each direction, so that to-day the manual board has, by the introduction of automatic features, reduced the amount of labor required to an extraordinary degree, and so far as has yet been demonstrated, the operators have been retained only at points where human intelligence has been found to be more advantageous than machinery, both from an economic and a service point of view.

Mr. **Miller**: I think I agree in substance with everything Mr. Gherardi has said. The manual people have had a chance to do their developing, whereas the automatic people have not. The automatic people have not yet reached as high a degree with the automatic plant as the manual people have with the manual. I believe that every telephone engineer has balked at the automatic. I have. It is not attractive to the engineer. It is attractive to the mechanician and it seems to be attractive to the people.

Mr. P. B. **Delany**: I want to make an observation or two as to the tendency of the people to run wild in enthusiasm in the direction of the automatic. I am interested in the automatic subject myself and although in a somewhat different line, I am a little bit jealous of any aspersion on the insecurity or instability of that line of work. I say, in the first place. I do not think people have been anxious to run wild on automatics. it is rather slow work. Furthermore, the tendency of the best engineering, as I understand it, has, from the beginning, been in the direction of making things automatic, as far as possible and consistent with good practicable work. In every branch of telephony, so far as I have been able to observe, the effort has been to substitute automatic work wherever it could serve the interests, even though the expense was not any less. The mere fact that the present automatic machinery of exchanges is recognized to be of an inferior class of workmanship is, I think, very strong testimony of its efficiency under the circumstances. Of course, it must be acknowledged that as time goes on, the efficiency, working principles, and the details of such systems will naturally be improved, whereas I think it is generally acknowledged that the physical ability of the manual system and its operators has been pretty well brought to the limit at this time. It does seem to me that with the future before the automatic development, and the finished condition, we might say, of the manual system, there is a great deal to be expected in the way of advancement of automatic systems generally.

Mr. J. T. **McNaier**: This paper simply presents the question. The question of automatic exchanges has been launched a little prematurely and, therefore, suffers for that reason. It is premature in the sense that the people are not yet ready for automatic service, because the manual board has not yet reached the point where its capacity has been passed; and also suffering because the automatic board has not yet reached much more than laboratory success. The automatic exchange work that has been does so far certainly promises a great deal to us, and as the telephone becomes more popular, we will undoubtedly reach the point where the manual exchange will be insufficient to handle the traffic. At that time, the automatic exchange will step in and solve the problem when it arrives. I do not think the automatic exchange is at the present time solving any problem, because the manual exchange is taking care of present conditions to a very satisfactory degree. I do not think the manual exchange will be able to do it, however, as the telephone business increases.

Mr. **Gherardi**: The last speaker raises a point on which I should like to ask for information. As I understand him, he considers that at some time in the growth of a large city a point is reached where the so-called "Manual System" will be insufficient to handle the traffic. If such is the case I am particularly interested, because as one of the engineers responsible for planning the telephone system of Greater New York, I would naturally be among the first to be confronted by this condition. I should like to know, therefore, what are the conditions which place any limit upon the size of a manual operating system? In as far as my experience has gone, and as far as the study which our people in New York have given this matter, we have found no such difficulties. Notwithstanding most careful study and examination on this point, we have been unable to discover any difficulties, except that the directory grows larger with the system, in handling 1,000,000 or 2,000,000 telephones in accordance with our methods now in use in New York city.

Mr. **McNaier**: There are certain elements to be considered. There are certain times of the day in the larger exchanges, when the operators at some of the sections are utterly unable to attend to the calls. I have frequently seen two and sometimes three operators at one case trying to answer the calls. The wire chiefs are constantly taking and shifting the lines, so that each operator will have a few busy lines and the rest infrequent. As the telephone service is to-day, I admit that the gentleman is right in that it is able to meet the existing conditions. I am referring to the time when every dwelling-house will have a telephone — possibly more than that; perhaps one on each floor. When that condition arises, telephone calls will be so frequent that an operator will not be able to handle more than, say, about fifty lines in front of her, then the switchboards which are now planned for 200 lines to an operator would have to be just four times as long. By that time the automatic exchange will undoubtedly be perfected and able to meet those new conditions.

Mr. **Miller**: I desire to take issue with the gentleman on his statement of facts in regard to New York exchanges and the operator's capability of handling the work. I do not want anything that I have said in the line of the probable development of the manual exchanges to be taken as indicating that I think that systems employing in some measure manual operation have reached the limit as to their development. It has been said that the final solution was going to be a cross between the manual and automatic. I think there will be remarkable developments along the line of manual exchanges, employing to an even greater degree than at present automatic functions. I do not look for any startling improvements in multiple switchboards as we know them to-day.

Mr. H. Linton Reber: There has been considerable discussion about the physical features of the automatic switchboard, and it seems that the questions of operation are entitled to as much weight as the engineering questions, which have just been referred to. From the statements which have just been made, it would seem to be the concensus of opinion that the faults of the automatic board in its present state may be corrected, and objections on this score overcome; while there seems to be no remedy for the operation objections to such type of equipment. Operating questions may, therefore, be the deciding factor in selection of the proper form of switchboard. Such assumption seems warranted for the reason that the subscribers to an exchange, or the public, will give its patronage where they receive the most convenient and reliable service.

In making a comparison of the manual with the automatic type of switchboard, on questions of operation, we are forced to base our conclusions upon the experience obtained with the manual boards, as the use of the automatic is of such recent date that no reliable data is available. The only information in this respect that seems definite, in that where the automatic boards have been recently installed, the subscriber as a rule, is pleased with the service. There are two points in common with both types of switchboard, from which we might draw conclusions: one might be called a service condition, and the other an operating maintenance condition. The service conditions are quite well known with the manual board, where we find a certain percentage of errors in operation, made in securing connections. These errors are made both by the subscriber and by the operators; our experience is the greater part being chargeable to the subscribers.

Under the present conditions with the modern equipment of the common-battery manual type of board, the percentage of errors made in operation, I believe, averages about 2½ per cent of the number of connections that are put up. In the use of the automatic board, the trained operator is replaced by the subscriber, or general public, in making connections, which will result in a materially larger percentage of errors made in wrong connections. With the novelty of the service at the present time, the subscriber seems to be charitable in respect to this feature. It is, however, a question which later will have considerable effect in competition between the two types of boards. In respect to the question of operating maintenance, reference is made to the method of locating, reporting and clearing physical faults which develop in operation.

Under the present practice with manual boards, there is an average of from 80 to 85 per cent of faults or troubles reported by a trained operative force. With the automatic board, we have nothing as a substitute, so that instead of having a skilled force to report and clear trouble, before the subscriber is aware that anything is wrong and thus prevent complaint, with the automatic, the subscriber will be compelled to report all difficulties with his equipment, which would be of considerable inconvenience when he is unable to obtain connection with the exchange. It is fair to assume that the automatic boards now in use will develop more and more trouble the longer the equipment is in use, so that this question will not appeal so strongly to the subscriber or have its effect on competition until later. The statement that where the automatic service is used, the subscribers are at present satisfied, suggested the question as to their verdict in the future.

Mr. **Gherardi**: Referring to the remarks made by Mr. McNaier a few moments ago about the conditions under which operators work in New York city, I think that any one here who is familiar with such conditions and with the New York service will be able to contradict, from his own personal knowledge, the statements made by Mr. McNaier. In fact I fear that his remarks in regard to the conditions under which the operators work must be due to his having been misled by appearances, as any one may easily be casually observing a central office and who is not familiar with operating methods. An examination of the time elements of the service given to the subscribers in New York is of interest in this connection. Mr. Dommerque has recently spoken of some tests made by him of the New York service. I should like to ask Mr. Dommerque if his tests were made at night and on Sundays, or during the busy hours of the day when the exchanges were carrying their full loads.

Mr. **Dommerque**: At all hours of the day, commencing at seven o'clock in the morning, and all during the day until about eight o'clock. We did not make any tests after eight o'clock.

Mr. **Gherardi**: The results represented the average?

Mr. **Dommerque**: Yes, the average of eight or nine hours during the day. I made several calls during the busy hour about eleven o'clock in the morning.

Col. **Samuel Reber**: I had occasion to use daily, when in New York for a period of a year and a half, the service at both the Cortland and Broad Street boards at all times of the day and night and I must confess that I never encountered any such delay as Mr. McNaier has described. In fact, after the installation of the new equipment of the boards at both these stations, I believe that these exchanges gave as good service as anybody could expect with the present development of the art.

Mr. **Gherardi**: I might go on to say that in my position as chief engineer of the New York & New Jersey Company, I receive the reports of service tests made by the New York people for their own information and I also get the results of our own people's tests on New York service. On account of the intercommunicating between the two companies, each company makes tests and becomes familiar with the service tests of the other. The company I am with does not operate Manhattan Island, but it operates Brooklyn and, as might be expected, there is naturally a very strong rivalry between New York and Brooklyn, and, therefore, the natural feeling of our people would be to look for anything in their results which might be tending to make them unsatisfactory. I know it is a fact that the service given on Manhattan Island in New York city during the busy hours of the day is as follows: —

The average time that elapses from the removal of the telephone from the hook by the subscriber to the answering by the central-office operator is 3½ seconds: the average time from this answer by the central-office operator to the beginning of conversation between the calling subscriber and the called station is 25 seconds, of which one-half is the time taken by the called subscriber in answering after his bell begins to ring; the average time from the hanging up by the subscriber to the disconnection by the operator is 3 seconds.

Mr. McNaier: I have not said the manual telephone service was slow in the larger exchanges, but I have said, and I certainly believe it is absolutely correct, that conditions will eventually arise in those larger exchanges when the manual switchboards, as at present planned and arranged, will be inadequate for the service. In order to illustrate that, I stated that it frequently takes two and sometimes three operators at a busy case to handle the calls as they come in.

THURSDAY MORNING SESSION, SEPTEMBER 15.

The Section was called to order by Chairman Jones at nine a. m.

Chairman Jones: I have the honor to introduce to you our honorary chairman, Mr. H. E. Harrison.

Mr. Harrison: It gives me great pleasure to attend this meeting. I have unfortunately been prevented from attending any former one, and desire now to express my appreciation of the honor which was conferred upon me in appointing me honorary chairman.

Chairman Jones: I have also the honor and pleasure of introducing to you M. Ferrié, a representative of the Government of France in this Congress, and our vice-chairman.

M. Ferrié addressed the Section in French.

Chairman Jones: The program for to-day has been entirely devoted to wireless telegraphy, and we have the honor of having present with us Marquis Luigi Solari, who is to present a paper upon this subject. I have the pleasure of introducing him to you.

Marquis Solari presented the following paper:

THE DEVELOPMENT AND LATEST ACHIEVEMENTS OF THE WIRELESS TELEGRAPH EMPLOYED BY THE ITALIAN GOVERNMENT.

BY MARQUIS LUIGI SOLARI, *General Director of Wireless Telegraphs, Ministry of Posts and Telegraphs of Italy.*

Prior to 1895, as is well known, much successful research work had been carried out in the determination of the properties and actions of high-frequency electrical oscillations. Credit is due to Franklin, Henry, Faraday, and Kelvin for their profound studies of the discharge of a Leyden jar; to Maxwell for his electromagnetic theory of light; to Hertz for his actual discovery of the existence of these oscillations and his experiments in verification of Maxwell's prophecy; to Varley, who noticed the increase in conductivity of metallic powders during thunder storms; to Calzecchi-Onesti and Branly for their observation that the resistance of metal powers was decreased when an electric spark occurred in their neighborhood; to Sir Oliver Lodge who also demonstrated some of the properties of electrical waves by means of a coherer or Branly tube; to Professor Righi, who with an oscillator of special design made many brilliant quasi-optical experiments; to Professor Popoff, who with a special receiver repeated Varley's experiments in the detection of atmospheric disturbances; to Rutherford for his researches into the action of Hertzian waves upon magnetized bodies, and to Poincaré and Elihu Thomson for their invaluable contributions to the knowledge of the subject.

It is, however, a matter of note that by none of these eminent scientists was mention made of the possibility of utilizing high-frequency electrical waves for the purpose of actual telegraphy. As a matter of fact, the very nature and characteristics of the waves employed by them would have precluded any action except at very short distances.

In the spring of 1895 the first experiments in wireless telegraphy were carrried out in Italy by G. Marconi at his father's country residence, Villa Griffone, Pontecchio, near Bologna. These experiments took place in the presence of Signor Mario Monti, engineer, and other persons who are living at the present time, and were based on the transmission of signals responding to a telegraphic code by means of high-frequency electrical oscillations. At this time he discovered that a vertical wire or antenna leading to earth and divided in the lower part by a spark-gap formed a remarkably efficient radiator of electric waves, and that the employment of a similar vertical wire connected through a coherer to earth enabled him to detect the presence of waves over comparatively great distances.

In other words, he made the great discovery that two rods of metal placed upright in the ground and at some distance apart formed a gigantic and novel oscillator in which electric oscillations set up in the one part are propagated through the earth to the other part; and at the same time, electrical waves formed by the alterations of electric strain directed perpendicularly to the earth and the associated magnetic forces parallel to the earth, are propagated through the ether between and above the two vertical wires.

In this arrangement each change or movement of a semi-loop of electric strain above ground had its equivalent change or movement below ground, where the ends of this semi-loop or half-wave terminated; and it was only by the association of these physical actions that the detection of oscillations at a distance became possible.

The invention was completed by very ingenious details. An induction coil, of which the secondary possessed small ohmic resistance to insure a small time-constant, was employed to produce in the vertical wire at the transmitting station a sufficiently high pressure to break down the air-gap insulating it from earth, with the result that electric waves were propagated through the ether and electrical oscillations through the earth as above described.

The e.m.fs. which were set up in the receiving vertical wire by the action of these waves and oscillations were detected by a coherer of much greater reliability and sensitiveness than any that had heretofore been used, and recorded by means of regular telegraphic instruments. The coherer after the receipt of each impulse was automatically restored to normal condition, or decohered, by means of an electromagnetic tapper operated by a relay circuit controlled directly by the coherer, the tapper being adjustable in length of action and also in period of vibration, as required by the sensitiveness of a particular tube. The coherer embodied many points of novelty and improvement over all previously employed by Branly and Lodge in their laboratory experiments — in its general dimensions, in the use of a mixture of definite proportions of nickel and silver, in the use of mercury, in the employment of a vacuum, in the use of metal plugs to confine the metallic filings, which were of a definite size, within a space of definite limits. These improvements transformed the laboratory instrument of uncertain and irregular action into an appliance valuable for telegraphic purposes.

Provision was also made by choke-coils to prevent dissipation of the received energy through the relay coils; the resistance of the relay was regulated according to the resistance of the tube in action; the relay, tapper, and telegraphic recording instruments were all shunted, to prevent local disturbances in the receiver. The combination of these details first made wireless telegraphy practically possible.

By means of these appliances Marconi in the year 1895 established for the first time wireless communication over distances of 200, 500, and 2000 metres. In the beginning of 1896 he went to England for the purpose of developing his invention, and having previously informed the Italian embassy in London of the result of his experiments, on the 4th of Jan., 1896, he received an official letter from Ambassador Ferrero, which established the date of his invention as of 1895.

After the practicability of his invention was amply demonstrated by repeated experiments, Mr. Marconi obtained on June 2, 1896, his first patent for wireless telegraph apparatus, specification No. 12,039, filed with the British Patent Office. The specification clearly shows that up to this date Mr. Marconi had not only made the first practical application of Hertzian waves to wireless telegraphy, but had conceived a theory of their action which was broader and more comprehensive than that imagined by Maxwell and contemplated by Hertz, neither of whom had evidenced their belief that the effect of these waves might not be bounded by the limitations of the electromagnetic theory of light.

In support of this, the above-mentioned patent, after description of the details of Marconi's apparatus which are now generally known and represented by Figs. 1, 2, and 3, mentions the attunement of wireless telegraph stations, and contains the following important declaration which was contrary to the theories and

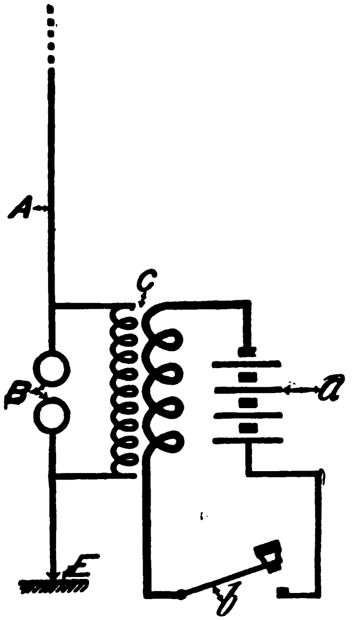


Fig. 1.—Simple untuned transmitter connections.

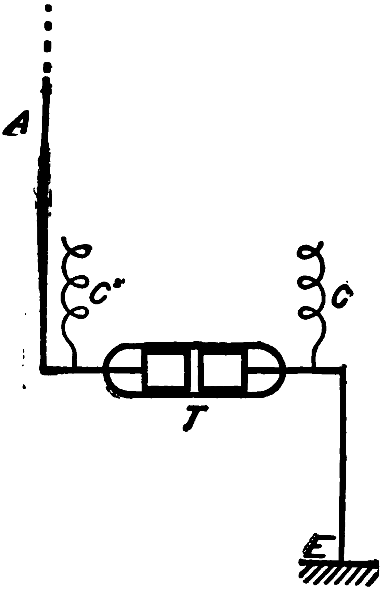


Fig. 2.—Simple untuned receiver connections.

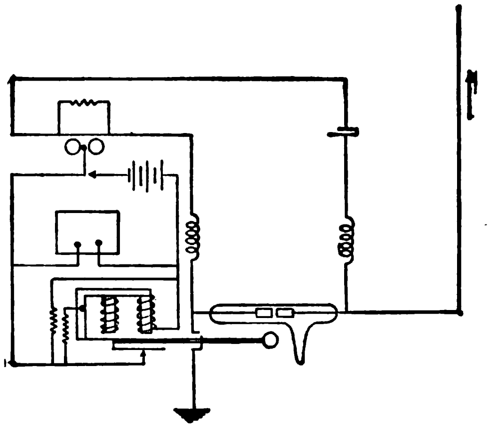


Fig. 3.—Complete untuned receiver connections.

opinions prevalent up to that date: "* * * * With modification of the above apparatus it is possible to transmit signals not only through comparatively small obstacles, such as brick-walls, trees, etc., but also through or across masses of metal or hills or mountains which may intervene between the transmitting and receiving instruments."

So important were esteemed these first results of Marconi's experiments that at the desire of the German government, Professor Slaby of the Imperial Technical School at Charlottenburg asked permission to be present at further trials and his request was granted. In an address delivered on the 1st of November, 1897, he referred to them as follows:

"What I saw was something new. Marconi had made a discovery. He worked with means, the full importance of which had not been recognized, and which alone explained the secret of his success. * * * The production of Hertzian waves, their radiation through space, the sensitiveness of 'the electric eye,' all are known. Very good. With this means 50 metres are attained, but no more. In the first place, Marconi has devised for the process an ingenious apparatus which, with the simplest means, attains a sure technical effect. He thus first showed how by connecting the apparatus to the earth on the one side and by using long, extended, vertical wires on the other side, telegraphy was possible."

That is what Professor Slaby wrote in November, 1897.

At the request and at the expense of the Italian government, Mr. Marconi at the end of June, 1897, proceeded to Rome in order to carry out demonstrations for the Italian government. Various demonstrations were made in the presence of their majesties, the King and Queen, and the ministers of State. These tests were considered so novel and successful that the Italian government requested Marconi to proceed to Spezia in order to establish communication between ship and shore. The battleship "S. Martino" was placed at his disposal and very important experiments were carried out between the "S. Martino" and the land wireless station situated at S. Bartolomeo, near Spezia, on the 14th, 15th, 16th, and 18th of July, 1897, at a distance of 18 km. An official report was made of these experiments by a special commission of which Admiral Grillo was president, and the report concluded with a reference to the great importance of the result obtained with Marconi's apparatus, and to the great future before this new means of communication.

In consequence of these experiments the Italian navy erected in 1898 a permanent wireless telegraph station (Marconi system) on the heights of the Island of Palmaria (Gulf of Spezia) close to the semaphore station, a similar station on the heights of the Island of Gorgona, and another station in the grounds of the Royal Naval Academy at Livorno. The following are the respective distances in nautical miles and in kilometres between the places just mentioned.

	Nauts.	Km.
Gorgona-Livorno	19	35
Livorno-Palmaria	39	72
Palmaria-Gorgona	42	77

From 1898 until the present day these stations have been kept working by the Italian admiralty for the trial of new inventions subsequently made in wireless telegraphy, and in experimenting.

Soon after the installation of these stations the following problems presented themselves for solution:

1). Independent communication between any two was found to be urgently desirable.

2). Communication with ships at greater distances became necessary.

For the solution of the first problem several methods immediately offered themselves for trial, based upon electrical sympathy, mechanical synchronism and the quasi-optical properties of electric waves.

Early in 1898 Marconi communicated to the Italian government his method, patented in England on the 31st of May, 1898 (No. 12,326), for the application of the principle of electrical resonance to wireless telegraphy for the purpose of effecting independent communication.

According to this patent the receiving aerial was no longer insulated (Fig. 4), but was connected to earth through the primary of an induction coil, whilst the ends of the sensitive device were connected to the ends of the secondary, the secondary circuit including also a condenser. This induction coil consisted preferably of two windings, of a variable number of turns of thin insulated wire. The two circuits of this coil had a particular time period of electrical oscillation, depending upon the capacity and self-induction of each; when equal to that of the transmitting aerial the receiver was in tune or sympathy with the oscillation transmitted, and within certain limits responsive only to such transmitter. Thus not only was selectivity obtained, but the receiver became operative by a cumulative effect at greater distances, while much of the interference due to atmospheric influences was eliminated.

It became immediately apparent that a further improvement was certain to result from the use of a transmitting aerial conductor having a well-defined and decided time period; or, in other words, from the employment of a transmitting aerial possessing a large capacity and a large inductance. Lodge's syntonic arrangement of Leyden jars constituted a very good and persistent oscillator, but on the other hand was a feeble radiator, and, therefore, was not suitable for action at a distance. At the same time Braun's suggestion to create an induced oscillation in the aerial by means of a condenser circuit across the spark-gap failed in its object, until it was shown by Marconi that it was necessary to attune the aerial and condenser circuits very accurately to one another.

Marconi's British patent No. 7777 covers this important advance, providing that the product of capacity and inductance in all four circuits of the transmitter and receiver shall be equal. The transmitting transformer, described in this patent, consisted of two windings of insulated wire on a wooden frame. Its dimensions may be varied within wide limits, but satisfactory results were obtained when the primary consisted of one turn made up of a number of single turns connected in parallel, and the secondary of a number of turns of insulated wire wound closely over the primary, the transformer ratio being one to ten, or one to

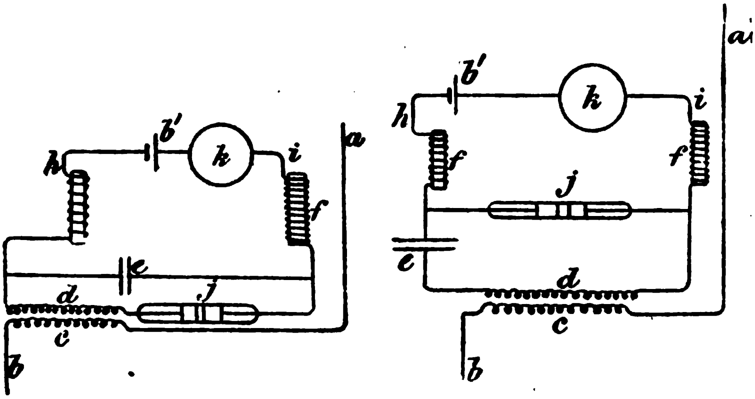
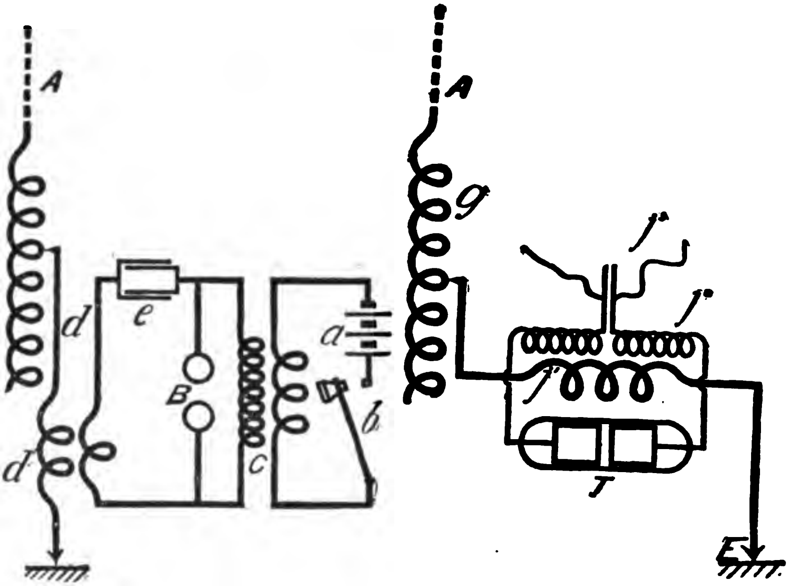


FIG. 4.—RECEIVER CONNECTIONS EMPLOYING TRANSFORMER.

twenty. The condensers used in connection with this transformer were usually three or four pint Leyden jars, but this capacity was varied if the inductance of the transformer were varied. (Figs. 5 and 6.)

The above arrangement was also the key to the solution of the problem of accumulating more energy in the aerial, and of producing more sustained oscillations in the transmitter for increasing the efficiency of the apparatus. In fact, in the primary circuit the condensers act to store energy, and this energy is radiated at intervals and with persistent oscillations corresponding to the fundamental note of the aerial and to the time period of the primary circuit.



FIGS. 5 AND 6.—CONNECTIONS OF TUNED TRANSMITTER AND RECEIVER.

Upon the Italian government becoming acquainted with these latest improvements, it was decided to send the writer to England, in order to ascertain the import of such improvements, with a view to their use in connection with the wireless installation between Rome and Maddalena in the Island of Sardegna, a distance of about 300 km. In August, 1901, I was officially present at the Marconi station, at Poole, Dorset, England, and during that month witnessed the following experiments in syntonic wireless telegraphy:

Two receivers were connected to the same aerial, about 50 ft. in length suspended from a mast. The circuits of these two receivers were tuned to different time periods of oscillations corresponding to the different time periods of the circuits of two transmitters connected to the same aerial at the station of St. Catherines, 30 miles away. Figs 7 and 8 show the connections of the transmitting and receiving station. Two operators were instructed to send simultaneously two different wireless messages to Poole, one in English and one in Italian; without delay or mistake, the two messages in different languages were correctly recorded and printed down at the same time in Morse signals on the tapes of the two corresponding receivers at Poole.

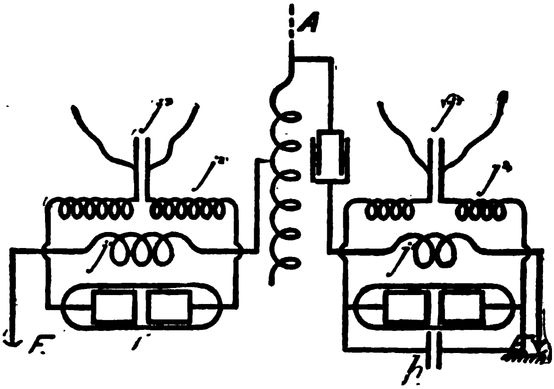


FIG. 7.— CONNECTIONS OF TUNED RECEIVERS.

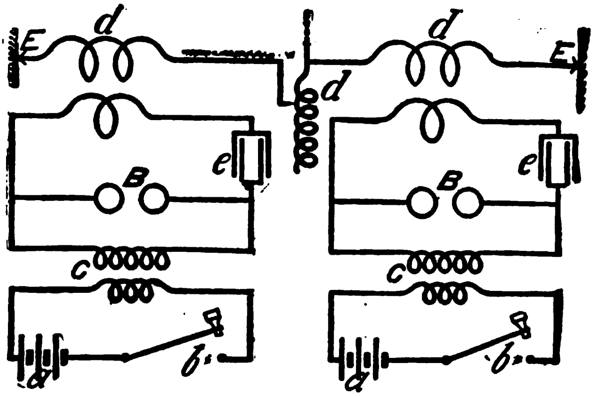


FIG. 8.— CONNECTIONS OF TUNED TRANSMITTERS.

It is worthy of note that while these experiments were proceeding, the British navy station at Portsmouth and Portland, situated close to St. Catherines and Poole, were in operation, but no interference was noticed, notwithstanding that the lines of communication crossed at right angles.

At the same time, it was noticed during the above-described experiment, that the degree to which it was a solution of syntonic wireless telegraphy depended to a considerable extent upon the nature of the detecting device employed. This important fact was pointed out by myself at the Berlin Conference to demonstrate the difficulty of assuring a regular intercommunicatory wireless telegraph service between various systems, merely by making known to the communicating parties the different wave lengths employed by the several systems, as was suggested at the Conference.

After these experiments had proved the possibility of excluding interference between a number of stations, the Italian government instructed me to inquire into Marconi's experiments at the Cape Lizard station, which were first carried out in the winter of 1900, with the object of extending the range of transmission at this station. From September to November, 1901, I witnessed daily regular wireless communication between the Lizard and St. Catherine's station, about 200 miles apart. In consequence of these results, which demonstrated for the first time the possibility of overcoming the curvature of the earth, I was delegated by the Italian government to test the Marconi apparatus which a few months later were installed at the wireless stations in Rome, Maddalene, Spezia, and on board the battleships "Sicilia," "Morosini," "Garibaldi," and "Carlo Alberto," all of which, up to the present time, have carried on a very useful service.

In December, 1901, Mr. Marconi informed me officially that the high power station at Poldhu, Cornwall, was ready to commence the transmission of wireless messages across the Atlantic ocean. The erection of this station was commenced in 1900, immediately after the establishment of communication between Cornwall and the Isle of Wight had dispelled the idea entertained by many, that the curvature of the earth would be a bar to long-distance working, and had shown conclusively that great distances could be bridged, providing that suitable power and also suitable wave-lengths were employed.

The efficient handling of large amounts of power now claimed attention, and it became necessary to determine.

1). What source of energy should be employed, and how to control this energy.

2). How to obtain a good disruptive or oscillatory discharge of a large condenser at voltages of 100,000 and upward.

3). What form of condenser to use to stand very high potentials, and store a great amount of electric energy.

4). What form of aerial would be the best radiator of electric waves, bearing in mind the restriction of height.

After a long series of careful experiments, involving the expenditure of large sums of money, Marconi arrived at the following conclusions, which were put into practice:

1). As a source of energy it was found convenient to employ an alternator of low frequency, its current being controlled by a most accurate attunement of the transformer primary to the condenser circuit, and by the inclusion of variable choke-coils. Special spark-arresters were used throughout. The choke-coils were preferably constructed of two cylindrical bobbins standing upon a cross-piece of laminated iron. By adjusting the position of the cores of these two choke-coils, it was found possible to fix a minimum value below which the current could not fall, or to increase the current up to a certain limit which could not be exceeded.

2). Several means had been suggested for obtaining a good disruptive or oscillatory discharge of a large condenser by the extinction of the arc which might be formed between the spark-balls. One of these is due to Tesla, and is based upon the use of a strong magnetic field, and another, due to Elihu Thomson, based upon the use of an air blast. But Marconi, assisted by Fleming, found that the desired result was more efficiently obtained by the careful adjustment to resonance of the capacity in connection with the spark-gap. At the same time, several ways were suggested for increasing the potential across the spark-gap without unduly increasing the length of the spark. The best results were obtained by the use of compressed air or liquid air, the use of the spark-gap in oil as suggested by Righi having been discarded.

3). In the search for the best form of condenser to stand very high potentials and to store great amounts of electric energy several different materials were tried as dielectrics, such as glass, micanite, ebonite, and others possessed of very high dielectric strength. After much experimenting, it was found that the most convenient, practical, and economical form of condenser for the purpose was one made up of sheets of glass about one-eighth or one-tenth of an inch in thickness, coated to within 1 in. of their edges on both sides with tinfoil, and arranged in a vessel containing resin or linseed oil, like the plates of a storage battery.

4). From 1895 until the present time Marconi has carried out many experiments in his attempts to find the most efficient form of aerial for long-distance work.

I have already described the form of aerial used in the original Marconi system. To increase the capacity of this aerial there were consecutively put up two, four, or more wires in contiguity joined together. It was found that the electrical capacity of several wires in parallel is not nearly equal to the sum of their individual capacities, but that the total capacity varies as the square root of the number of wires when the wires are separated by a distance equal to about 3 per cent of their length. This rule has been approximately applied in the design of several forms of aerials in general use, such as the fan, the inverted cone, or inverted square pyramid types, in which the wires are made all of equal length, and are arranged sufficiently far apart not to reduce each other's capacity.

Another important matter for consideration in connection with the aerial is the determination of the relation of its height to the distance to be covered. The rough rule first given was that, if the working energy is constant, the distance possible for an aerial of height L varies as the square of L; if the working power varies, and the height of aerial remains constant, the minimum working power varies inversely as the square of the distance between the aerials.

Later experiments, however, did not confirm this rule, and it was found that different dispositions of the aerial with respect to the earth, the different lengths of waves used, the different natures of the earth, and different conditions of the medium, exert great influences upon the distance possible to be covered with any given height of aerial.

A new form of aerial due to Marconi, consisting of a great number of wires which extend radially from an elevated conductor, has so far given the best results. The vertical part of the aerial may be comparatively short, and the necessary length and capacity may be obtained in the radial extensions. These extensions may be horizontal or their ends may approach the earth more nearly than the top of the vertical part; their free ends are suspended by short poles or otherwise, and must be very well insulated from the earth.

These matters having been satisfactorily settled, Marconi, in December, 1901, sailed for Newfoundland to test the efficiency of the Poldhu station, whilst I remained in Cornwall to watch the working of the transmitting station.

The arrangement of the machinery at these transmitting stations at Poldhu can be understood from Fig. 9. A monophase low-frequency alternator was driven by a 30-hp oil engine. The current from this alternator excited one or more transformers, *T*, by means of which the said current was brought up to a potential of 20,000 or 40,000 volts to charge a large condenser, C_1, which discharged across a primary spark-gap, S_1, through the primary coil of an oscillation transformer, T_1. The secondary circuit of this oscillation transformer was connected to a second pair of spark balls, S_2, which in turn were connected by a secondary condenser, C_2, and the primary circuit of a second transformer, T_2, and the secondary circuit of this last transformer were inserted between a large aerial, *A*, and the earth, *E*. When all these circuits were turned to resonance by Marconi's methods, an enormously powerful arrangement was obtained for radiating electric waves, or, rather, trains of electric waves. The signals were made by short-circuiting the first primary circuit.

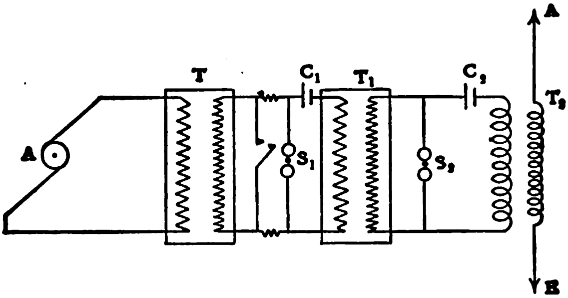


FIG. 9.—TRANSMITTING CONNECTIONS AT POLDHU.

The receiving apparatus used by Mr. Marconi in Newfoundland was that described in his above-mentioned patents, and in addition to these was tried a mercury coherer which was given to him by the Italian Admiralty, and which was made at Spezia under my direction in accordance with suggestions which I obtained from the Rydberg study of the vibration of mercury light in a magnetic field, the Wilson mercury coherer, patented in 1898, and the Tommasina mercury coherer, as disclosed in a lecture given in Geneva in 1899. As this mercury coherer was improved under the direction of the Royal Navy Staff, the Minister of Marine, at my suggestion, called it the "Italian Navy Coherer."

The results obtained by Mr. Marconi between Poldhu and Newfoundland were sufficiently successful to guarantee wireless communication between Europe and America, but, as the experiments gave rise to some doubt as to efficiency of the coherer for receiving over long distance, Mr. Marconi decided to bring to perfection an idea which he had as far back as 1898, for an entirely new device for the reception of electrical waves.

In the month of May, 1902, he communicated to the Italian Government particulars of the new receiver for wireless telegraphy invented by him, and described in his British patent No. 10,245 of May 3, 1902. This invention is based upon the effect of high-frequency electrical oscillations upon a core or rod of magnetic material. Some 60 years ago Henry noticed the effect of a spark upon the magnetization of needles; later, in 1896, Rutherford amplified the Henry discovery, and Finzi, Gerosa, and Ewing noticed the effect of electrical oscillations upon the hysteresis of iron; but these phenomena only became useful for the purposes of wireless telegraphy through Marconi's discovery that the effect of these oscillations is very much increased when the magnetic material is placed in a varying field.

The explanation of the stronger effect obtained by varying the field can be found, in my opinion, in the fact that the molecular movement produced by the varying field reduces the molecular viscosity of the magnetic material, and facilitates the rapid variation of the magnetization due to the high-frequency oscillations; whilst, when the magnetic field is constant, no assistance is rendered the oscillations, and appreciable effects can only be obtained by persistent oscillations produced at very short distances.

The Marconi magnetic detector is of the following general construction (Fig. 10): On a core consisting of some magnetic material, which may be iron, preferably in a subdivided state such as fine wires or needles, is wound one or several layers of insulated copper wire. Over this winding is placed insulating material, and over this the secondary winding of thin copper wire. The ends of the winding nearest to the iron core are connected, one to earth or to a capacity, and the other to an elevated conductor; or they may be connected to a secondary of a suitable transformer or intensifying coil such as is now used in connection with wireless telegraph receivers. The ends of the secondary winding are connected to the terminals of a telephone, galvanometer, or other suitable receiving instrument. At the ends of the core, or outside the coil in close proximity to it, is placed a magnet which is so moved as to cause a continual change in the magnetism of the iron core.

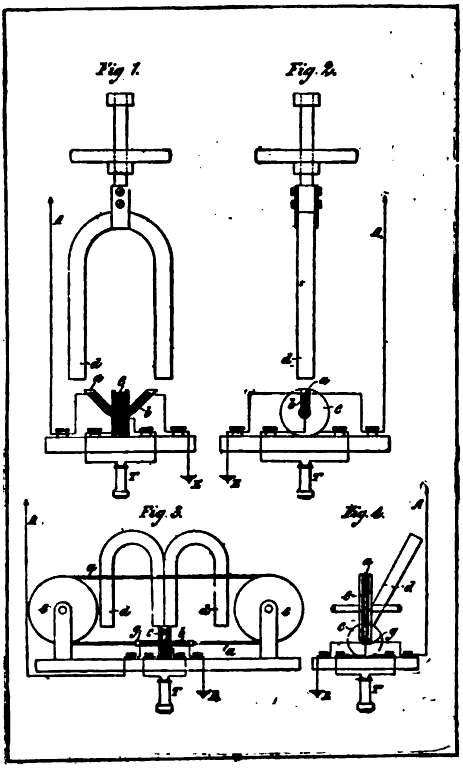


Fig. 10.— Magnetic detector.

When electrical oscillations of suitable period are received, the changes in magnetization of the iron produce rapid variations of magnetic flux in the secondary, and in consequence create in it e.m.f's., which in their turn reproduce in the telephone or receiving instrument the intelligible signals transmitted from the sending station.

Shortly after Mr. Marconi disclosed to the public (through his lecture delivered before the Royal Institution on the 2d of June, 1902) his invention of the magnetic detector, which was destined to open a new era of practicability in wireless telegraphy, the Italian Minister of Marine invited Mr. Marconi to pursue his experiments on board His Majesty's ship "Carlo Alberto." Mr. Marconi, therefore, sailed on this ship, shown in Fig. 11, on the 7th of July, 1902, from Dover, taking with him his first model of the magnetic detector. Throughout the voyage from Dover to Cronstadt, messages were received daily from Poldhu in the presence of the Admiral, the Captain, and the officers of the ship. It is important to observe that these messages had to cross the greater part of England, the North Sea, Denmark, Scandinavia, and the Baltic. The aerial used on the "Carlo Alberto" during this voyage consisted of four copper wires which extended horizontally from the fore-mast to the main-mast, and thence down into the wireless telegraph cabin. (Fig. 12.) The aerial at Poldhu was of the fan type. (Fig. 13.)

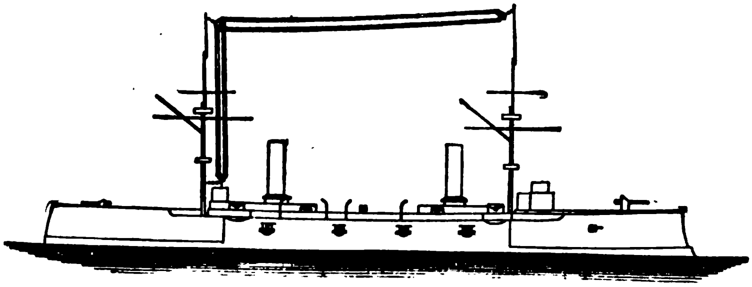


FIG. 12.—AERIAL ON "CARLO ALBERTO."

On the arrival of the "Carlo Alberto" at Cronstadt, Mr. Marconi decided to try a new form of aerial, consisting of 50 wires, connected to, and suspended from a horizontal wire extended between the tops of the ship's masts. (Fig. 14.) At the same time he instructed Poldhu to use the inverted pyramid form of aerial. (Fig. 15.)

FIG. 11.— H. M. S. "CARLO ALBERTO."

FIG. 13.— POLDHU MARCONI STATION.

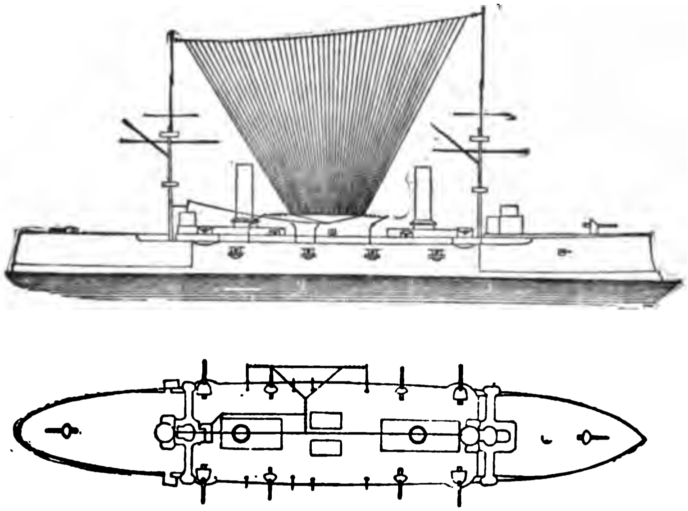


FIG. 14.—AERIAL ON "CARLO ALBERTO."

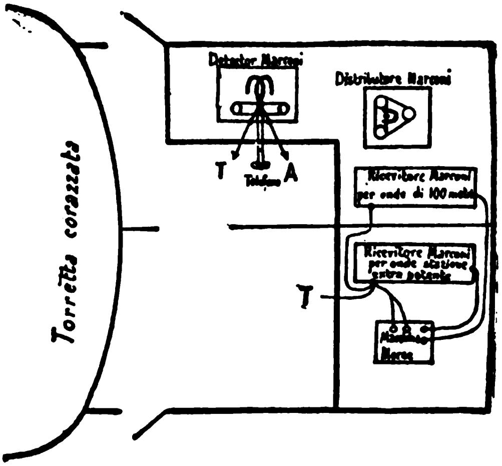


FIG. 14A.—PLAN OF APPARATUS ON "CARLO ALBERTA."

The results obtained were exceedingly satisfactory, and signals from Cornwall were received on the tape by means of Marconi's first apparatus, and also in a telephone by means of the magnetic detector, over a distance of more than 1000 miles, of which about 500 were overland. At the same time I tried a new cadmium coherer of my own design, which may be roughly described as consisting of a small grain of cadmium in imperfect contact with two small brushes made of very fine silver wire. Adjustment having been obtained by means of a telephone receiver, it was placed in connection with a battery cell and a galvanometer, the needle of the latter responding to the electrical impulses received.

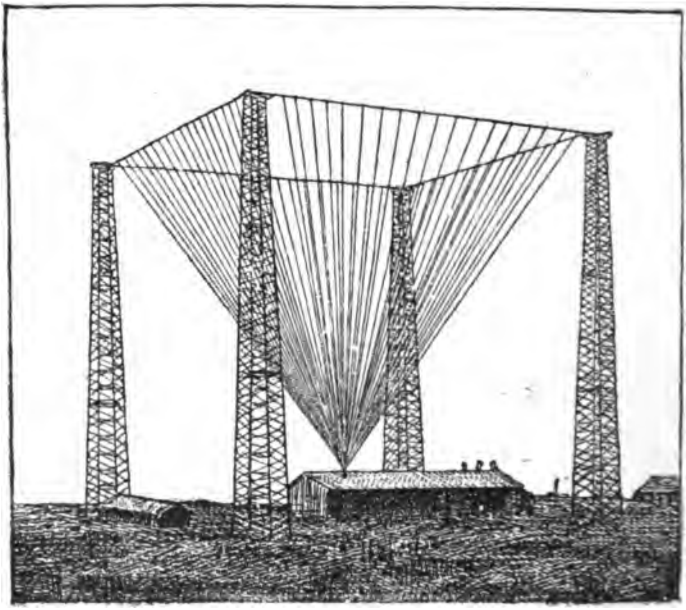
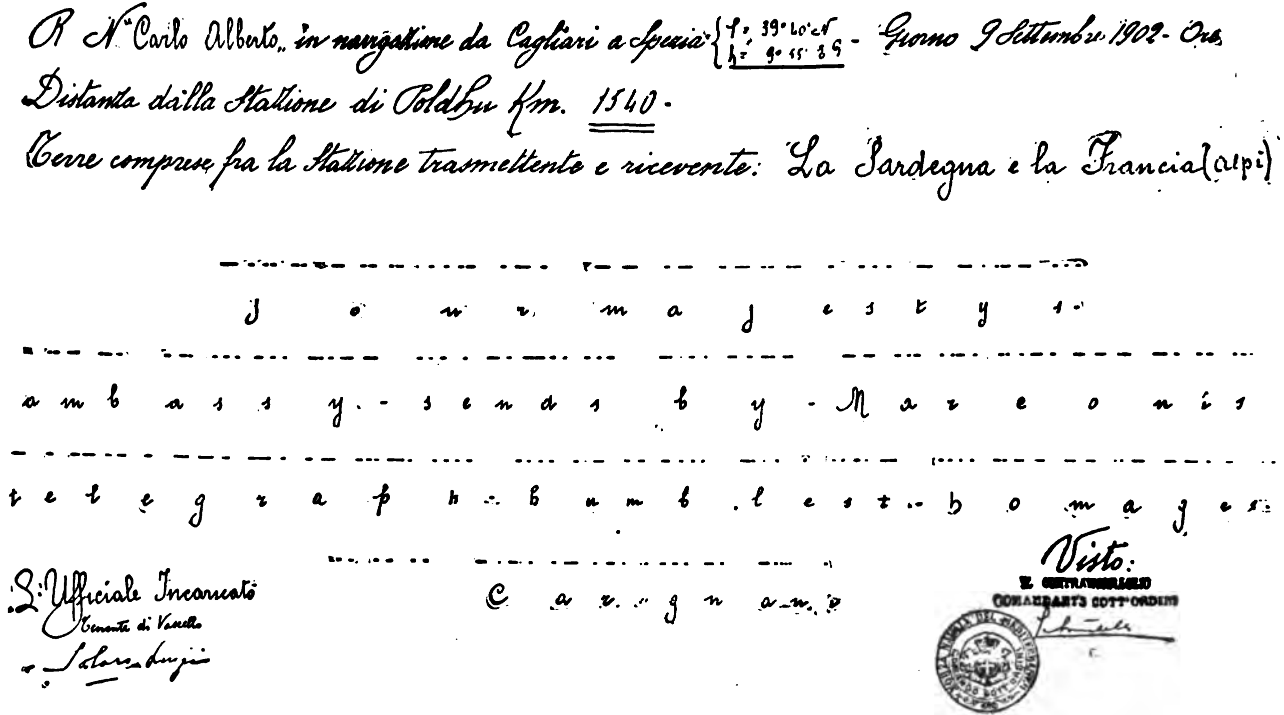


FIG. 15.—AERIAL AT POLDHU.

The movements of the needle were recorded upon a sensitive tape arranged similarly to that used by Pollak-Varag. I took out a provisional patent for this device, which gave very good results, but, as I found the magnetic detector so much superior in its action to all other forms of responsive devices, I have proceeded no further in the matter.



R. N. „Carlo Alberto„ in navigazione da Cagliari a Spezia { φ = 39°40'N / λ = 9°55'39 } - Giorno 9 Settembre 1902 - Ore

Distanza dalla Stazione di Poldhu Km. 1540.

Terre comprese fra la Stazione trasmettente e ricevente: La Sardegna e la Francia (alpi)

J o u r m a j e s t y s

a m b a s s y - s e n d s b y - M a r c o n i s

t e l e g r a p h h u m b l e s t h o m a g e s

C a v . g n a n .

L'Ufficiale Incaricato
Tenente di Vascello
Solari Luigi

Visto:
IL CONTRAMMIRAGLIO
COMANDANTE SOTT'ORDINI

FIG. 16.—POLDHU MESSAGE RECEIVED AT SPEZIA.

The results achieved during the return voyage to England were considered so important that the Italian Minister of Marine invited Marconi to proceed on the same ship to the Mediterranean. Therefore, on the 25th of August of the same year the "Carlo Alberto" left England for Italy, touching at Ferrol, Cadiz, Gibraltar, Cagliari, and Spezia. Throughout the entire voyage, and even when the ship was anchored close to very high mountains, messages were regularly received and read with the utmost ease. It may be mentioned that amongst these an official message was received near Spezia from Poldhu addressed to his Majesty the King of Italy and sent by the Italian Ambassador in London, which is reproduced in Fig. 16.

I made an official report of these experiments, which was duly signed by the Admiral and submitted to the Minister of Marine, and this report included the tapes containing the most important messages received. The following conclusions arrived at in connection with these experiments are referred to at the end of the above-mentioned report:

1). There is no limit to the distance across which electric waves can be propagated, provided the power and the length of waves used are proportionate to the distance to be covered.

2). No interruption whatever occurs in wireless communication from the intervention of land between the sending and receiving stations, when suitable wave-lengths are employed.

3). Daylight has the effect of reducing the range of electric waves, as was discovered by Mr. Marconi in February, 1902, during his experiments on board the SS. "Philadelphia."

4). It was recognized that the efficiency of a magnetic detector is much superior to that of any kind of coherer, as it does not require regulating and is exceedingly sensitive, practical, and constant.

5). The Marconi system of wireless telegraphy has, by reason of the latest improvements, proved to be of the greatest possible practical utility in its application for commercial and military purposes, irrespective of distance.

Soon after the Mediterranean experiments, at the express desire of His Majesty the King of Italy, the "Carlo Alberto" was again placed at the disposal of Mr. Marconi for the purpose of inaugurating wireless telegraph communication between Europe and America, and I had the good fortune and the honor to assist him

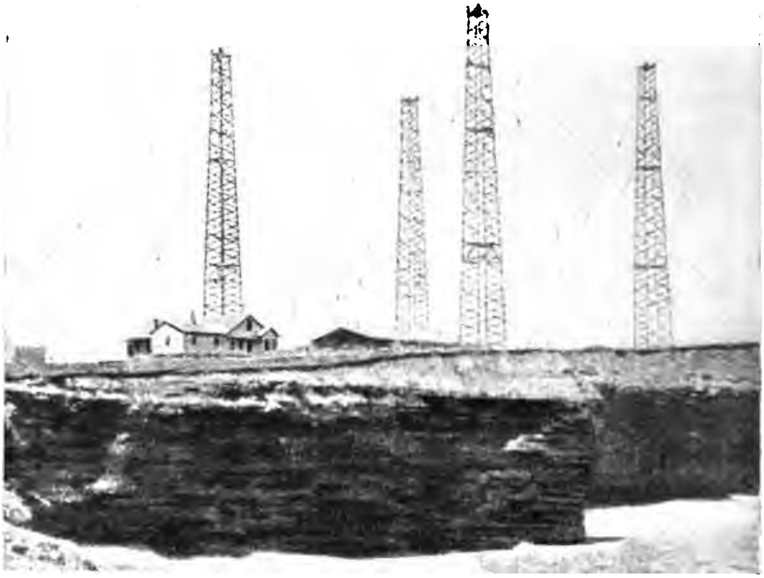


FIG. 17.— CAPE BRETON MARCONI STATION.

FIG. 18.— CAPE COD MARCONI STATION.

during the voyage from Plymouth, England, to Sydney, Cape Breton, Nova Scotia. The reception of the messages daily on board the "Carlo Alberto" from Poldhu across an ever-increasing extent of the Atlantic ocean was testified to by all the officers of the ship, and a bulletin of the news received from the distant shore was published daily for the benefit of the crew.

On Dec. 20, 1902, at 10 P. M., the first official wireless messages were sent from the Marconi station at Cape Breton (Fig. 17) via the Marconi station at Poldhu and were addressed to Their Majesties the King of England, the King of Italy, and Queen Margherita. A few days later the first trans-Atlantic messages from the United States were sent from the Marconi station at Cape Cod (Fig. 18) direct to Poldhu, including one addressed by President Roosevelt to King Edward VII.

After this great achievement, which marked an epoch in the application of electricity and cannot fail to have a considerable influence upon the welfare of mankind, every effort has been directed toward overcoming the few remaining difficulties, and at the same time prepare an organization to cope with the ever-increasing commercial developments.

Probably the most important and the most interesting of the problems remaining to be solved is that of the effect of daylight in reducing the range of transmission. One explanation given by Marconi attributes the effect to the dissipating action of light upon the negative charge, but another explanation may be offered, based upon the hypothesis of Prof. J. J. Thomson of the projection by the sun of streams of electrons into space, and upon the hypothesis of Professor Arrhenius that the portion of the earth's atmosphere facing the sun is more impregnated with electrons or gaseous ions than the portion not illuminated, and the clear sunlit air, though extremely transparent for light waves, may well act as a turbid medium for long electric waves. Doubtless by the employment of greater amounts of energy, or by some improvement in the form of the radiator, and the better utilization of the earth in propagation, the difficulty will be overcome.

The organization of the great commercial end of wireless telegraphy has occupied the greater part of the time devoted to this subject during the past year. It was evidently not easy to organize in a few months a service which is already open to the public in some 14 different countries, in addition to some 200 ships which are fitted with the Marconi system.

The land stations are distributed throughout the world as follows:

20 in Great Britain.
14 in Italy.
5 in Canada.
9 in United States.
2 in Germany.
7 in Newfoundland.
1 in Belgium.
3 in Congo.
1 in Holland.
1 in Montenegro.
3 in China.
2 in Chili.
1 in Malta.
1 in Bermuda.

The ships fitted include all the more important vessels of the British and Italian navies, the fast Belgium subsidized fleet, the Cunard line, the American line, Red Star line, French line, North German Lloyd, Holland-American line, Hamburg-American line, Atlantic Transport line, Allan line, and Navigazione Generale Italiana. Most of these trans-Atlantic liners publish newspapers on board many hours before they reach port, the information contained in them being telegraphed by the wireless system. The four fast Cunarders with special long-distance receiving apparatus are now enabled to publish daily news items transmitted to them direct by the Marconi stations at Poldhu, Cape Breton, and Cape Cod. Their range of reception has been found to be about 2000 miles, and in mid-ocean news is received on board from both continents.

On behalf of the Italian government, I was present at the reception of the first news messages transmitted to the Lucania by the Marconi coast stations in Europe and America daily throughout the trip for publication on board.

An agreement has been made with Mr. Marconi by the Italian government similar to those of the British and Canadian governments, to open to the public service commercial wireless telegraphic communication between America and Italy. The Minister of Posts and Telegraphs of Italy, Count Stelluti Scala, has published the regulations which are now applied for the public wireless telegraphic service between the Marconi station at Bari and the sister station of Antivari, Montenegro — stations inaugurated one month ago in the presence of His Royal Highness the Prince of Montenegro, by the transmission of messages in French, German, and Slavic to several sovereigns of Europe.

The regulations published by the Minister of Posts and Telegraphs will form a supplement to the regulations approved by International Telegraphic Convention. These regulations make special provision for the control of the commercial wireless telegraph service when several ships of different speed, of different routes, and in different positions wish to communicate at the same time with Bari and Antivari, whilst those are communicating with each other.

It is proposed shortly to open the Bari station to the public service for wireless telegraphic communication between England and Italy, under an agreement about to be made by the two governments.

The Italian government has with great interest followed the efforts made by many experimenters in different countries toward the development of wireless telegraphy. It is well known that by the quasi-general use of the Marconi radiator and of new devices for detecting electric waves, some considerable results have been obtained. Many kinds of detectors of electric waves have been patented. Professor Righi in a paper sent to the International Electrical Congress of the Paris Exhibition, 1900, mentioned 14 different radioconductors; Professor Fleming has divided into six classes the various kumascopes devised up to the present date. But none of them, in the experience of the Italian government stations, has been found more reliable, sensitive, and constant than the Marconi magnetic detector, of which Admiral Mirabello (the present Minister of Marine of Italy), after having watched for several months on his flagship "Carlo Alberto" the working of this device, as compared with that of other receivers, concluded his official report with the following statement:

"Marconi's magnetic detector * * * will be the receiver of the future. It is of an extraordinary simplicity of construction, requires no adjustment, is never out of adjustment, is faithful and regular in its reproduction of the signals transmitted, and never fails in its range, as I have been personally able to confirm."

The Italian government has not been informed of any results obtained in wireless communication superior to those mentioned in this official statement. But as the great aim of this Congress is to facilitate the international communication of new electrical studies and discoveries, I will be very glad to take note on behalf of my government of what has been achieved by systems other than that which Italy has adopted.

The Italian government voted last year 1,000,000 francs for the erection in Italy of a high-power Marconi station, the range of which will be sufficient for communication with Marconi stations in America, and it is the warm hope of the Italian government that this new means of communication will more and more strengthen the friendly relations existing between the American and Italian peoples.

DISCUSSION.

CHAIRMAN JONES: It is unnecessary for me to say that we are very fortunate in having this paper, which is so complete, historically and technically, in the description of the Marconi system, and by such a distinguished gentleman as Marquis Solari, who has been closely associated with Marconi in the development of this system.

Col. **SAMUEL REBER:** I am sure I voice the sentiment of the entire assemblage in saying that we are doubly grateful to the Marquis for his clear and lucid historical method of treatment of Mr. Marconi's claims for the development of commercial wireless telegraphy. I am confident nothing could be said here to add the slightest to the renown which Mr. Marconi has justly received for the part he has played in the development of wireless telegraphy up to the present day. I would also like to add that I think the Marquis' own modesty has kept in the background the most important part which he had played in assisting in the development of this art. While he may modestly say that the coherer was developed by the Italian navy, that coherer is better known in this country as the Solari coherer.

Marquis **SOLARI:** I thank you for your very kind words. It was not my merit. I only tried my best to execute the order that I was given by the Government, and every officer of every navy or army would have done what I have done without any personal merit.

Col. **REBER:** It was the manner in which the Marquis carried out his orders which has made the impression upon all of us in the service.

Dr. A. G. **WEBSTER:** Might I ask the single question as to the horsepower of the latest station erected in Italy?

Marquis **SOLARI:** We have not yet decided what will be the power, but at the present moment we think it will be 500 horse power.

CHAIRMAN JONES: The next paper to be presented is upon the "Theory of Wireless Telegraphy," and the gentleman who presents the paper is Mr. John Stone Stone, whom I have much pleasure in introducing.

THE THEORY OF WIRELESS TELEGRAPHY.

BY JOHN STONE STONE.

The theory of modern wireless telegraphy may be treated in at least two widely different ways depending upon whether it be the object to produce a simple mental picture of the phenomena involved, or whether it be the object to lay the foundations for engineering calculations and quantitative research. The first mode of treatment leads to what may be termed the "Popular Theory," and the latter to what may be termed the "Working or Engineering Theory."

In this paper only that form of wireless telegraphy will be considered in which electrical vibrations are set up in electrical oscillators whose axes are normal to the earth's surface, and which are connected to the earth's surface at their lower extremities.

PART I.—POPULAR THEORY.

If the equations for the moving field produced by Dr. Hertz's dumb-bell oscillator be examined, they will be found to show that, in the equatorial plane of the oscillator, the potential is everywhere zero, that there is no component of magnetic force normal to that plane, and that there is no component of electric force parallel to that plane. From this it would follow that if a perfectly conducting sheet, which is initially at zero potential, be passed through the equatorial plane of the oscillator, no currents will be induced in it by the field of the oscillator. In other words, the presence of the conducting sheet should not distort or otherwise affect the field of force produced by the oscillator.

On each surface of the conducting sheet will exist currents which, in their reaction upon the electric and magnetic field on the corresponding side of the sheet, will be the exact equivalent and take the place of the field of force on the other side of the sheet. These currents will extend radially from the point of intersection of the axis of the oscillator with the conducting sheet, and at any point in the sheet will be equal in amplitude but opposite in direction or phase on the two surfaces of the sheet. For a radial distance measured along the sheet from the point of intersection with the axis of the oscillator, approximately equal to one-quarter of the length of the wave radiated by the oscillator, there will be a gradually diminishing difference in phase between the currents on the sheet and the electric force at the corresponding surface of the sheet, the result of which will be that within this radius the energy of the currents will travel out from and a portion of it back to the oscillator in the time of each oscillation, whereas for points beyond this radius the energy will all flow away from the oscillator, never to return to it, provided only the conducting sheet be infinitely extended in all directions.

Since the infinitely conducting sheet is a complete barrier between the two regions it separates, it is easy to see that each half of the Hertz oscillator, with its appropriate infinitely conducting and infinitely extensive surface is a complete oscillating system entirely independent of anything which may take place on the other side of the conducting sheet, and that the field of force at or above the conducting sheet is the same as that which would be found at or above the equatorial plane of the complete Hertz oscillator were the conducting sheet absent. These considerations lead to a very simple and popular theory or means of explaining the manner in which the electromagnetic waves of wireless telegraphy are developed and propagated.[1]

This theory regards the vertical transmitting oscillator of wireless telegraphy as one-half of a Hertz oscillator normal to the earth's surface, which must be regarded as practically infinitely conductive in the immediate neighborhood of the oscillator, or for about a quarter of a wave length from the point at which the oscillator is connected to the surface of the earth. By this theory, therefore, the waves of wireless telegraphy are developed in exactly the same manner as if the vertical oscillator and its electrical image below the surface of the earth together formed the real oscillator of which the surface of the earth is the equatorial plane.

A graphical representation of this theory is given in Figs. 1 and 2.

This theory which for convenience may be termed the "Electrical Image" theory, bears a close resemblance to that mode of

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[1] Blondel, "Sur la théorie des antennes dans la télégraphie sans fil." *Comptes Rendus* de l'Association française pour l'avancement des Sciences. Congrès de Nantes, 1898.

treating a single wire or grounded telegraph or telephone circuit as one-half of a two-wire or metallic circuit which was first suggested by Mr. Oliver Heaviside.[2] He conceives a metallic circuit such as that shown in Fig. 3, cut in half longitudinally by an infinitely conducting plane at zero potential as shown in Fig. 4. Since the points on the metallic circuit cut by the plane would normally be at zero potential, no change in the distribution of currents results from the connection with the infinitely conductive plane. A little consideration will also show that the electrostatic capacity and inductance of the circuit will moreover remain

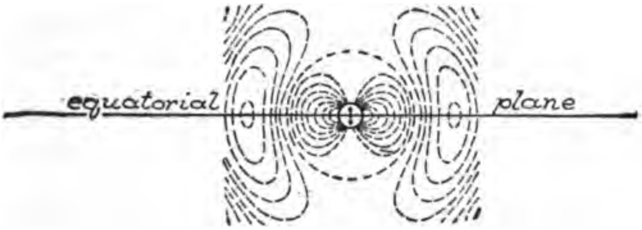

FIG. 1.

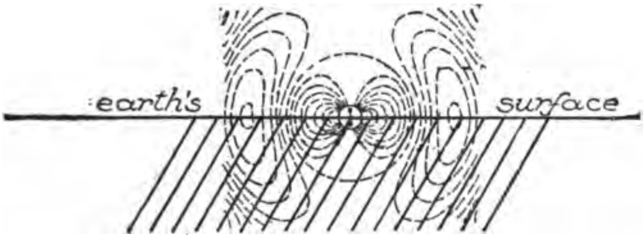

FIG. 2.

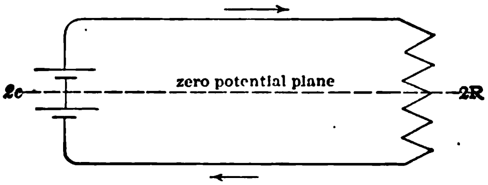

FIG. 3.

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[2] Heaviside, "Electrical Papers," Vol. II, Art. 41, App. A, pp. 323 to 334. Also see footnote to Ab. IX, p. 140, Vol. 1.

unchanged. The surface of the earth is not infinitely conductive, however, and therefore neither the assumptions made in the electrical image theory of the transmitting oscillator of wireless telegraphy nor the electrical image theory of the grounded telephone line are completely justified,[3] though the conditions of the theory may be more nearly approximated in the case of wireless telegraphy, as will become apparent later.

Before proceeding to a consideration of a more comprehensive theory, some of the more obvious conclusions to be drawn from this theory may well be stated. These are:

1). The waves which emanate from the vertical oscillator are horizontally polarized electromagnetic waves.

2). The energy of these waves will diminish as the square of the distance from the oscillator if the surface of the earth be assumed to be flat.

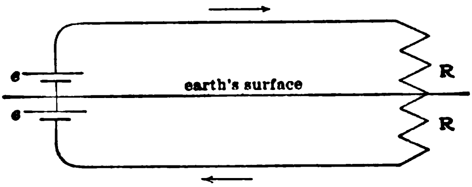

FIG. 4.

3). The energy of the waves is greatest at the earth's surface and diminishes gradually as the point of observation is raised above the earth's surface.

4). The waves do not induce currents in the earth's surface except when the surface deviates from the equatorial plane of the system formed by the vertical oscillator and its electrical image.

5). At points where the earth's surface is at an angle to the equatorial plane of the system formed by the oscillator and its electrical image, the currents which will be induced in the earth's surface tend to bend the wave front at the earth's surface into a position normal to that surface.

6). In consequence of the tendency of the wave front at the earth's surface to maintain itself normal to that surface, the waves will not necessarily travel in straight lines, but will tend to follow the earth's surface, whatever be its contour.

7). Owing to the fact that when the waves meet irregularities

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[3] Heaviside, Vol. II, pp. 220 to 221. Vol. II, pp. 302 to 307.

in the earth's surface, currents are developed in that surface which dissipate a portion of the energy of the waves,·the energy of the waves will in general be better conserved when the transmission takes place over the surface of the sea than when it takes place over land, and more particularly when the land is mountainous or heavily wooded.

The first four consequences of the electrical image theory, above cited, follow directly from the ordinary theory of the Hertz oscillator, while the sixth and seventh consequences cited above are self explanatory. It therefore remains to consider the fifth consequence. For this purpose it will be sufficient to consider what happens to the wave front when a plane-polarized electromagnetic wave falls upon a conducting surface inclined at a definite angle to the plane of the electric force and at a definite angle to the plane of the magnetic force. Under those conditions only that component of the electric force which is parallel to the conducting surface is effective in producing a current in the surface, and the energy of this component of the electric force is therefore dissipated or redistributed, partly in the form of heat in the surface and partly in a reflected wave which travels off in a direction normal to the surface.

The remainder of the electric force of the primary wave at the conducting surface is therefore normal to that surface.

That component of the magnetic field at the conducting surface which is normal to that surface likewise tends to develop a current in the surface, and its energy is likewise redistributed in the form of heat and in the production of a reflected wave. The remaining magnetic force of the primary wave at the conducting surface is therefore parallel to that surface. The direction of motion of the primary wave must be normal both to the magnetic force and to the electric force, and will therefore be parallel to the conducting surface. It follows, therefore, that the electromagnetic waves of wireless telegraphy emanating from a vertical oscillator grounded at its lower extremity will pass over and around hills and other irregularities in the surface of the earth, and that they will also follow the general curvature of the earth.

The electrical image theory lends itself to the explanation of most of the phenomena of wireless telegraphy in a gross and qualitative way, for it is not in general a very difficult task to make the surface of the earth in the immediate neighborhood of the oscillator highly conductive, and at greater distances from the oscillator the current-density in the surface of the earth is so slight that the conductivity need itself be but slight in order to guide the waves without great loss of energy. This theory is, however, ill adapted to give quantitative results, and particularly the class of quantitative results most desired by the wireless telegraph engineer, for he is as much, if not more, interested in the currents and potential in the vertical oscillator as he is in the field surrounding the oscillator. Moreover, the vertical oscillators best adapted for wireless telegraph purposes are quite different from the Hertz dumb-bell oscillator, and the field produced by the electrical oscillations of a system formed of one of these oscillators and its electrical image would in many instances be difficult to predetermine.

Some roughly quantitative results which may be predicted by this theory are: The rate of radiation of energy is *caeteris paribus* proportional to the square of the length of the oscillator, the square of the quantity of electricity set in motion in the oscillator and the fourth power of the frequency of the oscillations.

If we assume that the receiving vertical oscillator is exactly similar to the transmitting oscillator, and is as good an absorber as it is a radiator, then the energy received should be directly proportional to the fourth power of the length of the oscillators and inversely proportional to the square of the distance separating them, and we should therefore expect that with a receiver of a given sensitiveness, i. e., requiring a given amount of energy to operate it, the distance to which transmission could be carried on between these two stations would *caeteris paribus* be proportional to the square of the lengths of the oscillators at the two stations.[4]

PART II.—WORKING THEORY.

When the effects of radiation may be neglected, it is in general not excessively difficult to predetermine the electrical vibrations in simple electrical systems. The problem is then much the same as that of determining the mechanical vibration of mechanical systems, and the modes of attacking such problems have been exhaustively treated and are to be found collected in "The Theory of Sound," by Lord Rayleigh, and in "Electrical Papers" and "Electromagnetic Theory," by Mr. Oliver Heaviside.

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[4] This relation has been observed empirically by Mr. Marconi, and is termed "Marconi's law," by Prof. Fleming.

In wireless telegraphy, however, the damping of the vibrations in the vertical oscillator is almost wholly due to the radiation of energy from the oscillator and the effect of this radiation can not be neglected whether the oscillator considered be a transmitting or a receiving oscillator. Much useful information may be gained however by the use of the same mathematical methods in treating those cases which involve radiation as are applicable in the study of cases with no radiation, and in order to illustrate this point, a very simple system may first be considered.

Let a source of e.m.f. be connected in a straight uniform wire at a point distant (a) from the end of the wire, which end shall be assumed to be insulated, and let the wire extend to infinity on the other side of the source. Such a system is illustrate ddiagramatically in Fig. 5.

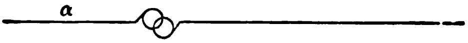

FIG. 5.

In order to exclude the possibility of radiation from this wire, it may be assumed to lie in the axis of a perfectly conducting cylindrical shell. The conductor will then have uniformly distributed resistance, inductance, leakage and permittance as in the case of a single-wire cable. If now the e.m.f. of the source vary abruptly by changing from one constant value to another, two waves of potential and current will be developed in the wire. This, of course, means two waves of electric and magnetic force about the wire. One of these waves will travel off from the source to infinity along the wire, carrying with it a portion of the energy developed by the source, while the other wave travels from the source to the insulated terminal of the wire, is there reflected and returns along the wire past the source and on to infinity along the wire, taking with it the remainder of the energy developed by the source with the exception of that which has been converted into heat in the wire and dielectric.

The distance apart of the two waves as they travel off to infinity will be four times the distance from the source to the insulated end of the wire, or if the distance between the two waves' fronts be designated by λ, then

$$\lambda = 4\,a.$$

It will be readily seen that the infinite wire to the right of the source shown in the system illustrated in Fig. 5 draws off the energy from the source and the rest of the system in much the same way as that in which the conducting surface of the earth is supposed to draw off the energy from the vertical oscillator in the electrical image theory considered in Part I of this paper. The wire to the left of the source may therefore be likened to the vertical oscillator and the infinite wire to the right may be likened in its function to the infinite conducting plane of that theory.

The operational solution of the problem just considered in the case of pure diffusion has been given by Mr. Heaviside[5] who also shows how such operational solutions may be readily converted into the ordinary algebraic form, both in the case in which the impressed e.m.f. varies as a simple harmonic function of the time, and in the case in which it abruptly changes from one constant value to another.

Let the impressed e.m.f. be e. Let the resistance, inductance, leakage conductance and permittance per unit of length of the wire be respectively R, L, K and S.

Then if distances along the wire be measured from the insulated end of the wire and be designated by x, the potential for points to the right of the source will be:

$$V_1 = \frac{e}{2}\left(\varepsilon^{-q(x-a)} - \varepsilon^{-(a+x)}\right)$$

and for points to the left of the source the potential will be[6]:—

$$V_2 = -\frac{e}{2}\left(\varepsilon^{-q(a-x)} + \varepsilon^{-q(a+x)}\right)$$

where

$$q = \left\{(K + Sp)(R + Lp)\right\}^{\frac{1}{2}}$$

$$\text{and } p = \frac{d}{dt}$$

The corresponding currents are:

$$C_1 = \tfrac{1}{2}\, e \sqrt{\frac{K + Sp}{R + Lp}}\left(\varepsilon^{-q(x-a)} - \varepsilon^{-q(a+x)}\right)$$

to the right, and

$$C_2 = \tfrac{1}{2}\, e \sqrt{\frac{K + Sp}{R + Lp}}\left(\varepsilon^{-q(a-x)} - \varepsilon^{-q(a+x)}\right)$$

to the left.

[5] Heaviside. "Electromagnetic Theory," Vol. II, Chap. VI, Sec. 255, and more generally at Sec. 259.

At the source the current is:

$$C_0 = \tfrac{1}{2}\, e \sqrt{\frac{K + Sp}{R + Lp}} \left(1 - \epsilon^{-2qa}\right)$$

At the source, the potential on the right and left of the source is:

$$V_{01} = \tfrac{1}{2}\, e \left(1 - \epsilon^{-2qa}\right)$$

to the right, and

$$V_{02} = -\tfrac{1}{2}\, e \left(1 + \epsilon^{-2qa}\right)$$

to the left.

The resistance operator of the wire measured from the source to the right is:

$$Z_1 = \frac{V_{01}}{C_0} = \sqrt{\frac{R + Lp}{K + Sp}}$$

while the resistance operator measured to the left from the source is:

$$Z_2 = \frac{V_{02}}{C_0} = -\sqrt{\frac{R + Lp}{K + Sp}}\, \frac{1 + \epsilon^{-2qa}}{1 - \epsilon^{-2qa}}$$

If e be a simple harmonic function of the time and of frequency $\frac{n}{2\pi}$, it is sufficient to substitute ni for p in the above expressions in order to algebraize them.

In this case, therefore,

$$Z_1 = \left(\frac{RK + LS n^2}{K^2 + S^2 n^2} + in \frac{KL - RS}{K^2 + S^2 n^2}\right)^{\frac{1}{2}}$$

which shows that so far as the currents and potential in the rest of the system are concerned, the infinite length of wire to the right of the source may be replaced by any device having dissipative resistance—

$$\left\{\frac{1}{2\,(K^2 + S^2 n^2)} \left(\sqrt{(R^2 + L^2 n^2)(K^2 + S^2 n^2)} + RK + LS n^2\right)\right\}^{\frac{1}{2}}$$

and reactance

$$\left\{\frac{1}{2\,(K^2 + S^2 n^2)} \left(\sqrt{(R^2 + L^2 n^2)(K^2 + S^2 n^2)} - RK - LS n^2\right)\right\}^{\frac{1}{2}}$$

such device being grounded as shown in Fig. 6.

Another arrangement which is the exact equivalent of the systems shown in Figs. 5 and 6 is shown in Fig. 7.

If the wire be of copper and the frequency of e be sufficiently great, a condition always present in the vertical oscillators of wireless telegraphy, Z_1 reduces to $\left(\frac{L}{S}\right)^{\frac{1}{2}}$ or by the relation $S = \frac{1}{Lv}$ it further reduces to Lv, where v is the velocity of light.

Under these conditions, the device A of Figs. 6 and 7, which takes the place of the infinite wire to the right of the source in Fig. 5, becomes a simple resistance of value Lv.

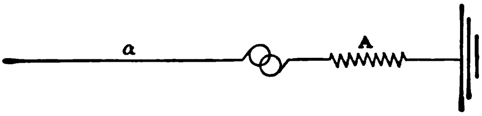

FIG. 6.

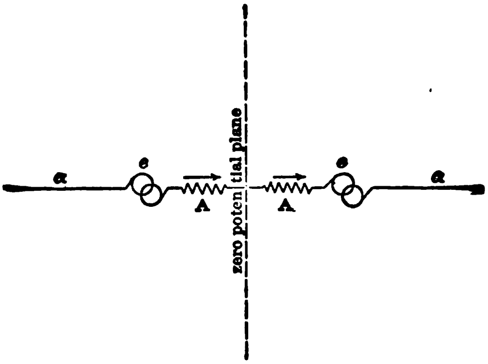

FIG. 7.

This resistance is such as to completely absorb the energy of the waves which emanate directly from the source, and of those which are reflected from the insulated end of the wire to the left of the source. It corresponds exactly, therefore, in its reaction on the rest of the system, to the reaction produced by the infinite extension of the wire to the right of the source in drawing away the energy from the rest of the system. It may be likened to the reaction produced on the system by the complete radiation of its energy in each half period.

To illustrate the application of the foregoing considerations to an oscillator of known form, they may be employed to determine the relation between the impressed force and current in the Hertz dumb-bell oscillator.

In the case of this oscillator the energy radiated per second is $\frac{\Phi^2 n^4}{3 v^3}$ where Φ is the maximum electrical moment of the oscillator expressed in absolute electrostatic units. The amplitude of the current is $\frac{\Phi n}{2 a}$ in the same units, $2a$ being the length of the oscillator; therefore, the value of the resistance which must be conceived to be placed in the oscillator in order to simulate the effect of radiation from the oscillator is $\frac{8 a^2 n^2}{3 v}$ in absolute electromagnetic units, or $\frac{8 a^2 n^2}{9 \times 10^{19}}$ ohms. The oscillator may now be treated as if it were a circuit from which there is no radiation, but having resistance

$$2 R a + R^1 = 2 R a + \frac{8 a^2 n^2}{3 v},$$

inductance

$$L^1 + 4 a \left(\log_e \frac{4 a}{\rho} - \frac{3}{2}\right)$$

and permittance $S^1 = \frac{r}{2 v^2}$, where ρ is the radius of the wire connecting the two spheres of the oscillator and r is the common radius of the spheres. If then e_0 be the amplitude of the impressed simple harmonic force which maintains the oscillations of periodicity $n = \frac{2 \pi}{T}$ and C_0 be the amplitude of the resulting current:

$$e_0 = \left\{ 2 (R a + R^1)^2 + \left(L^1 n - \frac{1}{S^1 n}\right)^2 \right\}^{\frac{1}{2}} C_0$$

which suggest the more general expression

$$e = \left(2 R a + L^1 p + \frac{1}{S^1 p} - \frac{8 a^2}{3 v} p^2\right) C.$$

Where, as before, p stands for the operation of differentiation with respect to time, p^{-1} for the inverse operation of integration with respect to the time, and where R is the true dissipative resistance per unit of length of the wire connecting the spheres of the oscillator. It should be carefully noted, however, that the mathematical solutions so far obtained for the field of force about a Hertz oscillator are only applicable when the length of the oscillator is a small fraction of one-half of the length of the wave radiated by it into space. When this condition is fulfilled, the oscillator may be regarded as a straight current element of length $2a$, the current at every point of which is $\frac{\Phi}{2}\frac{n}{a}$. The expressions for the field at great distances from the oscillator are then applicable as are therefore also the expressions for the energy radiated. Since a straight linear oscillator is the equivalent of an infinite number of such current elements varying in lengths from zero to the full length of the oscillator, the field at a distance from such an oscillator may be determined as the vector sum of the fields produced by the separate uniform current elements.

By considering the straight linear oscillator as composed of a limited or finite number of uniform current elements, the field at a distance from the oscillator and the energy radiated may be determined to any desired degree of precision for any given or assumed distribution of current along the oscillator. The value of R^1, or what may be termed the resistance equivalent of the radiation, may then be determined and the relation of the impressed e.m.f. to the currents and potentials along the oscillator may thereafter be treated as if there were no radiation from the oscillator, as in the case of the Hertz oscillator considered above.

The exact predetermination of the distribution of current and potential in a linear oscillator consisting of a straight wire of length $2a$ alone in space, or of a straight wire of length a normal to the earth's surface and connected to the earth at its lower extremity, presents grave difficulties which as yet have not, as far as I am aware, been completely overcome. Fortunately, however, a great deal may be learned about the behavior of such oscillators by treating the problem upon the assumption that the waves of potential and current travel along the conductor of the vertical oscillator with a constant velocity v.

The distribution of current and potential in a straight wire grounded at its lower extremity through a source of e.m.f. e and through a system A whose resistance operator is Z_0, as illustrated in Fig. 6, may next be considered under the above-mentioned assumption. In this instance it will be convenient to regard distances as measured from the earthed terminal of the oscillator. The circuital operations for the wire are then:

$$-\frac{dV}{dx} = Lp\,C \text{ and } -\frac{dC}{dx} = Sp\,V$$

from which flow

$$\frac{dV^2}{dx^2} = \frac{p^2}{v^2} V \text{ and } \frac{d^2C}{dx^2} = \frac{p^2}{v^2}\,C.$$

The most general solution of these equations is:

$$V = A \cosh\frac{p}{v}x + B \sinh\frac{p}{v}x$$

$$C = -\frac{1}{Lv}\left(B \cosh\frac{p}{v}x \;\; B\,A \sinh\frac{p}{v}x\right)$$

$$\text{at } x = a,\; C = o$$

$$\therefore B = -A \tanh\frac{p}{v}a$$

$$\text{at } x = o,\; V_0 = A \text{ and } C_0 = \frac{A}{Lv}\tanh\frac{p}{v}a$$

$$\frac{V_0}{C_0} = Lv \coth\frac{p}{v}a.$$

This is the resistance operator measured from the source in the direction of the insulated end of the wire and shall be designated by Z.

It follows that

$$C_0 = \frac{e}{Z + Z_0}$$

$$\therefore A = \frac{e\,Z}{Z + Z_0} \text{ and } B = -\frac{e\,Lv}{Z_0 + Z}$$

$$V = \frac{e}{Z_0 + Z}\left(Z \cosh\frac{p}{v}x - Lv \sinh\frac{p}{v}x\right)$$

$$C_0 = \frac{e}{Lv\,(Z_0 + Z)}\left(Lv \cosh\frac{p}{v}x - Z \sinh\frac{p}{v}x\right).$$

In the simple harmonic regime $p = in$ and the hyperbolic functions are converted into the corresponding circular functions.

The chief interest to the engineer lies in the functions Z and Z_0, and more particularly in the former which becomes

$$-Lv \cot \frac{n}{v} a \text{ or } -\frac{1}{Sv} \cot \frac{n}{v} a$$

We see that Z vanishes when $n = m \cdot \frac{\pi v}{2a}$, where m is an odd integer. This corresponds to the case of $m\lambda = 4a$ where λ is the length of the waves on the wire. For the fundamental or gravest mode of vibration of the oscillator, $m = 1$ and $\lambda = 4a$.

It appears, therefore, that for oscillations graver than the fundamental of the oscillator formed by the wire *per se* and its electrical image, the reactance Z is negative, or a capacity or permittance reactance, whereas for periodicities higher than that of such fundamental the reactance of the oscillator becomes positive, or an inductance reactance. In other words, the reactance of the wire measured at the source or driving point of the system may be the equivalent of a condenser of capacity,

$$S^1 = \frac{1}{Lvn} \tan \frac{n}{v} a = \frac{Sv}{n} \tan \frac{n}{v} a$$

or of an inductance,

$$L^1 = \frac{Lv}{n} \cot \frac{n}{v} a = \frac{1}{Sv\,n} \cot \frac{n}{v} a$$

depending upon whether $\cot \frac{n}{v} a$ is positive or negative respectively.

Curve *I* (Fig. 8) shows the variation of the reactance Z, i. e., the reactance of the wire a of Fig. 6 *per se* for different periodicities n of the impressed force.

Curve 2 (Fig. 8) shows the equivalent capacity and curve 3 the equivalent inductance of the same wire for different values of the periodicity n of the impressed force.

With regard to the resistance operator of the system A of Fig. 6, if this be a simple dissipative resistance R_0 then $Z_0 = R_0 + R^1$. If if be coil of resistance R_0 and inductance L_0, $Z_0 = R_0 + L_0\,p + R^1$. If there be a condenser of permittance S_0 in sequence with the coil then $Z_0 = R_0 + L_0\,p + \frac{1}{S_0 p} + R^1$, and if the condenser be in parallel with the coil, $Z_0 = \left(\frac{1 + R_0\,S_0\,p + L_0\,S_0\,p^2}{R_0 + L_0\,p}\right)^{-1} + R^1$

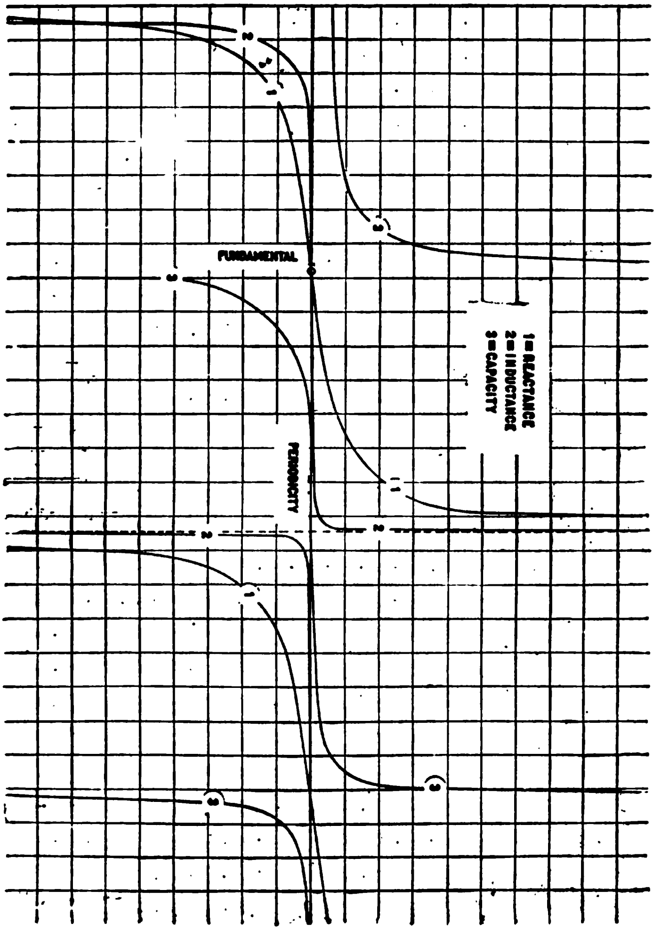
FUNDAMENTAL
PERIODICITY
1=REACTANCE
2=INDUCTANCE
3=CAPACITY
1
2
3

Fig. 8.

In every case the resistance equivalent of radiation must be added to the resistance operator of the system A. For the high values of the time rate of change of current employed in wireless telegraphy,

$$Z_0 = R^1 + R_0$$
$$Z_0 = R^1 + L_0 p$$
$$Z_0 = R^1 + L_0 p + \frac{1}{S_0 p}$$
$$\text{or } Z_0 = R^1 + \left(R_0 \frac{S_0}{L_0} + S_0 p + \frac{1}{L_0 p}\right)^{-1}$$

for the four cases considered above.

For more complex systems the resistance operator may be readily determined by the simple operational method devised by Mr. Oliver Heaviside. The algebraizing in the case of a simple harmonic regimen is also easily accomplished by the substitution of ni for p.

The foregoing treatment applies more specifically to a transmitting linear oscillator. In the case where the oscillator is employed for receiving, the circuital equations become:

$$E - \frac{dV}{dx} = LpC \text{ and } - \frac{dC}{dx} = s p V$$

in which E is the induced e.m.f. per unit of length of the wire.

From these equations result

$$\frac{d^2 V}{dx^2} = \frac{p^2}{v^2} V \text{ and } \frac{d^2 C}{dx^2} = \frac{p^2}{v^2} C - Esp.$$

The general solution is:

$$V = A \cosh \frac{p}{v} x + B \sinh \frac{p}{v} x$$

$$C = \frac{1}{Lp} \left\{ E - \frac{p}{v} \left(B \cosh \frac{p}{v} x + A \sinh \frac{p}{v} x\right) \right\}$$

$$\text{at } x = a,\ C = o \therefore B = \frac{E - A \frac{p}{v} \sinh \frac{p}{v} a}{\frac{p}{v} \cosh \frac{p}{v} a}$$

$$\text{at } x = o,\ V_0 = A = - Z_0 C_0$$

$$\therefore C_0 = E \frac{\cosh \frac{p}{v} a - 1}{Lp \cosh \frac{p}{v} a + Z_0 \sinh \frac{p}{v} a}.$$

In the foregoing the explicit assumption has been made that the inductance and capacity are uniformly distributed along the oscillator and that the velocity of propagation of the waves along the oscillator is equal to that of light. This was done in order to simplify the mathematical analysis and to present the theory in a concrete and easily understood form; but these conditions do not completely limit the applications of the formulas deduced, for it is capable of demonstration that even when L and S are functions of x, provided only that the ratio of $\frac{L}{S}$ be independent of x, then, though the velocity of the waves will vary from point to point along the oscillator, yet there will be no reflection of the waves except at the ends of the wire, and the most important function, namely, Z_1, the resistance operator of the oscillator, does not change its form. It is sufficient under these circumstances to substitute a^1 for a in the expressions for Z_1 and C_1 where $\frac{a}{v} = \frac{a^1}{v^1}$, v^1 being the average velocity of the waves along the oscillator.

Another important case which may occur is that in which L and S are both functions of x but in which the product LS is constant. Under these conditions, the quantity $\frac{1}{\sqrt{LS}}$, which is of the nature of a velocity, is constant along the oscillator, but reflection takes place at every point, giving rise to a variable wave velocity. The solution in this case is no longer of the same form as that considered above, but may be readily obtained in the form of cylindrical harmonics provided L and S are respectively proportioned to x^m and x^{-m} where m is any quantity integral or fractional, positive or negative.

Some writers have regarded the vertical oscillator as a simple capacity area. This is obviously inadmissible.

The first approximation to a more complete theory is to regard the vertical oscillator as a capacity area connected to the earth through an inductance. This mode of treatment corresponds to the first approximation to the theory of the transverse vibration of a stretched string in which the mass of the string is assumed to be collected at its center.

The theory here outlined corresponds to the second approximation to the complete theory of the transverse vibrations of a stretched string in which the mass is assumed to be uniformly distributed along the length of the string.

It is not to be expected that the results of experiments should verify in all details the conclusions to be drawn from the theory which has been presented, but all the most important characteristics of the behavior of a vertical oscillator as indicated by this theory are found to be confirmed by certain experiments, the results of which are presented in the form of curves in Figs. 9, 10, 11 and 12.

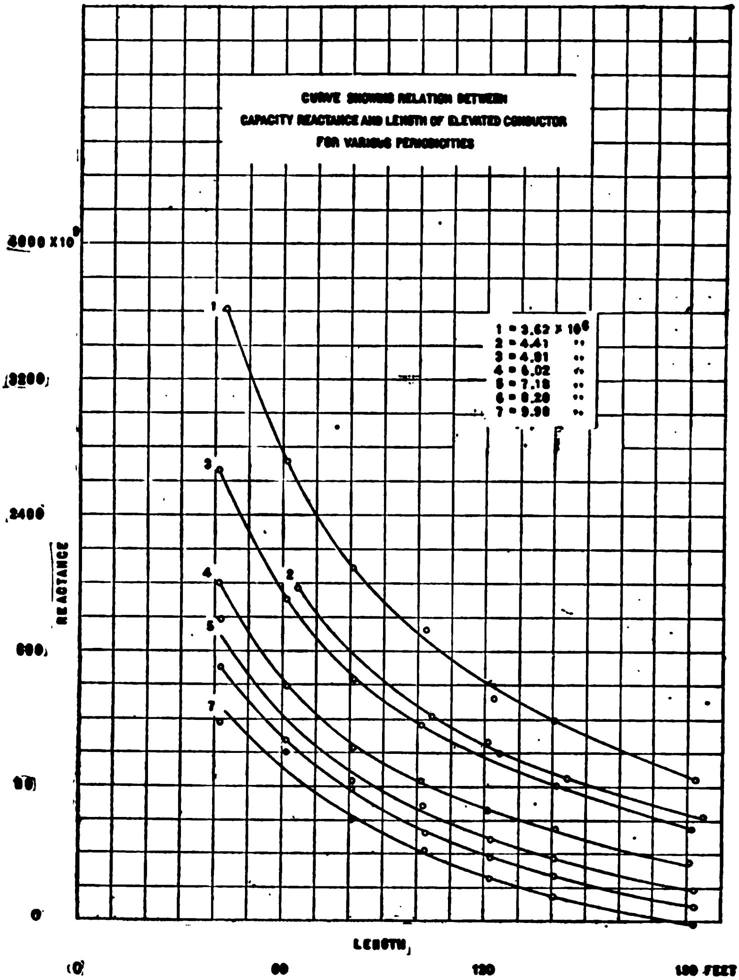

FIG. 9.

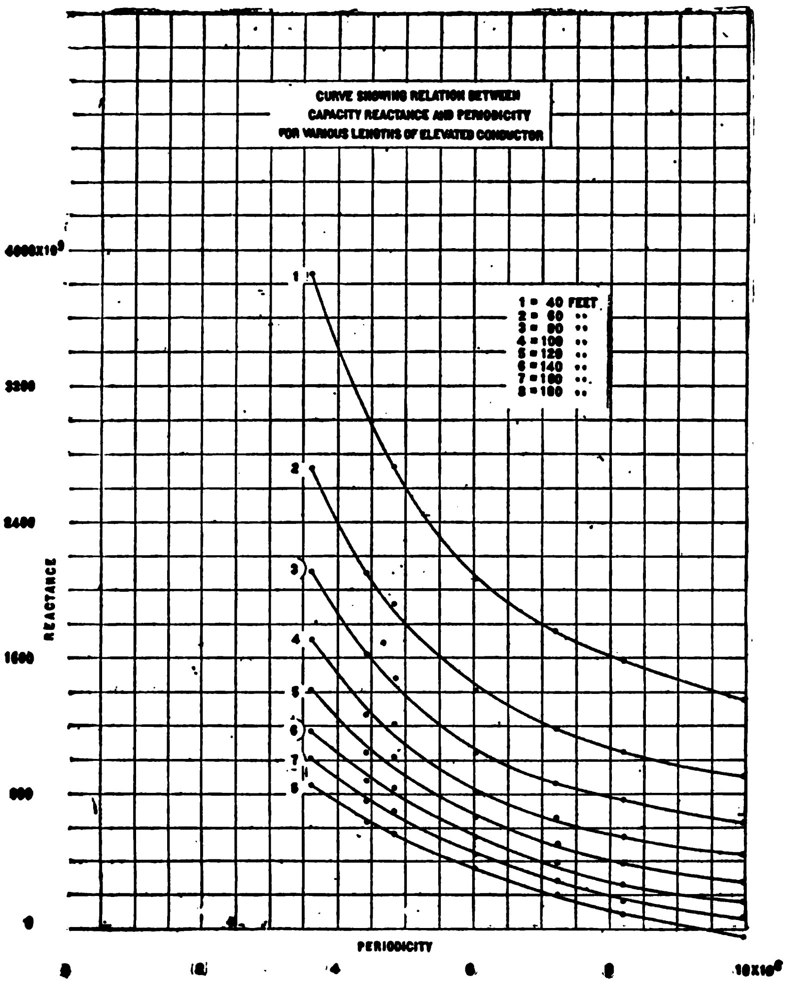
CURVE SHOWING RELATION BETWEEN
CAPACITY REACTANCE AND PERIODICITY
FOR VARIOUS LENGTHS OF ELEVATED CONDUCTOR
1 = 40 FEET
2 = 60 "
3 = 80 "
4 = 100 "
5 = 120 "
6 = 140 "
7 = 160 "
8 = 180 "
1
2
3
4
5
6
7
8
REACTANCE
4000×10^3
3200
2400
1600
800
0
PERIODICITY
0
2
4
6
8
10×10^6

FIG 10.

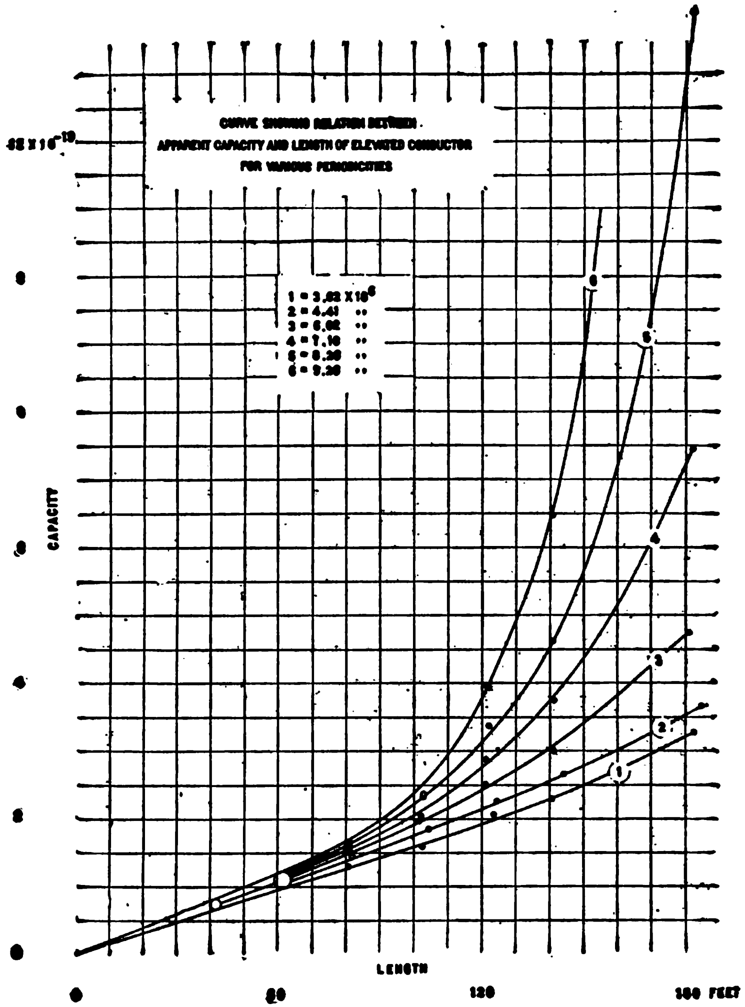
CURVE SHOWING RELATION BETWEEN
APPARENT CAPACITY AND LENGTH OF ELEVATED CONDUCTOR
FOR VARIOUS PERIODICITIES
1 = 3.62 X 10^6
2 = 4.41 "
3 = 6.02 "
4 = 7.18 "
5 = 8.28 "
6 = 9.28 "
12 X 10^-10
CAPACITY
LENGTH
0
80
120
160 FEET
1
2
3
4
5
6

Fig. 11.

These curves need no explanation, the title of each showing sufficiently clearly its purport.

Figs. 11 and 12 are the most instructive, showing as they do very clearly the increase of the apparent capacity of the oscillator as the frequency of the oscillations is gradually increased and the tendency of this apparent capacity to become infinite as the frequency of the oscillations approach the frequency of the fundamental of the oscillator *per se.*

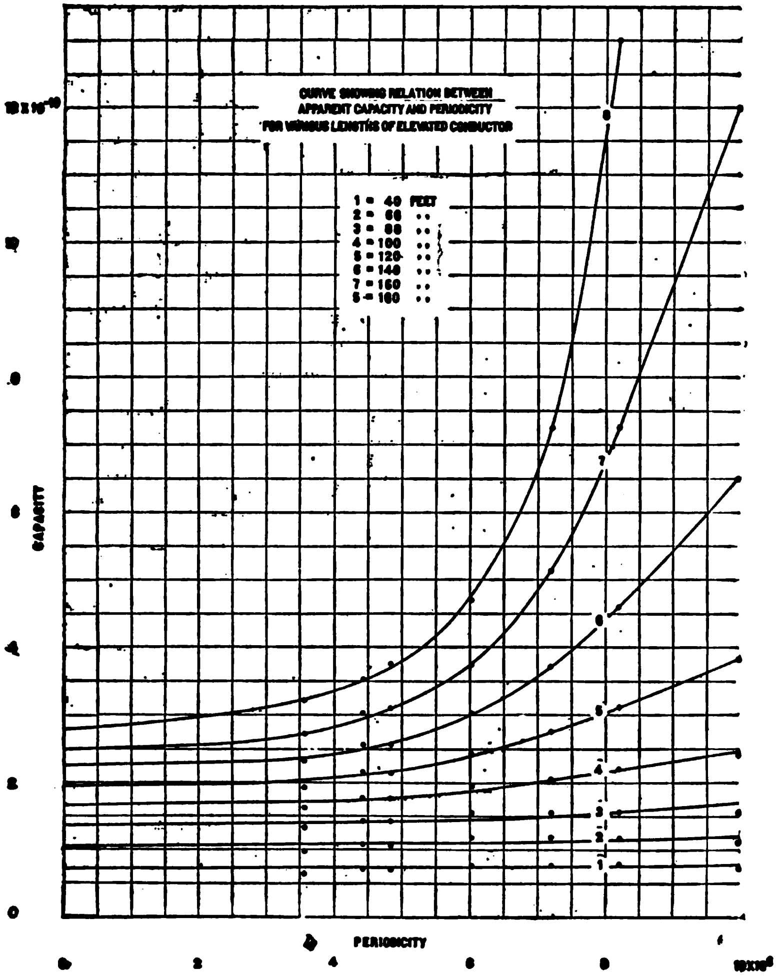

FIG. 12.

DISCUSSION.

CHAIRMAN JONES: This is a valuable paper, and I trust you will feel free to comment upon it. There are some gentlemen present who can say something that will be of value in the record.

Dr. A. G. WEBSTER: I have listened to this paper with very great interest indeed. Everybody knows how very difficult it is to get quantitative information on this subject. Everybody who has touched the theory knows how almost impossible it is, and I suppose will be for many years, to have a correct mathematical theory of the method of the production and propagation of these waves. What is necessary for the practical man is something which shall simplify the theory; in other words, an engineering method of proceeding. This, it seems to me, Mr. Stone has made a very important step toward giving us. It is interesting to see before us a formula of the sort he has shown us, and it is always interesting to see the experimental results which we have had presented to us with great fullness and apparently with the greatest regularity. It seems to me this is a very successful step in the right direction, and I do not see how any practical man can expect to get important results in the important matter of making wireless messages secret until he goes at his work guided by mathematical treatment of this sort.

Dr. LEE DE FOREST: I wish to indorse the remarks of the last speaker on the value and painstaking care represented by this work of Mr. Stone. Perhaps the most interesting feature that he brought out was the question of the quantitative dissipation of energy from the source relative to the distance. As applied practically over distances varying from a quarter of a mile to three hundred miles, over land and over sea, I have found no indication whatever that the received energy falls off as the inverse square. In fact, I cannot reconcile that theory with experience. Of course, you all appreciate the practical impossibility of making strictly quantitative measurements from the source of a two-horse power station, where the energy received on a single wire is practically infinitesimal. The nearest we can approximate to it is by the telephone and the human ear trained to make comparisons. The human ear is not a strictly quantitative instrument by any means, and the subjective impression made varies inversely as the energy received in the telephones. I cannot reconcile the theory with practical experiments. I would like to hear from any other gentlemen present if their experience has been in line with my own or to the contrary.

Mr. STONE: I neglected to make a statement in my paper which I had intended to make, namely, that I am extremely obliged to the naval authorities at Washington, and very particularly to Captain Moore, for giving me the use of the 180-foot mast at the Boston Navy Yard, where I made these experiments. I would also like to say that there are a number of curves here on the table which I shall be glad to have any of the gentlemen present examine at their leisure after the meeting. These curves refer to the tuning of vertical wires when the apparatus *A* consists of a coil, shunted by a condenser, and are rather more interesting than those which refer to case where *A* is a simple coil.

Lieut.-Comdr. L. J. Jayne, U. S. N.: With reference to Mr. Stone's remark, I wish to say that the Government is amply repaid for the use of the mast at the Boston Navy Yard, and I hope soon to see a copy of this paper in print, as I expect to get a good deal of valuable information from it.

Mr. John Hesketh: In reference to the remark made as to the apparent discrepancy between what was assumed to be the theoretically correct values of the energy received in the antennæ and the actual results obtained when using a telephone receiver and the ear for quantitative measurements, I do not doubt that Dr. De Forest will grant that the telephone receiver and the ear in conjunction are most unreliable as quantitative measuring instruments. Results obtained by those means cannot be taken as either confirming or contradicting theory, unless the telephone received sound is very, very widely different in two cases under comparison. I believe that recently a quantitative method has been tried by Mr. Duddell, of oscillograph fame, and that the results which are strictly quantitative will shortly be published.

Chairman Jones: We have present with us Dr. Lee De Forest, who will present a paper upon the subject of "Electrolytic Receivers in Wireless Telegraphy," and whom I now have the honor of introducing to you.

ELECTROLYTIC RECEIVERS IN WIRELESS TELEGRAPHY.

BY DR. LEE DE FOREST.

In the preparation of this paper I have made use of one upon the same subject, which the writer recently read before the Franklin Institute, as well as of laboratory notes of Dr. J. E. Ives, and those of Mr. Greenleaf W. Pickard, collaborators in this research work.

The form and nature of the ordinary filings-tube coherer, as applied today in wireless telegraphy, is fairly familiar. Branley discovered, in 1891, that the effect of electrical oscillations upon a body of metallic filings was to produce a marked increase in the conductivity of the mass, a conductivity which persisted until the particles were broken apart again by mechanical jar. Although Varley, Hughes, Onesti and others had previously noted this phenomenon, none of these investigators had fully appreciated the causes involved, or given to the world of science the benefit of their researches in thorough published reports.

The discovery of the "Coherer," therefore, is rightfully attributed to M. Branley, but to Prof. Popoff, of St. Petersburg, and to Sir Oliver Lodge, of England, must be given the credit of applying the relay and mechanical tapper to the filings tube, the addition of antennal wings, of upright wire and earth connections, and the first steps toward refinement and an appreciation of the possibilities of the new detector as applied to an unborn branch of human enterprise and progress.

The notable work of Marconi in still further adapting the Popoff-Lodge arrangement to commercial requirements resulted in the gradual increase of distance on which aerographic communication was established. Ingenious improvements in coherers by such men abroad as Tissot, Ducretet, Castelli, then by Lodge and Branley themselves, and in this country by Shoemaker, comprise the history of that form of detector.

Enormous is the bulk of research matter published regarding the coherer. Theories of the action involved have been numerous, but divided chiefly into two schools: First, that of Lodge, who demonstrated an actual welding together of metallic filings, after the same had been drawn into contract by the electrostatic attraction of the opposite charges induced upon the faces of the filings; and, second, that of Branley, who ascribed the action to a breaking down or puncturing by minute sparks of the dielectric film (either gaseous or a metallic oxide), which he held must exist between opposing surfaces of the filings.

The result of the years of investigation, which have followed the early work of these two pioneers, proves that in a measure both were right. The Branley effect undoubtedly exists and affords a satisfactory explanation of the self-decohering phenomena observed in the microphone type of auto-coherers. These insulating oxide or gaseous films inevitably form and cling to the surface of any metallic particles not inclosed in absolute vacuum, and where strictest care is not taken to prevent. They are, moreover, elastic, self-healing; and unless the electric impulses are of excessive violence, so that adjacent particles are actually welded firmly together, the original high resistance is automatically restored upon cessation of the electric impulse. This is notably the case when the elements of the radio-conductor are of carbon, hardened steel, carbon-mercury, aluminum, etc., where the formation of this resisting film is easily accomplished, or where, amid the minute roughnesses of the carbon surface, the adhesion of a gaseous film is made more easy.

If, however, the coherer consist of filings of some soft metal of relative low-fusing point — silver, gold, lead — the Lodge cohering effect through actual welding follows upon the Branley action, making the final fall of resistance far more marked, and necessitating a vigorous mechanical jar to break up the cohered filings and restore sensitiveness.

The filings tube frequently shows a change from hundreds of thousands of ohms down to a few ohms under the influence of exceedingly weak electrical impulses. It is on account of this enormous change in conductivity of the filings tube coherer that this form has been the standard used almost exclusively in the coherer systems of wireless telegraphy.

The result of all this has been necessarily a system employing delicate relays, tapping-back adjuncts, complications of apparatus requiring frequent and careful adjustments, a skill and delicacy on part of the receiving operator seldom found outside of the physics laboratory — least of all upon a man-of-war.

Again, despite numerous claims for speeds of word transmission by coherer systems, I have yet to see proof of anything exceeding 12 to 15 words per minute, while the actual everyday speed attained seldom exceeds half that amount.

For commercial applications of wireless telegraphy this pathetic speed limitation of itself renders the filings-tube systems today an impossibility, regardless of any other considerations, such as uncertainty of their action, ill-adaptability to electrical tuning, liability to interference (notably from atmospheric electricity), harmful effects from mechanical vibrations, etc.

Better commercial results are obtained with the auto-coherer, or so-called microphonic contact. Since no tapping-back is required, a relay is superfluous, although the charges of resistance in the auto-coherer are generally so slight, and the normal resistance such a shifting quantity, that no relay capable of operating reliably with the auto-coherer has yet been perfected. A telephone is invariably used today in place of the relay and inker, and, inasmuch as the auto-coherer is usually a quantitative instrument possessed of no critical voltage, its combination with the telephone affords an extremely sensitive wave-detector.

With this arrangement one obtains a word reception limited only by the ability of the operators to send dots and dashes with the transmitter spark and to translate them into words. Consequently, in this country, we find the alternating current of relatively high frequency and excellent regularity of action employed; with an ordinary Morse key, obtaining a speed of 25 to 35 words per minute, instead of the antiquated induction coil with its spluttering, sticking hammer interruper, or its messy, explosive mercury-break; and the pump handle "Zeichengeber," which is considered abroad as a fitting accompaniment to the coherer receiver, and is so well designed to hold down the impatient sender to a sloth sufficient for that form of receiver. As we occasionally have seen in the daily press, the spark-coil, coherer systems are excellently adapted to the trying requirements of a "Chess game by wireless telegraphy."

The auto or microphonic coherer is, however, not well suited to the requirements of close syntony or electrical tuning. This is on account of its variable normal resistance and normal capacity. The device is liable to close up under the effects of severe static discharge, requiring readjustment by tapping, rendering difficult its employment during time of severe atmospheric disturbances and lightning storms. Moreover, its inability to reliably operate by a relay a bell for calling purposes often necessitates the addition of a filings tube for that purpose.

Following this brief review of the field of cohering indicators of electric waves, I will call attention to an entirely distinct line of research leading up to forms of receivers which I believe may well be set in a class by themselves as regards sensitiveness, simplicity and general adaptability to most of the demands which can be made today in the field of wireless telegraphy.

In 1898 the German Neugschwender performed the following experiment: The silverplating of a strip of mirror-glass was divided into two parts by a sharp razor cut, leaving a narrow gap between two silver edges, completely insulating the two sections. Each of the sections was now connected to the terminals of a dry battery, and a telephone and galvanometer inserted in series in the circuit. No current was observed to pass until a film of moisture was deposited upon the slit, either by blowing the breath thereon, or by placing a saturated sponge nearby, or by placing a drop of water directly upon the slit. After a brief period the galvanometer began to show violent and irregular deflections; in the telephone a scratching, bubbling sound was heard, followed shortly by comparative quietness and a stable position of the galvanometer needle, indicating that the resistance of the gap in the silver mirror had been broken down until it measured but a few ohms.

If now electric waves were generated in the neighborhood, as from the spark of an induction coil, the galvanometer showed an increase of resistance in the circuit, while the listener in the telephone heard a humming sound, reproducing that of the induction-coil spark. Upon cessation of the electrical impulses the conductivity of the gap in the mirror instantly reasserted itself, and the sound in the telephone ceased.

Aschkinass, a year after Neugschwender discovered this strange action of the Hertzian waves, noted the same phenomena, the publication of which led the former further to pursue his researches, and to examine the action at the moist edges of the silver electrode under a powerful microscope. His observations thereon, and my own investigations in 1899, coincide in all essentials, and demonstrate that the phenomenon is one of electrolysis due to the combined action of the Hertzian and local currents. They demonstrate, however, several features new to the generally accepted ideas of electrolytic action, and open up lines of speculation and research of unusual interest to the physicist.

The phenomena noted above exist to a more prominent degree with tinfoil electrode in place of silver, and these I shall now attempt to describe. With the telephone to the ear and the eye at the microscope the action, thus doubly observed, affords in fact one of the most fascinating, most beautiful pastimes (as I may well term it) ever granted to the investigator in these fields.

When the local e.m.f. is first applied to the gap, minutest metallic particles, all but invisible, even with a thousand-power lens, are seen torn off from the anode, under the stress of the electric forces, apparently mechanical in action; and these dust-like particles, floating in the fluid, move across to the cathode; some rapidly, some slowly, by strange and grotesque pathways, or directly to their goal. Tiny ferry-boats, each laden with its little electric charge, and unloading its invisible cargo at the opposite electrode, retrace their journeyings, or caught by a cohesive force, build up little bridges, trees with branches of quaint and crystalline patterns.

During this formative period (lasting perhaps for half a minute) the ear hears an irregular boiling sound, and the average deflection of the galvanometer indicates a gradual decrease of resistance, until one or more of these tin trees or tentacles has been built completely across the gap. Then silence ensues until the current across the bridge is suddenly increased, as by the Hertzian oscillation from an electric spark made in the neighborhood, or even from a source of so low frequency as the ordinary 60 cycles alternating current. Instantly all is commotion and change among the tentacles, and especially where these join the cathode. Tiny bubbles of hydrogen gas appear, and enlarging suddenly, break or burst apart the bridges, while the click in the telephone indicates the rupture of the currents' path.

Yet they are persevering — these little pontoon ferrymen — and instantly reform, locking hands and hastening from their sudden rout back to build new paths and chains. So the process continues, the local current re-establishing, the electric oscillations breaking up, its highways of passage, with [illegible]rious bubblings and agitations — a veritable tempest in a microscopic teapot.

The hydrogen gas, having, of course, twice the volume of the oxygen, is most in evidence, and, therefore, the rupture of the tentacle occurs chiefly at its cathodic terminal, and where segregated branches of the tin trees are broken off the bubbles of gas are generally noticed at the cathode. The oxygen, to a large extent, enters into chemical combination with the tin, and after the slit has been used for some time a grayish deposit of stannous oxide may be scraped from the anode.

One fact must be borne in mind, that the fine tentacles (whose diameter, by the way, is of the order of some hundred thousandths of an inch) do not come into actual metallic contact with the anode terminal. A film of electrolyte of almost molecular thickness must exist between the two, conducting normally by electrolytic ionization and conduction, yet easily decomposed and transformed by a sudden increase of current into an insulating gaseous film, the expansion of which still further increases the resistance of the gap.

The nature of this electrolytic action when soft metals, such as tin, silver, lead, are used as anode, and when the distance to the cathode is decreased to the order of 1/100 in. or less, is rather surprising. The electromotive forces needed for electrodeposition from anode to cathode are extremely small, nowhere approaching the critical e.m.f. of polarization of the electrolyte.

Moreover, distilled water, so-called chemically pure glycerine, oils, etc., contain enough of impurities, such as acid traces, to enable them to act here like an electrolytic solution. I have in 10 minutes plated a firm deposit of tin on a gold cathode, using distilled water only and a potential difference not exceeding 1/10 volt.

For the same reasons it is possible to decompose the water films interposed between branches of these tin trees by a very minute difference of potential between; meaning that this electrolytic responder does not necessarily possess a "critical potential," as is common to a coherer. It does not, therefore, cease to respond to electric impulses, the potential of which is less than the e.m.f. of polarization of the electrolyte, as commonly understood.

If now the electrodes be slowly separated from one another, with one or more of the minute tentacles clinging thereto, a counter e.m.f. of polarization may be observed when the distance between the nearest electrodes exceeds a certain small limit. This counter e.m.f. exists whether the electrodes be of like or unlike material or shape.

Upon the first application of the local battery to the terminals of this cell, a temporary flow of current is observed, the resistance of the cell being at first slight, especially if a dilute alkali or acid form the electrolyte. Immediately thereafter, however, the current flow falls almost to nothing, and the counter e.m.f. of the cell asserts itself. This counter e.m.f. is due to the formation of a layer of gas insulating the faces of the electrodes. It means that unless some depolarizing means be added, the local applied e.m.f. must be raised above the opposing e.m.f. of the cell, or above the critical voltage required for the decomposition of the electrolyte.

Now when the cell is placed in the path of the high-frequency electrical oscillations, the effect is found to be a temporary, more or less complete, annulment of the counter e.m.f. of polarization. This effect is scarcely noticeable when the tentacles are made the cathode, but when made the anode so that oxygen is the gas surrounding and insulating the fine tentacles, the effect of the Hertzian oscillation is to decrease to a marked degree the apparent resistance of the cell.

The sensitiveness of the electrolytic cell to this action of the Hertzian oscillations is in a measure proportional to the exposed area of the anode. With such coarse anodes as are furnished by the point of a one-mil platinum wire, the action is extremely sensitive. I am using such in working from a St. Louis Exposition station to Springfield, Ill., 105 miles overland; yet the diameter of these electrodes is 100 times that of the fine tentacles or trees previously described.

Last year a German experimenter, Schlœmilch, reported the discovery of this same effect in what he called "Polarization cells." Anodes having diameters sufficiently small to give great sensitiveness to the responder may be obtained by mechanical means, using the Wollaston wire, having gold or platinum core and a silver sheath wherewith after drawing the whole to a fineness of 2 or 3 mils, the silver sheath is dissolved in concentrated acid, in a manner long known to the arts. The order of diameter thus obtained is comparable to that of the metallic trees built up by electrolytic deposit; and the wire anodes are more stable and better suited to the work in this second type of the electrolytic responder.

Prof. Fessenden maintains that the phenomenon observed in this form of the electrolytic responder is a heat effect, and on that supposition chooses to style this form of receiver a "liquid barreter." His theory is that the Hertzian currents passing from the fine electrode into the electrolytic heat this latter, and, since the thermal coefficient of most electrolytes is negative, such heating would result in a decrease of resistance of the electrolyte. I have been unable, however, to find a single fact warranting such a view.

First of all, the fact that the device is a valve-effect, not indifferent to the direction of applied local potential, but practically inoperative if the tentaode be made negative, shows that the effects obtained are not chiefly I^2R effects, as would be required were the action a heat phenomenon due to the amount of current flowing. Second, that it is a potential-operated and not a current-operated device, possessing a capacity and normally insulating the fine anode. Third, that its action is sensibly unaffected by extremes of temperature, high or low.

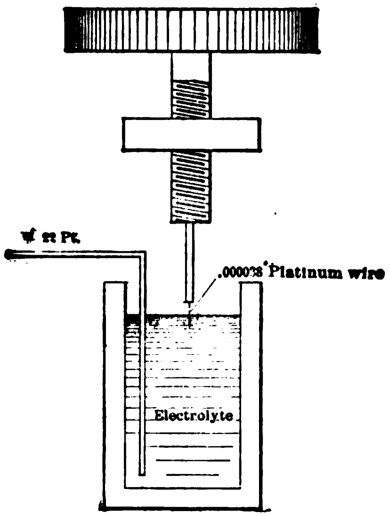

FIG. 1.

Numerous experiments have been pursued with scrupulous care, all of which show that this heat theory is untenable. A few of these I will outline. In these experiments form of the electrolytic cell was employed having the dimensions and constructions shown in Fig. 1.

It was first ncessary to determine quantitatively the effect of the received oscillations upon the local circuit of the detector. Preliminary experiments had shown that the magnitude of this effect depended upon the voltage of the local battery as well as the strength of the received oscillations. It was, therefore, important to determine the resistance changes for a constant intensity of received oscillation with varying battery potentials. For this purpose the circuits shown in Fig. 2 were set up.

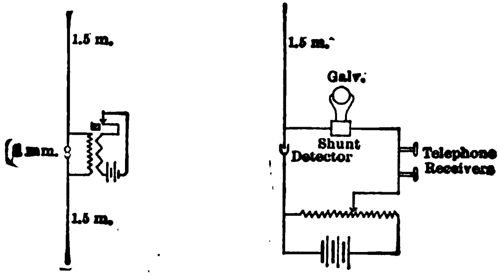

FIG. 2.

Galvanometer readings were taken every 0.2 volt between the limits 0 to 4.5 volts of the normal current flowing through the cell when no oscillations were being received, and the apparent resistance of the cell calculated from this by dividing the voltage of the local battery by the current value. This gave curve 1 of Fig. 3. Curve 2 was obtained in the same way, with the oscillator in operation.

These curves show several points of interest. It is apparent from the curves that the magnitude of the response, that is to say, the ratio of normal resistance to responding resistance, is greatest with low potentials. But the loudness of the sound in the telephone receivers is greater with the higher voltages. The reason for this is apparent when we consider that the intensity of sound in a telephone receiver is proportional to the square of the current variation, or in other words, a great variation of a feeble current does not give the sound that a slight variation of a relatively strong current produces. It so happens, however, that the human ear does not respond to sound in a linear ratio to its absolute intensity, so that the observed increase is more nearly linear than quadratic.

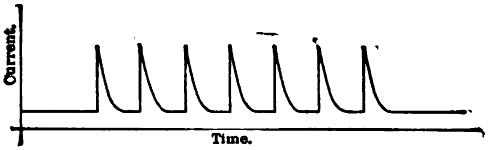

FIG. 3.

Inasmuch as the cell recovers its normal resistance very rapidly it must do this to a certain extent between oscillation groups, so that the curves really represent the integration of the alternating high and low-resistance states over the time of the complete signal. It is probably that the true minimum resistance is several times lower than that given in this curve. Assuming that the recovery of the high resistance is due to polarization of the small electrode, it is evident that if the electrode becomes in any way depolarized, and is then left to itself, repolarization would be very rapid. As the immersed area of the anode is of the order of a millionth of a square inch, the amount of separated gas required to completely polarize it would be infinitesimally small, and could readily be supplied by the decomposition resulting from a current flow of a few micro-amperes for a thousandth of a second. On this assumption the current flow through the cell before, during and after the passage of a group of oscillations would be something as shown in the curve of Fig. 3.

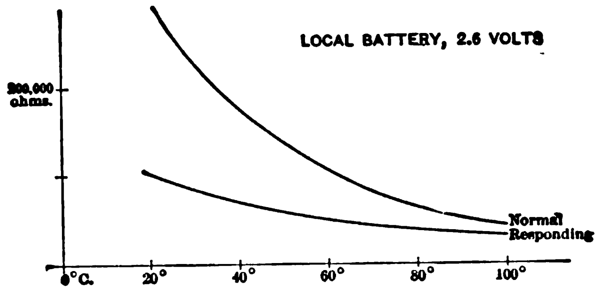

FIG. 4.

The actual observation of this current would require an exceedingly sensitive oscillograph. It is doubtful if our present knowledge of oscillograph construction would enable us to make such an instrument. But our knowledge of the polarization taking place in electrolytic cells with larger electrodes warrants the assumption of very rapid polarization.

Now to determine beyond peradventure that the action of the electrolytic detector is due to a breaking down of polarization, followed by a rapid restoration, several experiments were made under conditions that did not permit of anodic polarization. In one experiment a platinum wire 3 mils in diameter was substituted for the Wollaston wire. This anode gave a fair response when adjusted so that it just touched the surface of the alkaline electrolyte. Substituting for this solution dilute sulphuric acid, a fair response was still observed. The platinum anode was then replaced by an iron wire, also 3 mils in diameter. With this electrode no response could be obtained, even with very strong received oscillations. According to theory, the first action that took place with this electrode was the separation of oxygen at its surface, and the oxidation of the iron. As the oxide thus formed was soluble in the electrolyte it was removed as fast as formed, going into the solution as ferrous sulphate, the anode being rapidly eaten away. The electrode itself acted as the depolarizer in this experiment, preventing the formation of a polarization layer.

In a second experiment another method of preventing polarization was employed. It is well known in electrochemical operations that bright platinum electrodes are readily polarized, an almost infinitesimal amount of separated gas being sufficient. It is stated that the products of the decomposition of one-seventieth of a milligram of water on two platinum plates, each having an area of one square meter, will give an e.m.f. of about 1 volt. In measurements of the conductivity of electrolytes this effect can be practically eliminated by coating the electrodes with platinum black. This is usually accomplished electrolytically, by passing a current backward and forward between the electrodes, the cell being filled with a solution of platinic chloride, containing a trace of lead acetate. In this experiment a platinum wire 1 mil in diameter was used in place of the Wollaston wire. Using an alkaline solution, a very good response could be obtained. The cell was then filled with a dilute platinic chloride solution, and the electrode platinized in the method before mentioned. A very feeble current was used, so that an extremely thin coating was obtained — so thin that when examined under the microscope the diameter of the wire was seen to have been increased by less than 2 per cent. The alkaline solution was then replaced in the cell, and the electrode immersed as before, but no response could be obtained, even when the oscillations were made very strong.

A third experiment was performed, similar to the second, save that a Wollaston wire, thirty-eight millionths of an inch in diameter was used in place of the 1-mil platinum wire. With this wire performing the platinising under the microscope resulted in a coating so thin that the diameter of the wire was increased by only about 10 per cent, or a thickness of two-millionths of an inch. Despite the thinness of the coating the result of this experiment was that of the second; no response being obtained. This experiment has been repeated a large number of times, always with the same result; the thin coating of platinum black either stops the response to the Hertzian oscillations altogether or makes it extremely faint. A strong vigorous response in the telephone may be entirely stopped by a coating of platinum black too thin to visibly alter the diameter of the electrode as seen under a powerful microscope.

Now according to the thermal theory of the electrolytic detector, advanced by Fessenden, the platinizing of the anode should have but little effect, the increase of diameter being so slight that the dimensions of the minute circumscribed sphere or cylinder of liquid would not be greatly altered. Yet the experiments show an absolute cessation of response.

A fourth experiment was performed in direct consideration of the thermal theory. If this theory were correct, it is evident that an electrolytic detector would operate very feebly or not at all when the temperature of the electrolyte was raised to its boiling point. In fact, as any temperature elevation would generate steam, a reversal of effect might be expected, the resistance increasing in the responding condition. The cell of the detector was placed in a paraffin bath, and the temperature raised from that of the room to the boiling point of the electrolytic solution. The temperature was raised very slowly, and the operation of the detector observed with galvomoter and telephone. It was found that the action of the detector was the same at all temperatures, the only effect of the heating being to diminish the counter e.m.f. of polarization, so that a very much lessened potential of the local battery was needed.

The normal and responding resistances of the detector are given in Fig. 5, plotted for constant potential of local battery. If the curve is compared with the curves of Fig. 4, a rather striking similarity will be noticed. The effect of heating the electrolyte is similar to that produced by raising the voltage of the local battery. And although the loudness of the response in the telephone receiver is not increased the detector seems to be more sensitive when heated.

In a fifth experiment dilute nitric acid was used in place of the alkaline solution. The result was in no way different, save that there seemed to be considerable attack upon the anode with the acid near the boiling point.

Look now at another line of proof. It is well known that in general the temperature coefficients of the electrolytes is positive, that is to say, the conductivity of the electrolyte increases with rise of temperature. The conductivity of an electrolyte is dependent upon two factors: (1) The dissociation, and (2) the frictional resistance offered by the solution to the passage of the ions through it. Certain bodies, the weak acids, phosphoric, acetic and hydrofluoric, have negative heats of formation; that is, the heat of dissociation is positive, and, therefore, the dissociation becomes less with increasing temperature. If the temperature coefficient of fluidity either decreases with rise of temperature, keeps constant or increases more slowly than the negative coefficient of dissociation, it is clear that maximum conductivity must be reached at a certain temperature, beyond which any further heating will decrease the dissociation more than it increases the fluidity; and thus on the whole, diminish the conductivity.

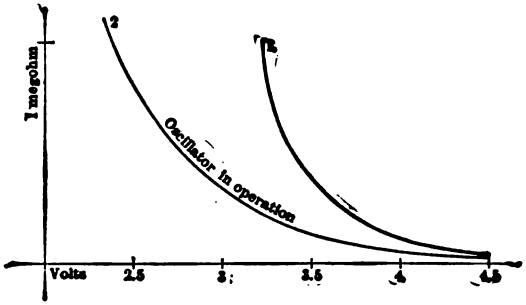

Fig. 5.

Thus in the next experiment an electrolyte with a negative temperature coefficient was used in the detector. This solution was dilute hypophosphorus acid, having a maximum conductivity at about 60 deg. C. Substituting this solution for the alkaline solution a very good response was obtained, the galvanometer showing an increased current when responding, the temperature being maintained at 60–65 deg. C. According to the thermal theory there should have been no response at 65 deg. and above that temperature the current should have decreased.

Again, when the usual alkaline solution was gradually heated to boiling point, no change in the sensitiveness of the wave response could be observed until the violent agitation of the surface due to the boiling destroyed the contact. A 1-mil platinum wire sealed into a glass tube and immersed operates perfectly when the liquid is boiling violently.

From these and many other proofs it is, therefore, evident that the wireless telegraph receiver employing a small electrode or electrodes immersed in an electrolyte depends for its action entirely upon electrolytic phenomena, and can in no sense be classed as bolometer, or barreter, or heat-operated detector.

It is interesting to note the phenomena as the distance between the fine electrode and the other is altered. Consider one electrode a silver sheet covered by a thin layer of electrolyte (water, alcohol, dilute acids or alkali). If the fine point be immersed without touching the silver sheet, we have the action just described, of the normal polarization layer momentarily absorbed or dissipated during the passage of the Hertzian wave train, and the normal apparent resistance of the cell greatly reduced. In this case, of course, the small electrode must be the anode; for if the gas layer surrounding it be hydrogen instead of oxygen, the sensitiveness is very slight. In this case we would expect the thickness of the gas dielectric film to be twice that which oxygen would allow, and that the capacity of the little condenser thus formed would be much less. Again, the hydrogen will be occluded, whereas oxygen will not be, and the polarization phenomena, on which the entire action depends, will be less marked.

Now let the fine platinum tentacle actually touch the metal sheet and become welded to it, by the application of a sufficient local e.m.f. We have here the true hot-wire effect, and the resistance of the device, nominally slight, is increased by the passage of the high-frequency current. Next make the plate the anode and separate from it the fine platinum point by a few thousandths of an inch. A bridge of fine silver particles will form, and by raising the cathode may soon be drawn up out of the liquid. The normal resistance of the responder is slight, and the action of the wave train is to decompose the thin layers of electrolyte between particles of the bridge, as at first described. But it can be shown that both the *increase* and the *decrease* of resistance under the wave influence exist in this latter form, popularly called the anti-coherer.

When one listens in a telephone receiver in the local circuit of the electrolytic anti-coherer to a transmitter giving oscillation groups with sufficient frequency to form a musical note, two distinct sounds are heard. The first, and usually the loudest, is an irregular rumbling sound overlaying the second, which is a pure musical note of the same frequency as that of the transmitter. In the seventh experiment a condenser of small capacity (two or three-thousandths of a microfarad) was shunted around the detector, which was placed in an untuned circuit. This condenser shunt had the effect of suppressing almost entirely the musical note in the receiver, but had very little effect upon the irregular rumble. In an untuned circuit, a condenser shunt has the effect of reducing the potential rise due to the received oscillation; as the rumbling note was but little affected by the shunt, we may assume that this is the anti-coherer action, the breaking down and reforming of the conducting bridge. This is a current-actuated effect and would be but little affected by the shunt. A galvanometer in the local circuit showed a greater decrease of current in the responding state with the shunt on than with it off. This would indicate that there were three states of resistance in the anti-coherer: (1) A very low resistance, due to the conducting bridge; (2) a comparatively high resistant state due to the rupture of the bridge; and (3) a very high resistant state, due to the rupture of the bridge, *and the polarization of the broken ends of the bridge.*

Represented graphically, as current flow in the local circuit, the response of this detector to a signal consisting of six impulses would be as shown in Fig. 6. For simplicity the six impulses are considered as single unidirectional impulses. The line *ab* represents the normal current flowing through the anti-coherer when no impulses are being received, and the detector is of low resistance. The first impulse breaks down the bridge, and the line *bc* represents the fall of current due to the rise in resistance, the detector passing rapidly through the second to the third state, or very high resistance polarized condition. The impulses in this signal may be considered to be one-hundredth of a second apart. From *cd* the

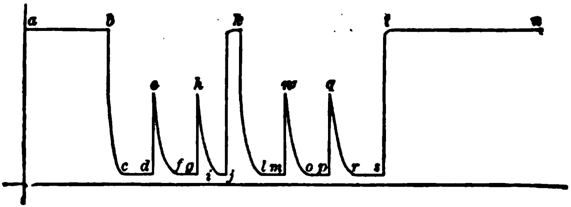

FIG. 6.

detector remains highly resistant, and at *d* the second impulse arives. This second impulse breaks down the polarization, and the detector falls momentarily to the second state of comparatively high resistance. It is then acting as an electrolytic coherer, the rise in current *de* being due to the breaking down of a polarization layer, which is almost instantly reformed, the current falling again as shown by *ef*. This is repeated by the third impulse. Between the third and fourth impulse the bridge succeeds in reforming, but is broken down again by the fourth impulse, as shown by the current fall *kl*. The fifth and sixth impulses operate the device to decrease the resistance, and after the last impulse the bridge has time to reform, shown by the current rise, *st*, the low resistant state *tu* continuing until the next signal. The rumbling note heard in the telephone is due to the occasional reforming of the bridge, as shown at *k*. It will be seen that while the breaking down of the bridge is accomplished by current, the opposite action is due to potential, so that the condenser shunt eliminates the current peaks *ehmq*, leaving the detector of very high resistance from *c* to *j*, and from *e* to *s*. This not only eliminates the musical note heard in the telephone receiver, but decreases the galvanometer deflection during the responding state. This curve is intended to be an ideal one, and no attempt is made to show real ratios of current.

Returning to the form of the electrolytic detector first considered, it is apparent that although it is capable of rectifying high-frequency currents, this rectification is not an important action. Like the metal filings coherer, the energy in the local circuit is derived from the local battery, the chief effect of the received oscillations being to release this energy. In its construction certain electrolytes are found to give better results than others. In all probability this is partly due to their relative capacity for absorbtion of oxygen. For example, hypophosphorus acid gives much better results than phosphoric acid, and nitric acid with a certain amount of nitrous is better than nitric alone. As the *ous* acids contain less oxygen than the *ic* acids, this is the probable reason for the difference.

The electrolytic responders which I have described seem to possess in the highest degree the qualities necessary to place the art of aerography on a basis to compete with existing telegraphic service by land as well as sea. They are extraordinarily sensitive; regular in response; strictly quantitative and automatic in action; have approximately constant normal factors as regards resistance and capacity, allowing thus a speed of word transmission limited only by the ability of operators to send and receive. By such means the problem of electrical tuning, or syntony, are enormously simplified; for heretofore the erratic nature of the coherer has rendered it impossible to closely regulate the constants of the tuned electrical circuits in which it is placed, thus making syntonization by its employ at best crude and uncertain.

In regularity of action the responder is strictly comparable with the Rutherford magnetic detector as developed by Wilson, Shoemaker, Marconi and Ewing; while as regards relative sensitiveness there is today no comparison between that of the magnetic detector and the electrolytic receiver. Moreover, the device is practically indestructible, while its syntonizing qualities enable us to so cut out foreign signals and electric disturbances as to render wireless communication by this means immune from interruption where the coherer or less sensitive magnetic detector is an impossibility.

DISCUSSION.

CHAIRMAN JONES: The paper before us is a valuable addition to those elucidating the theory and method of wireless communication. We are certainly indebted to Dr. De Forest for the able manner in which he has handled his subject.

MR. E. H. SMYTHE: I was very closely associated with Dr. De Forest in the invention and early development of this form of receiver, and there are a few statements made in the first part of his paper with which I do not quite agree. I should like to say something in regard to certain experiments, which seem to show that the responsive action is not electrolytic at all. He speaks of the formation of bridges between the two electrodes, and refers to it as being a very fascinating spectacle under the microscope. The formation seems to differ when electrodes of different metals are used. There is a characteristic formation with tin electrodes, and a formation that is different for electrodes of copper and of other metals. The tin bridges, for instance, seem to be very readily broken apart. In the copper bridges the tentacles are very much finer and more tenacious. I think my experiments, which I will mention briefly, show that the action is not electrolytic. I have taken electrodes and observed the action in an electrolyte composed of glycerine with just enough water in it to make it conductive, and the action takes place just as described in our patent; but as soon as the water is completely expelled from the glycerine by heating it, or otherwise, the bridge building immediately ceases, and the device becomes inoperative. I found it very difficult to obtain a medium which was entirely free from electrolyte, but when I succeeded the bridging action ceased, which would seem to indicate that the transfer of particles depends upon the electrolytic action and is not due to electro-mechanical stresses.

Another thing is that when the bridges have been formed, I find that they are sensitive and will remain formed, although the local battery is disconnected; and when the local battery is disconnected and an oscillation is received, the bridge is disrupted in the same way as when the local current is still passing. As the local current increases, the sensitiveness of the bridge seems to increase as the carrying capacity of the link is approached — that is, when the current flowing from the local battery is very close to what seems to be the fusing point of the bridge, the bridge is very sensitive to oscillations, and a very slight increase will disrupt it; whereas, if there is no local current flowing, it takes a considerably greater energy of oscillation to disrupt the formation. I have performed a great many experiments along this line which prove conclusively to my mind that the action is purely thermal and is not electrolytic at all.

Dr. De Forest: In regard to Mr. Smythe's remarks about the action being thermal purely, while I will not dispute that there may be a thermal action connected with the electrolytic anti-coherer, which, in cases where the current is excessive, would burn these bridges, still the action as observed under normal conditions shows a formation of gas there, which gas may remain for moments at a time, showing at least that the bubbles are not due to steam; that this formation of bubbles indicates the electrolytic action.

Mr. Smythe: In the theory I first formed with regard to the action that takes place, and which is explained in the patent issued to Dr. De Forest and myself, and has been adopted by Dr. De Forest as the correct explanation of the matter, the action, I thought, was due to a sort of electrolytic explosion; but I have since observed that in a great many cases the disruption takes place with absolutely no formation of gas, even under the highest power microscope; and when gas is formed I regard it almost certainly the result rather than the cause of the action. At first I was under the impression that it was the generation of hydrogen which caused the disruption and change of resistance, but later experiments have shown that the generation is the result of the electromotive force which is developed at the end of the chain when it is ruptured.

Mr. J. S. Stone: I think Mr. De Forest's paper is extremely interesting, and that the experiments tending to show that the action is electrolytic are very prettily conceived, and, so far as we can see, very well carried out. In listening to his discussion of the electrolytic receiver a point occurred to me. It seems to me that there are two classes, one in which the action seems to depend upon breaking up little bridges that form between the electrodes, and the other, which seems to depend upon the collapsing of a film of gas surrounding the electrode. In one of the experiments that he mentioned, where the electrodes were very small and very close together, both of these actions, I understand, take place. However, when you remove one of the electrodes, so that it is really a very fine wire dipping to a very small extent into the electrolyte, I would like to ask if the apparatus of that experiment does not operate without the formation of bridges and merely by the collapse of the little film, the little layer of gas?

Dr. De Forest: Mr. Stone is correct.

Mr. Stone: Does the current, when the battery is first applied, drop almost instantly to practically zero?

Dr. De Forest: Yes, that is true. As soon as the polarization of the film was broken down, the work of the receiver, so far as we are interested, was performed. Of course, this sudden increase of current would produce the heat effect, but that would be a secondary matter.

Dr. J. E. Ives (communicated): The interesting paper of Dr. De Forest discussing electrolytic receivers is of particular interest to me, since, as Dr. De Forest has stated, I have recently been engaged in investigating the properties of such detectors.

My investigations with the different forms of electrolytic receivers have convinced me that polarization is the property which underlies the action of them all. Whether the detector consists of a chain of minute metallic particles stretching from one electrode to the other, or whether it consists of a minute metallic terminal immersed freely in a liquid, the essential feature is the polarization layer of oxygen surrounding the very small anodic surface. The *shape* of the small free terminal is found to be of no importance, the *area* of contact with the electrolyte being the only important fact. When in operation, the polarization layer is partially broken down, or disintegrated, by the impulse of the Hertzian oscillation in the aerial wire, thus allowing an increased flow of current through the detector from the local battery.

A simple form of electrolytic detector is the one described by Dr. De Forest in his paper, in which the anode is a fine platinum wire slightly immersed beneath the surface of an electrolyte, and the cathode is a much heavier wire immersed to a considerable depth.

Prof. Fessenden holds that this detector is operated by the generation of heat in the electrolyte surrounding the fine platinum wire, and is, therefore, a form of barretter. As Dr. De Forest has stated in his paper, his own experiments, and those of Mr. G. W. Pickard and myself, lead unmistakably to an electrolytic theory of action. Every experiment that we have performed points to the formation of a polarization layer upon the small surface of the anode, and to this polarization layer as the source of the operativeness of the detector. The testimony of other investigators is almost unanimously in favor of the electrolytic theory of action. For example, see W. Schloemilch, *Elektrotechnische Zeitschrift*, November 19, 1903; M. Reich, *Physikalische Zeitschrift*, June 15, 1904; and M. Dieckmann, *Physikalische Zeitschrift*, August 15, 1904.

Dr. De Forest has discussed our experiments so fully, that there is little or nothing that I can add to his paper, but I may perhaps be permitted to enumerate briefly some of my reasons for the belief that the operativeness of this detector depends upon the formation of a polarization layer upon the minute platinum anode, and not upon the generation of heat in the electrolyte surrounding it.

1. The device is not reversible, as it should be if it were a heat-operated device.

2. It is found that the minute metallic point making contact with the electrolyte must be of a metal which is chemically inert with respect to

the electrolyte. If it were a heat-operated device, chemical reaction at the contact surface would not materially affect its operativeness.

3. The apparent resistance of the device is very high, so high that it cannot be due to the true resistance of the electrolyte, but must be due to a polarization layer upon the surface of the fine platinum wire.

4. The value of this apparent resistance depends upon the value of the electromotive force in the local circuit; increasing rapidly as the electromotive force in the local circuit decreases. For small electromotive forces of less than one volt the apparent resistance may be several megohms. For larger electromotive forces of three or four volts the apparent resistance may be only a few thousand ohms.

5. The sensitiveness of the device depends upon the area of the contact point and not upon its shape.

6. It is found to be a potential operated device, and not a current operated device, as it should be if its action were due to the generation of heat.

7. It responds just as well when the electrolyte is boiling, as when it is at ordinary temperatures.

8. It will work perfectly when the electrolyte has a zero temperature coefficient of resistance. For instance, a good response is obtained when the electrolyte is a 2½ per cent solution of hypophosphorous acid at a temperature of 60° C. According to the heat theory, it should not respond at all in this electrolyte at this temperature, as at this temperature, the temperature coefficient of this electrolyte changes from a negative to a positive value. As a matter of fact, the device was found to respond equally well with this electrolyte all the way from ordinary temperatures up to its boiling point.

9. The ability of the device to respond to Hertzian waves may be entirely destroyed by coating the fine platinum wire with a very thin layer of platinum black, the coating of platinum black being so thin that it does not appreciably change the diameter of the fine wire. Although this layer of platinum black could not interfere with any heat effect in the neighborhood of the wire, if such existed, it would prevent the formation of a polarization layer upon the wire.

10. It is found that this device is particularly responsive to electrical tuning. This would not be the case if it were a heat-operated device, as the energy of the Hertzian oscillations would be transformed into heat energy, and the oscillations would consequently be so strongly damped, that the device could not respond so readily as it does to tuning.

Mr. E. H. SMYTHE (communicated): I feel that certain statements made by Dr. De Forest relating to the character of the action that takes place in the receiving device or "responder" of our invention require somewhat more detailed mention than I was prepared to give them in the brief discussion with which I followed the presentation of Dr. De Forest's paper at the meeting.

I was rather surprised, upon glancing over the paper shortly before it was read, to see that Dr. De Forest still holds to the view of the nature of the action that we took during the development of the device; namely, that the breaking up of the conducting chains is due to disruptive electrolysis in films of electrolyte interposed between contiguous metallic particles of the chain; and that the formation of these chains is effected by particles of metal torn bodily from the anode by the electric stress created between the electrodes by the local battery. My subsequent experiments lead me directly to a diametrically opposite view of the matter; that is, that electrolytic action is responsible for the building up of the chains, while their destruction is due to the thermal effect of the received oscillation, the action that takes place being in a way analogous to the blowing of a fuse.

In the first place, although I have had the opportunity of observing through the highest power microscopes the formation of hundreds of bridging chains between electrodes of various metals separated by various media, I have never, in any typical case, been able to see in transit the particles that are responsible for the growth of the metallic formations upon the cathode. There is often evident a current in the liquid, in which may float minute particles of impurities and the debris of previously disrupted chains, but nothing which would indicate that there is any bodily tearing off of particles from one electrode and transfer to the other. If the action were of such a nature, we might reasonably expect particles to be torn from the surface of the cathode and transported, impelled by their electrical charges, to the anode, but no such migration takes place, the transfer being uniformly from anode to cathode.

If the action were of such a nature, we might expect that it would take place to a greater or less degree through all liquid media which might be interposed between a pair of electrodes, so long as the media did not differ greatly in their specific inductive capacity and frictional resistance offered to the passage of the metallic particles through them, but I find that in certain media such as castor oil and absolute alcohol, there is no indication, either in the microscope or the telephone, of deposit on the cathode, even after a relatively high potential (some twenty volts) has been maintained for an indefinite time across tin electrodes separated by not more than a few thousandths of an inch. When the electrodes are moved into and out of contact the make and break is as clean cut as though in air, and there is no indication of the characteristic responder action. If the medium employed is chemically pure glycerine, and proper precautions have been taken to make it perfectly anhydrous, it behaves as castor oil and absolute alcohol, and apparently does not permit any transfer through it of the material of which the bridges are built; but if the medium is exposed to the air for a few minutes, or breathed upon, the bridge building promptly commences, the change in behavior evidently resulting from the addition to the medium of moisture which the hygroscopic nature of the glycerine enables it readily to abstract from the atmosphere. It is very difficult to keep glycerine, when interposed between the electrodes, free from a trace of moisture, and it requires only a trace to allow electro-deposition of the infinitesimal order involved in the formation of the bridging structures. It is this that misled us in our earlier experiments and seems to have misled Dr. De Forest since into believing that the transfer between the electrodes is due to electro-mechanical stress.

It was evident from the first that the operation of the device required an electrolyte, but we supposed that it played its part under the influence of the received oscillation and local current in bringing about the destruction of the bridges after they had been completed. This destruction, I am convinced, is due to the heating effect of the oscillation. The bridge formation is merely such an irregular electro-deposition as may be expected to take place between electrodes brought unusually close together in a medium unusually deficient in ions and consequently having abrupt and irregular potential gradients. I have noticed that as the percentage of electrolyte is increased, and the conductivity of the medium lessened, the character of the deposit alters, becoming more compact and homogeneous, and taking on more the appearance of electro-deposits formed by the ordinary processes. But as long as the proportion of electrolyte is small, the formations are limited in number and slender and crystalline in form.

They seem to possess considerable mechanical strength, and are capable of retaining their original form almost indefinitely, when allowed to stand with the local battery disconnected. This would not be the case if their constituent particles were held together by electric forces originating in the local battery. Even when completely detached from the electrodes, they often float in the medium unaltered in form. The completion of a bridge between the electrodes is marked by a sharp click in the telephone and an abrupt fall in the resistance of the device, frequently from 50,000, or 100,000 ohms, to a few hundred ohms, the observed resistance of the bridge not differing greatly from that calculated for a wire of the electrode metal having approximately the same dimensions. I have never noticed any well-defined polarization when a bridge is completed. It is not impossible that polarization between contiguous particles of the chain exists, but its effects would necessarily be very slight and difficult to detect, and it seems to me that the probabilities are rather against it.

Assuming now that the bridge between the electrodes is a solid metallic filament, as would appear from the foregoing, it is evident that the disruption upon the passage of the received oscillation cannot be accounted for on the basis of an electrolytic explosion in a film separating adjacent particles of metal in the bridge. The natural and obvious explanation is that it is due to the direct action of the current on the bridge itself, and I have observed nothing in the responder action that would negative this hypothesis. We know that the mass of the metallic chain is extremely small as compared with its resistance, and, therefore, that only a very small amount of current is required to raise its temperature, through a considerable degree, and when the metal utilized in the electrodes is one, such as tin, which has a very low fusing point, it is not unreasonable to suppose that the suddenly exerted heating effect of the oscillation may be sufficient to raise the filament to that critical temperature where it will be fused and destroyed, notwithstanding the fact that the filament is surrounded by a medium having a certain capacity for dissipating the heat. I think it significant that tin, which has been found to be particularly well adapted to manifest the responder action, has a comparatively low melting point, while those metals which require a comparatively high temperature to melt them, such as gold, platinum and copper, display the characteristic responder action only to a slight degree, if at all. If the disruptive action is due to thermal effects, it may be expected that the ideal metal for use in the responder will combine high specific resistance and low specific heat with the prime requisite of a low melting point, in order that a maximum heating effect on the filament may be obtained with the minimum current. These three characteristics, it will be observed, are combined in tin. Copper, for instance, does not have them, and I have found it almost impossible to get the responder action when employing electrodes of that metal.

After a bridging chain has formed, it may be broken by a received oscillation without as well as with the current from the local battery flowing through it. This is entirely consistent with the thermal hypothesis, but it is not clear how the oscillatory current alone could affect the result, if it is to be accounted for on the basis of electrolytic action in the chain. The extent to which a chain is destroyed seems to depend somewhat upon the energy of the received impulse. If the impulse is strong, it may be broken simultaneously at several points. Usually, however, there is but a single break and that, so far as I have been able to observe, is almost invariably at a point near the *anode*, not the *cathode*, as Dr. De Forest states in his paper. I have thought that this may be due to the fact that the growth of the filament is usually noticeably accelerated as it approaches the anode, with the probable result that that portion is less compactly built, of higher resistance, and, therefore, more easily raised to the critical temperature than the portion near the cathode.

If local e.m.f. is absent when the rupture occurs, the chain remains quiescent in its broken condition; if present, the breaking of the circuit through the chain causes the immediate establishment of the electromotive force of the local battery across the break, and the renewed deposition, that instantly ensues, effects the repair of the chain almost as soon as it is broken. The completion of the circuit through the chain lowers the electromotive force between the electrodes to an almost negligible value, and instantly and automatically puts a stop to the bridge building until it is again needed. If the medium contains an electrolyte, the decomposition of which sets free a gas, the gas is evolved at the point of rupture and, appearing as it does coincidentally with the rupture, may seem to cause it. However, the fact that the break may be produced by the oscillatory current alone, the local battery being disconnected, without any accompanying evolution of gas would seem to indicate that the gas observed when the local current is flowing is an effect rather than the cause of the break.

Another observed peculiarity that seems to support the theory that the disruptive action in the responder is thermal is the fact that as the current flow from the local battery through the device is increased the chain or filament becomes more sensitive to the oscillatory current. The chain may be destroyed by the local current alone if the flow is sufficient to raise it to the critical temperature; if it is not sufficient, the strength of the received impulse necessary to operate the device depends upon the current increment required to carry the current in the chain beyond the critical value. The closer the normal current is to the critical current, the less energy need be supplied by the received oscillation to effect the interruption of the circuit.

If the action is due to thermal effects in the chain, it may be expected that a response will be obtained due to the resistance alteration of the delicate conductor, even when the energy of the oscillation is insufficient to break it, and this I have found to be the case, the response, however, being slight in comparison with that obtained when the impulse is sufficient to break the chain. I think it not improbable that it was this effect that Mr. De Forest observed superposed upon the more marked effect due to the rupture of the chain, and which he ascribes to the polarization of the broken ends of the bridge, as it hardly seems likely that the polarization effects would manifest themselves between electrodes having as relatively large exposed surfaces as those employed in the metallic bridge responder, and separated by a medium containing an electrolyte capable of dissolving and the electro-depositing the metal of the electrodes.

Superficially there is a resemblance between the action of the "responder" and that of the electrolytic detector comprising a fine platinum point contacting with an electrolyte, such as described in Mr. De Forest's paper, but I do not believe that there is any good ground for contending that the peculiar pheonomena of the latter manifest themselves in the structure of the former, the elements best adapted for use in one being, by the very nature of the action that takes place; the poorest adapted for use in the other. Both detectors involve electrolytic action in certain stages of their operation, and both combine extraordinary sensitiveness with regularity of response and instantaneous and automatic return to normal condition, but this, I think, is as far as the resemblance goes.

Chairman Jones: The next paper on our programme this morning is by Prof. J. A. Fleming, of University College, London. As Prof. Fleming is not with us to-day, the paper will be read by title.

THE PRESENT STATE OF WIRELESS TELEGRAPHY.

BY PROFESSOR J. A. FLEMING, D. Sc., F. R. S., *University College, London.*

In response to a request to contribute a paper on Wireless Telegraphy to the Congress now in session, the writer has made it his aim to present a broad general statement concerning the present state of the art, rather than to offer any special contribution to new knowledge on the subject.

In view of the exclusive position occupied by wireless telegraphy as conducted by Hertzian waves, it may be taken that references to any other methods are hardly necessary and that when we speak of wireless telegraphy at the present date every one understands this to mean the method by Hertzian waves, originated by Dr. Marconi.

In discussing this subject before the present audience there will be no need to enter into explanations of elementary facts and principles. We may at once proceed to describe the forms of apparatus now in use and the extent to which the functions of the various parts have been determined.

Up to the present time no one has discovered any method for producing a powerful electric wave of the Hertzian type which does not involve or depend upon the oscillatory discharge of a condenser of some kind. Necessarily therefore this process is intermittent. The condenser has to be charged and then discharged, and this operation results in the production of a group of decadent oscillations and waves and the process is then repeated. Generally speaking the frequency of the oscillations employed in wireless telegraphy is of the order of a million, and from 20 to 100 oscillations may form a group. The frequency of the charge and discharge period may be from 10 to 100. The time over which the oscillations extend is therefore as a rule not much more than one per cent of the whole time. In other words the actual radiation is taking place only at most during about one-hundredth part of the time the operations are continuing.

This fact has induced many inventors to hope for a more efficient method which shall consist in manufacturing a continuous train of waves resembling those emitted by an organ pipe rather than a series of intermittent explosions.

Although an alternator is said to have been made, giving a frequency of 120,000, it is without doubt beyond the limits of practical achievement to construct an alternator having a frequency of a million. In spite of the statements made that low-frequency alternations of frequency, say of the order of 100, give rise to correspondingly long electric waves of wave length $3\times10^{10}/n$ centimeters, where n is the frequency, the author believes that this is not the case, and that to detach a true free electric wave from a radiator it is necessary to have a certain far higher frequency, perhaps not sharply defined, but at any rate involving a relatively very sudden reversal of electric force. The same is the case with the production of a wave in air or water. In order that the energy may be detached from a wave-making vibrating body in air or water and travel away through the medium in the form of a free wave, it is necessary that the reversal in direction of the mechanical force, or which comes to the same thing, the acceleration positive or negative of the wave-making body, shall exceed a certain limit. Otherwise there is no detachment of energy. To put the matter in a popular form, the blow administered to the fluid must be sufficiently sudden to call into operation the inertia quality of the medium, in order that a wave may be detached.

The loudness of the sound produced by an explosive depends quite as much, if not more, upon the suddenness of the explosion as upon the energy stored up. It has been found for instance that four ounces of gun cotton exploded in the air will yield a sound quite as loud as that given by three pounds of gunpowder. On the other hand, the production of a continuous sound from a steam- or air-siren for coast-signal purposes, involves very large amounts of power; as much as 600 horse-power having been in some cases consumed. Reasoning from analogy, the inference is probably correct that the production of a solitary ether wave involves the reversal, with a certain ill-defined but high degree of suddenness, of an electric force, and that the amplitude of the disturbance, and hence what may be called its space-penetrating power, depends quite as much, if not more, upon the extreme suddenness of its creation as upon the amount of energy employed.

All the electric wave generating appliances at present in use in connection with wireless telegraph transmitting plants involve therefore (i) an arrangement consisting of a condenser, inductance and disruptive spark-gap in series with each other. (ii) Some apparatus such as an induction coil, transformer or high tension alternator or high tension dynamo for charging the condenser and (iii) means for controlling the repeated discharges and cutting them up into groups as required in accordance with some signalling code. The possibility of setting up electrical oscillations in the condenser and inductance circuit by the above arrangement depends essentially upon the peculiar property of air and other gases, viz.:—that whilst they are very perfect insulators for electric forces less than a certain value, they pass instantly into the condition of a conductor when the electric force exceeds this value. When we are operating on a layer of air at a pressure of 760 mm or so, of about 1 millimetre in thickness, it is fairly correct to say that an electric force of 4500 volts per millimetre, (equivalent to 150 electrostatic units) forms the limiting value at which this transformation takes place. The above rule holds good when the bounding surfaces are metallic balls of one or more centimetres in diameter.

If we are operating in air at greater distances, say one centimetre of more, then we may say that the limiting electric force approximates to a force of 100 electrostatic units.

It is well known that the dielectric strength of very thin layers of air is greater than that of thick layers and also that the potential difference required to produce a spark, however short, cannot be less than a certain value which for air at atmospheric temperature and pressure is about 300 to 400 volts.

Again, the potential difference required to create a spark of given length is greater for large discharge balls than for small ones, and the value attains a maximum as the discharge surfaces approximate to planes.

When the discharge takes place in air above normal or atmospheric pressure, the electric force required to begin the discharge between metal balls, say 10 cms in diameter, the air pressure being x atmospheres, can be calculated from a formula given by Wolf (*Wied. Ann.* 37. 306, 1889) which is

$$E = 107x + 39$$

E being the electric force in electrostatic units. This formula holds good from 1 to 5 atmospheres or up to 70 lbs. on the square inch.

According to Paschen's Law (See J. J. Thomson "Conduction of Electricity Through Gases" p. 367.) spark potential depends only upon the product of spark-length and gas pressure, i. e., upon the mass of gas between the electrodes.

For a given potential difference, the spark length, for lengths greater than about 1 mm, varies almost inversely as the pressure. Thus in air at normal pressure, the spark length between balls one inch in diameter would be about 7 mm for 20,000 volts and if the pressure is increased to 42 lbs. on the square inch the same potential difference will create a spark of about 2 mm in length.

In connection with this subject of spark discharge in air of greater normal pressure, the writer may mention that he has during the past winter conducted some experiments on Wireless Telegraphy across London between University College and his own private house, the distance being about four miles. Working with a certain aerial and employing a Marconi receiving arrangement, very good results were obtained by the employment of a 7-mm spark in air at ordinary pressure, the capacity employed being 1/110 of a microfarad. In comparison with this, experiments were made with an arrangement devised by the writer for working with discharges in air at greater than atmospheric pressure. The discharge surfaces were two steel balls one inch in diameter and when these were placed 2 mm apart in air at 40 lbs. pressure, even better signals were obtained than when working with a 7 or 8-mm spark in air at ordinary pressure. On the other hand, whereas the air spark was exceedingly noisy, the 2-mm spark taking place in a cast-iron vessel in air under 40 lbs. pressure was absolutely silent.

The importance of employing a perfectly silent discharger on board ship is very considerable. Great annoyance is caused to passengers who have cabins in the vicinity of the wireless telegraph cabin on board passenger ships by the noise of the spark and moreover, if the messages are not sent in cipher, any one who can read the Morse alphabet hears what is being said.

It has become usual to include the spark balls in a glass vessel and in some cases in working Tesla coils, instrument makers have begun to employ such glass vessels to contain compressed air, the spark balls being included in it.[1] This, however, is a dangerous proceeding, as even thick glass is rendered brittle in course of time by the

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[1] See Mr. F. J. Jervis-Smith. "On a High Pressure Spark-Gap Used in Connection with a Tesla Coil." *Phil. Mag.:* August, 1902, Vol. 4, Series 6, p. 224.

action of the radiation from the spark and if the vessel contains compressed air an unpleasant accident may happen. Moreover, such a vessel will not render the spark perfectly noiseless. This can only be done by employing, as the writer has done for some time past, a cast-iron vessel with thick walls which are perfectly rigid and in which the spark balls are contained and insulated.

One drawback which presents itself when working with a discharge spark in compressed air is the continual production of nitric acid in the interior of the enclosed vessel. This difficulty is only partly overcome by introducing caustic potash or quicklime into the interior of the closed chamber. A better plan is to take the spark in compressed nitrogen. This gas can be prepared quite easily in sufficient quantity by burning pieces of phosphorus within a small closed gasometer full of air, standing over water. This nitrogen generated can then be pumped into the closed cast-iron vessel containing the spark balls by the aid of such a hand pump as is employed for inflating the tires of motor car wheels and when once the vessel has been filled with nitrogen under the requisite pressure, no further difficulties as regards the production of acid vapors will occur, and it need only be renewed at considerable intervals.

Certain other difficulties however occur when using very short sparks and large capacities, because then special arrangements have to be made to destroy the arc discharge.

It need hardly be pointed out that if the transformer which is charging the condenser continues to send its own discharge in the form of an alternating arc between the spark balls after the oscillatory discharged is finished, the condenser cannot be charged again until this arc is extinguished.

One attempt to obviate the necessity for any discharge at all in producing electrical oscillations from a condenser, has been in the application by Mr. Cooper-Hewitt of the well known properties of mercury vapor of passing into a conductive condition only when the applied electric force exceeds a certain definite value. He employs instead of the spark gap a mercury vapor electric lamp in conjunction with an inductive resistance.

As soon as the condenser has become charged, a current traverses the lamp and at that moment the difference of potential at its terminals is enormously reduced and the condenser therefore discharges or feeds a circuit between itself and the lamp in which it sets up electrical oscillations.

It is characteristic of these lamps that they may be constructed not to pass an appreciable amount of current below a given voltage which can be determined, and therefore at the end of certain definite periods the current ceases to pass and the light goes out.[2]

Since the operation is continuous, it is concluded that the result is to furnish a non-intermittent series of electrical oscillations. It may be remarked however, that the arrangement is only electrically equivalent to that which is now known under the name of the Duddell Singing Arc, in which a continuous-current electric arc has its carbons short circuited by a condenser and inductance in series with one another. Under these circumstances the continuous series of discharges from the condenser take place through the arc. Any device will effect this continuous operation which has properties similar to that of mercury vapor or the carbon vapor in the continuous current arc, viz.:— that the passage of a large current through the medium greatly lowers the potential difference between its terminals.

Although however it has been asserted that the employment of the Cooper-Hewitt mercury lamp in place of the spark gap would result in very great advantages, the writer has not been able to verify this statement and in the only case which has come to his knowledge where the attempt was made to use the device with powerful discharges, it was not successful.

Careful consideration of facts connected with the production of electric waves shows that the production of a powerful wave is not merely a question of energy, that is to say, not merely of energy stored in the condenser, it is very greatly dependent on the mode of release of this energy and it is astonishing what results in ether wave-making can be achieved with extremely short sparks, that is with comparatively low voltages, if only the nature of the discharger is such as to permit an extremely sudden release of this energy.

It has been asserted by Fessenden[3] that the wave-producing effect of a given amount of energy can be greatly increased by taking the spark in air under a pressure greater than 60 lbs. per square inch, and that by operating in air at 80 lbs. pressure per square inch, the intensity of the radiation was enormously increased compared with that obtained when working at 50 lbs.; this improvement being

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[2] See Brit. Patent Specification, No. 9206 of 1903, P. Cooper-Hewitt.

[3] U. S. Letters Patent, 706,741. Aug. 12, 1902.

quite apart from any question of the diminution of length of the spark in the increased air pressure.

It is quite possible that such an improvement may come about owing to the greater suddenness with which the dielectric gives way in the case of air under greater pressure than 80 lbs. per square inch. The writer has not however been able to verify this fact and has met with some obstacles and complications due to the difficulty in suppressing arcing when very short sparks in high pressure air are employed.

For telegraphic purposes the spark must have a certain *quality,* which may perhaps be defined by saying that the discharge between the balls must be wholly due to the energy coming out of the condenser and not to any supplied directly by the voltage-producing device, whether transformer or alternator or induction coil. Moreover, these sparks must succeed one another with great uniformity and regularity.

As long as we are dealing only with small amounts of power, that is, with such small capacities as may be obtained by the use of Leyden jars charged by induction coils, no difficulty arises in connection with the disruptive or oscillatory spark discharge, except perhaps the great noise made by it. This is certainly very objectionable, but may be obviated by enclosing the discharger as above described, in a suitable cast-iron vessel with very thick walls. A peep-hole or window closed by a thick disc of glass, or a lens, permits inspection of the spark, and with this arrangement the discharger can be made perfectly silent. When however we employ large capacities and attempt to discharge across the gap electric energy, say equal to 100 joules at each discharge, the charging voltage being 20,000 or upwards, we meet with special difficulties. Discharges of this character tear away and destroy the surface of metal balls, and thus alter the nature and length of the spark gap and also we have superimposed upon the oscillatory discharge of the condenser, an electric arc discharge proceeding from the charging transformer.

At a very early stage in the attempt to use large powers for electric wave generating plants, the writer had to deal with these difficulties by the construction of devices for overcoming them. The simple arrangement of a pair of brass balls, half an inch in diameter connected to the secondary terminals of an induction coil which constituted the discharger used in early wireless telegraph experiments is applicable only when very small discharges, having energy, say of 1 to 10 joules, are in use.

In the case of more powerful arrangements, the discharger becomes a very important element and the design of a suitable appliance requires great experience.

The particular arrangements devised for this purpose by the writer, which have been very successful cannot be described in detail at present, as they are confidential.

The next important element in the transmitting arrangement is the condenser. It has been customary to employ for this purpose the ordinary Leyden jar or at least a glass tube, partly coated inside and out with tinfoil. The Leyden jar is however very bulky in comparison with its electric capacity, but it has the advantage that there is but one edge to the tinfoil from which glow-discharge can take place. It still continues to be employed to a very large extent for small land and ship plants, and a jar having a capacity of about 1/700 of a microfarad is in general use.*

For larger powers, Leyden panes or glass plates, coated with tinfoil and immersed in linseed oil or vaseline are employed. The glass must be carefully selected and free from flaws, as if used in series, the failure of one condenser is followed by that of all the others in the series.

The writer has made numerous experiments on different materials as dielectrics for condensers for this purpose. Micanite has greater dielectric strength than glass, but taking cost per unit of energy stored, into account, no dielectric is cheaper to employ than good sheet glass. Materials, such as ebonite, oiled-paper or paraffin are quite unsuitable for constructing condensers required to yield very powerful electric oscillations. It may be remarked in passing, that it is impossible to store up in glass, in the form of energy of electrostatic strain, more than about 40 to 50 foot-pounds per cubic foot of glass. The limit is fixed by the dielectric strength of glass and the figure shows how small is the electrostatic energy-storing capacity of a dielectric compared, say with the mechanical energy which can be stored in a cubic foot of compressed air. We require 500 cubic centimetres of glass to store up in it one joule of electric energy in the form of electrostatic strain.

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* Under the operation of frequencies greater than about one million, the dielectric constant of glass suffers great reduction as compared with its low-frequency value. Hence account of this fact must be taken in estimating glass condenser capacities.

In connecting up large numbers of condensers, so as to form a large capacity, it is important to pay attention to the equalization of the lengths of the discharge paths of each condenser. The writer believes he was the first to draw attention to this matter,[4] and others have since appreciated the importance of this arrangement.

So far, therefore, we may say that every form of transmitting or electric wave generating device in use in connection with Hertzian wave wireless telegraphy has involved the employment of an air spark gap, an inductance, and a condenser in series with each other, the electrical effect of the arrangement being that a series of high-frequency oscillations are produced in this condenser circuit. Such a circuit constitutes however, a closed or non-radiative circuit; and in order that electric waves may be thrown off into space by it, it has to be associated with an open or radiating circuit. We may make a thermal analogue by considering a boiler full of hot water, the boiler being well lagged with non-conducting material. The boiler would not cool or radiate. If however, we were to drive long metal pins through the lagging into the boiler shell and allow these pins to project beyond the covering, they would convey energy from the boiler to the air and ether outside and the boiler would radiate and cool.

In a precisely similar manner, the simplest arrangement for making the closed electric circuit radiate is to connect to it, at one point, a long straight wire or rod called an aerial or antenna, and to connect some other point on the closed circuit to the earth.

In order that the arrangement may radiate effectively, it is however essential that the natural electrical time period of the closed circuit shall be adjusted by so selecting its capacity and inductance that it shall be in agreement with the fundamental or with a harmonic of the electrical time period of the aerial or radiating wire.

As there is no necessity to enter here into the discussion of vexed questions of priority, we need not attempt to apportion the credit for the invention of this particular arrangement. If an invention could speak and were asked how it came into being, doubtless its answer would often be similar to that of Topsy in the immortal tale of "Uncle Tom's Cabin," "I 'spect I growed." Inventions are like everything else, subject to the law of evolution. In this case, we probably have the germ of the arrangement in the experiment

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[4] See British Patent Specification, No. 3481 of 1901, P. 6. J. A. Fleming.

with a Leyden jar and two long wires described by Sir Oliver Lodge in 1888 under the name of the "Recoil kick"[5] and when Mr. Marconi had invented and intentionally applied the vertical aerial as a radiator, the obvious application of it to the closed circuit was made by Prof. F. Braun[6] but the latter did not at that time assert the necessity for a sympathetic tuning of the radiator and closed circuit and it was only after the publication of Dr. Marconi's researches on this subject[7] that the full necessity for this was realized generally. In a particular form, it has been employed by Prof. Slaby and Count Von Arco in the transmitter arrangement as made by the Allgemeine Elektricitäts Gesellschaft.[8]

The open radiating circuit may however be coupled inductively to the closed circuit by the intermediation of a suitable oscillation transformer. In this case, the primary circuit of this transformer forms the inductance of the closed circuit and the secondary is in the circuit of the open or radiating circuit.

The inductive coupling introduces more complexity both into the practical performance and the theoretical consideration of the arrangement. As described by Prof. F. Braun in his patent specifications, no statements were made which gave evidence that he considered the adjustment of the time-periods of the open and closed circuit essential. He has however, since declared that he was aware of this necessity.[9] Dr. Marconi, however, who independently devised the inductive coupling and worked out step-by-step with great ingenuity the practical details necessary to make it effective, arrived very early at the conclusion that the equalization of the time-periods of the two circuits was the very essence of the invention.[10]

In the construction of the oscillation transformers used for this purpose, Marconi has generally employed square frames on which the primary and secondary circuits are wound, a very usual trans-

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[5] See Lodge. *Proc. British Assoc.* Bath, 1888. Also *The Electrician*, Vol. XXI, p. 607. "On Measurement of Electromagnetic Wave Length." Also *Proc. Roy. Soc.*, Vol. 50, 1891, p. 23. Also Lodge & Muirhead, British Patent Specification No. 11,348 of 1901.

[6] See F. Braun. British Patent Specification No. 1,862, Jan. 26, 1899, and German Patent No. 111,578 of October 14, 1898.

[7] See British Patent Specification, Marconi, No. 7,777, 1900.

[8] See an article in *Traction and Transmission*, Vol. VI, March, 1903, p. 193, where a description of the Slaby-Arco System is given by C. Arldt. Also, a pamphlet published by the Algemeine Elektricitäts Gesellschaft.

[9] See letter in the *Electrician*, Vol. 52, April 15, 1904, p. 1033.

[10] See Marconi British Specification No. 7,777 of 1900. Also a Lecture before the Society of Arts of London, May 17, 1901. *Journal* Soc. Arts., Vol 49, p. 506.

formation ratio being 1:10. There is no advantage in multiplying the turns of the primary circuit as it is essential to keep the inductance of that circuit as low as possible. A modification of the foregoing is the multiple system of transformation, devised by the writer in the autumn of 1900 and first described in 1901.[11] In this arrangement, a series of two or more closed oscillatory circuits are inductively interconnected, the voltage being raised at each transformation. The final link in the chain is the open or radiating circuit and all the circuits have their time-periods adjusted to be in syntony with each other. When operated by means of high tension transformers this constitutes a very effective arrangement for producing prolonged trains of electric waves.

If we now compare the two above described wave-producing arrangements with the original method described by Marconi in his first patents, we shall see that this last consists simply in making the aerial or antenna the condenser, by the discharge of which the oscillations are established. If the secondary terminals of an induction-coil are connected to two spark balls, one of which is joined to the earth and the other to an insulated aerial wire, we have simply a combination in one, of the oscillatory and radiating circuits. No novelty is introduced by merely joining an additional condenser across the spark gap as some subsequent patentees have done and little utility is obtained thereby.

All the numerous arrangements of transmitters or wave producers for Hertzian wave telegraphy which have yet been devised are only modifications of the above described three methods, and however much patentees have rung the changes upon them or disguised their form for the sake of inducing patent offices to grant a patent, every transmitting arrangement in practical use for wireless telegraphy by electric waves consists simply of an oscillatory circuit in which energy is stored electrostatically and released in the form of electric oscillations this circuit being generally a nearly closed circuit connected directly or inductively with an open or radiating circuit. The original simple circuit of Marconi in which the energy-storing and radiating circuits were one and the same, being the type from which the other two have been developed.

The appropriate method of expressing the energy-storing capacity of any such arrangement would be to state the energy in joules

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[11] See British Patent Specification, J. A. Fleming, No. 3,481 of 1901. Date of application, Feb. 18, 1901.

stored up before each discharge. This may vary from 1 to 100 joules or more.

We have then to consider the important function of the radiating circuit, viz.:—the aerial or antenna. The object of the whole apparatus being to make waves in the ether, it is not merely important to consider how much energy the system will store up but how much it throws off at each discharge. The original simple nearly vertical wire, devised by Marconi, has in course of time been modified by him into more complicated arrangements. The single wire has been multiplied into a group of wires arranged parallel in cage fashion, or in fan or inverted umbrella shape. The purpose of this multiplication is to increase the surface so as to obtain more capacity, with respect to the earth, but another reason is to reduce the inductance. On the electronic theory an electrical oscillation established in a wire, implies that electrons are rushing backwards and forwards in it, or rather that there is an atom-to-atom exchange of electrons which is equivalent to such a motion. The electron only radiates when it is being accelerated positively or negatively.[12] Hence, to obtain the greatest radiative effect from an open circuit there must be as little inductance in it as possible, that is, there must be as little obstacle as possible to the rapid reversal of motion of the electrons. This involves giving the largest possible *surface* to the aerial and hence multiple wire aerials suitably arranged are more effective radiators than sheets of metal. For ship purposes a couple of 7/18 or 7/22 stranded wire cables of bare tinned copper wire are generally used. These are placed about 6 feet apart and are about 180 feet in length. They are upheld by insulators from a special wooden gaff, which is secured to the top of the ship's mast. The capacity of such an aerial is about 0.0005 or 0.0006 of a microfarad or say 1/2000 of a microfarad. When used as a transmitting aerial it is essential to have very good insulation at the top of the aerial where the potential amplitude may be equivalent to that required to produce a spark 10 or 20 centimetres in length.

On the other hand, when used as a receiving aerial good insulation near the base is essential to prevent a sensible part of the current being shunted round the receiving appliances. In the case of very large aerials, the capacity may run up to 0.1 of a microfarad or more and when used as transmitting aerials with very

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[12] See J. Larmor, "Æther and Matter," Adams Prize Essay, p. 236.

high potentials, the currents flowing into and out of the base of the aerial may be something enormous. The mean equivalent heating current may even be 40 or 50 amperes but of course the maximum instantaneous value at the commencement of a train of oscillations may reach hundreds of amperes. The wave radiated from an aerial may of course correspond either to its fundamental electrical oscillator or to any higher odd harmonic which complies with the condition that the summit of the aerial is a potential antinode or loop and the base or earthed end is a node.

The practical problem which presents itself in setting an aerial into operation is, in the first place, the syntonization of the aerial with its associated condenser or energy-storing circuit. This equalization of the time-periods of the two associated circuits is for the most part accomplished by a process of trial and failure in which the personal skill of the operator counts for a good deal. The auto-syntonization of the transmitter circuits may be roughly obtained by placing a hot wire voltmeter across a section of the lower part of the aerial and adjusting the condenser circuit until the maximum reading of the instrument is reached. The guidance so obtained is however only approximate, because it is obvious that variation of the constants of the condenser circuit varies the frequency of the sparking and this again affects the mean value of the current into the aerial. A better method is to adjust until the maximum effect is obtained on a not very sensitive receiver at a little distance.

A more important practical matter is to ascertain the wave-length of the radiation sent out from any given transmitting aerial. Appliances for this purpose of various kinds have been devised, but it is clear that no reliance can be placed upon any instrument which has to be placed in contact with the aerial itself as this act will certainly alter the capacity of the aerial and therefore affect the wave length. The general requirements of such an appliance have been well stated by Prof. A. Slaby (Elektrotechnische Zeitschrift Vol. 24, p. 1007, Dec. 10, 1903).

Such an instrument must give the wave-length of the radiation in free space, be portable and easily calibrated and accurate. Prof. Slaby's solution of the problem is to provide a series of solenoids of wire of various lengths, wound on glass tubes, the turns being insulated slightly from each other. These solenoids are capable of being effectively shortened by short circuiting more or less of the turns. A solenoid is held in the hand by one end and the other end presented to the aerial. The solenoid has its effective length then varied until the maximum glow appears at its outer end. This is detected by the fluorescence produced on a barium platinocyanide screen and then it is assumed that the solenoid has had an oscillation set up in it corresponding to its fundamental oscillation and having a wave length therefore equal to four times the length of the solenoid wire. The end of the solenoid must not be brought nearer to the aerial than one or two feet.

It appears that very similar arrangements employing an open or straight resonance coil had previously been employed by Dr. G. Seibt (*Elektrotechnische Zeitschrift* 1901, No. 22) and also by Count Von Arco. (*Elektrotechnische Zeitschrift* 1903, No. 1, or the *Electrician,* Vol. L., p. 777.)

In the use however of a straight resonance coil for this purpose, great care is necessary to ascertain that the oscillation set up in the resonance solenoid is the fundamental and not a higher harmonic.

In view of these difficulties a closed circuit wave meter has been designed by J. Donitz.[13] He employs an arrangement consisting of a circular coil having a definite inductance in series with a condenser made of series of semi-circular discs, the capacity of which can be varied within limits by the revolution of these discs on an axis, the arrangement of the condenser plates somewhat resembling that of a Kelvin multi-cellular voltmeter. These plates are immersed in insulating oil. In inductive connection with part of the circuit is another small circuit including a fine wire platinum coil, sealed up in the bulb of an air thermometer. Hence, the production of the maximum current in the inductance coil and condenser is estimated by the reading of the air thermometer becoming a maximum. The instrument is used, as follows:— If it is desired to measure the frequency and therefore the wave length of the oscillations in any circuit open or closed, a loop is formed on that circuit, which is placed parallel to, and at some little distance from the circular coil of the wave meter. The oscillations in the first circuit are then permitted to induce others in the wave meter circuit and the capacity of this last is altered by varying the condenser, until the air thermometer gives its maximum reading. When this is the case, it is assumed that the time period of the two oscillations is the same, that of the wave meter being of course

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13. See *Elektrotechnische Zeitschrift*, Vol. 24, pp. 920–925, No. 5, 1903. Also *Electrician*, Vol. 52, Jan. 1, 1904, p. 407.

known from the known inductance and capacity of the circuit. Various coils are provided with the instrument to give it a suitable range of measuring power.

The writer has recently devised an arrangement for measuring the lengths of waves used in wireless telegraphy which he has called a *Kummeter*.

The principle involved consists in causing the wireless telegraph transmitter to act inductively upon a long straight solenoid of wire and set up in its stationary electric waves. The effective length of this solenoid is varied by means of a metal saddle which slides along it and is earthed. The position of the nodes and loops of electric force is ascertained by the employment of one or more vacuum tubes filled with rarefied Neon which the writer has found to be a most sensitive detector.*

The length of solenoid employed is varied by moving the earthed saddle until the Neon tube shows that the distance from saddle to open end is equal to one complete stationary wave length. The velocity of the wave along the solenoid can be ascertained from the measured values of its inductance and capacity and hence the frequency of the oscillations in the transmitter circuit is deduced. Knowing that the free wave travels away from the aerial with the velocity of light we have at once the means of measuring the length of the radiated electric waves sent out by the aerial.

All instruments so far devised for measuring the frequency or wave lengths in oscillating circuits depend essentially upon the same principle, but all of them require to be used in close contiguity to the radiating circuit. No practical instrument has yet been devised which will enable the wave length of the radiation to be determined at a considerable distance from the radiating source in the manner that we can determine the wave length of light rays at any distance from the source of light. No attempt has yet been made either to classify or to organize the wave lengths in use in connection with wireless telegraphy, or to earmark those wave lengths which are most suitable for particular purposes.

It is well known however, that wave lengths of 30 to 50 feet which travel well over a free sea surface are easily obstructed by houses, buildings or elevations on the ground and that for cross-country work a longer wave length is essential. The writer has

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*See a Paper on "The Propagation of Electric Waves along Spiral Wires and on an Appliance for Measuring the Length of Waves used in Wireless Telegraphy." By J. A. Fleming, *Phil. Mag.* October, 1904.

found that a wave of about 1000 feet in length passes quite easily through the buildings and houses of a large town and has worked with such wave lengths across London. When we consider the mass of iron and lead pipes contained in ordinary houses and the immense entanglements of telegraph and telephone wires overhead in large cities it is surprising to find that an electric wave of this length passes so easily through these obstacles.

It has been shown by striking demonstrations made by Dr. Marconi both in the presence of the writer and also subsequently of Admiralty officials, that the waves sent out from his power station at Poldhu, do not in the least degree affect the working of the instrument which he places on board ship for ordinary super-marine signalling.[14]

Hence the conclusions which have been drawn by those who possess insufficient information, that the working of power stations would play havoc with valuable ship to shore, and ship to ship wireless telegraphy on the Marconi system, are entirely without foundation.

We may at this stage make brief reference to the nature of the effect propagated through space from the radiator. In scientific language this is called an electromagnetic wave. It consists of a periodic and alternating creation of electric and magnetic force in a plane perpendicular to the direction in which the energy is traveling. In the particular case of a Hertz oscillator consisting of a pair of rods in one line, their approximated ends forming a spark gap, the effect produced in outer space, as Hertz showed, consists in throwing off closed loops of electric strain which move outwards from the rod. The mode of production of these electric strain loops can be deduced from a consideration of the oscillation as consisting in the movement of electrons in the rod rapid enough to bring into play the inertia quality of the medium or ether outside. We may in fact consider that the process of generating light consists in such a dispersal of closed loops of electric strain by the vibrating electrons of the atoms.

If however we plant in the earth a vertical rod and set up in it electrical oscillations then the space effect round it will consist in casting off or detaching from it semi-loops of electric strain which move away in all directions from the rod. The exact process

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[14] See Cantor Lectures (Lecture IV.) on "Hertzian Wave Telegraphy," *Journal* Soc. of Arts, London. 1903. Also a letter to the London *Times*, April, 1903, by J. A. Fleming.

of production of these has been considered more in detail by the author in other publications.[15]

The outward movement of these semi-loops of electric strain having their ends, so to speak, resting on electrons in the ground and the accompanying production of rings of magnetic force, constitutes the physical phenomena in the external space. We may fix our attention either upon the oscillatory movement of the electrons in the aerial wire or radiator or upon the effect which this produces in the outer space, just as we may pay attention to the movement of the air particles in an organ pipe or the changes in pressure and velocity which constitute the air wave sent out into the space outside.

In this case of oscillations set up in an earthed vertical rod we have not quite the same state of affairs as when we have oscillations set up in a perfectly insulated rod.

According to the view taken by the writer, in the first case we have semi-loops of electric strain sent off into space which can only move outwards if there are accompanying atom-to-atom exchanges of electrons in the earth or sea surface over which the strain loops move. Hence, a good conductivity is necessary for this and at the same time a good earth connection for the rod. The earth therefore plays a very important part in this propagation, and the case of electric radiation sent out from a perfectly insulated Hertz radiator has to be differentiated from that of the radiation from a wireless telegraph aerial earthed at the lower end. It is now well known that the "earthing" of the aerial or antennæ at both sending and receiving stations, as first done by Mr. Marconi, is an essential condition for conducting long distance wireless telegraphy. Whilst it is not denied that telegraphy over small distances can be achieved with perfectly insulated arrangements or by the employment of suitable capacity to balance the capacity of this aerial, yet the earthing seems undoubtedly necessary for practical work, and the waves sent out from an earthed vertical aerial have unquestionably a power of overcoming the earth curvature in a manner which is somewhat anomalous.

Lord Rayleigh has remarked that Marconi's achievement in sending electric waves across the Atlantic still required some scientific explanation.

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[15] See Cantor Lectures before the Society of Arts on Hertzian Wave Telegraphy, by J. A. Fleming, March 2, 9, 16, and 23, 1903. Also "Hertzian Wave Wireless Telegraphy," by J. A. Fleming, *The Popular Science Monthly*, June-December, 1903.

The waves he first employed had a wave length of about 1000 feet or say, one-fifth of a mile. The earth being a globe 8000 miles in diameter, the ratio of the above wave length to this diameter is 1: 40,000.

Imagine then an ivory ball one inch in diameter placed in a beam of parallel red light. This ball would be illuminated on one-half and dark on the other, and although there would be a very slight diffraction into the geometrical boundary of the shadow, there would certainly be no bending or diffraction of the rays for a distance equal to 45° of a great circle.

In the case of Marconi's transatlantic wireless telegraphy however, we have electric radiation sent out nearly parallel to the earth at one place and detected at another place distant by 45° of longitude on a great circle. How is it that this bending of the electric radiation takes place? If it is due to a simple diffraction, then it is proportionately to the wave length vastly greater than anything of the kind we find in connection with the ether waves which produce luminous sensations. It may be suggested that we have here one of the facts which indicate that the radiation sent off from an earthed aerial or Marconi radiator is not identical in every way with that sent out from an insulated Hertz oscillator. In the former case the semi-loop of electric strain propagated outwards has its feet or ends guided round the conducting surface over which it moves. The earth takes a very important share in the process, but since it is not possible to sever the earth we cannot ascertain how far the continuity of the earth or sea between the two places is a necessary condition for the unusual degree in which these long electric waves can as it were, be propagated round the corner. It is clear, however, that more scientific observations are requisite before we can confidently state an opinion as to the part played by the earth in the phenomena.

Space will only permit a very short reference to the interesting observation of Marconi made in a voyage across the Atlantic on board SS. "Philadelphia" in February, 1902, viz.:— That in long distance wireless telegraphy, a given transmitting arrangement is effective over a greater distance by night than by day.[16] Practically this means that it is rather more difficult to send Hertzian waves long distances through that portion of the atmosphere facing the

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[16] See *Proc.* Roy. Soc. June 12, 1902, p. 344, "A Note on the Effect of Daylight upon the Propagation of Electromagnetic Impulses over Long Distances," by G. Marconi.

sun than that portion turned away from it. The same thing may be expressed by saying that it requires a more powerful wave to traverse the sunlit air. The effect is not detectable under a distance of several hundred miles, but in his transatlantic experiments in 1902, Marconi found that the waves sent out from a particular aerial and transmitter at Poldhu were detectable on the Atlantic at a distance of 2100 miles by night, but only about 700 by day. Since that day, by modifications of the transmitting plant he has been able to greatly extend the daylight distance.

An interesting scientific question arises as to the causes of this difference. Prof. J. J. Thomson has shown[17] that electric waves passing through space will exert an action upon electrons or negatively electrified corpuscles disseminated through it. These electrons will be urged forward in the direction in which the wave is travelling. The action is proportional to the square of the wave length and is very small for light waves, but may become considerable for long Hertzian waves. Hence, if there are present in sunlit air free electrons due to the ionizing action of the light on the gaseous atoms, then this medium will absorb some of the energy of long Hertzian waves passing through it and the observed effect would be accounted for, at least in a general sense.

Captain H. B. Jackson of the British navy has placed on record much interesting information as to the relative opacity and transparency of the atmosphere to telegraphic Hertzian waves under particular conditions; and the effects of atmospheric electricity upon the accuracy of signalling.[18]

Just as ordinary telegraphy with wires is interfered with by earth currents and magnetic storms, so space-telegraphy conducted with electric waves meets with difficulties under some circumstances due to atmospheric electricity and particular conditions of the gaseous medium through which it takes place. We must, in the next place, consider the receiving arrangements now in use for detecting the waves sent out by the transmitter.

At the receiving station, an aerial wire antenna has to be erected. The electric waves cut through this wire and as the direction of

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[17] See J. J. Thomson, *Phil. Mag.*, August, 1902, Vol. 4, Ser. 6, p. 253. "On Some of the Consequences of the Emission of Negatively Electrified Corpuscles by Hot Bodies."

[18] See Capt. H. B. Jackson, R.N. F.R.S., *Proc.* Roy. Soc., May 15, 1902, "On Some Phenomena Affecting the Transmission of Electric Waves over the Surface of the Sea and Earth."

their electric force is parallel to it, the moving magnetic force creates an electromotive force in the stationary aerial by cutting through it just as the moving wire of a dynamo has electromotive force generated in it when it cuts across the stationary magnetic field.

This electromotive is however alternating and of high frequency. Hence, if the natural electrical time period of the aerial agrees with that of the incident wave, considerable electrical oscillations may be created. Stationary waves will be set up in the aerial and these will be fundamental or harmonic, conditioned however by the fact that the current in the aerial must zero at the summit and have an antinode or loop at the earthed end.

For the detection of these stationary waves in the aerial, devices are employed which the author has ventured to christen *kumascopes* (from *κυμα*, a wave). These kumascopes may be classified according to the physical principle which underlies their operation. Those in use for telegraphic work are, as follows:—

(i) Imperfect contact kumascopes, often called coherers or anti-coherers.
(ii) Magnetic kumascopes.
(iii) Thermal kumascopes.
(iv) Electrolytic or chemical kumascopes.

The first class, or imperfect contact kumascopes, depend for their operation on the fact that if two masses of electric conducting material are in very light contact or separated by a very thin film of dielectric, the conductivity will be changed considerably if a certain difference of potential is made between the conductors. In some cases (the majority) the change is from poor to better conductivity, in other cases it is to worse conductivity. In some cases (the majority) the initial state can only be restored by administering a slight shock or shear and in others the original state is recovered spontaneously. Hence, we have four classes to consider. The first class of these variable conductors have generally been called ***coherers.***

A small mass of metallic filings, preferably nickel or iron in loose contact in a tube between two metal plugs, is a typical case. The mass has a very high resistance until a certain potential difference, not far from two volts, is made between the plugs and it then passes instantly into a highly conducting condition and is restored again by slight shocks. Such an arrangement can be used as a relay or relay upon a relay in connection with the kind of telegraphy now considered. For if the receiving aerial wire has inserted near its base the primary circuit of a suitable oscillation transformer and if the filings tube has its plugs connected to the secondary, then the impact of an electric wave on the aerial will be followed by the creation of an electromotive force in it which will be applied to create a conductivity-change in the filings tube. By joining also in series with the tube a single voltaic cell and an ordinary telegraphic relay we have the means of creating a telegraphic signal, by recording the change in the conductivity of the kumascope.

The principal kumascope in use at the present time of this type is the Marconi nickel-silver filings tube, which is not self-restoring. but requires tapping. The Braney tripod and steel ball contact kumascopes are also not self-restoring. The Lodge-Muirhead steel disc and Mercury kumascope, the mercury having a film of paraffin oil upon it, is however restored to sensibility by the continual rotation of the steel disc.

The mercury-carbon or mercury-steel contact kumascope of Tommasina, on the other hand is a self-restoring contact kumascope.

For the details of these kumascopes, the reader must be referred to other sources of information.[19]

The contact kumascopes consisting of metallic filings in tubes require a carefully adjusted tapping in order to be able to record a Morse *dash* as well as a *dot* on the telegraphic tape of the inker used in connection with them. This tapping process limits the speed of working to about 15 to 18 words a minute, but it has the advantage that there is a printed record of the message.

The second class of kumascope comprises those depending upon the power of electric oscillations to demagnetize iron or to decrease or increase its magnetic hysteresis.

Rutherford discovered in 1896 the power of electric oscillations set up by electric waves in an open circuit to demagnetize a small bundle of iron wire, and Marconi in 1902 invented a most ingenious telegraphic kumascope depending upon the power of electric-oscillations to annul the hysteresis of an iron core of hard iron wires. He adopted a simple method of detecting this variation of magnetic state. The iron wire is made to move forward in a feeble

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[19] See Cantor Lectures on Hertzian Wave Telegraphy, by H. A. Fleming, *Journal* of Society of Arts. 1903.

constant magnetic field, parallel to the lines of force. It is embraced by two overlaid coils. Through one of these the oscillations set up in the receiving aerial pass and the other is connected in series with a telephone. Hence, as the wire advances through the field, the portion magnetized is carried forward by hysteresis, but caused to slip back as soon as the electric oscillation takes place around it, and this by changing the flux through the coil in series with the telephone, causes an electromotive force in it and hence a sound in the telephone. The apparatus is more sensitive than the metallic filings tube as a kumascope and was employed by Marconi in his telegraphic experiments across the Atlantic in 1902 and 1903 and in those in which he sent messages across sea and land from Poldhu to Kronstadt and from Poldhu to Spezzia and to Gibraltar. The writer has also devised a solenoidal form of magnetic kumascope which is metrical and is operated with a galvanometer as indicator.[20]

More recently, Ewing and Walter have found that electrical oscillations have the power to *increase* the magnetic hysteresis of hard steel wire and have constructed a kumascope in which this fact is utilized.[21]

There are forms of kumascope which essentially depend upon the heating power of electrical oscillations. Fessenden has constructed one form in which an exquisitely fine platinum wire is mounted in a vacuous bulb, like the filament of an incandescent lamp. When this metallic loop is traversed by an electrical oscillation it is heated and its resistance is changed. By joining it in connection with a voltaic cell and telephone it can be so arranged that the sudden change in resistance of the fine wire alters the current flowing through the telephone and thus causes a sound in it.

Fessenden has also employed a fine column of liquid as the resistance to be heated by the oscillations, and this has an advantage over a fine metal wire in respect of greater temperature coefficient and larger specific resistance.

Lastly, there are interesting forms of kumascope which depend on electrolytic action. One of the earliest of these was due to

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[20] See J. A. Fleming, "A Note on a Form of Magnetic Detector for Electric Waves, Adapted for Quantitative Work," *Proc.* Roy. Soc., Lond., Vol. 71, p. 398, 1903.

[21] See Ewing and Walter, "A New Method of Detecting Electrical Oscillations," *Proc.* Roy. Soc., Lond., 1904, Vol. 74, p. 120, or *The Electrician*, Vol. 52, p. 783.

Schäfer and another form to Neugschwender. De Forest has employed one in which a continuous electric current flowing through a very small cell containing a mixture of electrolytes and metallic particles is said to produce a chain of metallic particles between the electrodes. The passage through the cell of an electrical oscillation breaks up this chain and varies the electrical resistance of the cell.

It is impossible to describe here a tithe of the forms of kumascope which have been devised, but it is probably correct to say that all the effective Hertzian wave telegraphic work is being done at present either by means of a few forms of contact kumascope, the principal one of which is the nickel-silver filings tube of Marconi, or else by means of some form of Magnetic Kumascope.

In the first case, the message is printed telegraphically on paper tape and in the second case, it is *heard* in a telephone as a series of ticks and longer sounds equivalent to the dot and dash of the Morse code. The telephonic method has the advantage in speed and can be read up to 30 or 35 words a minute depending on the skill of the operator, but it has the disadvantage that there is no permanent record of the message and everything depends therefore on the operator being able to hear and take down at the same moment.

The telephonic method enables communication to be established at a rate quite equal to that possible by hand sending over land lines and quicker than hand sending over any long submarine line.

The author has devised arrangements by which a punched paper tape can be employed to operate the switch or key in the primary circuit of the induction coil or transformer and so obtain the speed and certainty due to mechanical signalling. Such a method has the great advantage of perfect spacing and duration of signals. By the use of this device *dots* can be interpolated at regular intervals so as to render it more difficult to decipher any tapped message, and a long message can be cut up and the different parts sent simultaneously. In perfecting this automatic sending apparatus, the author has devised an arrangement which enables a signalling switch requiring considerable power to operate it, to be moved quickly by an exceedingly small electric current. There is no doubt that for code messages, especially if received and read by a telephone method, the automatic sending should be adopted and the message repeated at least twice.

Some attempts have been made to record the wireless messages directly upon a steel wire or tape in the manner of Poulsen's telegraphone and it would be an obvious advantage if the arriving trains of waves could thus be made to record themselves on a travelling magnetized wire, the record being then afterward read off at leisure by the telephone. Coupled with a method of automatic sending, this would give the highest degree of security for precision in the transmission of commercial messages in which so much depends on the accuracy of every letter.

One of the matters which has excited most controversy in connection with this subject of Hertzian wave telegraphy is the degree to which isolation of the communicating stations is possible. If we except certain experimental methods which have not yet stood the test of practice, we may say that the only plan which has yet been found to afford a basis for such isolation is that depending upon the employment of the facts of electrical resonance. If feeble electromotive forces act in a circuit open or closed, which possesses capacity and inductance and therefore a definite natural time period of oscillation, these impulses will set up in the circuit electrical oscillations of considerable amplitude provided that their frequency agrees with that of the natural time period of the circuit. If C is the capacity of the circuit in microfarads and L its inductance in centimeters, then if the frequency of the applied electromotive impulses is equal to $5\times10^6/\sqrt{C\,L}$ the condition of resonance will be fulfilled. In order that there shall be a certain rigidity about the electrical system the inductance must not be too small. In fact the larger the inductance, the less liable will the electrical system be to be set in oscillation by a few feeble or discordant impulses. Hence the method which has been found successful within certain limits for rendering a receiving station sensitive only to electric waves of one particular frequency, is to provide a transmitting appliance sending out waves as little damped as possible, i. e., long trains of isochronous oscillations; next, arranging the receiving appliances, aerial and closed associated circuits to be in syntony with the transmitter, and thirdly, bestowing on the receiving circuit as much inductance as possible.

It is difficult without numerous diagrams to describe the details of the various arrangements that have been proposed to fulfil the above conditions. Many of them are explained in the author's Cantor Lectures on Hertizan Wave Telegraphy delivered before the Society of Arts in 1903. Dr. Marconi's own arrangements for

Syntonic telegraphy have also been described by him before the Society of Arts.[22]

Briefly speaking, his method is to insert in the base of the receiving aerial the primary circuit of an oscillation transformer, the secondary circuit of which forms with certain adjustable condensers a closed syntonic circuit. The receiving circuits inductively connected are in syntony with each other and with those of the transmitter.

The kumascope is attached to certain points on this circuit and the arrangements are such that if a metallic filings kumascope is employed it is only affected when the amplitude of the induced electromotive force in the closed circuit has in virtue of resonance reached a certain value.

Marconi was the first to show that with his syntonic arrangements he could both send and receive simultaneously two independent messages on the same transmitting and receiving aerials.[23] Theoretically there is of course no limit to the possibility of such multiple telegraphy. In practice it is found that the harmonic oscillations cannot be too near each other, and also that no syntonic circuits are entirely impregnable to attack by powerful vagrant waves, or strong waves of nearly the same period.

On the other hand, if the wave lengths differ considerably, remarkable feats may be performed with syntonic arrangements. Marconi has again and again demonstrated that such waves as are emitted from his power stations are quite without influence or the receiving arrangements designed by him for ordinary marine intercommunication between ships and shore.[24]

Space will not permit us, neither is it the object of this paper, to enter into detailed description of the various arrangements suggested with the object of isolating completely the intercommunication of wireless stations.

Dr. Marconi's work has rendered it possible for his Company to establish a widespread system of intercommunication between ships, and ships and shore, which is necessarily conducted with the same

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[22] G. Marconi. "Syntonic Wireless Telegraphy," *Journal* of Society of Arts, May, 1901, Vol. 49, p. 505.

[23] See a letter to the *Times*, by J. A. Fleming, London, October 4, 1900.

[24] See a letter to the *Times*, April 14, 1903, describing experiments performed before the writer; and also an article in the *Times* for November 10, 1903, describing similar demonstrations made before British Admiralty Officials.

wave length of frequency. In the next place he has shown that he can operate large power stations intended for long distance work without in any degree interfering with the operation of the valuable ship communication, and in the third place, what may be called short distance power stations for work up to 300 or 400 miles have been established which are not affected by the waves from the larger power stations.

From time to time a good deal has been said as to the facility with which wireless messages can be tapped but it must be remembered that as regards messages sent with wires, the privacy attaching to them is not due to any difficulty in tapping but to the legal penalties attending the operation.

The question of locating the position of a sending station or of directing a beam of radiation in any required direction has been much discussed. In some of his earliest experiments Marconi used mirrors and was successful in this manner in limiting the direction of radiation when telegraphy was conducted over a distance of about a couple of miles. Patentees have again and again recurred to the idea of using lenses and mirrors for this purpose. The scientific difficulty which presents itself is that the wave lengths which must be used for telegraphic purposes are very long compared with the size of any apparatus which we can practically construct. Wave lengths as short as 30 feet do not travel well through buildings or over irregular or hilly ground and when we come to using wave lengths of several hundred feet in length, then any mirrors or lenses that we can construct are necessarily small compared with this wave length and the attempt to focus or direct a beam of electric radiation of this character is as impossible as it would be to conduct optical experiment if our lenses and mirrors could only be 0.00001 of an inch in diameter.

No really successful experiments have yet been made in limiting the diffusion of radiation in all directions when electric waves are employed of the character required to travel considerable distances over land or sea. Numerous patents have been filed or applied for, asserted to accomplish this desired end, but by far the larger portion of the patents taken out every year in connection with the subject of wireless telegraphy involve merely ideas or anticipations but not results. Nevertheless, it is not an impossible thing that improvements may be devised for determining both the distance and the direction of the sending station and such an invention would be of the greatest possible use in connection with Marine Wireless Telegraphy, provided that the detecting apparatus is such as could be placed on board ship.

It is impossible in a short paper such as the present one to do justice to the numerous inventions that have been made in connection with this subject, it is also a matter of great difficulty to separate the chaff from the wheat in reading the innumerable patent specifications which continue to be lodged for various inventions connected with wireless telegraphy. Probably not one per cent of them are of any real value, or mark a distinct advance on what has already been done. It is a matter of impossibility of course, to test these innumerable ideas without an expenditure of time and money totally impracticable.

If we endeavor to sum up the position generally at the present moment with regard to practical achievement, we find that in the last three years the Marconi system of wireless telegraphy by Hertzian waves, and his form of apparatus have established themselves as a standard system of communication between ship and shore, and ship and ship, and that thereby a most valuable addition has been made to our means of communication totally distinct from other previously existing methods of telegraphy. The Marconi Company have already equipped 50 or more vessels of important lines with these appliances. Eight of these are vessels in the Cunard Steamship Company, five in the Norddeutscher Lloyd, three in the Allan Line, three in the Atlantic Transport Co., four in the American Line, six in the Compagnie Transatlantique, nine in the Belgian Mail Packet Service, four in the Red Star Line, five in the Hamburg-American Line and one in the Isle of Man Steam Packet Company. Meanwhile a system of communication of news to Transatlantic liners in transit has been inaugurated by the Marconi Wireless Telegraph Company. From Poldhu and from Cape Breton Stations news is daily dispatched to these vessels by Marconi telegraphy and is reproduced in newspapers, written, printed and published daily on board these vessels.

Important questions have arisen, which it is not the object of this paper to discuss, in connection with a proposed regulation by international legislation of wireless telegraphy for shipping purposes, with the result that a Conference for this purpose was called by the German Government and met in Berlin in August in 1903. This Conference was of a preliminary character and whilst the majority of the Powers represented were in favor of inter-communication between all ships equipped with wireless apparatus, irrespective of the system employed, the Governments of Great Britain and Italy placed themselves outside this proposal.

More recently, serious questions have arisen in connection with employment of wireless telegraphy by neutrals in case of war for the communication of information for journalistic purposes. The Government of Russia has made a pronouncement upon this matter which has already secured the serious attention of the principal Governments of the world who are interested in this matter and no doubt important decisions may before long be reached. During the present year (1904) the British Government felt that the matter required legislation. Lord Stanley, the British Postmaster-General, accordingly introduced a bill into the House of Commons which became law before the conclusion of the session. This bill entitled "A bill to provide for the regulation of wireless telegraphy" makes it illegal for any one to establish within territorial limits or on a British ship apparatus for effecting wireless telegraphy without first obtaining a license from the Postmaster-General. The administration of British self-governing colonies and the Governments of other great Powers have already assumed the control of wireless telegraphy and the important influence which it has been shown by the Russo-Japanese war to exercise over naval warfare has been the chief ground for the action of the British Government.

There can be no doubt that some national control over the ether when used for this purpose is necessary. On the other hand, it is to be hoped that it will be so exercised that private invention and commercial enterprise will not be crippled or hindered.

In addition to its employment by the mercantile marine for the purpose for the conveyance of news to ships at sea, the chief navies of the world have adopted it as a most important auxiliary to their present methods of signalling. The Governments of Great Britain, the United States, Germany and above all Italy have been particularly active in this matter and much valuable information has been accumulated by the scientific officers who are concerned with this particular department.

No communication on the subject of wireless telegraphy could be considered other than imperfect in which reference was not made to the matter which has chiefly occupied Dr. Marconi's mind and energy during the last three years, viz.:— The accomplishment of transatlantic wireless telegraphy. As the information which the writer has on this subject is confidential, no communication can be made of facts which are not already before the public, but merely for the sake of placing them on record here, a brief mention of the events connected with this great enterprise may be given.

In July, 1900, Marconi came to the conclusion that his previous achievements warranted him in seriously attacking this problem and after much preliminary scientific consideration of the subject, a locality was selected at Poldhu in Cornwall in the extreme west of England for the first power station for the production of electric waves for transatlantic telegraphic purposes. The first building began to be erected, to the writer's designs and under his superintendence, in October, 1900, and the electrical apparatus in January, 1901, and this was practically completed in August, 1901, at least in such condition that Dr. Marconi was able to begin preliminary experiments with it.

An accident to the masts upholding the aerial in September, 1901, a little delayed experiments, but on the 27th of November, 1901, Dr. Marconi left England in SS. "Sardinian" for St. Johns, Newfoundland, having previously arranged a programme of operations. On Monday, December 9, 1901, he commenced his experiments and on Thursday, December 12th, he received "S" signals at St. Johns which were unquestionably sent from the station at Poldhu in Cornwall and public announcement of this great achievement was made in the English newspapers on the morning of December 16, 1901. He returned to England at the end of January, 1902, and left again in February on board the SS. "Philadelphia" and arrived in New York, March 1, 1902, having received signals and messages on board the "Philadelphia" all the way up to 2000 miles from Poldhu.

The remainder of the year was occupied in completing a new station at Cape Breton, Nova Scotia, and when this was completed messages were despatched across back to Poldhu to their Majesties the King of Italy and the King of England, and numerous other illustrious persons.

During the year 1902 another power station had been completed at Cape Cod, Mass., U. S. A., and in January, 1903, a message was sent by wireless telegraphy across the Atlantic from President

Roosevelt to King Edward VII. Meanwhile Dr. Marconi had been busy with other investigations to determine the distance at which these signals could be received in other directions.

In July, 1902, he went to Kronstadt on board the Italian warship, "Carlo Alberto," and received messages with his magnetic detector despatched from Poldhu. In the following Autumn on the "Carlo Alberto" he went through the Bay of Biscay to Spezzia, via Gibraltar and received messages from Poldhu in the harbor of Spezzia. Subsequently the "Carlo Alberto" was placed at his disposal by the Italian Government for experiments across the Atlantic continued up to Cape Breton, Nova Scotia.

In April, 1903, press messages were sent across from Cape Breton to the London "Times." Since that date, improvements have been in active progress at this station, necessitated by subsequent inventions of Marconi.

Criticism has not been wanting on this great practical achievement and many of those who are interested in submarine telegraphy have not hesitated to declare that it can never be brought into a condition in which it can compare with cables as a means of communication. He, however, is a bold prophet who will venture to say what 50 years or even less will not bring forth, and submarine cable telegraphy has had just 50 years start of supermarine wireless telegraphy. Even the delays and difficulties in connection with the transatlantic wireless telegraphy have only repeated those of the early days of transatlantic submarine telegraphy. It will be remembered that the first attempt to lay a cable across the Atlantic was made in August, 1857, and was a failure. In 1858, a cable was laid successfully, which broke down after a life of three months, after about 700 messages had been passed through it. From that date there was an interval of nearly seven years before a new attempt was made to lay the 1865 cable and it was only in 1866, or nine years after the first attempt, that a cable was laid which established uninterrupted transatlantic telegraphic communication.[25] It is not yet nine years since Marconi filed his first British patent specification and if we look back at what he has achieved in the past eight years, there is no reason to doubt that he, if he lives, or at any rate those who come after him will carry through the great

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[25] See "Story of the Atlantic Cable," by Charles Bright. Newnes & Co., London, 1903.

enterprise he has initiated, to commercial, and successful completion.

Hundreds of wireless messages have already crossed the Atlantic and in that one single fact we have the guarantee of subsequent achievement.

No one who was connected, in their early days, with the then new enterprises of incandescent electric lighting or urban telephony, and who can look back at what has been accomplished in 20 years from apparently the most unpromising beginnings, will need assurance that commercial success can always be obtained where there is a substantial scientific achievement at the bottom of it.

A great part of invention however is concerned in discovering. first of all, what will not succeed and this is a matter which involves time and an expenditure of money. The inducements however to succeed are so great that having regard to what has already been accomplished it is more than probable that the full completion of hopes that have been entertained will not be long deferred.

This paper, however, is not concerned with prophecy, but with accomplished facts and a simple record of the present state of an art, which founded on scientific principles has given a new means of communication, proved already to be of inestimable utility. Hence we do not indulge in any speculations as to the immediate future development of it, but we are confident that the fruitful field of practical invention laid open by the genius of Marconi will continue to be actively cultivated by discoverers and improvers in Europe and in the United States.

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CHAIRMAN JONES: The next paper is by Dr. Hammond V. Hayes, who is not present with us to-day.

Upon motion of Mr. Hesketh, Secretary Gherardi read Dr. Hayes' paper, as follows:

LOADED TELEPHONE LINES IN PRACTICE.

BY DR. HAMMOND VINTON HAYES.

The mathematical discussion of the theory of loaded telephone lines has been fully given in the writings of Prof. M. I. Pupin[1] and Dr. G. A. Campbell.[2] In the present paper it is intended to state briefly the results which have been obtained by the use of loading coils on many of the telephone circuits of the Bell companies.

In every problem affecting the transmission of telephone waves over a line, there are two factors to be considered,— the attenuation and the distortion of the waves. The loss of energy of the waves upon the line must be kept at a minimum and the several component waves of the telephone or voice waves must be transmitted without unequal relative impairment.

DISTORTION.

The introduction of lumped inductance in the form of loading coils upon a telephone line tends to increase the distortion by the possible unequal reflection of the component waves of different periodicities, and by the possible unequal attenuation of the several waves in passing through the coils.

REFLECTION LOSSES.

The mathematical work of both Pupin and Campbell showed conclusively that if several loading coils lay within a wave length on any particular loaded circuit, and the coils themselves were theoretically perfect, the circuit was distortionless. The spacing of the coils upon a circuit in practice, therefore, depends simply upon a determination of the highest periodicity that should be retained in the telephone waves in order to maintain the character of the voice waves unimpaired. It has been found convenient in studying the spacing of loading coils to consider the number of coils which

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[1] *Trans.* Am. Math. Soc., July, 1900; *Trans.* Amer. Inst. Elec. Eng., Vol. xvii, May, 1900.

[2] *Phil. Mag.*, March, 1903.

would be passed by a wave front on each particular circuit in the unit of time, or a second. As the velocity of all waves upon a given circuit is the same, and as the wave length for any periodicity can be readily determined from the velocity, this convention makes it possible to readily determine the number of coils lying within any particular wave length.

A large number of long telephone circuits have been equipped with loading coils, the spacing of the coils upon the several circuits being such as to produce a range of the number of coils per second between 13,000 and 7000. A comparison of the transmission over these several circuits has shown that the quality of transmission is not appreciably impaired even with the lower number of coils per second. This seems to indicate the lack of importance of the overtones of very high periodicity in the successful transmission of speech.

It can be said, therefore, with considerable certainty that the distortion due to reflection losses in a loaded telephone circuit can be neglected, provided the coils are so spaced upon the line as to give at least 7000 coils per second, and that this spacing of the coils is substantially uniform throughout the line.

DISTORTION IN COIL.

To entirely eliminate distortion in a loading coil, it is necessary to have it so designed that the effective resistance of the coil to all the essential periodicities of the telephone waves shall be the same. Such a coil is theoretical, and cannot be obtained in practice. A loading coil is primarily one so designed as to provide a required amount of inductance, and must, of necessity, consist of several turns of wire. Moreover, to prevent attenuation, it is imperative that the resistance of the coil be kept as low as possible. To make the resistance of the coil low, the wire employed should be of copper of large size, and the number of turns of wire in the coil should be kept small. A reduction in the turns can, other things being equal, be most easily obtained by the use of iron for the core of the coil. If the coil is made entirely of copper, the effective resistance of the coil with the frequencies within the range of telephone periodicities will differ from the resistance by an amount corresponding to the losses due to eddy currents in the copper. If iron forms a portion of the coil, there will be, in addition to the eddy-current losses in the copper, eddy-current losses in the core, as well as hysteresis losses in the iron, which will augment the difference between the resistance and the effective resistance. As it is impossible to eliminate the eddy current and hysteresis losses entirely, the effective resistance of a loading coil will vary with different periodicities, and thereby tend to produce distortional losses in the transmitted telephone waves. The difference between the resistance and the effective resistance, at telephonic periodicities, can be made much smaller in a coil composed entirely of copper than in one having an iron core.

Practical and commercial reasons demand an iron-cored loading coil, provided that such a coil can be so designed that its use in a telephone circuit will not be productive of appreciable distortion. To determine whether, in practice, there was appreciably more distortion introduced by loading coils having iron cores, as compared with those made entirely of copper, the two circuits first loaded were equipped, one with iron-cored coils, and the other with copper inductance coils. The circuits were each about 1000 miles in length. The coils used on these two circuits were spaced alike, and had the same inductance and approximately the same resistance. The effective resistance of the coil having an iron core,was about 15.5 ohms at a periodicity of 2000 per second and that of the copper coil 11.8 ohms at the same periodicity. These circuits thus loaded were compared with each other with the greatest care and no difference was apparent either in the character, or quality, of the telephone transmission. These tests are again confirmatory of the fact that the suppression or reduction of the waves of the highest periodicities of the voice waves does not appreciably affect the quality or intelligibilty of transmitted speech. This experiment was considered as demonstrating conclusively the possibility of the commercial use of loading coils having cores of iron.

LOADING COIL.

A discussion of the theoretical dimensions of loading coils for different classes of circuits may be found in Dr. Campbell's paper, to which reference is above made. In practice the size and cost of the coil are factors requiring serious consideration. For aerial circuits, where the size of the line wire is large, and consequently the resistance of the circuit small, it is of the utmost importance that the effective time-constant, $\frac{L^1}{R^1}$ of the coil should be made as large as is consistent with reasonable cost. Except so far as the cost is affected, the size of the aerial loading coil is of no special moment, as the coils can be mounted singly upon the poles. The time-constant of a coil can be increased by enlarging its size, but such increase in size increases its cost. The best commercial loading coil is, therefore, the smallest coil that will give the required inductance and the largest effective time-constant.

Following the theoretical considerations as deduced by Dr. Campbell[3], the resistance of the coils which have been used on aerial circuits has been made 2.4 ohms. The design of the core, the permeability of the iron, the subdivision of the iron and the copper have been made such that a loading coil has been produced having an inductance of .25 of a henry, a time-constant of .048 second, at a periodicity of 1000 periods per second, and a bulk of approximately 314 cu. ins. This coil is toroidal in shape, 10 in. in diameter and 4 in. high. It has an effective resistance of 15.5 ohms at 2000 periods per second.

Coils designed to be used on cable circuits in which the size of wire employed is much smaller do not require to be made of as low resistance as the coil above described; consequently their size and time-constant may be made much smaller. Large numbers of cable loading coils have been placed in service, their design varying with the character of the circuit upon which they are to be used.

REFLECTION.

In the terminal apparatus at present used in telephony, or where there is a condition of non-uniformity in the character of the line, the telephone waves suffer a reflection, which, in many cases, is effective in materially increasing the attenuation. This reflection is particularly pronounced at the point where an unloaded section of line is connected to a loaded section. The amount of reflection is greater the greater the divergence from homogeneity. Thus a section having large inductance per mile, when connected with a non-loaded section, exerts a larger reflective action than one having a small inductance per mile.

In practice, the effect of reflection is of very considerable importance, particularly when the loaded section is not relatively long. Theoretically, these reflection losses may be eliminated by the

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[3] *Philosophical Magazine*, G. A. Campbell, March, 1903.

use of a perfect transformer introduced at every point of non-uniformity in the line. Even could such a perfect transformer be made its introduction on commercial circuits is open to practical objections, and, as a substitute, its equivalent, in the shape of a series of coils of varying inductance, has been employed. This arrangement of coils of varied inductance is known as a "terminal taper." The arrangement of the several coils constituting the taper is such that a coil having an inductance somewhat less than that of the coils used on the loaded section is placed nearest the loaded line, a coil of inductance somewhat less than the first taper coil is placed next in order, and a coil of small inductance is placed nearest the non-loaded section, or the terminal apparatus. The spacing of the coils in the taper corresponds with that of the coils of the line of which it is to form the terminal.

RESULTS OBTAINED ON COMMERCIAL CIRCUITS.

The following figures illustrate the results which have been obtained on several typical commercial circuits. In what follows, all comparisons are made on the basis of relative attenuation between similar circuits loaded and unloaded, without reference in any way to distortion or quality of the transmitted speech. The curves shown in these figures are the results of actual tests, made on commercial loaded circuits, using standard terminal apparatus at the transmitting and receiving stations.

LOADED CABLE.

In Fig. 1 are shown the results obtained in tests of a heavily loaded standard telephone cable. In this cable the wires are .03589 of an inch in diameter, having a resistance of about 96 ohms per mile of circuit. The mutual capacity between the two wires of the circuit is .068 of a microfarad per mile. The inductance added to the circuit by the loading coils amounted to about .6 of a henry per mile. In this figure the abscissæ represent lengths of cable and the ordinates the relative strengths of current. Curve 1 is that representing the attenuation of current on an unloaded circuit as the length of cable is increased.

It will be seen that the attenuation increases very rapidly as the length of cable is increased. Curve 2 represents the attenuation on a similar circuit but loaded as above described, the terminal telephone apparatus being placed directly at the ends of the loaded cable, thereby obtaining the full effects of reflection. It will be noticed that the initial current on the loaded circuit is about one-quarter of what it is on the unloaded circuit. Moreover, the transmission on shorter lengths of the loaded circuit under these conditions is much poorer than the transmission over similar lengths of the same cable circuit unloaded. But the rate of attenuation per unit of distance is much less on the loaded than on the unloaded circuit; so that for the longer lengths of circuit the transmission is superior on the loaded circuit to that on the same lengths of unloaded circuit. Curve 2 shows the attenuation when no terminal tapers are employed and the reflection is a maximum. If terminal tapers are employed at the two ends of the loaded circuit and the telephone transmitting and receiving apparatus is

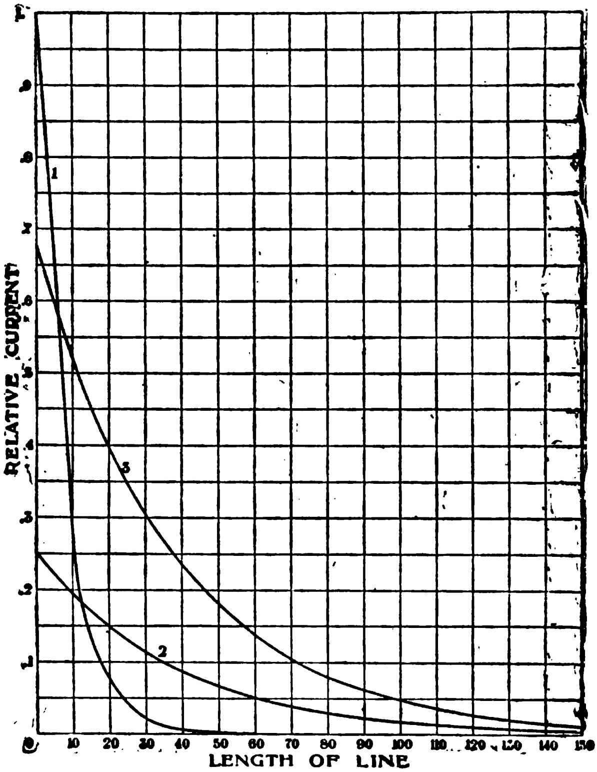


Fig. 1.

connected directly to the tapers, the attenuation on the loaded circuit is represented by Curve 3. Here again it is seen that the initial current is considerably less than that on the unloaded circuit and that the transmission on short lengths of circuit is better on the unloaded than on the loaded conductors, but the introduction of the tapers on the loaded circuit has more than doubled the initial current and has shortened by about one-half the length of circuit which showed the unloaded circuit superior. A comparison of Curves 2 and 3 shows how great a factor the reflection losses are between the terminal apparatus and a loaded circuit and the importance of the taper in reducing these losses. In practice it has been found that reflection losses can be still further reduced and under special conditions almost, if not entirely, eliminated.

In the case above described a large amount of inductance has been added to the circuit. The results which have been obtained upon cables where less inductance has been added are shown in Fig. 2. In this case the cable is substantially similar to that previously described. Upon it loading coils are placed so as to bring the inductance of the circuits up to approximately .17 of a henry per mile. In other words the inductance is less than one-third of that in the case just described.

In Fig. 2, Curve 1 is similar to that in Fig. 1 and represents the attenuation of the telephone current in an unloaded circuit in the cable. Curve 2 represents the attenuation in the lightly loaded circuit when no tapers are employed and the telephone transmitting and receiving apparatus are placed at the terminals of the loaded cable. It is to be noted that the reflection losses are much less in the case of the lightly loaded cable than is the case in that having the heavier loading. In fact for shorter lengths of cable the lighter loading is more effective in transmitting the telephone wave than the heavier. For longer lengths, however, the heavier loading gives better results. With proper apparatus at the terminals of the loaded cable to reduce reflection losses, much less attenuation would result than is indicated by Curve 2.

LOADED AERIAL CIRCUITS.

In Fig. 3 are shown the results which have been obtained on open-wire circuits composed of copper wire weighing 435 lbs. to the mile. On these circuits loading coils were so placed as to make an inductance of about one-tenth of a henry to the mile. Curve 1 shows the attenuation with various lengths of line upon a similar unloaded circuit, and Curve 2 shows the attenuation on the loaded circuit when the telephone transmitting and receiving apparatus are placed directly at the ends of the line without tapers. Curve 3 shows the attenuation under similar conditions when tapers

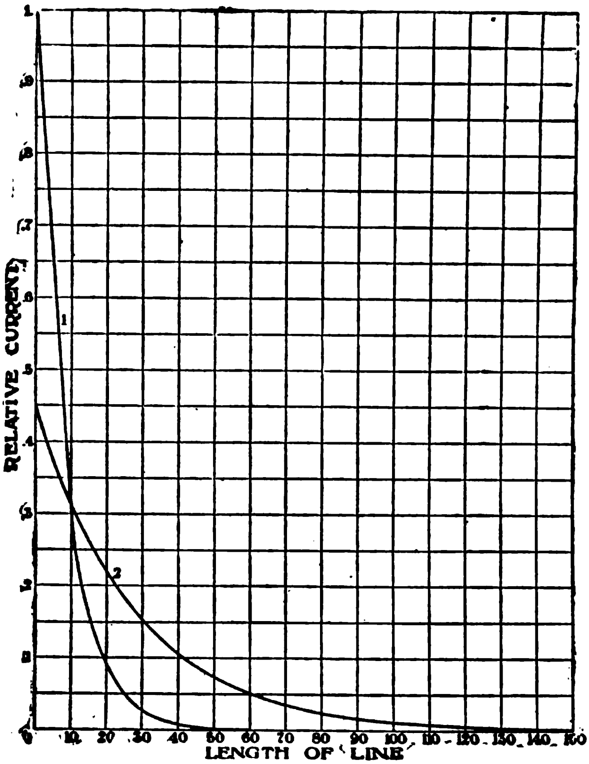


FIG. 2.

are employed. The results resemble those obtained with loaded and unloaded cable. There is a large reflection loss which is considerably reduced when tapers are employed. Even with tapers the loaded line for shorter distances is inferior to the unloaded. The point particularly to be noticed is the relative slope of the curves in the two cases indicating that the benefits to be obained from loading open-wire circuits are less than with cable circuits.

Fig. 4 illustrates the results which have been obtained from loading open-wire circuits using a conductor weighing 176 lbs. to the mile and having an added inductance equal to about .1 of a henry to the mile. As before, Curve 1 represents the attenuation on a similar unloaded circuit; Curve 2, the loaded circuit without tapers, and Curve 3, the loaded circuit with tapers.

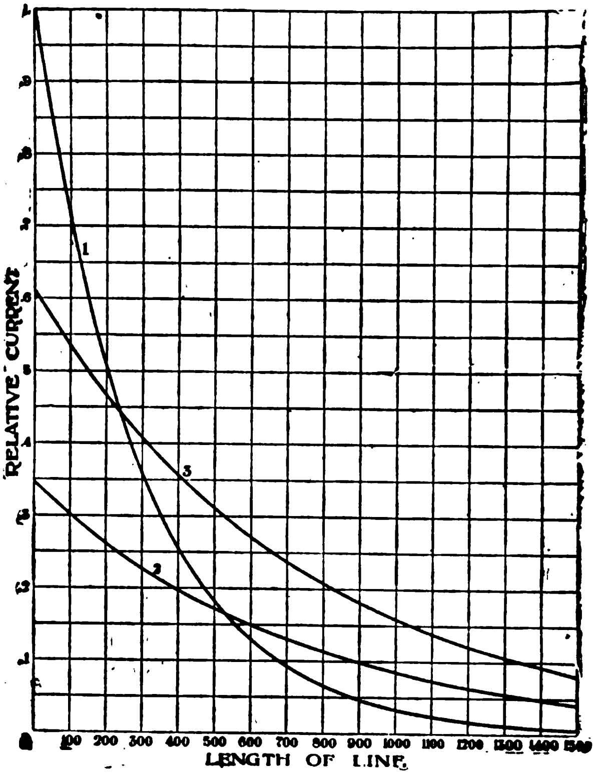


FIG. 3.

GENERAL CONSIDERATIONS.

The above curves show the results which have been obtained by the use of coils of considerable inductance added to open-wire and cable-telephone circuits and may be considered as typical of the results obtained on similar circuits of different capacity or composed of wire of different size. As before stated the curves illustrate simply the relative volumes of transmission under the various conditions described.

In the case of cables there is a distinct improvement in the quality of the transmission produced by the introduction of the loading coils, the voice of the speaker being received more distinctly. The high insulation which can be maintained at all times on cable circuits renders it possible to introduce loading coils upon the circuits without danger of materially augmenting leakage losses. The marked diminution in attenuation, the improvement in quality of transmission and the ease with which inductance coils can be placed on cable circuits without introducing other injurious factors, such as leakage or cross-talk with other circuits, renders the use of loaded cable circuits especially attractive.

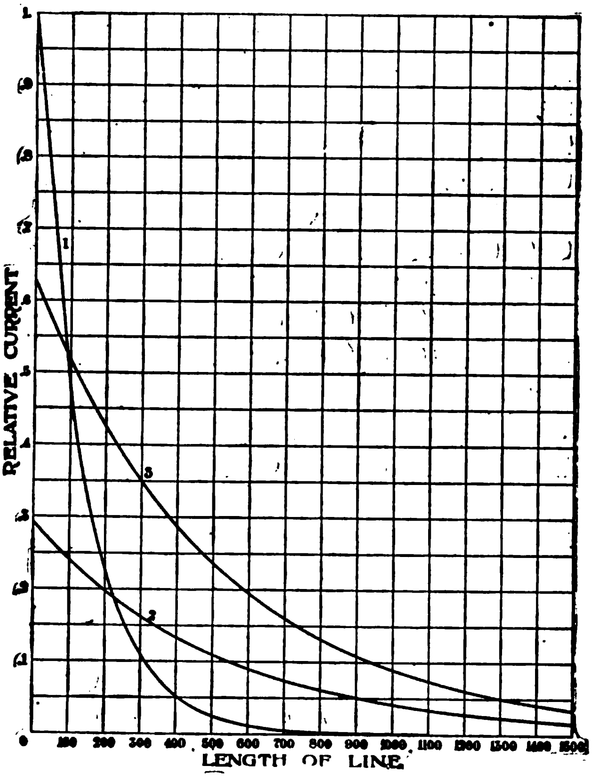


FIG. 4.

The reduction of attenuation that can be obtained by the introduction of loading coils on air-line circuits, even under theoretically perfect conditions, is less than can be obtained on cable circuits. This difference in the effectiveness of loading between the two classes of circuits, as far as attenuation is concerned, can be explained by the fact that on a cable circuit the capacity is large and the inductance of the circuit itself is practically negligible, due to the proximity of the two wires of the pair. On aerial circuits, on the other hand, the distance between the outgoing and return wire is such as to make the capacity of the circuit much less, and its inductance much greater. This larger self-induction of the open-wire circuit operates to decrease the attenuation, and, as it were, to rob the loading coils of part of their usefulness. Again, the insulation of an aerial circuit cannot be maintained as high as that of a cable circuit, so that the added inductance due to the introduction of loading coils upon the line tends to increase the losses due to leakage.

Moreover, there is not the same improvement in the quality of transmission on a loaded aerial circuit as compared with a similar circuit unloaded, as is found between loaded and unloaded cables. Initially, open-wire circuits are practically free from distortion, whereas the distortion on cable circuits of long length is considerable. The addition, therefore, of loading coils to aerial circuits cannot be expected to effect any improvement in the quality of transmission, whereas in the case of cables the introduction of the additional inductance renders the circuits practically distortionless and effects a marked improvement in the clearness of the transmitted speech.

In presenting this brief summary of the operation of loaded telephone circuits, it is desired to make acknowledgment to Mr. H. S. Warren and Mr. E. H. Colpitts for the solution of the many problems involved in the design of suitable coils for use in carrying out this invention, and to Mr. W. L. Richards and Mr. A. N. Mansfield for the careful tests upon which the curves above shown are based.

DISCUSSION.

Dr. A. E. Kennelly: I desire to congratulate this section upon obtaining so valuable a paper as this, not merely from a practical, but also from a theoretical standpoint. The paper is eminently practical, and yet it leads to theoretical deductions of very great importance. I wish to call attention to one only. Curve 1 of Fig. 1 represents, I believe, the relative current strengths which are received from different lengths of cable line. You will see that the current practically vanishes at sixty miles and is about 10 per cent of the initial value on a short circuit at seventeen or eighteen miles. These curves 1, 2, and 3, represent practical observations, as deduced from numerous practical experiments. They are also, however, when considered geometrically, extremely close approximations to logarithmic curves. In any of these three curves, if the line loss is 50 per cent in a certain length, it will be 50 per cent in the same length beyond that, 50 per cent in the same length beyond that, and so on. The natural logarithm of curve No. 1 is, I think, $-0.128l$, where l is the length in miles. When that is submitted to analysis and interpreted, it means that the actual cable behaves as though it were being operated at one frequency, and that particular frequency is, I think, about 803 cycles per second or corresponding to an angular velocity of 5050 radians per second. That means that according to actual observations, conducted on unloaded cables in service, the circuits behave, under telephonic conditions, as though the speaker's voice had a *single* frequency of 800 cycles of a second — that is, up on the top of the treble clef, between G″ and A″, so that a cable circuit behaves as though the conversation were conducted, to use a colloquial phrase, "away up in G." That is an easy formula to carry in the mind and it is one that ought to be of great value, representing that on cables — (I don't know whether the proposition can be extended to aerial lines), the vocal transmission is virtually conducted in G, or G sharp, above the treble.

Mr. J. S. **Stone**: I think this paper is of peculiar interest, in that it brings out the great importance of the reflection of energy at every heterogenity of the line. Even prior to the work that was done by Mr. Campbell and Prof. Pupin on loading lines, I had, receiving my suggestion from the work of Mr. Oliver Heaviside, pointed out not only that losses resulted from attenuation and distortation, but that there was a very serious loss every time a telephone current had to pass from an overhead line into a cable or from a cable into an overhead line. Strangely enough, I found a particular solution of the problem, which, if we may neglect the difference in resistance of the overhead wires and of the cable, resolves itself into making the ratio of the inductance per unit length to the capacity per unit length the same in the cable and overhead line. If you wish to prevent reflection at the juncture of a cable with an overhead line, it is practically sufficient to make the ratio of the inductance per unit of length of the overhead wire to the capacity per unit of length of the overhead wire equal to the ratio of the inductance per unit of length of the cable wire to the capacity per unit of length of the cable wire.

This paper also is interesting when taken in connection with the paper read by Dr. Kennelly in Section A. From the theory of the subject we see that the transmitting apparatus for loaded lines should be of higher impedance than for unloaded lines, and this has an important bearing on the results exhibited in the curves accompanying this paper.

By the curves we see that, in all instances, the unloaded line has the advantage over the loaded line for short lengths of line, whereas the loaded line has the advantage over the unloaded line for long lines. This is probably due to the experiments having been performed with standard apparatus at both ends of the line. This standard apparatus, having been developed for unloaded lines, is, therefore, better adapted to such lines than to loaded lines.

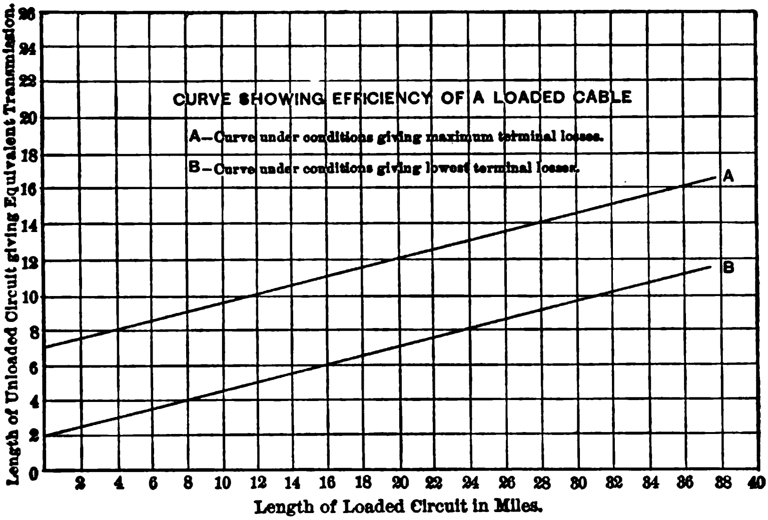
Had the transmitting apparatus in these experiments been of higher impedance, the short as well as great lengths of loaded line would have compared more favorably with the corresponding length of unloaded line.

The reason for using apparatus of higher impedance at the transmitting end of a loaded line than is advantageous in the case of unloaded lines, is most readily seen by considering the transmitting end impedance of an infinite or very long overhead line. The impedance of such a line is practically Lv, where L is the inductance per unit of length of the line and v is the velocity of light. This impedance is practically the same for currents of all frequencies essential to telephony, and for unloaded lines is about 600 or 700 ohms, but for loaded lines this impedance is greater and, in practice, much greater.

Mr. **Bancroft Gherardi**: I have listened with very great interest to Dr. Hayes' paper on "Loaded Telephone Lines in Practice." While this subject is being discussed, some information about the commercial applications of the loading invention may be of interest to the section. The first commercial application of this invention to the loading of underground cables was made under the joint direction of Mr. Carty and myself on a cable extending between the Cortlandt Street office of the New York Telephone Company and the Newark office of the New York and New Jersey Telephone Company, the length of the cable being about ten miles. Loading coils were placed in each circuit at intervals of about three-fourths of a mile. The results of this loading were that, whereas before the application of the loading coils to the cable, Newark and Cortlandt were telephonically ten miles apart, after the application of such loading to the cable, the points in question were telephonically only five miles apart; that is to say, the same grade of transmission was obtained over these loaded circuits as was obtained over five miles of unloaded cable. After obtaining such satisfactory results from this first loading, we have made a number of other applications to various cables in our system; so that at the present time there are 200 pairs of loaded circuits extending from Cortlandt street to various points in Jersey, 100 pairs of loaded circuits extending from Cortlandt street toward the north, and 150 pairs of loaded circuits extending from Brooklyn out on Long Island. The greatest length of any one of these loaded cables is about twenty-five miles, this being the cable from Cortlandt street to Paterson. The circuits in this cable between Cortlandt street and Paterson give transmission equivalent to what would have been obtained over about ten miles of the same cable unloaded. The method of applying the loading coils to the cables was as follows:

The coils were mounted on spindles, with 7 coils on each spindle. Seven of these spindles were placed in an iron pot of sufficient capacity to hold them, one spindle being placed in the center and six others radially around the central one. The pot was then filled with a waterproof compound and the cover bolted on. A lead-covered cable containing ninety-eight pairs of wires was brought out from an opening in the cover. These wires brought out all of the terminals of the loading coils. By splicing this short cable to the main line cable in a proper manner, the loading coils were placed in the circuit.

In the diagram which I have attached hereto, I have shown in a typical case the results which we have obtained from loading one of our cables. There are two curves shown on this diagram, both of which show the results of actual talking tests made over the circuits. One of these curves (A) shows the results under conditions which give maximum terminal losses. The other (B) shows the results under conditions giving the smallest terminal losses. In the case of this latter curve, not only were all other conditions such as to reduce terminal losses as much as practicable, but special terminal tapers designed to reduce reflection losses were introduced in the circuit. By examining this second curve, it will be seen that even under most favorable conditions and after everything possible has been done to reduce terminal losses, such losses are still the equivalent of about two miles of unloaded cable and that it is not until this cable is used in lengths over three miles that there is any gain whatever due to the loading. On greater lengths of cable, notably those above ten miles, the gains over unloaded cable are most substantial and gratifying. These results, while very much better than those obtained by the use of unloaded cable, are, however, even under the most favorable conditions, far inferior to what can be obtained from open wires on poles.



We have had some experience in working underground loaded cables in connection with long overhead lines. It has been found that the most practical use for loaded cables under such conditions is at the end of long lines where congested wire conditions are found. Even in such cases the results obtained from loaded cable are by no means as satisfactory as those which could be obtained from overhead wires. No satisfactory method has yet been found of introducing short lengths of loaded cables in long overhead lines. This arises from several causes, among which may be mentioned reflection losses. When it is sought to overcome these reflection losses, practical results show that beyond a certain point other losses are introduced; but even regardless of these reflection losses, adding loaded cable of the very best type to a long overhead line produces a serious drag upon transmission and places severe limitations upon the distance to which it is possible to talk successfully.

Mr. J. H. **Cuntz**: Àpropos of these terminal losses, it is said in this paper that, under certain circumstances, they can be entirely eliminated. Is it not possible, by making the taper gradual, to eliminate these losses?

Mr. **Gherardi**: I do not think so; the apparatus put in constituting the taper brings in very appreciable losses. I think the sentence in Mr. Hayes' paper must be considered with reference to the very large initial losses he is talking about. He starts off by talking about terminal losses amounting to ten miles. To get rid of these altogether is, I think, impracticable, at least at the present time. I do not know any way of doing it and have not heard of any method that would not involve theoretically perfect apparatus.

Mr. **Cuntz**: Have any of the submarine cables been loaded thus, and if so, what is the form of coil?

Mr. **Gherardi**: I have never heard of anything of that kind.

Mr. **John Hesketh**: Have any experiments been made in this country with a conductor made up of different metals, as, for instance, a copper core with an iron tape around it, as has been tried in some cases in Europe with beneficial results? If so, what were the results here?

Mr. **Gherardi**: I do not know of anything practical that has been done in this country along the lines referred to by Mr. Hesketh.

Upon motion of Col. Reber, the Section adjourned to nine a. m. Friday, September 16, 1904.

FRIDAY MORNING SESSION, SEPTEMBER 16.

The Section was called to order promptly at nine o'clock by Chairman Jones.

Chairman Jones: In the absence of the author, M. G. de la Touanne, his paper on the "Theory of Telephone Exchange Development" will be read by title.

THEORY OF TELEPHONE-EXCHANGE DEVELOPMENT.

BY G. DE LA TOUANNE.

The question of telephone rates is one of widespread interest, but, although daily discussed, it is generally little understood by the public and sometimes even by telephone managers. When looking at a large railway station and its extensive switching system, any one understands that every new track is a source of complication; but strange to say, as to the telephone, everything seems simple and cheap, because the subscriber's instrument is simple and easy to handle. It is just as if we considered the railroad industry easy, simple and cheap, because we have only to sit down in a car. The fault does not lie, perhaps, entirely with the public; the current opinion would possibly be less erroneous if the public were allowed more freely to learn what is behind the walls of a telephone office and what is the organization of the big telephone exchanges. Even the fact that to satisfy the call of one subscriber for any other of only 10,000 subscribers, involves provision for about 50,000,000 circuit combinations, does not make clear to the public the amount of capital, skill and inexhaustible care necessitated.

Thus, in spite of efforts to develop a better understanding of telephone affairs, it may not be useless to call to mind from time to time some of the conditions to which the telephone industry is subject. The following is an attempt to summarize the principal commercial questions met in starting a new telephone exchange. This attempt is necessarily academic, for I assume my city to be virgin ground, telephonically, and I leave competition out of account. These conditions are hardly to be found in practice, but it may not be without interest for others to compare with the theory here developed the data derived from experience, and I hope that some members of the section may be induced to make statistical contributions of actual results.

For illustration, let us consider a simple case, a single-office exchange to be started in a city of 50,000 inhabitants, one subscriber's instrument on each line. The income must cover expenses and provide a dividend. The outlay depends on the prospects of development. The first question is, therefore,— What are these? It is exceedingly difficult to answer, even from what is known of old exchanges; the demand is quite different today from what it was in the early days. For want of precise data, we may reckon on 6 subscribers per 100 of population in, say 12 years, and perhaps 12 in 20 years; the 6 per cent in 12 years seems very likely, and in 20 years the telephone will probably be more common than gas is today. Taking as the rate of increase of population in the city only the general rate of increase, 20 per cent, of the United States between the two censuses of 1890 and 1900, the present city of 50,000 inhabitants will have a population exceeding 60,000 in 12 years, and 72,000 in 20 years, that is for the exchange 3600 and nearly 8500 subscribers, respectively. Let us plot the curve Fig. 1 of the mean yearly number *n* of subscribers supposed to be provided for.

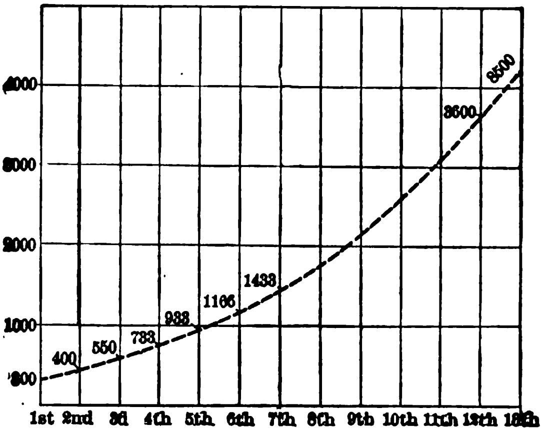


FIG. 1.—MEAN YEARLY NUMBER OF SUBSCRIBERS.

The charges on the enterprise correspond first to the total capital invested; second, to the annual expense of working the exchange. Two portions are to be made of the total capital T, one, P for permanent investment, another, F, as a portion of the floating capital necessary for the payment of the working expenses.

$$T = P + F.$$

PERMANENT INVESTMENT, *P*.

The part *P* is devoted to four classes of expenses, lines, land, building and apparatus (subscribers' instruments and central office apparatus), each presenting very distinct features.

LINES.

The line plant includes the wires and the distributing system of these wires.

As to the distribution of the circuits, there is no doubt that, the exchange being planned for several thousand subscribers, the distribution will be almost entirely underground; nowhere, probably, shall we again see a new Stockholm telephone tower, however remarkable a piece of work it may be. Both the interest of the public in the street and the interest of the enterprise will forbid frequent underground construction or reconstruction. We want, therefore, sewers with cable racks or some form of conduit, but in any case of ample capacity. The former system is probably the ideal one, but much too costly for an exchange of the size considered, unless the sewer system exists and is available for the purpose, as in Paris. We turn, therefore, to conduits; and as a properly built conduit lasts for years, there is no risk, and our policy will be to plan at once a system of conduits substantial and flexible, and devised for the full number of subscribers contemplated, 8500.

Except for spare plant, it would suffice to have 43 ducts, one per cable, for as many 200-pair cables, divided at the office into three or four routes, then, further away, into routes of 10, 8 ducts and less for 100 and 50-pair cables. But spare plant is one of the most difficult things to foresee. In the conduits you are bound to have spare ducts, first, because you cannot determine the ultimate number of lines in every direction; you can only approximate; secondly, because spare ducts facilitate repairs; thirdly, because the addition of a few ducts at the start costs very little, but becomes very expensive later on. The best practice allows an average of 40 per cent spare ducts.

Outside the conduit system the lines must be completed in different ways — inside house wiring, short sections of cable, pole lines, etc. An estimate of the probable average length l and of the probable average price p' per unit length (reserves included) will give the probable average price *lp'* of this complement of the subscriber's line, while the principal part will be the cables drawn into the general system of conduits; the lines in the outlying districts are often disproportionately expensive; it is necessary to allow for this in estimating the average cost per subscriber.

As to lines in general ducts, the cost is that of the metallic circuit in the cable, laying and spares included. The lowest average proportion of spares is about 40 per cent; this means that, in the calculations, the average length *l'* of underground circuit for a connected subscriber must be taken as 66.6 per cent greater than it really is.

If there are rights of way to be paid for in any form — cash, free telephones, etc., this is a charge on capital, to the extent to which it involves immediate outlay; for a free telephone it will be the price of the user's instrument, line, jack, etc., and a proper proportion of land and building.

LAND, BUILDING, APPARATUS.

Apparatus comprises subscribers' instruments and central office equipment.

Calling the cost of a subscriber's set *t*, the total cost of the subscribers' instruments is *nt*.

Location and building must suit the type of switchboard adopted; storerooms, repair shops and offices can be leased almost anywhere; the switchboard with its accessories affords the only reason for buying land and erecting a building. The question of the switchboard must, therefore, be examined before the two others.

At the beginning we shall use standard switchboards (cost *b*) for three reasons: First, they are cheap; second, untrained operators and inspectors cannot be charged with the handling of a multiple, with a complicated power plant and other accessories; third, up to, say, 600 answering jacks, there is little or no gain to the service in the multiple switchboard. But, of course, the land must be bought from quite other data and in view of the remote future, or what is considered a remote future in telephony, say 20 years; that is the space should provide a single floor for a multiple switchboard, to accommodate the ultimate number of subscribers, estimated at 8500; if we put the average subscriber's connections per year ultimately at 3000, or 10 per working-day, this will give 85,000 connections a day, which, with two-thirds of the traffic in five hours means a load of 11,333 connections per hour; at 200 per operator and per hour these 11,333 require 56.66 operators during the busy hours, let us say 57, able to reach the total number of jacks; this they will do with 19 sections, equipped with 450 answering jacks each; the 19 sections, with two end-sections, will have in a straight line (or in horseshoe shape) a length of about 129 feet. In dealing with the working capacity of the switchboard, we shall do better to abandon the old expression "subscribers per operator," and talk of "connections per operator hour." "How many subscribers do the operators attend to?" is a question of idle curiosity, if not completed by another one as to the average number of connections per subscriber during the busy hours. "How many connections per operator and per hour, or more briefly, per operator hour, do you admit?" has a definite and practical meaning.

Coming back to the switchboard-room, we need a surface of about 3700 sq. ft. to be doubled, if possible, for the cloakroom, the tearoom, etc. In round numbers the area of the land to buy will be 8000 sq. ft. Such a purchase is almost free of risk, especially if not all built on, for the price *L* of the land is not likely to fall, and will probably rise: during the first years one floor will answer all the requirements of the service; if there is no existing building a light structure, one-story high, will suit all purposes, and the saving in building will partly make up for the price of a large piece of ground, leaving the land as good security for a loan, if necessary. The cost of this first construction, equipment included (protection against fire, heating apparatus, service telephones, furniture, lighting appliances, etc.), will be quite moderate. Some years later, when the enterprise is a success, a more substantial building (cost *E*) will be erected. Some may consider that the adoption of a single office is wrong, that it is better to have branch offices, and that, therefore, the above provisions for the head office are too costly.

The problem of sub-offices versus a single office is too important to be treated here, and we are leaving it out of consideration; we are studying simply the equipment of this single office. Taking the mean number of subscribers during the first year at 300, and for the second year at 400, we shall have four 100 line standards at once, another one the next year which will provide spare jacks for a time, and yet another one at the beginning of the third year. As the mean number of subscribers during this third year is assumed to be 550 (Fig. 1) we should have a margin of only about 100 at the beginning of the year, quite inadequate, unless, at the same time, we order a multiple switchboard to be furnished in about six months. As to this, to reduce the annoyance from frequent extensions in the switchroom when extensions are needed, we shall endeavor to make them for at least two years at a time. Even if it was not for the small size of the first multiple, we should, in consequence, order it for at least the mean number of subscribers in the fifth year, 933 from Fig. 1. In five years the traffic will be a known quantity, but to figure the probable cost *B* of the multiple switchboard, we must assume something; we can suppose that the average annual number of connections for these 933 first subscribers has reached its ultimate figure, say 3000, which corresponds to a traffic of 9330 connections per working-day, two-thirds of which concentrated on five hours at 1244 per hour is not full work for seven operators.

This shows, first, that it will be amply sufficient to get three sections with one end-section, three operators' positions for the section, 150 answering jacks per position; second, that seven operators, or even six, during the busy hours will easily handle the work, facilities being afforded for calling in two or three extra operators either to relieve the others or for learning the service during the busy hours; third, that the multiple must be provided with electrically worked signals (self-restoring drops or lamps), thus permitting three operators only being used most of the day, without being worried to replace signals in position; fourth, that, if proper precautions are taken at the beginning, the mounting of the multiple will be easy.

WORKING CAPITAL, *F*.

Working capital is a necessity, and it must be liberally provided for. For some time, and before the earning power of the exchange has become substantial, the only source from which it can be derived is the capital invested: a part *F* of the total capital *T* will constitute the working capital.

As a resumé we have $T = P + F$ where

$P = p +$	$nlp' +$	$nl'p'' +$	$nt +$	$\left\{\begin{matrix} b \\ B \end{matrix}\right. +$	$L +$	$\left\{\begin{matrix} e \\ E \end{matrix}\right.$
Permanent Investment. **Conduit.**	**Complements of subscribers' lines.**	**Subscribers' circuits in general conduits.**	**Subscribers' instruments.**	**Switchboard.**	**Land.**	**Building.**

ANNUAL EXPENSES, *A*.

These include:

Working Expenses	W
Maintenance	M
Depreciation	D
Sinking Fund	S
Contingencies	C
Reserves and Dividends	R

WORKING EXPENSES, *W*.

Under this head may be grouped:

Taxes.
Fire and Accident Insurance.
Rights of Way and Royalties.
Management.
Operating Force.
Labor.

As to taxes and insurance there is little to be said. Rights of way and royalties paid under one name or another include a certain proportion of annual expenses; for instance, on the free telephone hypothesis, the user's service (maintenance of instruments, lines and switchboards, operators' pay, etc.) is a charge which must be taken into account.

As to expenses of management, or generally speaking as to staff, for a few subscribers the staff may be proportionally very small; but when the system grows and becomes more complicated, it is otherwise; you want numerous statistics, accurate records for every part of the business, strictly kept accounts of the various kinds of expenses and earnings, a high grade of maintenance of the plant, that is you want a numerous and skilled staff, without which you will lose money, and dissatisfy the subscribers by an inefficient service. Telephony is purely an industry of the age. The product to be delivered, a quick service with good commercial transmission, is to be delivered in large quantity; it is a wholesale industry: like a big manufacturing or commercial house it can make money; or it may fail completely, if the whole machine is not kept in perfect order and if every detail is not constantly watched. From actual needs, the proportion in big exchanges has gradually risen to one employee to every 12 subscribers; the manager must bear this in mind to prevent any further necessity of raising the rates; when fixing rates at the start, he is bound to consider the inevitable expenses of the future and not the low ones of the present.

MAINTENANCE, M.

Maintenance includes materials and salaries.

The money provided for salaries is part of the above working expenses and is not considered here.

The cost of materials M can be divided into: Materials for general conduits; cost p_1.

Materials for the complements of the subscribers' lines outside of the conduits; cost nlp'_1.

Materials for the portion of circuits in the conduits; cost $nl'p''_1$.

Materials for the subscribers' instruments; cost nt_1.

Materials for switchboard and accessories; cost $\left\{\begin{matrix} b_1 \\ B_1 \end{matrix}\right.$.

Maintenance $\left\{\begin{matrix} e_1 \\ E_1 \end{matrix}\right.$ for the building will be added, but done as it is for the most part on contract, there will be no distinction between materials and labor.

The conduit being of substantial construction will not cost much; maintenance may be put at 3 per cent of the initial cost. As a more delicate piece of apparatus and submitted to hard work, the switchboard will cost more for maintenance, probably between 5 and 10 per cent.

$$M = p_1 + nlp'_1 + nl'p''_1 + nt_1 + \left\{\begin{matrix} b_1 \\ B_1 \end{matrix}\right. + 0 + \left\{\begin{matrix} e_1 \\ E_1 \end{matrix}\right..$$

DEPRECIATION, *D*.

Depreciation differs widely for the different parts of the system. For the reason just given, the conduit depreciation will be small and 5 per cent is probably more than enough, but as we have no sufficient data as to the life of the modern conduits, we may retain this percentage.

The same percentage, 5 per cent, seems reasonable for cables in conduits.

The aerial subscribers' lines, which are of less durable construction, we put at 20 per cent, and the subscribers' instruments, which are often roughly handled, at 33 per cent.

The first building may have to be replaced in eight or ten years; we shall take 12.50 per cent depreciation. The second building being assumed to be of first-class construction, 5 per cent seems proper.

Switchboards of the standard type are assumed not to be used after the end of the third year, because of the growth of the exchange; there will be probably an opportunity to use them again in the future; but we shall not rely upon this and shall, therefore, count 33 per cent depreciation on the price of the six standards, in spite of the very short service of the sixth.

For the multiple switchboard, we could, on the basis of the manufacture of today, count 10 years' use; but it is hard to say that any system can be considered as fulfilling all requirements more than six or eight years, owing to rapid changes in type; we think today that we are pretty nearly perfect; the same has been supposed in the past and has always been proved erroneous by the remarkable improvements of the switchboard. Therefore, if our aim is to give the best service obtainable (and that is the only way to make the telephone popular), we are bound to consider changing our switchboards even when in good working order; from the commercial point of view alone there may be strong reasons for the prompt adoption of a new and more efficient system; putting the maximum certain life of the switchboard at eight years corresponds to a depreciation of 12.50 per cent. If later improvements do not necessitate changing the switchboard, it will be used two years more, thus saving so much for other purposes.

$$D = 0.05p + 0.20nlp' + 0.05nl'p'' + 0.33nt + \begin{cases} 0.33b \\ 0.125B \end{cases} + \begin{cases} 0.125e \\ 0.05E \end{cases}.$$

SINKING FUND AND INTEREST, S.

It will be perhaps difficult to avoid some borrowing; we shall assume that this is the case for a fraction mT of the total capital T and we have, therefore, to provide for a special sinking fund; we shall hasten, of course, the redemption of this debt as much as possible, in 10 years at the most; at 4 per cent interest for 10 years, the annuity to be allowed is $0.1233mT$.

For the redemption of the capital $(1-m)\ T$ we shall figure $0.05\ (1-m)\ T$ corresponding to redemption in 20 years.

$$S = 0.1233mT + 0.05(1-m)T.$$

CONTINGENCIES, C.

Whatever expenses we may have provided for, there are always contingencies, gas explosions in manholes, flooding of the conduits, breaking down of fixtures or poles, accidents, etc. For such contingencies we shall add at least 10 per cent to the above general expenses.

$$C = 0.10\ (W + D + M).$$

RESERVES AND DIVIDENDS, R.

The gross earnings must allow a certain sum to be put aside for further extensions or improvements. Considering the development of telephony, 10 per cent of the total capital will not be too much to face the corresponding expenses.

Finally will come the dividends. Very little is to be expected in that respect for the first two or three years; later on a dividend of 7 per cent, when possible, will be only fair; but an increase of this dividend is not to be advocated even if the profits increase, until the reserves equal the capital, in one form or another.

As to annual charges, we allow 17 per cent on the capital as a minimum to cover reserves and dividends, whenever circumstances permit, I mean when the rates calculated on that assumption remain within reasonable limits.

$$R = 0.17T \text{ (minimum)}.$$

INCOME.

The revenue is derived entirely from the rates paid by the subscribers (flat rate or measured service). The average sum to be paid per subscriber (or per conversation) is the quotient of the division of the annual charges A into the number of subscribers n' (or number of conversations, i. e., number of subscribers × average number of conversations). The number of subscribers n' to be now considered is lower than the number n used in the calculation of the expenses. We are not sure to get the subscribers for whom we have provided; and as the expenses are for the largest part not proportional to the number of actual subscribers, it would be unsafe to fix the rates from the numbers n. For instance, the three great elements of cost are the underground plant, land and building; it is obvious that you cannot wait until you have 8500 subscribers to be repaid for your outlay. The ideal would be to adopt what the well-known economist, Mr. Cheysson, has called the "Tarif avantageux." If you sell any desirable product for nothing, you will sell much of it and get no return; if you sell at a prohibitive price, you could have a profit if there was any selling, but as there is none, the return is again naught. Between these two extremes the curve of total return (number of pieces sold × profit per piece) reaches a maximum and the corresponding price is the most advantageous, the one giving the maximum profit. This we could determine if it were possible to get from the public true answers to a circular stating the different rates which could be accorded by the exchange on different numbers of subscribers and asking them to state the highest rate at which they agree to subscribe. For a time the exchange would stand by this "advantageous tariff;" later on, when the financial situation is stronger (loan repaid or reserves laid by for plant renewals), the rates will be reduced and a new "advantageous tariff" applied, benefiting both the enterprise and the public; if the subscribers knew that with a certain growth their own rates would be reduced, they would become soliciting agents. But this is impracticable, and the manager must base his rates on other data. He might plot the probable charges for a certain number of years and not only for the two or three first ones, and thus get a better idea of a scheme of rates to apply progressively and methodically, but only a knowledge of the local conditions will allow him to start on a proper basis.

Two general remarks may be added.

As has been noted above, conduit construction and land purchase are two heavy burdens on the enterprise. Therefore, if for some reason the cost of conduit is practically eliminated or considerably reduced, as by the use of a system of sewers or by the payment of a small rent for municipal or private subways, the telephone enterprise will be able to reduce rates very appreciably. Similarly a reduction will be possible if the concession is a long one and if only a small sinking fund rate is applied to the land, being justified by the nature of the property.

The next most important feature is the discipline, care and close co-operation of the whole staff. Since in many cases maintenance is a third or more of the gross earnings, it is needless to say that not only must the best construction be done at the start, but also that the greatest care is called for in the use of the plant and in its up-keep. As to the operating force, the necessity of discipline is still more striking. Discipline can increase the efficiency of this force as one to three or four. In this connection some may think 200 connections per operator hour too high, but in reality this should be taken as a minimum; it is a mere question of training. I remember in the Paris system of the old times with an average of two trunkings for each connection, a certain operator who could usually make 120 connections per hour; her work represented something like 400 connections an hour with a modern switchboard in a single office exchange. And about 1890, the operators at Nashville, Tenn., series multiple switchboard, with testing as distinct from connecting plugs, actually made 300 connections per hour and thought they could make 30 in five minutes (rate: 360 per hour) on a spurt. These same operators could doubtless handle 400 connections per hour with the improved switchboards of today (say one-fourth to one-third less, if the connections are trunked). This was due to discipline. The operators knew what they had to do and not to do, never talked with a subscriber, but connected him with the chief operator as soon as he began to say anything besides the number of the subscriber wanted, and so on. The force was well disciplined, so were the subscribers. The result was an efficient co-operation of both, giving the public the kind of service paid for.

If for any reason the management is afraid to give the operators more than say 1500 connections a day to handle, this has nothing to do with the operating capacity of the switchboard nor with the number of connections per operator hour; that means simply a special distribution of the force through the day, three gangs of operators for instance, instead of two. The operator when at work must get all that can be got out of the switchboard, then go home; that is the place for rest, not the exchange. Let her work hard six hours or even five, and go; she will enjoy her rest and work more cheerfully. Hard work, good rest, is a sound rule everywhere.

JOINT MEETING WITH SECTION F.

A joint meeting with Section F was convened for the purpose of joint discussion of paper by Prof. G. F. Sever, of Columbia University, on "Electrolysis of Underground Conductors." President Duncan, of Section F, was introduced, and presided over the joint session.

Prof. Sever was introduced and presented the following paper on the subject of "Electrolysis of Underground Conductors:"

ELECTROLYSIS OF UNDERGROUND CONDUCTORS.

BY PROF. GEORGE F. SEVER, *Columbia University.*

In the spring of 1903, Mr. L. B. Stillwell, Mr. F. N. Waterman and the writer felt that it was desirable to compile and coordinate as much information as could be procured on the subject of the electrolysis of underground conductors, due to the operation of electric railways. It was felt that both the opinions regarding electrolysis and the practice in remedying the same were so diverse that it would be of value to collect all this information and present it before the International Electrical Congress. Through the efforts of the first-named gentlemen the practice of the electric street railways was secured, and all the world's literature, which was available, was collected and put into the form of a digest. The writer collected information regarding the attitude of the municipalities, including such ordinances regarding electrolysis as had been put into effect up to that time. The data was put into tabular form by Mr. Waterman, and through the courtesy of both Mr. Stillwell and Mr. Waterman the writer has been able to present the final results before this Congress.

The data is presented in the five tables which are attached hereto.

Table I shows the street railway practice in the United States regarding the use of return feeders and the effect of increasing the capacity of these feeders. The reports are shown from 102 electric railways.

Table II shows the recommendations which have been made to 29 municipalities by city and other engineers. The results of these recommendations are shown in a few cases.

Table III shows the most essential electrical features of the municipal ordinances which are in force in 12 different municipalities. The inconsistencies in some of these ordinances are remarkable, particularly in the cases of Atlantic City and Altoona.

Table IV presents a summary of the opinions of municipal officers as extracted from the letters received from them. Fifty municipalities, widely distributed, were heard from.

Table V presents a summary of expert opinion concerning electrolysis. This expert opinion shows many differences in the recommendations as to remedy. It is the writer's hope that the discussion on this presentation may be full and that some definite conclusions may be arrived at for the betterment of the conditions which are known to exist in some localities.

TAB

SUMMARY OF STREET RAILWAY

Number.	State.	City.	Population served.	Name of electric street railway company.	System of operation.	Date of electrical installation.	Miles of track.	Weight of rails.	Bonding system.	Number and size of bond per joint.	Nature of return feeder system.
1	Ala...	Birmingham.....	38,400	Birmingham Ry. Lt. & Pw. Co....	......	1894	99	60–88	W. & M..	4-0	None........
2	Ala...	Huntsville	8,100	Huntsville Ry. Lt. & Pw. Co........	......	1900	5	60	Copper ..	....	None ....
3	Conn.	Bristol...........	9,600	B. & P. Ry. Co....	......	1895	8	56–60	Copper ..	4-0	None ....
4	Conn.	Middletown	9,600	M. St. Ry. Co......	......	....	10	60	Copper ..	2-0	No. 2 track wire ....
5	Conn.	Montville........	2,400	M. St. Ry. Co......	......	....	18	60	Copper ..	2 4-0	None ....
6	Fla ..	Jacksonville	28,500	J. Elec. Co.........	......	....	18	45–70	Chase S..	....	1 ret. feeder.
7	Ga...	Athens	10,200	A. Elec. Ry. Co....	......	1895	7	40–60	Protect..	1-0 2-0	None ....
8	Ga...	Dahlonga	12,000	G. & D. Elec. Ry. Co	......	....	27	70	All wire .	2 2-0	None ....
9	Ill....	Alton............	22,500	A. Ry. Gas & Elec. Co	......	....	12	60–75	....	2 4-0	On all lines..
10	Ill....	Chicago	1,700,000	C. City Ry. Co.....	......	....	184	95	Cast weld	....	On all main lines.......
11	Ill....	Decatur	25,000	D. Tr. & Elec. Co..	......	....	14	60–70	Copper ..	2-0	None ....
12	Ill....	Freeport	13,300	F. Ry. Lt. & Pw. Co	......	....	7	56	Wire	4-0	Ret. feed....
13	Ill....	Jacksonville	15,100	J. Ry. Co..........	......	....	5	40–60	Protect..	4-0	None ....
14	Ind ..	Madison	7,800	M. Lt. & Ry. Co...	......	....	4	56	Wire.....	2-0	None ....
15	Ind ..	Columbus	10,500	J. S. Cramp's Elec. St. Ry...........	......	....	7	30–36	Wire.....	4	None ....
16	Ind ..	LaFayette	18,100	L. F. St. Ry. Co...	......	....	18	60	A. S.& W.	4-0	On one line..
17	Iowa.	Keokuk	15,000	K. Elec. Ry. & Power Co........	......	....	8	56	Wire	1-0	None ....
18	Ky...	Louisville	205,000	L. Ry. Co..........	......	....	142	60–100	A. S.& W.	....	½ to 2 miles from P. S..
19	Me...	Bangor	22,000	Penobscot Central Ry. Co...........	......	....	27	56	Chase S. protect.	....	None ....
20	Me...	Calais.	8,000	C. St. Ry. Co......	......	....	7	48–56	Chicago protect.	2-0 4-0	Ret. feeds...
21	Me...	Kennebunkport..	2,100	Atlantic Shore Line Ry.........	......	....	2	60	Brown crown ..	....	None ....
22	Md...	Cumberland.....	17,100	C. Elec. Ry. Co....	......	....	7	40–73	Copper ..	....	No. 2 gr. wire
23	Md...	Hagerstown.....	13,600	H. Ry. Co..........	......	....	14	56–72	Copper ..	2-0 4-0	None ....

LE I.

PRACTICE IN THE UNITED STATES.

Are pipes tapped to rails?	Are pipes tapped to bus?	What area is drained?	No. of power stations.	Maximum current from each.	Minimum line voltage.	Nature of soil.	Nature of corrosion.	Extent of corrosion.	Any claim against railway company?	What remedy applied?	Effect of remedy.
No	No	None	1		350			Some.	No	None	
No	No	None	1	300	475	Fav.		None	No		
No	No	None	1	500	600			Some.	No		
No	Yes		1	500	450			None	No		
No	No	None	1	2,500	350			Some	Yes	Larger bonds.	No more trouble.
No	No	None	1	700	375			None	No		
No	No	None	1	400	450	Unfav.		None	No		
No	No	None	1	500	400			None	No		
No	No	None	1	1,200	450			None	No		
No	Yes		4	12,000	400			Some.	Nothing definite.	None	
No	No	None	1	2,500	450	Fav.		Some.	No	None	
No	No	None	1	400	425			Some.	No	None	
No	No	None	1		450			None	Once	Analysis showed rust.	
Yes	Yes		1	250	480			None	No		
No	No	None	1.		500	Unfav.		None	Once.	Proved earth corrosion.	
No	No	None	1	500	450			None	No		
No	No	None	1	500	450	Clay		None	No		
Yes	Yes	+	1	10,000	500			Some	Yes	Ret. feeds.	Less complaint.
No	No	None	2		480			None	No		
Yes	Yes	+	1	350	450			Some	Yes	Improving return.	Less trouble.
No	No	None	3	1,000	330			None	No		
No								None	No		
No	No	None	1	800	350	Fav. at point.		At one point.	No	None	

TABLE I—

Number.	State.	City.	Population served.	Name of electric street railway company.	System of operation.	Date of electrical installation.	Miles of track.	Weight of rails.	Bonding system.	Number and size of bond per joint.	Nature of return feeder system.
24	Mass.	Amherst	5,000	A. & S. St. Ry. Co.			15	60	Copper	4-0	Few gr. wires
25	Mass.	Athol	7,100	A. & O. St. Ry.			7	50-90			Ret. feed
26	Mass.	Cottage City		C. C. & E. Traction Co			5	50			Gr. wire
27	Mass.	Conway	1,600	C. Elec. St. Ry. Co.			6	60	S.V. & B.		None
28	Mass.	Fitchburg	12,400	F. & L. St. Ry. Co.			32	70-90	Crown	4-0	On all lines
29	Mass.	Gardner	10,000	G. W. & F. St. R. R. Co			16	45-60		1-0 2-0	None
30	Mass.	Greenfield	8,000	G. D. & N. St. Ry. Co G. & T. F. St. Ry. Co			23	48-60		4-0	None
31	Mass.	Holyoke	45,700	Mt. Tom R. R.			1			4-0	None
32	Mass.	Holyoke	45,700	H. St. Ry. Co.			43		Crown	4-0	On one line
33	Mass.	Lowell	658,000	B. & N. U. Ry. Co.			440	90		2 4-0	On nearly all lines
34	Mass.	Maynard	3,100	C. M. & H. St. Ry. Co			18	60-90	Crown		None
35	Mich.	Escanaba	9,500	E. Elec. St. Ry. Co.			8	45-60			None
36	N. H.	Chester	2,500	C. & D. Ry. Ass'n.			8	48			Some
37	N. J.	Asbury Park	4,000	A. C. Elec. R. R. Co			24	60-70		2-0	2-0 for each track
38	N. J.	Camden	76,000	C. & Sub. Ry. Co.			67	70-90		2 4-0	None
39	N. J.	Keyport	3,100	J. C. Traction Co.			6	65-70			
40	N. J.	Millville	10,600	M. Traction Co.			12	60			None
41	N. Y.	Albany		A. & H. R. R. Co	Third rail.		42	80	M. & E.	4-0	None
42	N. Y.	Binghamton	60,000	B. Ry. Co			37				Ret. feed
43	N. Y.	Canandaigua	6,000	Ont. Lt. & Trac. Co			3	40	Copper		Ret. feed
44	N. Y.	Corning	12,500	C. & P. P. St. Ry.			6	56-90	Crown	4-0	None
45	N. Y.	Elmira	35,700	E. Wat. Lt. & R. R. Co			27	50-90	M. & E.	2 4-0	Ret. feed
46	N. Y.	Fishkill	3,700	Citizen R. R. Lt. & Pw. Co			7	56	Chicago plastic wire		Ret. feeds
47	N. Y.	Fredonia	18,500	D. & F. R. R. Co.			4	48-60	M. & E. O.B.Co.	4-0	
48	N. Y.	Gloversville	18.000	F. J. & G. R. R.			19	56-80	Copper	2-0	None
49	N.Y.	Hornellsville	12,000	H. Elec. Ry. Co.			5	56	Copper	4-0	Ret. feed

(*Continued*).

Are pipes tapped to rails?	Are pipes tapped to bus?	What area is drained?	No. of power stations.	Maximum current from each.	Minimum line voltage.	Nature of soil.	Nature of corrosion.	Extent of corrosion.	Any claim against railway company?	What remedy applied?	Effect of remedy.
No	No	None	2	600	400			None	No		
No	Yes		1		525			None	No		
No	No	None	1		450			None	No		
No	No	None	2	200	500			None	No		
No	No	None	1	1,700	450			None	No		
No		Wet places	1			Sand, lime, clay		None	No		
+ Area	No	None	4					None	No		
No	No	None	1	500	390			None	No		
No	Yes		1	750	375			None	No		
	Yes	+	1	8,500	400			Some	Yes	Gr. wires	Reduced P. D.
No			1		400			None	No		
No	No	None	1		550			None	No		
No	Yes							None	No		
No	No	None	2	1,600	575			None	No		
+ Area	No	None	4		450			Little	Yes	Investigation	No more trouble.
No	No	None	2	500 1,000	400			None	No		
No	No	None	1					None	No		
No	No	None	8		400	Clay		None	No		
No	No	None	2		450			None	No		
No	Yes		1	150	400			None	No		
No	No	None	1	850	475	Fav.		None	No		
No	No	None	1		825	Gravel		On rails	Yes	Ret. feed	Economy.
No	Yes		1		500			Some	Indefinitely	Ignored it	
No	No	None	1	800	500	Clay, gravel		Some	No	Better bonding	Suppressed.
No			8		400	Fav.		Some	No	None	
No			1		470			None	None		

TABLE I—

Number.	State.	City.	Population served.	Name of electric street railway company.	System of operation.	Date of electrical installation.	Miles of track.	Weight of rails.	Bonding system.	Number and size of bond per joint.	Nature of return feeder system.
50	N. Y.	Hoosick	30,000	Ben. H. Valley Ry. Co	......	....	17	60	Plastic wire	1-0	None
51	N. Y.	Huntington	3,000	H. R. R. Co.	......	....	3	56	....	....	None
52	N. Y.	Ithaca	18,000	I. St. Ry. Co.	......	....	8	45-60	Wire	2 1-0	None
53	N. Y.	Jamestown	23,000	J. St. Ry. Co	......	....	21	45-80	....	2-0 3-0	No. 2 to No. 0 gr. wire
54	N. Y.	Port Chester	7,500	N. Y. & S. Ry. Co.	......	....	17	80-100	O. B. Co.	2 300-000	None
55	N. Y.	Seneca Falls	10,500	G. W., S. F., & C. L. Tr. Co.	......	....	18	45-73	Wire	2-0	1-0 ret. feed.
56	N. Y.	Utica	114,000	U. & Mo. Val. Ry. Co	......	....	88	80-90	....	2 250-000	None
57	Ohio.	Chillicothe	15,500	C. Elec. St. Ry. & Pw. Co.	......	....	6	50	Wire	2-0	....
58	Ohio.	Cincinnati	1,400,000	C. L. & A. Elec. St. Ry. Co	......	....	42	70	Protect.	....	None
59	Ohio.	Cleveland	382,000	East O. Tr. Co.	......	....	95	...	....	....	....
60	Ohio.	Columbus	126,000	C. L. & S. Ry. Co. and others	......	....	50	70-90	Copper	....	None
61	Ohio.	Dennison	3,800	U. Elec. Co.	......	....	2	48	Wire	....	....
62	Ohio.	Toledo	125,000	T. B. G. & So. Tr. Co	......	....	60	60	Copper	4-0	None
63	Ohio.	Lima	22,000	L. Elec. Ry. & Lt. Co	......	....	12	60-70	Crown	4-0	Ret. feed
64	Ohio.	Lima	22,000	W. O. Ry. Co.	......	....	47	60-72	Crown	4-0	None
65	Ohio.	East Liverpool	16,500	U. Pw. Co.	......	....	12	56-82	Copper	2 4-0	None
66	Ohio.	Marion	12,000	M. St. Ry. Co.	......	....	5	60	Plastic	....	Gr. wire at sw
67	Pa...	Copley	1,600	C. E. & I. St. Ry. Co	......	....	...	70-80	M. & E.	....	None
68	Pa...	Carlisle	9,600	C. & Mt. H. Ry. Co	......	....	6	65	....	3-0	None
69	Pa...	Erie	53,000	E. Elec. Motor Co.	......	....	31	80	Copper	4-0	None
70	Pa...	....	....	Media, Middletown, A. & C. El. Ry.	......	....	19	70	Copper	4-0	None
71	Pa...	Harrisburg	50,000	H. Traction Co.	......	....	49	60-90	....	2 4-0	....
72	Pa...	Hazleton	14,000	L. Tr. Co.	......	....	20	56	Plastic wire	4-0	4-0 ret. feed.
73	Pa...	Lancaster	41,000	C. Tr. Co.	......	....	92	60-90	Copper	....	None
74	Pa...	Lebanon	18,000	L. V. St. Ry.	......	....	24	90	....	4-0	None

(*Continued*).

Are pipes tapped to rails?	Are pipes tapped to bus?	What area is drained?	No. of power stations.	Maximum current from each.	Minimum line voltage.	Nature of soil.	Nature of corrosion.	Extent of corrosion.	Any claim against railway company?	What remedy applied?	Effect of remedy.
No	No	None	1		350			None	Yes	None	
No			1		450			None			
No	No	None	1	1,000	350			One case.	No	Renewed bonds.	
Yes	Yes		1	2,000	500			Some	Yes		
	+ Area.		1		450	Fav.		None	No		
No	No	None	1		375			None	No		
No	Yes		5		300			None	No		
					500			None	No		
No			1	10,000	400			None	No		
			2					None	No		
No	No	None	9		400			None	No		
No			1	800	560			None	No		
No	No	None	4	800	400			None	No		
No	Yes		1	1,200	275			None	No		
No	No	None	6	900	595			None	No		
No	Yes		2	1,060				Some	No		
No	No	None	1	500	500			None	No		
No	No	None	1		400	Yes		None	No		
No			1		550			None	No		
No	Yes		1	2,000	400	In some places.		Alleged.	Yes		
			1					Some	No		
Yes	No	None	2	1,800	390			Some	No	Repaired bonds.	No more trouble.
No	No	None	2	500	350	Fav.		None	No		
No	No	None	1	1,809	400				Nothing serious	Investigation.	
No	No	None	1	5,500				None	No		

TABLE I—

Number.	State.	City.	Population served.	Name of electric street railway company.	System of operation.	Date of electrical installation.	Miles of track.	Weight of rails.	Bonding system.	Number and size of bond per joint.	Nature of return feeder system.
75	Pa...	Lewistown	4,500	L. & R. Elec. Ry. Co	......	....	6	60–70	....	3-0 4-0	None
76	Pa...	McKeesport	21,000	P. McK. & C. Ry. Co.	......	....	85	70–90	A. S.& W.	4-0	4-0 ret. feed.
77	Pa...	Philadelphia	....	Am. Rys. Co.	......	....	...	60–90	Protect..	4-0	None
78	Pa...	Scranton	102,000	S. Ry. Co.	......	....	77	40–80	Many	....	Ret. feed
79	Pa...	Philadelphia	....	Rys. Co. General	......	....	50	50–70	....	2 4-0	Ret. feed
80	Tenn.	Bristol	5,000	B. B. L. Ry. Co	......	....	7	35–60	Copper ..	1-0	Ret. feed
81	Tenn.	Chatanooga	32,500	R. T. Co. of C.	......	....	16	60	....	4-0	None
82	Tenn.	Chatanooga.	32,500	C. E. Ry. Co.	......	....	41	45–75	Copper, iron ...	....	½ mile from P. S.
83	Tenn.	Jackson	14,500	J. & Sub. St. R. R. Co.	......	....	8	60	....	....	Ret. feed
84	Vt....	Burlington	19,000	M. P. St. Ry. Co.	......	....	5	60	Chicago .	....	Gr. wires
85	Vt....	Springfield	3,500	S. Elec. Ry. Co.	......	....	9	50–60	Crown...	....	None
86	Va...	Charlottsville	10,000	C. C. & Sub. Ry. Co.	......	....	4	...	....	....	....
87	Va...	Danville	16,500	D. Ry. & Elec. Co.	......	....	6	90	Protect..	....	None
88	Va...	Lynchburg	28,000	L. Tr. & Lt. Co., R. Ry. & Elec. Co.	......	....	16	45–100	Crown, G. E...	4-0	Ret. feed
89	W.Va	Parkersburg	20,000	P. M. & I. Ry. Co..	......	....	29	60	Protect..	4-0	None
90	Wis..	Eau Claire	17,500	C. V. Elec. Ry. Co.	......	....	22	45–70	A. S.& W.	4-0	None
91	Wis..	Manitowac	18,500	M. & N. Tr. Co	......	....	...	60	Crown, G. E...	4-0	None
92	Wis..	Merrill	10,800	M. Ry. & Lt. Co.	D'ble trol.	..	2	...	None	....	Metallic
93	Ill....	Champaign	17,000	....	......	....	11	60–70	A.S. & W.	....	....
94	Mass.	Boston	....	Boston Elevated Ry. Co.	......	....	...	54–94	Protect. steel plug ..	1 4-0 2 4-0 3 4-0	Ret. feeds on a heavy traffic line.

(*Continued*).

Are pipes tapped to rails?	Are pipes tapped to bus?	What area is drained?	No. of power stations.	Maximum current from each.	Minimum line voltage.	Nature of soil.	Nature of corrosion.	Extent of corrosion.	Any claim against railway company?	What remedy applied?	Effect of remedy.
No...	No...	None .	1	600	375	....	....	None	No.........	....	....
No...	......	....	2	1,200	450	Fav....	....	None	No.........	....	....
......	......	....	..	......	...	....	....	Some	Yes........	Rebond ret. feed	No more trouble.
+ Pipes	Yes..	....	2	2,100	350	....	....	Some	No.........	Taps to pipes bonding	No more trouble.
No...	No...	None .	2	......	550	....	....	At two places.	Yes........	Rebond 4-0 C. S.............	1-3 volt P. D.
No...	Yes..	....	1	......	450	....	....	None	No.........	....	....
Yes..	Yes..	....	1	1,500	400	....	....	Some ...	No.........	Repaired poor bonds........	....
No...	No...	None .	2	1,100	450	....	....	None	No.........	....	....
......	......	....	1	......	450	....	....	None	No.........	....	....
Yes..	Yes..	....	1	......	400	....	....	Some ...	No.........	....	....
No...	Yes..	....	2	......	475	....	....	On rails..	No.........	River plates...	Improved power.
......	......	....	..	......	...	....	....	None	No.........	....	....
No...	No...	None .	1	450	500	....	....	None	No.........	....	....
No...	Yes..	....	1	1,600	600	....	....	None	No.........	....	....
No...	Yes..	+	2	600	450	....	....	None	No.........	....	....
No...	No...	None .	2	350	450	....	....	Some ...	Yes........	Doubled bond .	No more claims.
No...	......	....	1	500	350	....	....	None	No.........	....	....
......	......	....	1	30	500	....	....	....	No.........	....	....
Pipes	No...	None .	1	......	550	....	....	None	No.........	....	....
No...	No...	None .	3	3,300	400	Fav....	Graphitic	Some ...	Yes........	Heavier return	Reduced danger areas.

TABLE I—

Number.	State.	City.	Population served.	Name of electric street railway company.	System of operation.	Date of electrical installation.	Miles of track.	Weight of rails.	Bonding system.	Number and size of bond per joint.	Nature of return feeder system.
95	Mass.	Middleboro......	6,900	Mid. W. & B. B. St. Ry. Co..........	......	....	30	70	....	2 4-0	500,000 C. M. ret.........
96	N. J.	....	....	Pub. Serv. Corp. of N. J.............	......	....	...	70-107	Cast protect....	4-0	Ret. feed....
97	N. Y.	Buffalo..........	....	International Ry. Co.	......	....	..	..	....	....	....
98	Ohio.	Columbus.	125,500	C. Ry. & Lt. Co...	......	....	106	40-107	Copper ..	....	Ret. feed....
99	Ohio.	Newark	....	C. B. L. & N. Tr. Co	......	....	...	70	....	4-0	None ....
100	S. C.	Columbia.	21,000	C. El. St. Ry. Lt. & Pw. Co........	......	....	14	48-60	Roebling	2-0	3 ret. feed...
101	Tenn.	Knoxville	32,700	K. Tr. Co..........	......	....	24	40-100	Copper ..	4-0	....
102	Wis ..	Madison.	....	M. Tr. Co	......	....	...	50-55	....	1-0	None ....

(*Concluded*).

Are pipes tapped to rails?	Are pipes tapped to bus?	What area is drained?	No. of power stations.	Maximum current from each.	Minimum line voltage.	Nature of soil.	Nature of corrosion.	Extent of corrosion.	Any claim against railway company?	What remedy applied?	Effect of remedy.
......	No...	None .	2	500	400	Gravel, sand .	....	None	No.........	....	....
No...	No...	None .	6	......	...	....	....	None	No.........	....	....
......	......	....	..	......	...	....	....	None	....	....	....
......	......	....	2	3,000	400	....	....	None	Some	None	....
No...	Yes..	....	4	1,500	450	....	....	None	No.........	....	....
No...	No...	None .	1	1,400	400	....	....	None	Yes........	None	....
No...	No...	None .	2	1,500	400	Fav. ...	Due to soil	Some	Yes........	Improved bonds..	Considerable improvem't.
Pipes	Yes..	....	1	800	450	....	....	Some	Yes........	Tap pipes to station......	No more trouble.

TAB

SUMMARY OF MUNICIPAL

Number.	State.	City.	Date.	Report to.	Report by.	Was electrolysis alleged?	What pipes were affected?	Was electric railway company blamed?
1	Conn .	Hartford	1901	Council	Water Comm'rs.......	Yes..	Water .	Yes..
2	Conn .	Middletown..	1902	Water Comm'r......	....	Yes..	Water .	Yes..
3	Ill	Peoria	1898	....	....	Yes..	Water .	Yes..
4	Ind....	Indianapolis.	1901	....	....	Yes..	....	......
5	Ky ...	Newport	1902	City	Water Works Com....	Yes..	Water .	Yes..
6	Md....	Baltimore ...	1901	....	Ch. Eng. Elec. Com...	Some	....	Yes..
7	Mass ..	Chelsea	1902	City	Water Comm'rs.......	Yes..	Water .	Yes..
8	Mass ..	Worcester ..	1901	....	City Engineer.........	No...	....	......
9	Mich .	Detroit	1896	Bd. Water Comm'rs.	City Engineer.........	Yes..	Water .	Yes..
10	Minn..	Minneapolis .	1901	....	City Engineer.........	Little	Gas....	......
11	Minn..	St. Paul......	1901	Water Comm'r......	D. B. Maury, G. H. Benzenburg & Co....	Yes..	Water, gas ..	Yes..
12	Minn..	St. Paul......	1903	City..................	Water Comm'rs	Yes..	Water	Yes..
13	Mo....	St. Joseph...	1894	....	City Electrician	Yes..	....	......
14	Mo....	St. Louis	1903	Water Department.	E. E. Brownell	Yes..	Water, gas ..	Yes..
15	N. J ..	Newark	1901	....	Engineer Water Dept.	No...	....	......
16	N. Y..	Albany	1901	....	Supt. Bur. of Water..	1898..	Water .	Yes..
17	N. Y..	Buffalo.......	1901	....	Chief Engineer	No...	....	......
18	N. Y..	Rochester ...	1901	Com. Public Works..	E. A. Fisher...........	Yes..	Water .	Yes..
19	Ohio..	Cincinnati ...	1899	Am. Soc. Mun. Im...	Com. Water Works...	No...	....	......
20	Ohio..	Cleveland....	1899	....	Supt. Water Works...	Yes..	Water .	Yes..
21	Ohio..	Columbus....	....	Public Works.......	F. C. Caldwell	......	....	......
22	Ohio..	Dayton.......	1899	....	....	......	....	......
23	Pa	Philadelphia.	1899	....	Ch. Elec. Bureau	No...	....	......
24	Pa	Reading	1900	Water Com..........	A. A. Knudson	Yes..	Water .	Yes..
25	R. I ..	Pawtucket ..	....	City Engineers......	A. A. Knudson	Yes..	Water .	Yes..
26	R. I ..	Providence .	1900	Com. Public Works.	A. A. Knudson	Yes..	Water .	Yes..
27	Wis ..	Madison	1899	....	City Water Works	Yes..	Water .	Yes..
28	Wis ..	Racine	....	....	G. H. Benzenburg	Yes..	Water .	......
29	Va....	Richmond...	1899	Supt. Water Works.	A. Schoen	Yes..	Water .	Yes..

LE II.

REPORTS ON ELECTROLYSIS.

What remedy suggested?	What remedy applied?	Result of improvement.	Was legal action instigated?	Plaintiff.
Double trolley........	....	....	......	....
Better return.........	Rebonding	No more trouble......	......	....
Double trolley........	....	....	Yes..	Peoria Water Co.
....	....	....	......	....
....	....	....	......	....
Efficient bonds.......	....	....	......	....
....	....	....	......	....
....	....	....	......	....
Efficient return.......	Return feeders........	Reduced P. D.'s.......	......	....
....	....	....	......	....
....	....	....	......	....
....	....	....	......	....
....	....	....	......	....
Good return...........	....	....	......	....
....	....	....	......	....
Return feeders........	+ Drainage	No more trouble......	......	....
....	....	....	......	....
Better return.........	Better return..........	Reduced P. D.'s.......	......	....
....	....	....	......	....
....	....	....	......	....
Efficient return.......	....	....	......	....
....	....	....	Yes..	....
....	Efficient return drainage........	....	......	....
Efficient return, double trolley.......	....	....	......	....
Double trolley........	....	....	......	....
Efficient return.......	....	....	......	....
....	Connected track and pipes	No improvement......	......	....
....	....	....	......	....
Double trolley........	....	....	Yes..	....

TAB

SUMMARY OF MUNICIPAL ORDINANCES

Number.	State.	City.	Date.	Immediate cause for ordinance.	System required.	Are taps from pipes to rails allowed?	Is drainage in + area allowed?	Is drainage in other areas allowed?
1	Conn.	Montville	....	....	....	....	....	....
2	D. C.	Washington	....	....	Double trolley or equivalent	....	....	....
3	Ill.	Chicago	1900	....	....	....	....	....
4	Ill.	Freeport	....	Franchise	....	....	....	....
5	Ga.	Atlanta	1898	....	....	....	....	....
6	Mass.	Fitchburg	....	....	....	....	....	....
7	Mich.	Battle Creek	....	....	Double trolley if demanded	No.	....	....
8	N. J.	Atlantic City	1902	....	....	No.	No.	No.
9	N. Y.	N. Y. city	....	....	....	....	....	....
10	Pa.	Altoona	1902	....	....	....	....	....
11	Pa.	Philadelphia	....	....	....	....	....	....
12	Va.	Richmond	1896	....	....	....	....	....

LE III.

Concerning Electrolysis.

Is railway company made liable for corrosion?	Maximum + P. D. pipes to rails.	Maximum − P. D. pipes to rails.	Allowable leakage of current.	Drop allowed in return.	Drop per mile allowed in return.	Remarks.
....	....	....	....	....	....	Capacity of return not less than + feeders.
....	....	....	....	....	....	....
....	1	1	....	½-300′	8.8	....
All damage to water and gas pipes	....	....	....	....	....	....
....	....	....	No leakage.........	....	....	....
For all damage ...	....	....	....	....	....	....
....	¼	¼	No more than one amp. in any pipe.	⅛-200′	3.3	....
Yes..............	¼	¼	No leakage.........	¼-200′	6.6	....
....	....	....	....	25	....	Electric code of city department.
Yes..............	....	....	No leakage.........	....	....	Periodic tests and excavations.
....	¼	¼	....	⅛-200′	3.3	....
Yes..............	....	....	....	....	....	....

TABLE IV.

SUMMARY OF MUNICIPAL LETTERS CONCERNING ELECTROLYSIS IN JUNE, 1903.

Number.	State.	City.	Information received from.	Report concerning electrolysis.	Report concerning electrolytic survey.	Are water pipes owned by city?	Remarks.
1	Ala.	Birmingham	City Engineer	None			
2	Ala.	Montgomery	Mayor	None			Investigation being made by City Elec. Report, October, 1903.
3	Cal.	Oakland	Secretary to Mayor	None			
4	Col.	Denver	Secretary to Mayor	None			
5	Conn.	Bridgport	Mayor	None		No.	
6	Conn.	Hartford	Mayor				President Water Board reports "but little damage"
7	Conn.	Waterbury	Mayor	None			
8	Del.	Wilmington	City Clerk	Only from Water Dep't.			
9	D. C.	Washington	Electric Engineer	1898-9, 1900	Yes		
10	Ga.	Atlanta	City Electrician	None			
11	Ind.	Fort Wayne	Mayor	None			Railway company to take care of all damage.
12	Ind.	South Bend	Mayor	None			
13	Iowa	CouncilBluffs	Mayor	None			
14	Iowa	Dubuque	Mayor	None	None		
15	Ky.	Covington	Supt. Water Works	None			
16	La.	New Orleans	Secretary to Mayor	None	Has received some attention.		"We do not believe damage was serious."
17	Me.	Portland	Com. Pub. Works	None			"We have had very little trouble."
18	Md.	Baltimore	Chief Engineer	None			"Few complaints." "The trouble is generally local."
19	Mass.	Cambridge	City Electrician	Report by C. H. Morse			
20	Mass.	Holyoke	City Engineer	None			"No trouble whatever."
21	Mass.	Lawrence	Supt. Water Board	None			"We have not been troubled in any way."
22	Mass.	Lynn	Clerk	None			
23	Mass.	Malden	Clerk	None			
24	Mass.	New Bedford	Mayor	None	Now investigating		"As far as we know none of our water piping has been damaged to any great extent."

25	Mass.	Newton	City Engineer	By Stone & Webster, 1895.			"Up to present time, there has been little or no complaint." Gas company installed insulating joints.
26	Mass.	Springfield	Mayor	None			"Little complaint of it, but none of importance."
27	Mich.	Bay City	Mayor	A. A. Knudson, 1902			Report not printed.
28	Mich	Grand Rapids.	Mayor's Secretary	None			
29	Minn.	Duluth	Mayor	None			"We have none." "We have never been bothered."
30	Mo.	St. Joseph	Mayor	None			
31	N. H.	Manchester	Mayor	None			"Manchester has never suffered annoyance."
32	N. J.	Bayonne	Secretary to Mayor	None			
33	N. J.	Elizabeth	Mayor	None			"Have had but few complaints."
34	N. Y.	Buffalo	Dep. Water Comm'r.	Report of deputy, 1902.			"I have not found a leak." (From electrolysis.)
35	N. Y.	Troy	City Engineer				"We have not been seriously troubled."
36	N. Y.	Utica	Mayor	None			
37	Ohio	Canton	Sec. Water Works	None			"We have had but very slight trouble."
38	Ohio	Cincinnati	City Electrician	None			"It is a condition unknown in this city."
39	Ohio	Cleveland	City Clerk	Water Works Report			
40	Ohio	Columbus	Sec. Bd. Pub. Service	Water Works Rep't, 1901.	F. C. Caldwell		Franchises specify "double trolley or equivalent."
41	Ohio	Toledo	Mayor	None			
42	Pa.	Lancaster	Mayor	None			
43	Pa.	Williamsport.	City Engineer	None		No.	Have noticed spongy or porous pipes.
44	R. I.	Providence	Com. Dep. Pub. Works.	A. A. Knudson			Railway companies "have taken such steps to prevent electrolysis as best they can and continue to use the single trolley system."
45	Tenn.	Memphis	Mayor	None			
46	Tenn.	Nashville.	Secretary to Mayor	None	Now investigating		Suit v. Railway Company just entered by gas company.
47	Va.	Norfolk	Supt. Water Dep't	A. A. Knudson			
48	Wash.	Seattle	City Engineer	None	Now investigating		
49	W. Va.	Wheeling	Mayor	None			
50	Wis.	Milwaukee	Ass't City Engineer.	None	"No systematic survey."		

TAB

SUMMARY OF EXPERT OPINION

Number.	Name of expert.	Title of article.	Where published.	Date.	Can electrolysis be sufficiently mitigated with single trolley system?	Most suitable remedy.
1	A. V. Abbott	Electrol. from Ry. Cur.	Cassiers' Mag.	1899	Yes	
2	Baylis	Electrolysis	Canadian Elec. Assn.	1894	No	Only cure is double trolley
3	Wm. Brophy	Prevention of Electrol.	Insurance Eng'r'g		Yes	
4	H. P. Brown	Remedy for Electrol.		1895		Neg. booster
5	Ellicott		Report in Chicago			
6	I. H. Farnham		Cassiers' Mag.	1895	Yes	
7	Fisher	Legal Status		1894		
8	A. B. Herrick				Yes	Eff. return
9	D. C. Jackson	Electrol. of Iron Pipes	Street Ry. Jour.	1894		
10	“	Corrosion of Iron Pipes.	“	1894	Yes	
11	Kalsey		Report to Salt Lake City			
12	H. R. Keithley	How to Prevent Electrol.	Street Ry. Review	1894	No	Complete metal circuit
13	A. A. Knudson	Corros. of Metal by Elec.	Amer. Elec-ch. Soc.	1908	No	Double trolley
14	G. Low	Rail Bonding & Elec. Corros.		1895		
15	M. R. McAddo					
16	W. H. Merrill	Electrol. of Buried Pipes	Western Electric	1896	Yes	Double trolley + drainage
17	C. H. Morse	Electrol. of Water Pipes	Street Ry. Review		No	
18	O'Reilly		Report to St. Louis	1895		
19	Parshall	Electrolysis	Jour. Inst. of E. Es.	1898	Yes	
20	J. Swinburne	Electrol. of Gas Mains	Incor. Gas Inst. Eng.	1902		
21	Stone & Webster	Rochester Report		1901		
22	H. C. Townsend		Cassiers' Mag.	1895		Double trolley
23		Results of Electrol.	Boston Report	1895	Yes	
24		More About Electrol.	Street Ry. Review	1898	Yes	
25		How to Cure Electrol.	Street Ry. Review	1894	Yes	

LE V.

Concerning Electrolysis.

Requirements as to track construction.	Requirements as to bonding system.	Requirements as to return feeder system.	Are taps from rails to pipes recommended?	Is drainage in + area recommended?	Is drainage in other area recommended?	Are electric railway companies legally liable?	Remarks.
Good	Good	Substantial		Yes			
Good	Good						
Good	Good			No			Suggests insulating pipe joints.
			Yes				
Good	Good		No	Yes	No		Suggests balanced feeder system.
						Yes	
Good	Good						
			+ Area				
		Along entire tracks	Yes				
							Advises good bonding for comp. met. cir.
Good	Good			Yes			
Good	Good	Good		Yes			
				Yes			
				Yes			
			With precaution				Almost no trouble in St. Louis.
Good	Good		No	Yes			
Good	Good			Yes			
				Yes			
						Yes	
				Yes			
Good	Good	Good	Yes				
Good	Good	Good		Yes			

DISCUSSION.

Mr. **JOHN HESKETH**: Being in the position of having had experience on both sides of the problem I have had reason to give the question very close study. There are certain well-defined lines and conclusions from which I think we cannot escape. To begin with, the onus of protecting underground works from electrolysis or from damage by tramway systems cannot possibly be considered as resting on one or the other party exclusively. It must, if it is to be a successful work, be a mutual one. It is impossible for the telephone company, even by the adoption of all known reasonable methods, to protect their works if the tramway company, on their part, neglect well-known methods. Further, it is impossible for the tramway company to so run their system as to avoid damage, if the telephone company or others interested are laying their works in an unnecessarily dangerous manner. As an instance: In one case which I have in mind, a water company laid its lead service pipes within six inches of the rails of a tramway system. They invited electrolysis; they got it; and then they complained. Further, there are conditions which are easily imaginable, where a system of water pipes acts as a feeder from the zone in which danger is existent to a zone which otherwise would not be dangerous. In such cases the water-supply company, or the gas company, should so insulate its pipes as to prevent the feeding of danger from the one zone into the other. Further, it has been the effort in one or two places to prevent damage by laying down hard and fast rules as to the drop in the return circuit. For instance, the Board of Trade of London laid down an arbitrary figure of seven volts as the maximum difference of potential between the ends of the return. But any figure of drop in the return must take into consideration the length of the line. It is not necessarily the drop along the return that does the damage. It is rather the difference of potential between the return and the other metal bodies in the neighborhood; and yet not altogether so. It is not the difference of potential only, but the capacity for current carrying from the return into the pipe. There may be a huge difference of potential and yet no passage of current into the pipe. There may be a very small difference of potential, and yet a very dangerous current. There we strike another main principle — the method of testing for possible danger, which ought to be clearly defined. It is not sufficient to measure the difference of potential between the pipe and the return. I rather incline to the belief that the method which has during the past year been suggested in Germany, of measuring the difference of potential between the rail and the earth nearest to the rail, is a more correct method. It takes into account the electrolyte between the two bodies.

Recently the Australian Government met in conference the engineers of the telegraph department and engineers representing electric supply industries. In conference, we agreed on certain regulations for the protection of the works of the Postmaster-General of Australia, and the points just mentioned were the salient points brought out in the discussion on the question of electrolysis. When I heard that this Congress was to be held, it appeared to me as rather desirable that an effort be made to have an expression of opinion from the technical associations of different nations on this most important subjejct, and I mention that now for your consideration, if deemed advisable. It is rather a problem as to how such an expression of opinion could be obtained, but it seems to me, in view of the diversity of regulations throughout the world and the lack of authoritative statements based on a scientific principle, that such a statement prepared by scientific bodies would be invaluable to both sides.

Prof. F. C. **CALDWELL**: In Columbus, Ohio, as has been mentioned by Prof. Sever, we have made some investigation of this matter, and our conditions there are particularly favorable for absence from the trouble. I believe the soil there is not such as to produce much electrolysis, and the lay of the railway system is particularly favorable for freedom from it. It seems to me there are two points upon which definite information is needed in connection with this matter of electrolysis. The first is whether we should look for trouble only where the current leaves to go to other metallic structures, or whether we are to look also to the joints of the pipes. There is much difference of opinion upon this question. It has been claimed that trouble has been found at the joints, but on the other hand we find engineers taking very decidedly the stand that all that is necessary is to keep the current from leaving the pipes and going to other conducting material. Information on this subject would certainly be very valuable. The second point is as to how much current can be allowed in the pipes or to leave the pipes. This is especially important if it is true that we are to look for trouble at the joints. If we must keep the current out of the pipes practically altogether, then it becomes an important matter to know how much current can be allowed to flow and still not add an appreciable amount to their disintegration. There has been a little data along this line published in regard to the resistance of pipes. What is needed is data as to the resistance in the case of pipes laid in dry sandy soil. Where a pipe is laid through a street, if we make an attempt to measure its resistance we shall get the joint resistance of the pipe, the surrounding soil, and other conducting material, so that we cannot be sure that the resistance we get would show the current going through the pipe.

The other question as to how much damage is to be expected from the current when it leaves the pipe, I believe, depends very much upon the surrounding soil. In some cities much more damage may be anticipated, with the same current flowing, than in others. We have been carrying on, at the Ohio State University, some investigation along this line, obtaining earth from different cities and using an electrode which was weighed before and after the test. Our results so far have not been sufficient to warrant any conclusions, but they are interesting. We have found in two different tests a considerable difference in the amount of material in different cities. Soil from Dayton, Ohio, where there has been much trouble, gave a large amount of electrolysis, while that from Columbus gave a very small amount. It looks as if this was an important point to be considered.

Mr. H. E. **HARRISON**: It does not matter practically how much current or what current density flows into a pipe. It has been assumed that the current flowing into the pipe would come out more or less uniformly through the whole service; but I do not believe this is so. The pipe may pass through a considerable length of soil which will be a very fair insulator, and will then come upon a patch of soil that is conductive to a high degree, with the result that the current density is more visible and the damage greater.

Prof. **Sever**: The data which we have collected contains many references to underground conductors other than piping systems, so that I think it is perfectly proper that that phase of the situation should be brought before this meeting. About two years ago, when I became connected with the city government of New York, Mr. Jones brought me a cable sheath which he claimed had been destroyed by electrolysis. I know that on some cable sheaths in New York city, both on the telephone and the power circuits, there are large currents coming presumably from the operation of the electric railways. In the Bronx there has been considerable difficulty. In the borough of Manhattan there has been difficulty which to some extent has been remedied by the co-operation of the officials of the railway company and the telephone companies. I know of one instance where the sheaths were bonded at one point by a heavy copper conductor to a return of the Manhattan " L,"— approximately 1500 amperes passed over that wire — sufficient to heat it so one could not put his hand upon it. The Manhattan elevated road uses its structure completely bonded, its service rails completely bonded, and a large amount of return feeder, something like six or seven million circular mils, to get their current back without causing trouble to their own and other conductors. In spite of all their precautions, there are still thousands of amperes coming back on their cable sheaths as well as those of other companies. It has been drawn to the attention of the city officials for their recommendation, as there are at times a higher potential than twenty-five volts between the end of the line and the nearest sub-station, which is the maximum fixed by the city rules.

Mr. P. B. **Delany**: It seems to me there is one phase of this subject which has been overlooked, and that is the shunting of water and gas pipes or the cable sheath, by the grounding of telegraph wires in the city. This may, to a certain degree, account for the apparent discrepancies electrolytically, in different cities and towns and through different soils. We all know that there is in many places a very great leakage — what we call stray or vagrant currents — into the telegraph circuits by way of the ground return. I myself have had experience with wires about a hundred miles in length, and it was rather a disagreeable experience. I tried some synchronous experiments four years ago, and I found there was a voltage varying from three or four volts to seventy-five in that circuit — not constantly, but running up and down. If it had been constant, we might have been able to do something with it, but as it was fluctuating, it was rather disastrous to the experiments at the time. It has occurred to me that in cities where there are hundreds of ground connections made at different points to the pipes and where considerable electric energy is used in the operation of telegraph lines grounded in cities, some of the electrolysis may be even due to that source, as well as the protection of the pipes from power leakage by the shunting. I think this suggestion may throw some light on the subject, although I presume that this phase of the case has been taken into consideration by Mr. Sever and his associates. It has not been referred to in the discussion.

Mr. **Bancroft Gherardi**: One of the functions of my department is taking precautions against electrolysis trouble on our cables, and in that connection the bulk of our work has been in Brooklyn, on account of our very large underground plant there and the great extent of the overhead trolley system. It is not unusual for us to have to take care of currents as great as 200 or 300 amperes at a single point on our system. This shows that the aggregate amount of current that our system is carrying back to the power-houses amounts to thousands of amperes. There is a certain expense in connection with this work which is quite appreciable, and there still remains, after everything is done that we can do, a certain amount of trouble which is real trouble. The discussion of the responsibility for such trouble and expense is one that it seems to me is beyond the scope of this section and I shall not touch on it here.

Prof. **Sever**: In connection with the situation on the Virginia Passenger & Power Company, at Richmond, Va., Mr. Stillwell went at the matter in an engineering way by laying out very carefully on paper the whole railroad system, placing the cars in accordance with their various schedules, and ascertaining those points to which he could most profitably connect a return conductor. He decided upon four points about the city, almost at the corners of a rectangle, and carried directly back to the power station very heavy return feeders, as well as heavily bonding the tracks. From the results which they are getting, it would seem that that is a very satisfactory way in that particular locality to solve the problem. Chemical analyses were made also of the soils. I learned from him a short time ago that the city, through its engineering staff, approved of this scheme and accepted the efforts on the part of the railroad company as an expression of a desire to reduce the trouble. As stated in one of the tables which is presented, the city of Richmond insists that the railroad company must pay for all damage to pipes. How two men are going to agree as to whether damage is due to electrolysis or to ordinary tubercular action or rust, I do not know, and I do not know anybody who does know definitely. The other day we took up in Brooklyn cast-iron water pipes, which had been down fifty-two years, so filled with tubercular nodules that the area of the pipe was reduced to about one-half of its original area. In other places we took up lead pipe, part of which had entirely disappeared, undoubtedly through electrolytic action.

Mr. **J. Sigfrid Edström**: We have had very little trouble in Europe from electrolysis. There has been some, however, in the earliest railroads built in England, but lately we have experienced hardly any trouble. I think this is owing to the very solid construction in bonding and in cables carrying return current to the central station. In Berlin the city officials require that there shall be no larger voltage between any two points of the rails in the city system than two volts — that is, between any points in the rail system of the tramway there must be no greater pressure than two volts. This, or a similar stipulation, has been adopted by many other cities, including cities in Switzerland and Sweden, where I have had the pleasure to be a railway engineer. In these places we bond the rails with two heavy copper wires at each joint. We have double track generally, and consequently we have eight copper wires at each double pair of joints of the rails. We bond the rails between each other and also the tracks at certain distances. At crossing of bridges or water pipes, where the rails get close to iron in the earth, we insulate the rail with asphalt as much as possible. The rails themselves in the street are generally insulated through a layer of stones or concrete put under the rails. To take the current from the rail, we put it in an *insulated* cable of very heavy dimensions. It is very important to have the cable insulated, as a *bare* copper cable, which I know is often used and which generally is buried deep into the street, invites the current to seek other ways home. The general practice in Europe is that, where a feeding cable is connected to a certain part of the overhead wires, a return insulated cable of the same dimensions as the feeding cable is used. This has also the advantage that in case the positive cable becomes damaged, we can easily exchange it for the return cable until the positive cable has been repaired. All the negative returns are carried into the station through resistances, and these are regulated so that the actual current for which the cable is assigned arrives there; thus the current is split up and no cable is overloaded. In this way every feeding point becomes a "central station." These central stations are planted around in the city, and we have no long flows of current running through the city. Street railways built ten years ago in this way have given no trouble whatever.

As to disturbances on telephones in cities, where the telephones use the earth as a return, there has been some slight disturbance, as naturally a portion of the street-car current must go through the earth and thus some of it also through the telephone wires. In cities where we have a double-wire telephone system, there is no trouble whatsoever.

Mr. HESKETH: Although, as you stated, the regulations define the drop in voltage, I should like to ask what in actual practice is found to be the approximation to the regulation? How closely in Berlin do they comply with the regulations? It would be interesting to know, for the purposes of comparison simply, some of the leading dimensions of the system on which the regulations mentioned are found practicable — the mileage of track and the number of amperes output from the station per mile of track.

Mr. EDSTRÖM: I am here not loaded with figures, but I will try to give part of the information. When the plant is laid out, it is laid out according to a certain schedule, and consequently you know the loads on the several points of the city. According to this the dimensions of the cables are figured out. The track itself has the ordinary two heavy copper wires at each rail and four rails at the side of each other are considered to be sufficient for the two volts drop that should be the maximum in the city. Actual tests have not been taken, so far as I know. I have myself been opposed to the two volt requirement, as I consider this limit very low, and I do not think that on any day of heavy traffic — for instance, Sundays or Easterdays or Whitsundays — that the two volts will be the limit, but that you will actually find the drop far larger.

Chairman Jones: I perhaps might give you a few salient facts of the effect of electrolysis upon the Postal Telegraph. The Postal Telegraph Cable Company would be only too glad to submit any of the data it has upon the subject of destruction of their cables by electrolysis to Prof. Sever for the purposes of his paper. I think they would do this in the interest of electrical engineers everywhere, and in the interest of municipalities whose pipes are being eaten up, and also our good neighbors, the telephone people, who are in the same boat with us in that respect.

I can only, of course, as intimated, speak in a general way on the subject. The telegraph companies were urged to place their wires underground, commencing about the year 1880. Cities got tired of the crow's nests and networks of wires which were in their streets. Some of them were curiosities. Commencing with New York, Philadelphia, and other cities, the agitation became so great that eventually they started to put in their wires underground. As a rule, the cables of the telegraph company are not to be compared with the network of water pipes and gas pipes of cities, nor, except in a few cases, the rails of the tramways. The telegraph companies coming into a city and passing through generally follow a line of pipes, and lately the line of rails of the electric railroads, and we have had a great deal of trouble from electrolysis, in times past, in various cities, commencing with Boston, Hartford, Baltimore, Chicago, Atlanta, New Orleans, and other places. In almost all those places, our cables, that had been laid parallel with or near to the electric railroads, have been attacked, and sections have been eaten up, and our service stopped. We were helpless in the matter, because the cities in some cases had ordered us underground, and after having gone underground, our poles were taken down, and it was not possible to place the poles up again and put the wires on them very expeditiously; so we had to suffer and so the public had to suffer. Its telegrams could not be forwarded until we had made the repairs. We found out, however, that by applying the now universal remedy of bonding, where we could secure a good return wire from the point at which the currents were leaving our cable sheaths to get back to the negative brush of the generating station of the railroad companies, we were rendered entirely immune. We have not had any trouble since we have been properly bonded in any city. Quite recently, in New Orleans, our cable was attacked at one point; but we have since bonded and I think there will be no further trouble. In Hartford we have for some years been bonded, and no trouble has arisen there. In all other places where we have been properly bonded there has been no trouble. It of course follows that the currents which are carried through the trolley pole and down into the motor of the car and so into the rails, is seeking its way back to the generating station, and if the resistance is very high between the point where the car is resting upon the tracks and the negative brush of the machine at the station, it is going to seek a great many ways to get back. It will go all around and follow every route that is possible. As a matter of fact, we loan the sheaths of our cables to the railroad companies to allow them to get their current back to the station, and we bond our sheath to their return wire so they can have every use of it and get back the easiest way possible. We do that to prevent getting hurt.

It is not where their current comes on and starts in to go back that we suffer, but it is where the current leaves our sheath to go through moist ground or some electrolyte to reach the metallic conductor at the power station; so that we have found it was necessary for us to make that path just as good as possible. Our sheaths are one-eighth of an inch lead with 10 per cent of tin, and we have not yet had a case where the carrying capacity has been exceeded by the amount of current that our friends, the railroad people, want to have us carry back for them. It is lying there, doing us no good at all, and we feel no effect from any induction in that respect, and we are glad enough not to be eaten up in the undertaking.

It is pretty difficult to tell whether there is any serious electrolysis generated by telegraph currents or not. Of course, the companies are using much more current now than ever before, on account of their increased business, but prior to the time of electric lights and trolley systems, I have never yet heard of any electrolysis arising from telegraph currents, and do not think they are of sufficient quantity to figure in the case at all.

There is another question, in regard to alternating currents being used for transportation or trolley purposes. How are we going to be effected when alternating currents are used? That is an open question which I am not prepared to discuss, but I would like to call it to your attention.

Mr. L. W. Stanton was introduced by the Chairman and presented the following paper:

ECONOMIC FEATURES IN MODERN TELEPHONE ENGINEERING.

BY L. W. STANTON.

The past quarter of a century has seen a most marvelous development in every phase of industry. This is strikingly true in the art of telephony. There is probably not another line of industry in which there has been such a wonderful advancement and complete revolution in methods. From the present unparalleled demand for telephone service, the indications are that the next ten years will see improvements in design of equipment and methods of construction that will eclipse the past decade.

The unprecedented telephone development of the past few years has taxed the ingenuity of telephone engineers. While they have met the problems with remarkable success, there is room for even as great an improvement in the future as there has been in the past. This is especially true in equipping city exchanges where there are a large number of subscribers to be supplied with service. Owing to this fact, there have been developed two distinct methods of supplying service in large cities. One is by means of having a large individual office, while the other is accomplished by the use of multiple or branch offices connected with trunks. Each method has its advantages and its disadvantages. The single office possesses many advantages in small and medium-sized cities, while in our largest cities it becomes impracticable at the present state of the art, to supply telephone service from one central office, and as a result, branch offices are established and connected by trunks.

In cities which will develop a telephone population not exceeding 20,000 to 25,000 telephones, within a radius of four or five miles from the telephone center, an individual office built after the most modern ideas possesses many advantages over multiple or branch exchanges, such as more prompt and accurate service and in effecting a decided economy in operating. Each subscriber's call, when there is only one office, is handled directly by one operator instead of being handled by two operators through trunks connecting branch exchanges, thus saving time and expense in handling the traffic and reducing the liability of error. There is also a decided economy in other items of expense such as rent and taxes on office building, light, heat and additional office expense. The supervision in a single office is also better, being all in one office and under one management instead of being scattered in a number of small branch exchanges.

While in a single central office we effect a decided economy in operating expenses and give a superior service to the subscribers, we have a larger investment in the wire plant or distributing system, on which there is an annual fixed charge for interest and depreciation.

With the correct number of branch offices properly located, the average wire mileage per subscriber is reduced to a minimum, owing to the fact that the subscribers are located much nearer to some one of the branch offices than if there were but one main office.

The trunks connecting the branch offices add somewhat to the total average mileage of each subscriber's line, but in a well-designed multiple office plant the total trunk-wire mileage plus the total line mileage is considerably below that of the line mileage required to connect the same subscribers to one central office. However, if there are too great a number of branch offices, the total wire mileage exceeds that of the individual office, owing to the fact that the number of trunks joining the various offices increases in arithmetical progression, while the number of offices increases in direct ratio.

This is clearly illustrated if we consider each subscriber's station as a branch office and join each subscriber to every other subscriber with a pair of wires, which we will consider as a trunk. For example, to connect four subscribers would require six pairs of wires; to connect eight subscribers would require twenty-eight pairs, to connect sixteen would require 120, and so on. From this it will be seen that there is a limit to the number of branch offices for a city of a given size, and if this number of offices is exceeded, we not only increase the total wire mileage, but also the operating expenses and complications in trunking and decrease the efficiency of the service. In addition to the extra expense for trunks joining the various offices where multiple exchanges are employed, we have the additional expense of the trunking apparatus in the various central offices. This also increases as the number of exchanges increases, but the expense is offset more or less owing to the decrease in the cost of the subscriber's multiple in the various exchanges, which is due to the fewer number of lines entering any one office.

The number of branch offices that was the most economical to serve a given number of subscribers a few years ago, is far from the most economical number of offices for serving the same number of subscribers under modern conditions.

Recent improvements in the manufacture of lead-covered cables and improved methods in outside construction have very materially reduced the cost of the wire plant. This, together with the most advanced ideas in central-office equipment, has greatly increased the capacity and reduced the first cost of large individual exchanges.

Owing to improvements in switchboard construction there is at present no difficulty in securing a central-office equipment for handling at least 12,000 lines. In some cases switchboards having a capacity of 18,000 to 20,000 lines have been installed, but such large boards are not advisable, owing to the fact that the jacks have to be made too small and the plugs used for making connection have very little strength and are easily broken; there are also traffic disadvantages which prevents rapid and accurate work on the part of the operator.

Operators in making connections in the multiple, develop what would be known in psychology as the sense of muscular touch, which allows the operator to make connection almost without looking. Where small centers are used on the board, this, to a degree, is lost, operators also have to become familiar with the location of 20,000 jacks, which is beyond the capacity of most operators where rapid service is required. Four-division boards have also been resorted to, but the complications arising from the same make them impractical.

An exchange of 12,000 lines capacity equipped for furnishing modern four-party line service, together with a number of private branch exchanges, increases the capacity of a single central office to 20,000 or 25,000 telephones, and gives a far superior service to that furnished a few years ago over multiple boards of 5000 to 6000 lines capacity. Until within the last few years, large multiple boards have been a very formidable barrier to the building of large individual exchanges, on account of the size of the jack being too large, so that there could not be a sufficient number placed within reach of an operator to permit her to make connections with more than 5000 or 6000 lines. However, recent improvements in circuit designs which have eliminated the third conductor in multiple jacks and reduced the jack to the simplicity of two springs, together with the improvements in mechanical design, have reduced the size of the jack to a point where 12,000 lines can be brought within reach of an operator. In addition to the above improvements, the workmanship is much better and the price of multiple jacks has been reduced at least two-thirds below that of the much inferior product of a few years ago.

While there have been remarkable improvements in the central-office equipment, there have been also rapid strides made in bettering the distribution to subscribers. Improved methods in the manufacture of telephone cable have increased their efficiency and very materially reduced their cost, so that to-day cables can be installed in underground conduits at a cost per pair of wires far below that of a few years ago, and they have increased in like proportion the territory served by one exchange. Four-hundred-pair cables are not uncommon to-day and in some cases 600-pair cables have been used. A 400-pair cable carried near the outer boundaries of a territory to be supplied by an exchange and distributed from this point according to the most advanced practice in multiple-cable distribution, serves the territory in the most economical way, and where a portion of the lines are party lines, the capacity of the cable is equivalent to an exchange of from 800 to 1000 sub-stations. These figures are based on the average number of telephones per circuit found in a number of our leading cities.

It might also be noted that the outlying districts are heavier users of party lines than the central portion of the city. Under such conditions, groups of subscribers within a radius of four or five miles from the central office can be served much more economically, the expense of operation being below that of a branch exchange, and the first cost being very little, if any, greater, if we assume that there would be real estate purchased, a first-class building erected, modern central-office equipment installed, and that the two offices be connected by trunks through cable in underground conduit. The underground conduit system remains practically the same, whether the district five miles from the central office be supplied by the cable direct from the main office, or, whether it is served by a branch office with connecting trunks. The additional cost of a 400-pair cable over the cost of the trunking cable to connect to branch offices, will be considerably less than the cost of real estate, building and branch-office equipment, including switchboards, power-plant, terminals, etc. On the other hand, the expense of the extra multiple for the 400 additional lines entering the central office will be greater, but the extra trunking equipment and multiple for the same, which will be eliminated when branch offices are not used, will, more or less, balance the cost of the main-office multiple.

In summing up the advantages and disadvantages of individual and multiple exchanges, we find that large individual offices possess advantages of being cheaper to operate, and, through their use, a more prompt and accurate service can be furnished, while in the smaller sizes, they are cheaper in first cost.

With multiple exchanges, we find that at the present state of the art, they are necessary in the largest cities owing to the fact that satisfactory equipment cannot be secured for serving the number of subscribers that it would be necessary to serve; and from a financial standpoint, the first cost of the distributing system in large cities is too expensive. Another strong point in favor of the multiple office is that in case of fire, the service of the entire system is not crippled.

While the two systems just described are handling the telephone traffic of our cities in a fairly satisfactory manner, the day is probably not far distanct when they will be superseded by a combination of the two, together with the principles of automatic trunking, which will very material reduce the first cost of the telephone system, and also decidedly reduce the cost of operation. The writer has given some thought to a system which, broadly speaking, would be one central exchange from which trunks would radiate to all parts of the city, and terminate in small automatic branch exchanges to which the present form of common-battery, sub-station-equipment would be connected.

A subscriber upon lifting the receiver from the hook would operate in the branch office a line relay the same as is used in the modern lamp-signal boards, but instead of lighting a line lamp, it would energize a simple selector switch, which would select that trunk line to the main office which was not busy. The trunk, on being connected, would operate a line relay at the central office, the operation of which would operate a simple selector, which would select the operator that was not busy, and in turn select the connecting cord that was not busy, and light the lamp associated with the same. The current lighting this lamp would put the operator in talking connection with the subscriber, and upon receiving the number of the party wanted, which we will say is "Century, No. 78," she would insert the plug of the connecting cord in the jack of the outgoing trunk to the Century branch. By operating an ingeniously designed selective key, she automatically and almost instantly selects the station called for and starts automatic ringing on this line, which continues until the subscriber answers. Upon inserting the plug in the trunk jack, she extinguishes the lamp lighted by the party calling, and automatically disconnects her listening set from the subscriber's line, leaving the conversation of the two subscribers absolutely private and at the same time leaving her position open for another call. The subscribers, upon completing their conversation and restoring the receivers to the switch hook, are automatically disconnected, owing to the opening of the circuit of the subscribers' line relay which releases the automatic selector, thus leaving the trunk free for other calls and giving the subscribers an opportunity to call again immediately. It is true there is a plug left in the outgoing trunk (until the operator removes it) but upon the automatic disconnecting of the two subscribers, this cord and plug are cut dead, the busy test taken off the trunk jacks and the disconnect lamp signal lighted corresponding to this cord notifies the operator to take down the cord, the taking down of which leaves this cord so it will not test busy to incoming calls.

With the system as outlined it would not be a difficult problem to handle the extreme development of our largest cities from one central office. With a development of 100,000 telephones, which some of our cities have at the present time, there would not be required to be placed in front of an operator more than a few hundred trunk jacks. These being common to this position only, there would be required only a few trunk jacks for each branch office for each operator's position. The operator in plugging into one of these jacks would operate a selector which would automatically select a non-busy trunk to the branch exchange; over this trunk would be sent the impulses from the operator's selective key which selects the subscribers in the branch exchange. This method saves the operator the time and trouble in testing for non-busy trunks and eliminates a great number of trunk jacks which would otherwise be multiplied in front of all the other operators.

In medium-sized cities, all outgoing trunks could be multiplied in front of each operator. This would eliminate the outgoing trunk selector and the operator would test as usual for non-busy trunks. For incoming calls there would be no equipment placed in an operator's position except a few connecting cords with their indicating lamps. Incoming calls come in over trunks which terminate in a distributing room, and from there the calls are automatically distributed to the operators' positions. In large offices it would be necessary for the incoming trunks to be divided into sections so that the selector would not have to be built to distribute to too many operators' positions. Different classes of service, such as measured service, flat-rate service, etc., would come in over separate sets of trunks distributing to sections in which there are operators who handle these classes of service only.

The first cost of the wire plant in this system will be very materially reduced owing to the grouping of subscribers in small groups and automatically trunking the same direct to the main office.

It has been found from data compiled from a number of operating exchanges, that one trunk will, on the average, where the exchange is of sufficient size, carry the traffic of 12 to 15 subscribers' telephones. In this way we gain the advantages of party lines without their attending evils.

This principle of trunking has been taken advantage of to an extent in multiple exchanges, but the full benefits cannot be derived owing to the rapid increase of the number of the trunks with the increase in number of the branch offices.

When branch offices are used and connected as just described, 100 branch offices would require 4950 separate sets of trunks, while with the direct trunking to one central exchange, there will be only 100 sets of trunks required or the same number of sets of trunks as there are offices. Therefore, in direct trunking, we would use one set of trunks composed of a large number of circuits, instead of 100 sets of trunks with few circuits in each set of trunks.

It has been observed, in practice, that in offices which have only a few trunk circuits joining another office, the average maximum number of messages per trunk circuit per day did not exceed 70 to 80, while in large offices requiring a great number of trunk circuits, each circuit has been known to average as high as 157 messages per day. This is partially due to the greater fluctuation in traffic in small offices.

From the data just given it will be seen that trunks composed of a large number of circuits carry more than twice as much business per circuit per day as do trunks composed of few circuits. Therefore, direct trunking through one trunk with a large number of wires is much more economical than through several sets of trunks with few wires in each set. There is also a saving in the time of connecting due to automatic trunking, in disconnecting and in the elimination of order wires. On the other hand, all calls have to be trunked, but in small offices the number of calls trunked sometimes reaches 95 per cent of the total calls, so the extra trunking is not of great consequence.

The system allows the use of the present common-battery telephone set, which is simplicity itself, and it adds no complications to the telephones scattered over miles of area, all equipment liable to derangement being located in the central or branch offices. The branch offices would not require installation of expensive power equipment. All power or current required for operating the branch exchanges could be supplied from the central office. All current for talking would be fed from the cord circuits in the central office where 40 or 50 volts would be used, which would prevent an excessive drop of voltage on the long line.

This, in connection with the latest design of transmitters, which are especially designed to work on lines of high resistance, solves the problem of supplying the service of subscribers remote from the central office. In case the branch exchanges are too far from the central office, the subscribers' loops can be supplied with battery for operating their transmitters, from the branch exchanges, only a slight modification in the equipment being necessary to accomplish this result. There would be no ringing current required at the branch office and the current for operating the line relays and selector switches would be small and could be supplied by local storage batteries charged from 110-volt circuits or from the local lighting circuit over trunk wires from the central office.

This plan was devised by the writer a few years ago for supplying the private branch exchanges for the Cuyahoga Telephone Company, of Cleveland, Ohio, a company now operating nearly one hundred private branch lamp-signal boards from storage batteries charged over trunks as above described. The results are proving very satisfactory and quite economical. In charging the batteries, sufficient resistance is inserted in the trunks or feed wires, so that the batteries receive the proper amount of current to maintain them at full charge. Every two weeks an inspector tests the specific gravity of each cell, takes the voltage reading and inspects the private branch board. The cost of maintenance is in this way reduced to a minimum. By a plan similar to the one just described, small branches could be maintained at a minimum cost.

The space required for locating these branch exchanges would be small. An inexpensive room in one of the large office buildings would answer very well for supplying such buildings in the business districts. In the outlying districts suitable quarters could be secured at a much lower cost than where extensive equipment has to be housed and operators' quarters provided. The greater the number of branch exchanges, the less the wire mileage for each subscriber. One main underground cable could be tributary to a number of small branch exchanges. The system, besides being more economical in first cost, admits of a decided saving in operating expenses. The number of operators is very materially reduced. The trunking or *B* operators are eliminated entirely, and also quite a number of the regular *A* operators, due to the fact that each operator would be at her highest efficiency at all hours of the day. She would be constantly busy, and the service would be prompt and uniform, due to the fact that she would never be overloaded, as she can only receive one call at a time, due to the automatic distribution of the calls to the non-busy operators. The subscriber in lifting the telephone from the switch-hook, is immediately put in talking connection with the operator, and gives the number desired to the operator without her requesting "number;" she repeats the number and glances at the keyboard, sees a lighted lamp which indicates the cord to be used. Whereupon she plugs into the outgoing trunk jack and presses the selector key which selects the line desired. Owing to the few number of movements required on the part of the operator, and being kept constantly busy, she will probably answer two to three times the number of calls usually answered by an operator in the same length of time. For night service, Sunday service and such portions of the day when the load is light, a number of the operators could be dispensed with, owing to the fact that the first operator's positions receive all the calls and the last positions are called into service only during the rush hours of the morning. The system as outlined reduces the first cost of the wire plant, eliminates all multiple, answering jacks and line lamps and reduces the operating expenses. It employs equipment composed of parts of the manual and the simpler parts of the automatic and possesses the advantages of unit, multiple and automatic exchanges.

Upon motion of Mr. John Hesketh, Mr. J. C. Kelsey's paper on the "Two-Strand Common-Battery System" was presented by title.

FEATURES OF THE DUNBAR TWO-STRAND COMMON-BATTERY SYSTEMS.

BY PROF. J. C. KELSEY, *Purdue University.*

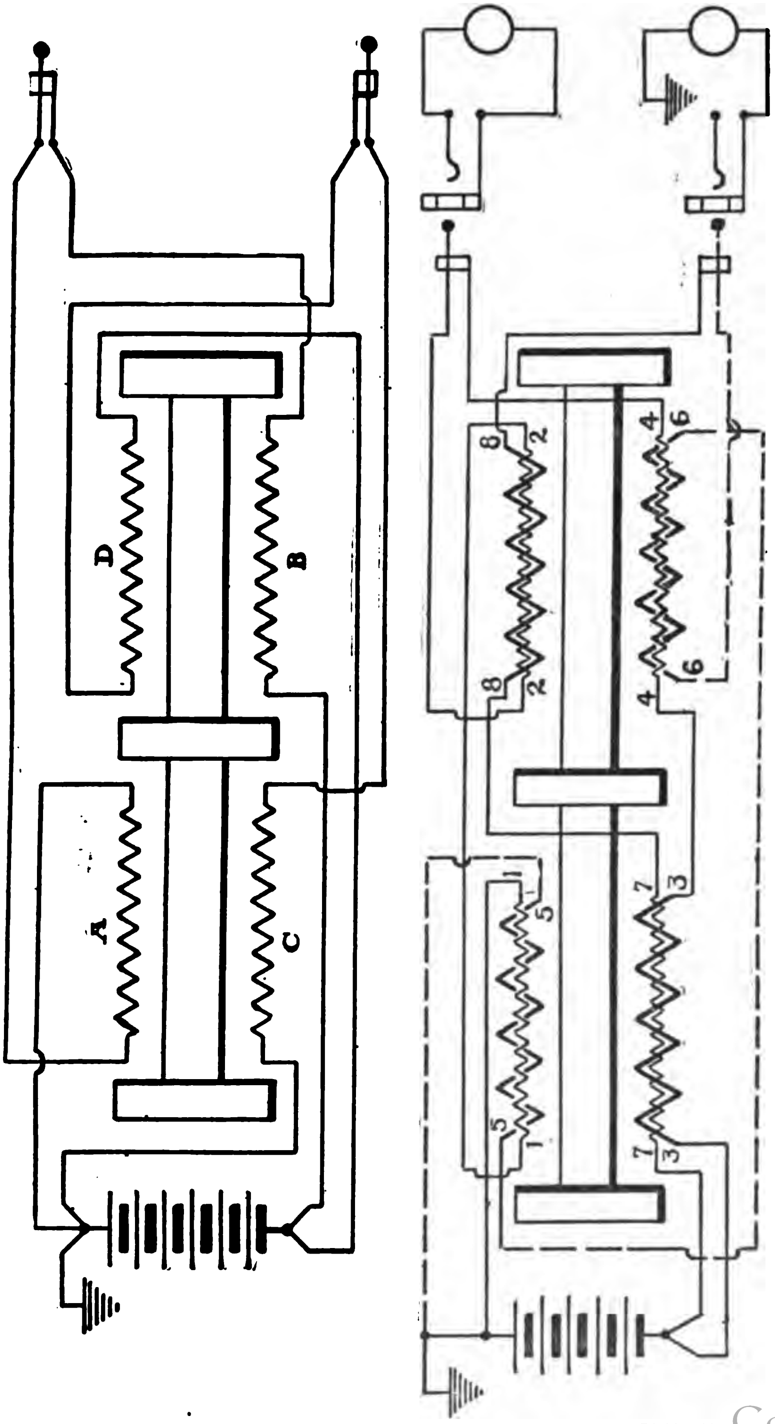
When a company, or engineer, or group of engineers enter upon the development of a certain line of business, based on an original idea, their succeeding efforts seem to follow along a well-defined and slowly widening path. Nothing revolutionary appears on the surface, and the improvements revealed to the customers are simply increments to the original idea. This is particularly true as concerns the telephone industry. During the period of Patent-Office protection, the various developments brought out by the engineers connected with the telephone interests followed each other in a quiet and logical manner, and at no time did they depart far from a beaten path. And when the independent interests were given freedom of thought and action, their efforts followed along this same beaten path. Only for a short time, however, for their work took on the marks of originality, and departed entirely from past traditions. In pointing out the instance where this was accomplished, the features of various succeeding commercial systems will be briefly considered.

One of the first efficient landmarks in the switchboard science is the series grounded system. The earth served as a return, and the low resistance line drop was necessarily disassociated from the line during connection. This was accomplished by a two-strand cut-off jack, having one spring for the talking contact, and a sleeve or thimble to guide the plug, and to hold it properly. The entrance of the plug raised the spring from a rest contact, which was connected to the drop. As the board grew in size, a busy test for the multiple of jacks became necessary, hence the use of sleeve as a test terminal. Having no operative function otherwise, the multiple of sleeves was normally insulated from everything. When the plug was inserted, being of solid metal, it brought the sleeves into contact with the talking circuit, which put them at the potential of the subscribers' earth. To utilize this changed condition of the sleeves during usage, a battery was placed in the operator's talking set in such a manner that when the listening key was closed, the tip of the plug assumed the potential of the battery, which upon coming into contact with a grounded sleeve caused a flow of current in the operator's receiver, and the subscribers' receivers, as well.

The advent of the trolley system changed the telephone map, so to speak. To avoid the disturbances, a metallic circuit became necessary for most of the lines, and its connection with a grounded board was nicely accomplished by placing a repeating coil directly in the metallic line. In many places, the number of metallic lines grew to exceed the number of grounded lines, which led to the demand for a board giving preference to metallic lines, as two repeating coils between two metallic subscribers was far from desirable. This resulted in a somewhat revolutionary step, the bridging self-restoring drop system.

This system began the era of local electrical actions in conjunction with the talking circuit. The sleeve was still the test terminal, and had the added function of conducting the current through the restoring winding of the drop. The test terminal was normally at earth potential, through the restoring winding, and was raised by the entrance of the plug. To detect this changed condition of the sleeve, the induction coil secondary and the receiver windings were halved, and a ground placed at their center, so that the closing of the listening key would give the test, and the circuit would not be unbalanced during ordinary operating. At this stage, the two-strand system stood a chance of usage, but for some reason the designers did not care to use the sleeve as a combination talking and testing terminal. So they added a third contact, or a second talking spring to the jack, and passed from one-strand into three-strand practice. The repeating coil was still evident, to connect dissimilar lines. But the main or revolutionary feature was the departure from the cut-off principle, by the use of a permanently bridged line drop, which was made possible in a multiple system by the simple effacement of the signal proper during a cord connection.

The use of a permanently bridged line signalling apparatus, and its effacement by auxiliary third-contact means, had it influence upon the next, or common-battery era. In this system, the battery and line relay is permanently bridged across the line circuit, and the line signal proper, or lamp, is effaced, or partially extinguished



FIGS. 1 AND 3.

by means of devices working in conjunction with the sleeves. For some reason, this system has not been given general adoption.

The next system, the present licensee common-battery system, shows a return to first principles, inasmuch as the line-signalling apparatus is entirely disassociated from the line when on connection, and the subscribers talk through the clearing out signal, now known as the disconnection signalling apparatus. The use of three strands came naturally into use, as the restoring winding had the same relation to the sleeve, or test terminal, as the cut-off relay winding of the present system has. In fact, there is not any evidence that the two-strand system was considered.

As the repeating coil is used in the first two-strand common battery system brought out by the independent interests, having double disconnect or supervisory signals, it must be shown that while they perform many of the same functions, in both licensee and Dunbar systems, there is a radical and necessary difference. The repeating coil that will operate successfully with the Dunbar circuit will not operate successfully with the licensee circuit. There is a reason, and that is, the Dunbar circuit is confined to metallic lines, while the licensee circuit embraces three conditions of service, metallic and metallic, metallic and grounded, and grounded with grounded.

When the common-battery systems were placed in operation, the cord circuits were equipped with a repeating coil, having four windings, arranged on a core, as shown in Fig. 1. The quarters of the coil belonging to the tips of the plugs, *A* and *C*, are wound on what we may call the left end of the core, while the quarters belonging to the rings, or other talking strands, *D* and *B*, are wound on the right, making two possible separate magnetic circuits, acting in the same direction. In Fig. 2, the use of the coil in circuit is illustrated, in which *A* and *B* are the quarters furnishing current to the metallic line, and *C* and *D* the quarters connecting the grounded party. According to practice, there are three grounds when a grounded line is concerned. One at the subscriber's station, one at the arrestor frame, and one at the battery. This means that, when a cord circuit is placed in connection with a grounded line, the tip quarter of the coil, *C*, is shortcircuited.

If, according to Fig. 2, the metallic line parallels the trolley for considerable distance, both its wires are subjected to an electrostatic potential, equivalent to the electromagnetic potential of the trolley wire. These electrostatic charges, alternating in character, are seeking the earth, and pass through windings *A* and *B* on their way. If *A* and *B* presented equal retarding effects to these alternating charges, then balance would result, and a quiet connection given. Unfortunately the windings *A* and *B* do not present equal effects toward these charges, and great noise results upon a grounded connection. The effects are unequal in *A* and *B*, because the windings *C* and *D* are unequally loaded. *C* is virtually shortcircuited, and has the greatest possible weakening effect on the inductive properties of winding *A*. Winding *D* having a line, instrument, and common return in circuit does not have as great a weakening effect on *B*, as *C* has on *A*, hence the unbalance, and the consequent noise.

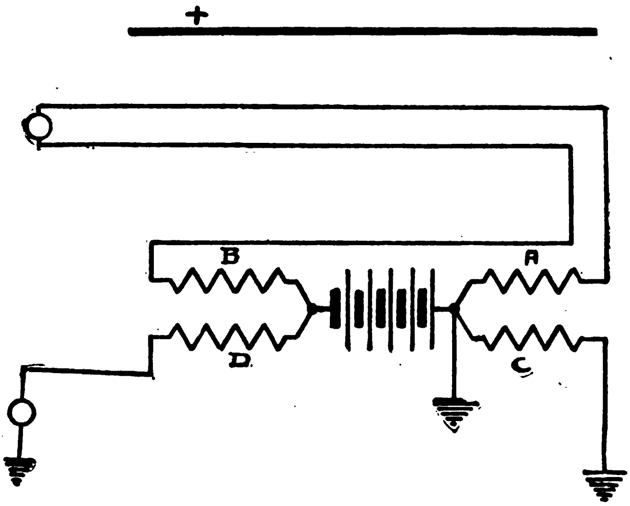


FIG. 2.

As the licensee companies had an object in maintaining grounded service, a coil had to be devised which would preserve the static balance under all conditions of service. The condition in question is the metallic and grounded connection, which means that the tip quarter of the coil on the grounded side is idle. In Fig. 3, the idle quarter has been represented by dotted lines, as section 5 and 6. Tip eighth, winding 1 of the metallic side, and the dotted tip eighth, winding 5 of the grounded side, start out in pairs at the same end of the core. Likewise, the metallic ring eighth 3 starts out in pairs with grounded ring eighth 7. On the other side of the core, or end, a double transposition takes place, as 8, the grounded ring eighth, pairs with 2, the metallic tip eighth, while 4, the metallic ring eighth, pairs with the dotted grounded tip eighth 6.

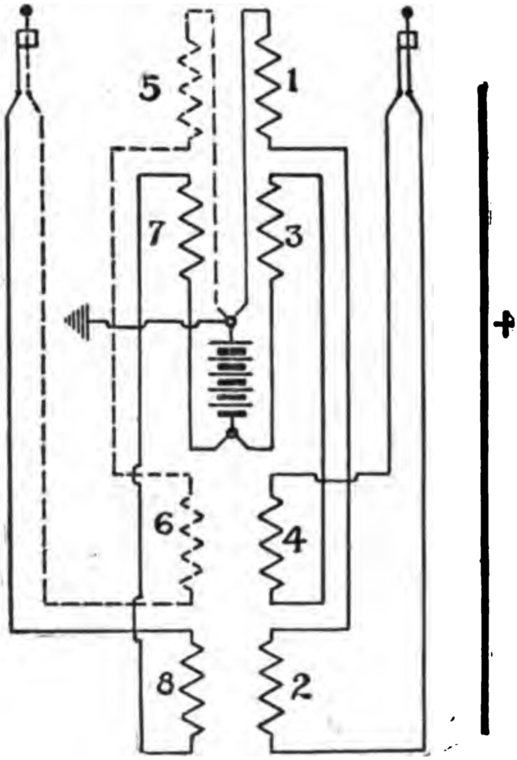


FIG. 4.

The balancing effect may be better shown by Fig. 4, in which the various sections are connected in circuit. As connection with a grounded line renders the grounded tip quarter useless, it will not be shown. An inspection shows that grounded rings 7 and 8 have equal loading effects on each end of the core. By transposition, winding 7 affects the ring side of the circuit at 3, exactly as 8 affects the tip side at 2. Therefore, each quarter of the coil on the metallic side presents equal inductive resistance to the alternating static charges.

There has been considerable conjecture among licensee employes as to the reason that the improved eight-section coil will not permit of a ground at the arrestor frame, or shortcircuiting of the grounded tip quarter, as did the older four-section type. When a coil gets down on a metallic circuit, the transmission is muffled to a serious degree, when the eight-section coil is used. The reason would be that the old coil had two separate magnetic fields, one of which could be shortcircuited or idle without affecting the other. In the newer coil, a shortcircuited quarter would affect the entire core, and render it non-inductive, and not efficient as a repeater.

As a non-inductive relay appeared in the Dunbar circuit, nothing yet appears of a revolutionary nature. The series grounded local battery system had a winding in the circuit as a clearing-out signal, through which the voice currents passed. The licensee system has a clearing-out signal through which the voice currents pass. So has the Dunbar original system. What is the difference? The licensee non-inductive supervisory relay has two windings, eleven ohms of copper, and one hundred ohms of German silver wire, wound on the exterior of the copper winding, of few turns, and having no inductive value. The 100-ohm shunt did not materially weaken the power of the 11-ohm copper winding in connection with its direct-current functions, but when in the path of voice currents, acts as a direct circuit without any magnetic energy being set up, and consequently does not affect the rapidly changing frequencies to their disadvantage. The non-inductive relay of the Dunbar system is a differential relay, having two windings of equal and opposite value, and having the same relation to the core. If the coils were wound on the respective ends of the core, lines of force would be set up in the respective ends of the core of opposite value, and neutralization would take place. But when alternating currents of extremely high frequency pass through these windings, a neutralization would tend to take place, but does not, because the lines of force do not have time to thread through the neighboring coil; hence energy is restored to the circuit, which makes the end-on relay inductive to a certain extent. To cause complete neutralization, it must be done electrically, and not through magnetic means. If the coils are superimposed upon each other, then a neutralization takes place between the forces tending to produce magnetic energy, thus killing the evil at its inception.

What is the difference then, between the Dunbar and the licensee systems, if each makes use of a cut-off relay, a repeating coil, and a non-inductive cord relay? There is a great difference in the electrical actions involved, necessitated by the use of a talking strand as the means of operating the cut-off relay, and acting as a test terminal, in addition to its natural function. And in the absence of the third strand, the act of testing a busy line has to be particularly safe-guarded, in order to prevent the subscriber from being seriously annoyed while talking to another party.

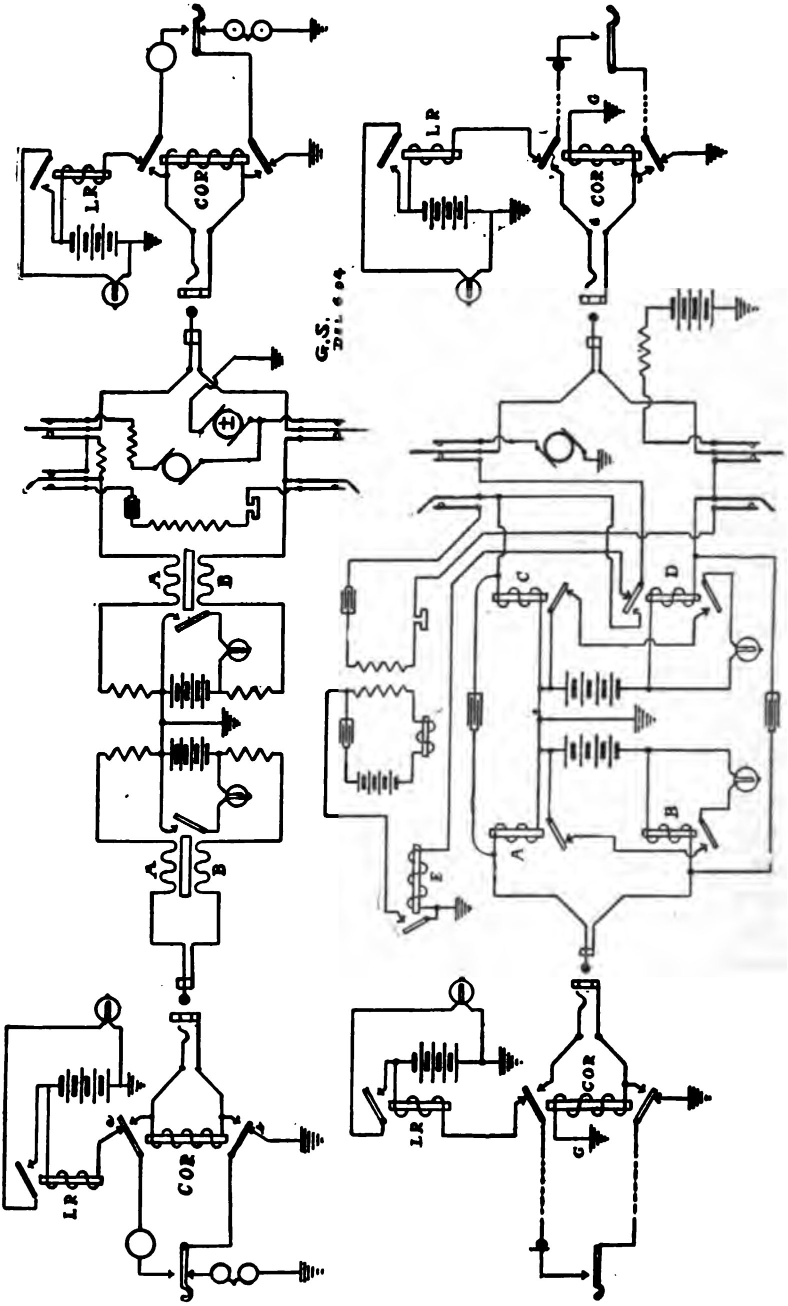
Fig. 5 shows the original Dunbar two-strand system. The subscriber called central by removal of receiver, which allowed battery to flow through line relay, *L R,* out on the line through contact at *a,* thence back to ground at *b.* The entrance of the plug causes battery to flow through winding *B,* relay *C O R,* thence back to ground through winding *A.* The current being equal in *A* and *B,* the relay has no magnetic strength, and the lamp circuit of *A L* remains open. Right here is the remarkable feature of the system, that the cut-off relay is energized by current flowing through the talking circuit, without impairing the talking qualities in the least. The energization of relay *C O R* brings out another original feature, the simultaneous disconnection of the line signalling apparatus, and the connection of a normally disconnected multiple jack. This normal disconnection of the multiple jack from the line gives the advantage of a reliable busy test.

Another marked feature is shown in the busy test method. The test is a natural one, and the touching of the calling cord tip to the sleeve of a busy line jack, and is similar to that of the licensee systems, inasmuch as the touching of the tip to the busy sleeve stores up energy in the tip quarter of the repeating coil. The withdrawal of the plug tip causes a discharge of this stored energy into the operator's bridged receiver, and into the circuit of the calling party. But the Dunbar subscriber would be painfully aware of the test being made, while the three-strand licensee subscriber would not. The touching of the grounded tip to the sleeve talking terminal would materially lower the potential of the terminal, and cause a vicious receiver click in both talking lines. To prevent this click, the listening key is arranged so that its use will remove a shortcircuit from about the 700-ohm resistance placed directly in the testing circuit. This modifies the testing click in the subscribers' receivers considerably. There might be an objection to this method, as it introduces a 700-ohm resistance in the talking circuit of two connected parties, should the operator listen in. As she has double supervision, there is no reason why she should do so.

Inserting the calling plug lights the supervisory lamp, because the low resistance ground on the sleeve line side unbalances the differential windings and causes magnetic energy to be operative on the relay armature. More current will flow through *B'* than through *A'*, until the ground is removed by the subscriber removing the receiver. Then the windings neutralize, and the lamp is extinguished.

Another marked feature is the necessity of a temporary source of energy to hold the cut-off relay during the act of ringing. As the multiple is normally disconnected from the line, and its connection with the line depends upon the energization of the cut-off relay, and the energization of the cut-off relay depends upon current flowing over the cord circuit, it follows that the necessary opening of the cord circuit in the act of ringing shall not deprive the cut-off relay of energy. This was accomplished by means of an alternating current generator, which was connected to the sleeve side only. A direct current generator was bridged across the circuit, and supplied the cut-off relay with direct current. Later, it was found that the ordinary exchange battery connected to the tip side through a suitable impedance would accomplish the same purpose as the direct-current generator. The idea is shown in Fig. 6, a later circuit, which supplied generator current out on the tip side, while the main exchange battery supplied energy to the cut-off relay.

At this stage the independent designers made a revolutionary move. They departed from the repeating coil, they departed from the non-inductive relay, the only semblance being in the cut-off relay principle, though utterly unlike in operation. The era of double disconnect retardation system began. What were the technical reasons why the differential system, with its repeating coil, its non-inductive relay, and ground at the subscriber's station should be relegated, and the retardation system made standard? Both are designed for metallic service exclusively. The principal weakness was in the ground at the subscriber's station, which is objectionable for many reasons. The difficulty of a fair ground for selective ringing is known, while this system had to have a good ground, a real ground, of lowest possible resistance, in order that the differential relay could be reliably operated. Supposing the grounds to be perfect, another difficulty presents itself — that unrelenting enemy of grounded telephone practice — earth currents due to the street railway companies. Potentials of different values exist on every line, making the operation of the differential relay a great uncertainty. And its peculiar dependence upon its external


LR
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connections as a switchboard makes it unique, though not a weakness.

When the ground at the subscriber's station was changed to the ground at one terminal of the cut-off relay, *G,* in Fig. 6, the differential relay had to be abandoned, because there is no possible way that a neutralization could take place between windings *A* and *B,* when the subscriber removed the receiver. The 500-ohm cut-off relay would shortcircuit winding *A* to a certain extent. So windings *A* and *B* were placed on separate cores, as it were, *B* being the winding of a back contact relay, while *A* is the winding of make contact relay. When a party calls in the usual manner, the operator would insert the plug, which would put relay *A* in series with cut-off relay *C O R.* Both would be energized, *C O R* cutting off line signalling apparatus, and connecting the multiple to the line, while relay *A* closed the circuit of the supervisory lamp. As the receiver is supposed to be off the hook, *B* is energized, and the lamp circuit broken.

The test feature is a distinctive one, consisting of a 5000-ohm relay, which armature contacts, when closed, put a ground on the primary circuit in such a manner as to cause a battery flow through the primary winding, and induce a current in the secondary. Being of a great number of turns, and highly inductive, it does not cause an appreciable reduction of the terminal potential, and only an experienced telephone user can detect the test made on his line. The testing relay serves the entire operator's position, and is necessarily disassociated from each talking connection. Relay *D,* acting in series with the cut-off relay, *C' O'R',* serves this purpose, and also closes the talking circuit, and the supervisory lamp circuit also. When the subscriber answers, relay *C* has a function liken to relay *B,* simply opening the supervisory lamp circuit.

Condensers connect the answering and calling circuits instead of repeating coils, and serve to repeat the fluctuating voice currents. The circuits are individualized by the relays, which also control the direct-current supply as well. The circuits in Figs. 5 and 6 bear a very close resemblance to each other, having the same features practically, first, the temporary energization of the cut-off relay during the act of ringing, second, the current of cut-off relay energization being supplied over the strands of the talking circuit, and third, the combined use of the sleeve as a testing and talking terminal.

Both systems have a normally disconnected multiple jack, a normally connected line-signalling apparatus, are designed for metallic service only, and it may be said that the four years' effort of the brainiest, cleverest, and most experienced telephone engineers ever assembled together in the employment of one company simply resulted in the removal of the ground from the subscribers' station to that of the ground at the exchange cut-off relay terminal, which fact strongly proves the genius of the inventor of the first double supervisory two-strand telephone system. And when one remembers the herculean difficulties confronting this, and other groups of independent telephone engineers, the limited experience of the past, working in an entirely new field of action, one cannot help but realize that this apparently simple transfer of grounds represents many mile posts in the advance of telephone development.

DISCUSSION.

Mr. F. J. DOMMERQUE: I only wish to state that the two-wire system that is described by Mr. Kelsey is in very close connection to the switchboards I spoke of in my paper on Wednesday last. This two-wire system is the one I referred to that makes it possible to build the large boards that are at present in use in Buffalo and other large cities, having 18,000 lines capacity. Experience with the two-wire system has shown that the difficulties that were feared at the beginning have not been realized, and that the system as described by Mr. Kelsey has given, since the time it has been tried, perfect satisfaction, and is at the present time probably as fully developed, not only for the multiple switchboard, but also all lines that are connected therewith, as anything that enters into the operation of a large telephone exchange. It can be easily compared with the vast development of the three-wire system. The original two-wire system was not completely carried out as it is shown at the present time in Mr. Kelsey's paper. The first two-wire plug was used in connection with a complete system here in St. Louis, but the feature of the St. Louis system was not the full two-wire system, as the test was not made the same as it is at the present time in the two-wire system. After this we have to take account of work that has been done by Mr. Kempster B. Miller, which, so far as I noticed, has not been recorded in Prof. Kelsey's paper. Mr. Dunbar has been to a great extent the developer of the two-wire system, and he was ably assisted by Mr. Miller. In fact, it is difficult to divide between the work of the two gentlemen and say who has accomplished the most in this line. I only mention this that Mr. Kempster B. Miller shall receive due credit for the work he has done.

Mr. F. C. McBERTY: No switching system should be adopted for use without consideration of both its advantages and its disadvantages. The two-wire system should be compared with the three-wire system in both respects. The chief advantages claimed for the two-wire system, as compared with the three-wire, are possible large size of switchboards and possible cheapness. As to the size of the switchboards, requirements have not yet reached the available capacity of three-wire switchboards, so that the assumed enlarged capacity of the two-wire switchboard cannot yet be considered to be an advantage. As to the possible advantages of the two-wire system in cost, so far as I am aware, the prices of the two switchboards are still about the same. No data as to the ultimate and necessary first costs of the two systems is available for comparison, but I should expect to find very little in favor of the two-wire in this feature also. On the other hand, it is known that some transmission losses and increased costs of maintenance may be characteristic of the two-wire switching system, which might easily offset a moderate difference in first cost.

Mr. P. B. **Delany**: I beg leave, on behalf of the gentlemen who have been in attendance during this Congress in Section G, to return our sincere thanks and acknowledgments to our Chairman and other Section officers who have been controlling our deliberations, and contributing so well and forcefully to our fund of information regarding the subjects that have been under discussion. Our Chairman has been enterprising, fair, and able to a degree, I am sure, that should make us feel very grateful to the governing board of this Congress for his selection, and selection of his assistants here, who have voluntarily taken up the work, and I believe have done us a great favor in their contributions to our knowledge of the different subjects under consideration. Mr. Gherardi and Mr. Hesketh have been untiring in their endeavors to make clear for our information every subject with which they have been acquainted, and I am sure I voice the sentiment of the gentlemen in Section G when I ask for a unanimous and hearty vote of thanks to these gentlemen for the work they have done.

Mr. Delany put the motion and the vote of thanks was unanimously extended as above set forth.

Chairman Jones: Mr. Delany and gentlemen, you could not have given me gold that I would prize more than I do the expression of confidence and good opinion you have made through Mr. Delany's motion. Personally I am not deserving of all this vote — only a very small portion of it. I have been so ably assisted by Mr. Gherardi, the secretary, and by our honorary chairman, Mr. Hesketh, and by your own actions and courtesies, and by the intelligence and fairness with which you have treated your subjects, that I found my duties exceedingly easy and pleasant. If I have performed the services of this office to your satisfaction, it is something of which I am very proud. I thank you very much.

The time has arrived for adjournment, and I believe a final adjournment, so far as this Section is concerned. Of course, in my confusion in trying to return thanks for the high compliment paid me, and trying to tell the truth about our secretary and honorary chairman, I did not think it necessary for me to say that I know we all highly prize the presence, from all parts of the world, including the antipodes, of these distinguished gentlemen who have favored us with their presence and their ideas, and it seems to be too bad that these opportunities for this interchange of valuable electrical knowledge cannot be more frequent. It is to be regretted that our sessions were not held under more advantageous conditions, as to comfortable rooms, than they have been here. We are not complaining at all. St. Louis has been most kind to us. We are truly grateful for the treatment we have received here. Again thanking you for your kindly treatment of myself personally, I will now entertain a motion to adjourn.

Mr. JOHN HESKETH: I move that Section G do now adjourn until its meeting in general convention with the other Sections to-morrow morning at ten o'clock at Congress Hall in the Fair grounds.

Motion adopted unanimously.

TRANSACTIONS

OF

SECTION H

Electrotherapeutics

Honorary Chairman, PROF. J. A. BERGONIE
Chairman, DR. WILLIAM J. MORTON
Vice President, M. G. de NERVILLE
Secretary, MR. WILLIAM J. JENKS

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Total number of papers presented before Section H, **20.**

Section H was called to order at 11 a. m., Monday, September 12, Dr. William J. Morton, presiding.

DR. MORTON: I am happy to say we have with us the author of the first paper to-day, Dr. T. Proctor Hall, of Chicago. Dr. Hall needs no introduction from the chairman of this section. I will call upon him for his paper and then for such other papers as may be ready to be presented.

THE PRINCIPLES OF ELECTROTHERAPEUTICS.

BY DR. T. PROCTOR HALL.

From the known physical, chemical and physiological effects of electric currents it is possible to draw fairly accurate conclusions as to their therapeutic uses; and when these data are combined with the results of clinical investigations, the principles of electrotherapeutics are set forth ready for application for the relief of mankind.

ELECTRIC CURRENTS.

It is essential that the practician should have first a clear concept of the nature of an electric current. For this purpose the Vortex theory of electricity and magnetism offers the simplest working hypothesis. According to this theory an electric current is a vortex ring, consisting of a bundle of chains of polarized and rotating atoms, each chain forming a complete circuit. Any substance, such as copper, which permits of the rotation of its atoms in such polarized chains is called a conductor. A substance, such as quartz, whose atoms are so firmly fixed in their relation to each other that no such continuous rotation is possible, is called a nonconductor.

By an electromotive force, which, according to this theory, is a polarizing and rotating force, the atoms of any substance may be rotated to some extent. In a nonconductor the extent of the rotation is in direct proportion to the force applied, and is therefore determined by the magnitude of the electromotive force.

The rotation of the atoms at the surface of a nonconductor is necessarily conveyed in part to the adjacent atoms. This capacity which every substance has for conveying an electric strain is known as dielectric capacity. The dielectric capacity of glass or mica is several times as great as that of air; in other words, the effect of an electromotive force is much more pronounced through a millimeter of glass or mica than through a millimeter of air. The dielectric capacity of a good conductor is almost infinite; in other words, the conductor conveys an electric strain from atom to atom with practically no loss.

If we assume that the right-handed rotation of a chain of atoms constitutes a positive current, then a left-handed rotation is a negative current. It will be observed, however, that a rotation which is right-handed to one person, is left-handed to the one who stands facing him. The same current (rotation) is therefore at the same time both positive and negative, according to the point of view. The difference between a positive and a negative current is relative only.

The direction of a current of low potential may be found in several ways. If the current passes near a magnetic needle which is free to turn, the north-seeking end of the needle tends to point in the direction of the atomic rotation near it. If two common sewing needles be inserted into a piece of beef, half an inch or more apart, the anode needle sticks fast and the kathode needle dissolves the surrounding tissues and becomes very loose. The direction of an intermittent current of high potential, such as is obtained from a static machine, may be determined from the appearance of the spark. When the spark gap is small the spark has a short white streak at the kathode, a long white streak at the anode, and a fainter violet line across the middle. When the electrodes are far apart the spark appears to branch from the anode or positive pole, which forms the trunk, and the branches, after disappearing, seem to recollect into a heavy white streak a short distance from the kathode. In either case the spark will follow a pointed stick which is moved across its path close to the anode, while it pays very little attention to the same stick moved across at the kathode.

A direct current is one whose rotation is in one direction only. If the direction of the rotation is periodically changed, the current is alternating. These, the direct and the alternating, are the two main classes of currents.

If some of the atoms in a polarized chain belong to a nonconductor they are unable to take part in a continuous rotation, consequently the chain cannot rotate, and there is no current. But if the electromotive force is sufficiently great the nonconducting atoms may be torn from their associations and compelled to rotate. The nonconductor is in this way pierced or broken, and the sudden expenditure of energy usually gives rise to a perceptible amount of heat and light. This phenomenon is called a spark discharge.

If the electromotive force is not great enough to cause a spark, the atoms at the surface of the nonconductor remain strained further than those in the interior. This strained condition of atoms at the surface is called an electric charge. It will be noticed that the strain on one side of the non-conductor is right-handed, forming a positive charge, while the strain on the other side is left-handed, forming a negative charge, the observer being supposed in each case to face the surface under consideration. The absolute direction of the rotation is of course the same on the two sides.

If the original electromotive force be removed, the strained atoms return to their normal position, and in so doing produce a current in the opposite direction. The positive charge, which was produced by a positive current passing toward the surface, produces a positive current from that surface, and similarly with the negative charge.

Along the sides of the rotating chains of atoms the elastic ether (which may be thought of as a soft solid) is displaced to a slight extent in the direction of the rotation. This displacement is magnetism. From the sides of an alternating current proceed magnetic waves which are plane-polarized. From the end of a conducting chain of atoms which are subjected to an alternating electromotive force proceed cylindrical waves which have all the essential characters of waves of ordinary light.

The rotating atoms in a conductor strike against each other and against other atoms, and impart to them an increase of vibratory velocity (heat). Some of the energy of the current is thus wasted in a conductor. The proportion of energy so wasted depends upon the physical and chemical conditions of the conductor, and is a measure of the resistance of the conductor. If a pure metal were cooled to the absolute zero of temperature there would be no waste of energy in this way and the resistance of the metal would then be zero.

The commercial units used in connection with electricity are arbitrary. The unit of current (total amount of rotation per second) is the ampere. The current used in a sixteen-candle power incandescent lamp is about six-tenths of an ampere. One-tenth of an ampere is considered the limit of current which may be safely passed through any vital portion of the body, for example, from one hand to the other, through the chest. Therapeutic currents are measured in milliamperes, or thousandths of an ampere.

The unit of electromotive force is the volt, which is approximately the force of a single salammoniac cell or a dry cell after it has been used a little time. The usual voltage of an incandescent light circuit is one hundred and ten. The voltage of trolley circuits is about five hundred.

The unit of resistance is the ohm. The resistance of two hundred and sixty feet (80 meters) of No. 18 copper wire is one ohm. The resistance of fine wire is proportionately greater. One foot of No. 40 copper wire has a resistance of one ohm. The resistance of the human body varies from about five hundred ohms upwards, according to the kind of contact made with its surface. Roughly speaking, the conductance of the various tissues is in proportion to the amount of water contained in each. The relation between these three elements, electromotive force (E), current (I), and resistance (R) is shown by Ohm's Law, which is:

$$E = RI, \text{ or numerically,}$$
$$\text{Volts} = \text{Ohms} \times \text{Amperes.}$$

This implies that the current may be increased by increasing the electromotive force or by decreasing the resistance.

ELECTROLYSIS.

When an electric current is passed through a liquid containing a salt in solution, the end of the conductor from the positive (carbon or copper) pole of the battery is considered to be the road by which the current enters the solution (according to the fluid theory of electricity). It stands, therefore, at the source of the electric stream in the solution and is called the anode (up-road). The other electrode at the bottom of the stream is called the kathode (down-road) and is in direct connection with the negative or zinc pole of the battery. The molecules of the salt are polarized by the electromotive force, and one after another are split into two parts by the current. This splitting is called electrolysis. The two parts into which each molecule is split are called ions (wanderers). The splitting takes place in the same way as in the double decomposition of chemical salts, namely, into a basic part and an acid part. The basic parts move in the direction of the positive current (down stream) toward the kathode, and hence are called kations. The acid parts move in the opposite direction (up-stream) toward the anode, and hence are called anions.

In the case of common salt ($NaCl$) the sodium atoms are the kations and collect around the kathode; the chlorin atoms are the anions and collect around the anode.

In every case the direct effect of the current is to split the molecule into two and only two parts. But in many cases secondary changes take place, which are undoubtedly electrical in character but which are most conveniently considered to be the chemical results of the unstable conditions formed by electrolysis. Metallic sodium decomposes water, setting free hydrogen gas and forming caustic soda: $2Na + 2HOH = 2NaOH + H_2$. At the anode the chlorin ions may decompose water, forming hydrochloric acid and oxygen gas: $2Cl_2 + 2H_2O = 4HCl + O_2$. Similar changes take place with other compounds. The secondary reactions are all of the same character, and may easily be written down by one who has a knowledge of elementary chemistry. The metals and alkaloids are kations; the acid radicles are anions.

The physiologic effects of a direct current are mainly in the vicinity of the electrodes. Since common salt is one of the most abundant of the salts in solution in the body, its behavior under electrolysis may be taken as a type of the changes produced by electricity in the tissues. Near the anode we have increased oxidization, and the hardening or astringent effect of the acid. Near the kathode we have deoxidization and the softening or dissolving of tissue by the alkali. Considering in particular the effect upon the smaller blood vessels, near the anode these are constricted and ischemia produced; near the kathode they are dilated, causing hyperemia. Pain usually results from pressure upon nerve endings, and in such cases relief can be obtained by the astringent effect of the anode. Defective nutrition in any part is frequently due to defective blood supply, and in such cases can be improved by the hyperemic effect of the kathode. Either the acid or the alkaline effect may be made so intense as to cause destruction of tissue. For the removal of dermal defects (warts, moles, nevi, etc.) either electrode may be used. The anode forms a hardened mass of coagulum and connective tissue. The kathode softens and dissolves so that the abnormal growth is more readily removed by the lymphatics. The anode is therefore to be preferred where cutting off the blood supply is the essential part of the treatment, and the kathode where the removal of all traces of hypertrophied tissue is more important. The kathode is successfully used for the relief of urethal, rectal, esophageal and other strictures. A current so mild as not to produce any marked degree of inflammation is used repeatedly, and this gradually dissolves the constricted scar tissue.

Kathode .... Electrodes .... Anode
Molecule
Kations....................Ions......*Anions*

Basic, metallic or	Non-metallic or
Alkaline,	Acid,
Relaxing,	Astringent,
Softens and dissolves,	Coagulates and hardens,
Causes hyperemia,	Causes ischemia,
Increases pain,	Reduces pain,
Excites,	Sedative,
Deoxidizes,	Oxidizes.

Foresis.

The term foresis is applied to the motions of the ions when made use of to carry medicaments into some particular part of the body. The motion of metallic and basic ions toward the kathode is termed kataforesis, and the motion of the acid ions toward the anode, anaforesis. The amount of foresis is dependent upon the intensity of the current, and has no direct relation to the electromotive force, so long as the latter exceeds a few volts. Kataforesis has been successfully used for the destruction of malignant tumors and the sterilization of adjacent tissues by heavy currents from amalgamated zinc needles.

When the current is alternating or when the polarity is frequently changed, foresis takes place in alternate directions. The result, instead of being zero, is a scattering of both sets of ions throughout the tissues. Molecular diffusion then takes place much more rapidly than it would without the action of the current.

Where a direct current passes through the tissues of the body there is a distinct interpolar action. In a homogenous conductor the interpolar effect of a steady current is confined to the production of heat. But each cell in the tissues gives an opportunity for foresis, and the current distributes heterogeneous ions so as to form new compounds as illustrated below:

Na	*Na*	*Na*	*K*	*K*	*Na*	*Na*
Cl	*Cl*	*Cl*	*I*	*I*	*Cl*	*Cl*

which becomes by foresis

Na	*K*	*K*	*Na*	*Na*	*Na*	*Na*
Cl	*Cl*	*Cl*	*Cl*	*I*	*I*	*Cl*

The remarks made up to this point regarding the polar effects of the electric current apply to direct currents only. When an alternating current is used there are no polar effects, provided the positive and negative portions of the current are symmetrical. The molecules are split into ions just as in the case of the direct current, but the ions have the opportunity of reuniting when the current is reversed. If the original molecules are stable under existing conditions this reunion takes place, leaving the chemical composition precisely as it was before. But such conditions are rarely, if ever, found in the tissues. The chemical changes by which the food is finally oxidized are constantly taking place. Electrolytic action facilitates these changes by assisting in the decomposition of molecules. Physiologically this means acceleration of metabolism. Therapeutically this stimulus is advantageous wherever metabolism is deficient, or where tissue debris has accumulated, or where local bactericidal infection occurs, or where abnormal growths are taking place. In all of these cases the completion of normal tissue changes removes the pabulum of pathological cells.

It is important in this connection to note that of the three essential life processes,— nutrition, metabolism and elimination,— the alternating current accelerates chiefly metabolism, and it is necessary to look closely after nutrition and elimination by other means.

SENSORY REFLEXES.

Some of the most marked effects of electricity upon the human body are produced through sensation. These effects are not peculiar to electricity, but they have been to a very considerable degree overlooked by other therapeutists. The involuntary muscular system maintains its tone in part by the reflex action of the unnoticed sensory impulses which are continually received through touch, hearing, sight, etc. If these mild and general sensations are increased in intensity, the reflexes become stronger. The blood vessels, for example, are constricted, raising the blood pressure, the heart beats more strongly, respiration is deeper, and there is greater tension in every part of the organism.

Locally these reactions may be used to great advantage. In case of local hyperemia, in which there is abnormal distension of the smaller blood vessels, a slight increase in the sensory reflexes in that region is frequently sufficient to cause a return to their normal size, which stop exudation and causes reabsorption of the exudate. If coagulation has not yet taken place this reabsorption is very rapid. The necessary stimulus may be given by brushing the skin with a soft feather or a camel's hair brush, or by passing the finger tips over it very lightly, or by tapping gently with a light stick, or by the lips of the mother who may "kiss the spot to make it well," or by the spray or breeze from a static electric machine. Similar effects may be produced near the surface by an astringent wash, and at a considerable depth under the anode by the direct current. Using a mild breeze from the positive electrode of a static machine the sensory and polar effects are combined. Bruises, varicosities, rheumatic swellings and similar painful hyperemic conditions are often promptly relieved by this treatment.

When sensations are greatly increased in intensity the normal reflex fails through overstimulation of the nerve centers. The effects are then irritating, the exact opposite to what they were before, resulting in a hyperemic condition of the part. This condition may be obtained electrically by any painful application of the current. It is advisable where hyperemia is desired to combine the chemical effect of the kathode with the sensory effect of pain. Violent stimulation results in a condition resembling shock, in which the reflex almost disappears.

In some persons and in some abnormal conditions the senses are excessively acute; in others very dull. The sensory effects are dependent upon the amount of sensation and the condition of the nerve centers, and not merely upon the amount of force applied.

MUSCULAR STIMULUS.

Upon the neuro-muscular system electricity acts directly to produce muscular contraction. These contractions are mainly caused by changes in the intensity of the current, and the more sudden the change the greater is the amount of contraction. For muscular effects it is important that the current changes be not too rapid to permit of complete relaxation, otherwise the circulation is impeded by the contractions and no benefit results. In treating the nerves the current changes may be made much more rapidly. When the changes are very rapid, say 5,000 per second, the conductance of the nerve for ordinary stimuli is temporarily lost.

IDEATION.

By ideation or suggestion is meant the production or reproduction of ideas or concepts in the mind of the patient. While this cannot be done directly by means of electricity, the conditions of electric treatment are in most cases unusually favorable for it and it becomes therefore an important part of the treatment. Ideas suggested to the patient are consciously or subconsciously accepted by his organism if the organism is in a receptive condition. The essence of receptivity is the absence of resolution on the part of the patient. He may be in a condition of complete rest, or of nervous excitement, or of surprise; in all these there is irresolution, and suggestion is then effective.

In taking an electrical treatment the patient is introduced to apparatus that is strange and mysterious. He is outside of his usual conditions. His ordinary mental routine is interrupted, and his subconscious mental acts are subjected to new directions and impulses. In this bewildering maze he looks to one source, the physician, for safety and direction. A statement from his physician regarding the changes which are being induced in his organism causes an expectant attitude of the subconscious personality of the patient which materially assists in bringing about the desired changes. It is not necessary, in fact it is injurious, to go beyond absolute truth in giving these suggestions. They must be made clearly, confidently and repeatedly, in order to produce the best results. Probably one-half of the total effect of electric treatment in general practice is due to the sensory reflexes and suggestion.

RADIATION.

The x-rays are believed to be pulsatory electric waves corresponding to some extent to waves of light. Clinical observation is in harmony with the view that the effects of waves of light and electricity are very like those of alternating electric currents, especially high frequency currents. There is first the stimulating influence upon metabolism. This may be mild, or strong, or destructive. In the second place there are the sensory reflexes already described. The treatment of abnormal growths by any form of electric wave is based upon the fact that as living organisms abnormal cells are less stable than normal cells. Consequently an irritation which is not sufficient to cause serious injury to normal cells may be strong enough to be destructive to abnormal cells. The essence of such treatment therefore consists in applying the stimulation so intensely as to cause gradual destruction of abnormal tissues, stopping short of serious injury to normal tissue.

If the abnormal tissues are of considerable size, as in pulmonary tuberculosis, large malignant tumors, and degenerative conditions of the blood or muscular system, there is danger of systemic poisoning by toxins formed from the diseased tissues by the radiations. The treatments must then be at first short and mild, and increased slowly, while all the channels of elimination are kept free.

The form of radiation to be selected depends chiefly upon its power to reach the part desired. Sunlight and artificial lights penetrate the tissue to a slight degree and are therefore advantageous for surface treatment only. X-rays of low penetrative power, which are obtained from a low vacuum tube, can also be applied only at or near the surface of the body. Rays of high penetration which are obtained from a tube of high vacuum, pass without difficulty through the soft tissues, and may be utilized for the treatment of deeper lesions.

Radiations that pass entirely through the tissues are wasted. Only those that are stopped by the tissues do work there. Consequently the vacuum of an x-ray tube must be so adjusted that its rays reach the part to be treated, but do not pass through to any considerable extent. Then all the available energy is expended in the desired region. The more highly differentiated tissues, such as hair and sweat glands, are more quickly injured by x-rays than the less differentiated tissues.

The part played by electrons in electric treatment is not yet very clear. The general effects of radium emanations are similar to those of electric waves of low penetration.

SUMMARY OF EFFECTS.

The known effects of electric currents may be summed up as follows:

1. Heat,
2. Magnetism,
3. Radiation,
4. Induced Currents,
5. Electrolysis and Foresis,
6. Neuro-muscular Stimulation,
7. Sensory Reflexes,
8. Ideation.

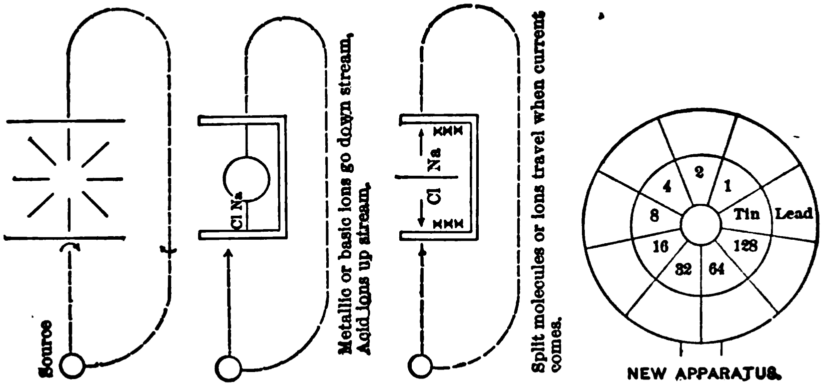
Heat is always produced in a conductor by an electric current, but the amount of heat is so small in comparison with the other effects that it may be neglected in therapeutics.

Around every current are magnetic strains of the ether. The effects of these upon the body are practically zero, except when the currents are alternating and the magnetism therefore constantly changing its polarity. Intermingling with these magnetic changes, and to a considerable extent identical with them, are induced alternating electric currents. Magnetism as a distinct factor in the treatment may consequently be disregarded, and the effects considered as due to the induced currents only.

Ether waves and streams of electrons exist almost everywhere. They undoubtedly play a large part in the question of health and disease. The negative electrons, which are much smaller and more rapidly moving than the positive electrons, are of great therapeutic importance, but beyond this we can at the present time say very little of them.

Electrolysis takes place wherever an electric current exists in a solution. Foresis always accompanies electrolysis. With direct currents the polar effects are very pronounced; the interpolar effects relatively insignificant. With alternating currents the electrolysis loses its polar character and becomes metabolic stimulation, and foresis becomes an assistance to molecular diffusion. These two processes accompany all forms of electric waves, and are characteristic of sinusoidal currents, high-frequency currents, x-rays, light, and heat.

There is nothing magical or mysterious about the therapeutic effects of electricity. In the physical world there is no form of energy that is more capable of adaptation to all conditions. In therapeutics also a great variety of effects may be obtained at the command of the operator. Electricity, therefore, is not in any sense a specific for any disease, nor on the other hand may it be considered as a cure-all. It is merely an exceedingly valuable physical agent, which, when applied intelligently and with the proper understanding of the human organism, can be depended upon for certain and definite results. The force applied can be exactly measured; the result can be foretold with certainty, so far as the electric side is concerned. Some uncertainty remains and always will remain on the side of the patient. The skill of the physician is constantly required to determine exactly the pathologic condition and recuperative power of the patient, and to judge of the form and extent of the curative agent best suited to his condition. The time has gone by when the physician is justified in using electricity alone in any of its forms for the purpose of determining its effect. The general nature of these effects has already been determined. The physician's duty now is to acquaint himself with them and to use them together with all other available measures to benefit his patient.



SKETCHES EMPLOYED TO ILLUSTRATE THE PAPER.

DISCUSSION.

Dr. Charles R. Dickson: In listening to Dr. Hall's paper one needs to do a good deal of thinking. There are so many things we have looked at askance in the past, that perhaps now are beginning to appear to us in a new light, and it may be that another remark I made to our chairman may prove true. I said we were making history in this section to-day, it being the first time in the history of electrotherapeutics that it finds a representation in America in an international electrical congress, and so it may be that this paper is making history. I say so for this reason: You have all heard that in years gone by the belief prevailed that any one afflicted with scrofula, which was called "king's evil," might be cured by the royal touch, that if the king touched the patient he would be cured of his disease. We were taught to laugh at that belief, but perhaps they were right in those days and that the evil was sometimes cured in that manner. Perhaps the king's touch acted through the sensory reflexes and through these the evil was cured. We must not be too over-positive about these things. Another statement from Finsen has opened our eyes also. There was at one time a great deal of fun made about General Pleasanton and his "blue-grass craze," but Finsen says perhaps General Pleasanton "approached the truth." There may be a great many other things that are right about which our minds will be enlightened at some future time. I hope Dr. Hall's theory is right. If it is it will save the expense of buying static machines and we may be able to accomplish the same results by a simple wave of the hand.

I am surprised to hear Dr. Hall admit that he has not his own family under control. (Laughter.) However, these remarks are not meant to be entirely facetious, but they are offered simply to open the discussion of this valuable paper.

Mr. **Wm. J. Jenks**: I quite agree with Dr. Dickson that the subject-matter of this paper is something that requires careful reading and thought. I do not feel that I am yet ready to enter into any discussion. To me the explanations, and particularly the sketches that Dr. Hall made, are very valuable and instructive. They enable me to form a better idea of what occurs in these phenomena than I ever had before.

Chairman Morton: In regard to these phenomena of electrolysis, I think the opinion to-day is that we are more likely to adopt the theory of Arrhenius, that the e.m.f. in a weak solution does not seize upon the molecule and disrupt it. Take for instance the chloride of sodium solution mentioned by Dr. Hall. My own impression is to the effect that the free sodium atom was the one that came under the influence of the electric polarization as well as the free chlorine atom, and that the particular quality of the solution depended upon the free ion. But the older theory of Faraday would claim that the molecule was disrupted.

Dr. Hall said he welcomed criticism, and I think I shall feel like entering criticism against placing too much importance upon suggestion or impression, however produced. It was remarked that perhaps 50 per cent of the effects of electrical treatment were due to the machinery, and to the wonderful character of the operation as impressed upon the patient's imagination. I was with Charcot in the early demonstrations of hypnotism. Later on I became satisfied that it was wrong to practice hypnotism upon a patient, because it causes a deterioration of the patient's character, and I do not believe that any human being has a right to interfere with the will power of an individual and make a different personage of him. I have always felt that hypnotism should not be practised, but my opinion only counts for what it is worth. While I have always been impressed with the exhibitions of suggestion upon the human mind, yet all of our life is an impression, it is all a suggestion. We are all living under continuous suggestions, and I consider suggestion a normal attribute of human existence; but I do not see how we can pick out particular instances, such as electrical treatments and term them hypnotic. There are some people who might be surprised at a blow given by Dr. Hall; they might be put in a hypnotic state which would undoubtedly be subjective and not objective, but I have never believed that any of the physical effects of electricity could be due to suggestion, and I wish to go on record as protesting against that point of view. I think in electrotherapeutics the sooner we put ourselves on a physical plane, the more rapid advancement we shall make, and as soon as we leave the metaphysical, we shall get back again to the scientific.

Dr. **John Stenhouse**: I do not feel in a position to make any special criticism of the paper, but I am indebted to Dr. Hall for what he has given us. As we are opening the discussion, I would like to say this in reference to Dr. Hall's terminology. I see in the paper as it has been presented he adopts phonetic spelling. I would like to protest against that. As physicians, we take the conclusions of other scientific bodies that come to us. If a scientific body gives us a particular result and says it is correct, we accept it. I think we ought to do the same thing in regard to our language. Those who study language have told us that we must stick to our derivatives, and I feel that if we are going to cut loose from scientific terminology we do not know where we shall land. I would prefer to see the *ph* in phoresis instead of the *f*. That carries out the idea of the Greek. Aside from that, I feel indebted to Dr. Hall for his paper.

Dr. **Hall**: My statements were not made as clearly, perhaps, as they should have been made. There is one point I can clear up, and that is that in some substances, such as common salt, decomposition begins with a very small electromotive force. But you take sulphuric acid and decomposition is almost infinitesimal until you get a larger electromotive force, and then it is more pronounced.

Of course, we insist upon our own opinion about hypnotism and things of that kind. I had intended the statements I made to be simply a summing up of my experiences, and the explanations I have to offer along that line are simply to help me to understand the facts which I have seen. I have no pronounced theory on that subject; I do not think we have gotten far enough along yet to have such a theory. Suggestion, as I understand it, is simply what the chairman has stated; it is something going on all the time, and our whole being is more or less actuated and influenced by suggestion, and if we can obtain a certain result through the conscious or subconscious self, I would call that ideation or suggestion. I do not approve of hypnotism; putting people to sleep, as I understand it, is hypnotism, although it might, under certain circumstances, be useful.

As to phonetic spelling, when the American Philological Association recommends certain changes in our spelling I think we ought to follow them out, and that is what I have tried to do.

On motion of Dr. Charles R. Dickson, the section adjourned.

TUESDAY MORNING SESSION, SEPTEMBER 13.

The section was called to order by Chairman Morton at 9.30 a. m., and the following paper was read by Dr. Dickson in the absence of the author:

THE ACTION OF THE CONSTANT CURRENT ON THE VITALITY OF MICROBES.

BY DR. S. SCHATZKY.

In my work, "Biological Data Relative to the Treatment of Acute Inflammations,"[1] it was possible for me to explain, by facts already determined in science, my observations on the favorable action of the current in local inflammations, in that way, that the current through increase of the local nourishment strengthens the resistance of the cellular elements against the harmful agent, of whatever nature the same may be. I also was able to explain the healing action in tuberculosis treatments,[2] partly through the increase in resistance of the cellular elements against the action of the tuberculosis bacilli, and partly through the elimination of the inflammation phenomena following these processes, caused by the participation of other microbes.

In order to more fully grasp the action of the constant current in inflammations of a microbe origin, I found it necessary also to learn its direct influence on the microbes themselves. I have devoted the present paper to this question.

Although this matter is of great importance, it has hitherto been discussed very little. The literature on the subject is very limited. Of the few authors who have published their observations in this direction, not one has so combined his experiments that they accord with the galvanization employed for therapeutical purposes. Krüger,[3] for example, galvanized microbe cultures, in the course of 24 to 30 hours, with a current of a strength up to 20,000 milliamperes. Apostoli and Laqueriere[4] employed a current of 50 to 300 milliamperes for only five minutes, and directed their

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[1] *Comptes Rendus* of the Second International Congress of Medical Electrology at Bern, 1902.

[2] S. Schatzky: "The Constant Current as a Cure for Tuberculosis." *Comptes Rendus* of the Second International Congress of Medical Electrology at Bern, 1902.

[3] Krüger: "Ueber den Einfluss des Konstanten Stromes auf Wachsthum und Virulenz der Bacterien" (*Zeit. f. Klin. Medicin.* XXII, 1893).

[4] Apostoli and Laqueriere: "De l'action polaire du courant galvanique constant sur les microbes et en particulier sur la bacteridie charbonneuse." *Comptes Rendus* Ac. Sc., Vol. 110, 1890.

observations mainly to the effect of the positive pole. Cohn and Mendelsohn[5] employed currents of very small pressure of from 2 to 12 volts, etc.

However important the results of such experiments may be in a theoretical way, they present only a moderate interest for practical conclusions. In order to define the advantages or disadvantages of the action of the constant current on microbes in its therapeutical application, it seemed rational to me to make the experiments in a manner approaching as closely as possible to the mode of application in therapeutics. I, therefore, endeavored to remain within the limits employed in therapeutics, both as regards power and duration of galvanization. I did not fix my observation on the polar action of the current, but on the phenomena which it exercises on the vitality of the microbes in the interpolar space. The following observations caused me to do this:

1) The actions of alkalis and acids on the vitality of microbes are sufficiently well known in bacteriology. We can, therefore, conclude, independently of experimental research, as to the specific influence of the poles, which corresponds to their chemical nature.

2) As the seat of inflammation always attacks, more or less, a part of the thickness of the tissues, it is a question, in the therapeutical employment of the current, of its interpolar action. Even in cases where we place the electrodes directly on the injured surface, we do not cause a specifically polar effect of the current — in the sense as understood in physics. Between the metal serving as pole and the injured surface there must always be an intermediate layer of liquid — moistened chamois, wadding, linen or similar material — without which galvanization, with the exception of a few special cases, is impossible.

3) In cases, however, where the seat of sickness is concentrated in internal organs, such as the lungs, liver, etc., there can be no question of the therapeutical application of the polar action of the current.

In view of these observations, I made my experiments in the following manner: In order to have a homogeneous medium, with uniformly distributed microbes, I made all cultures (with the exception of *M. Prodigiosus*) in beef bouillon. I kept the liquid

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[5] Cohn & Mendelsohn: "*Ueber* die Einwirkung des elektrischen Stromes auf die Vermehrung der Bacterien." *Beitrag* zur Biologie del Pflanzen, III, 1883.

containing the culture in a glass tube of a diameter of 1 cm and a length of 20 cm. The two ends of the tube extended into vertical arms, *a, a′*, each 8 cm long. From the middle of the tube there arose in the same direction a similar tube *b*. I placed in *a, a′* the electrodes of thick platinum needles, which were connected with a battery of 40 elements. A milliammeter was included in the circuit. Every time, before the galvanization, a culture was sowed from the liquid in the central tube, and in the case of experimentation with animals, there was also made an inoculation. These primary cultures and inoculated animals served as proofs. Then the circuit was closed, and at determined intervals — without breaking the current — experimental cultures and inoculations were made from the same central tube. After but a few experiments with *M. Prodigiosus* I became convinced that currents of 20 to 30 milliamperes during a period of 10, 15, 30, even 45 minutes, produce no sensible change in the vitality of the microbes open to our observation. Therefore I either had to increase the currents or lengthen their duration. But stronger currents heat the liquid and introduce a foreign agent — heat — which disturbs the clearness of the experiment. I, therefore, preferred to increase the duration of galvanization.

Results of the Experiments: — Micrococcus Prodigiosus.

The cultures of this microbe only were made in gelatine. I judged as to the changes which the current produced in the vitality of this microbe, by the quantity of thinned-out gelatine and the quantity of colored substance (pigment) produced by the microbe. Repeated experiments proved that cultures, which were made from microbes, subjected one and one-half hours to the current, showed themselves less developed after 24 hours, in comparison with the proofs, with respect both to the quantity of thinned gelatine and the degree of coloring. This difference was aggravated in the cultures, which developed from microbes galvanized for one and three-fourths hours. After a two-hour galvanization the growth of the microbes could be barely noticed. I did not observe the complete cessation of growth a single time within the limits of these experiments.

Chicken Cholera.

The experiments with these microbes had the purpose of learning the influence which galvanization exercises on its virulence and growing capacity. For this purpose I inoculated intramuscularly at every experiment three rabbits with 1/10 cc —: the first with a normal culture (proof), and the second and third (experiment subjects) with cultures which had been subjected to galvanization during different lengths of time. Simultaneously cultures were also made on bouillon. The experiment proved that a noticeable decrease in virulence occurs only, from the culture injected, after galvanization for one and one-half hours. The death of rabbits inoculated in this manner occurred 5, 10, and even 20 hours later than that of the proof. A galvanization of one and three-fourths hours or longer completely destroyed the virulence of the microbes. As regards the cultures, their growth did not cease even after a galvanization of 2 hours and 10 minutes. It interested me to test the degree of immunity of the rabbits which had remained alive after such an inoculation to this microbe. For this purpose I inoculated a rabbit which had been vaccinated 10 days before, and at the same time a check with 1/10 cc of a culture which had been subjected to galvanization for only 30 minutes. Both died, however, after 14 or 15 hours. A similar negative result was produced by an experiment with a rabbit which had been inoculated 13 days before, into which I injected — at the same time with a check — 1/10 cc of a culture which had been subjected to a galvanization of 45 minutes.[6]

As to the question whether galvanized microbes give cultures of a lesser virulence, I obtained positive results by experiments carried out as follows: I prepared a culture of microbes which was galvanized for 1 hour and 40 minutes, and which killed the rabbit only after 39 hours. The culture thus produced was again subjected to galvanization, and I inoculated one rabbit with 1/10 cc after 1 hour and 30 minutes, the second after 1 hour and 40 minutes, and the third after 2 hours and 10 minutes. Cultures were also made simultaneously. The result was that all the rabbits remained alive and none of the cultures developed. It is clear that the generations, which generated from microbes galvanized within these limits, are considerably weaker in their virulence and prove incapable of further generation.

Streptococcus.

The streptococcus, which I employed for my experiments, possessed very great virulence. Dr. Beszedko, who put this microbe

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[6] As the question of immunity did not come within the scope of this work, and requires a special minute examination, I dropped it entirely in the subsequent experiments.

at my disposal in the most amiable manner, increased its virulence in such a degree, that one-twenty-millionth in doses of 1/10 cc acted fatally on white mice.

The experiments with this, as with the previous microbes, were for the purpose of studying the action exercised by the current, with respect to virulence and propagation. The inoculations were made subcutaneously on white mice at the root of the tail with 1/10 cc.

In the first experiment, which may serve as prototype for all the others, there were inoculated:

I. Check with normal culture; died after 16 hours.

II. After galvanization of 45 minutes; died after 40 hours.

III. After galvanization of 1 hour and 10 minutes; died after 40 hours.

IV. After galvanization of 1 hour and 45 minutes; remained alive.

V. After galvanization of 2 hours and 10 minutes; remained alive.

The current strength was 25 to 30 milliamperes. All cultures made at the same time with the inoculations showed a prolific growth.

All other experiments made in this manner gave comparatively similar results. On the whole, it can be said that a noticeable decrease in virulence of this microbe can be detected only after a galvanization of 45 to 60 minutes. The decrease is in accordance with the lengthening of galvanization. After about one and three-fourths hours the virulence disappears entirely with the dose and current strength indicated.

I did not observe a noticeable influence of the current on the growth of the cultures in these experiments. Does the virulence also decrease in the generations of streptococci produced from galvanized microbes?

The experiments made for this purpose gave positive results.

The cultures which developed from microbes, galvanized for 2 hours and 10 minutes, did not kill the animals after 16 to 18 hours, but after 45 to 48 hours.[7]

As to the fact that I do not give definite but approximate figures in my observations, I can set forth the following reason in

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[7] In order to extend the scope of my experiments, I undertook similar experiments with the *Staphylococcus*. Its virulence proved, however, so low that the wounds caused by it were too slight to merit mention here.

justification: In the combination of experiments, such as mine, so many different influences enter that it is quite impossible to repeat the same experiment with absolute accuracy. Only that which relates to the current can be repeated with exactness. As regards, however, the fostering soil of the cultures, the animals employed in the experiments, and mainly the microbes themselves, these are factors which are only too changeable. It is an easy matter to carry out accurately one or two points, but to exactly group all elements in order to accurately repeat an experiment, is a matter of impossibility. Nevertheless, definite conclusions can be drawn from a series of observations.

CONCLUSIONS.

My observations cause me to conclude:

1) That the constant current exercises in the interpolar space a modifying influence on the vitality of the microbes.

2) That currents of 25 to 30 milliamperes in the duration of one and one-half to two hours exercise an action varying from a weakening to an entirely deadly effect in their virulence.

3) That generations, which develop from microbes galvanized in this manner, develop a lesser vitality than their generators.

By what means does the constant current act on the microbes in its interpolar space?

There are authors who believe that the study of the action of electricity on the animal body must consist in the explanation of the influence of a mysterious unit of a so-called pure electric agent, independently of other physical properties of this energy, such as heat, electrolysis, etc. Dr. Krüeger, for example, gives in his work, "On the Influence of the Constant Current on the Growth and Virulence of Bacteria,"[8] a whole series of special experiments, in order to fathom the influence of the "actual action of electricity." He says: "As with the entrance and exit of the current in liquids, the polarization and chemical decomposition of the same almost entirely cover the real action of electricity, it is absolutely necessary in order to exclude this disturbing secondary action * * *." He does not explain what he means by "real action of electricity." The results of his experiments are recapitulated by him in the following manner: "It follows from these experiments that the constant electric current can, by excluding as much as possible the chemical action of the ions, if not kill,

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8. *Zeit. f. Klin. Medicin.* XXII, 1893.

undoubtedly completely arrest, the bacteria in their growth." But he gives no explanation, excepting as to the ionic action, in what the influence of the current exists.

Apostoli and Laqueriere set forth their observations in their work, "De l'action polaire du courant galvanique constant sur les microbes,"[9] in the following manner:

4) "The general conclusion which follows from our researches is that the continuous current in medical doses (50 to 300) has no action *sui generis* on the microbe cultures * * *." The authors explain the results observed by them by the chemical action of the positive pole. This is quite rational, but it is incomprehensible as to what other action "sui generis" they expected of electricity. I make free to add that in personal conversation with many important scientists I have heard similar views expressed.

Such a view of the action of electricity on the animal body is, in my opinion, a complete error. Electricity, as a physical agent, influences matter irrespective of its nature, through the combined action of all its properties. And only in this way can the phenomena produced in the body be explained.

It is true that each time, in the different forms of this energy, its different properties appear as predominating. But there is no form of electricity in which any one of its properties is absent. Such an energy would then not be an electrical one, but one which is still unknown to us. In the action of the constant current in properties and limits, as employed by us in our experiments, its electrolytic properties are predominant. We must, therefore, look to them for the explanation of the results observed. There is no doubt that the constant current produces at the same time with chemical, also molecular changes in the animal body. But they continually go hand in hand, and can in no manner be studied separately. It is a matter of absolute impossibility to isolate the molecular from the chemical phenomena. This would also be entirely useless, as in the present condition of science these two phenomena are considered as identical in their nature.

In my work, "The Bases of the Therapeutical Action of the Constant Current,"[10] I came to the conviction by way of experiments that:

a) The electrolytic phenomena, which the passage of a constant

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[9] *Comptes Rendus* Ac. Sc. Vol. 110, 1890.
[10] *Zeit. f. Elektrotherapie*, March, 1900.

current through the electrolyte causes, take place in the interpolar space as well as at the poles.

b) In the entire distance traversed, the ions travel, as though charged with pressure electricity, to the poles as to the extreme points of highest attraction.—This process will doubtless also take place, under the action of the current, in the liquid in which the microbes are suspended. The dividing of the electrolyte into ions and their migration will not only take place in the liquid alone, but also in the microbes, in their protoplasm, which certainly contains electrolytes, as salts and water. This alone suffices to act in a modifying way on the vitality of the microbes. It has been determined in bacteriology that even a simple plasmolysis may prove deadly for microbes at a certain strength. The more reason to assume, that an electrolytical decomposition of the plasm must cause large changes in the physiological functions of the microbe. It is also known that the microbes, although they have a great death-resisting capacity, are quite easily affected by several exterior influences, and easily react on the same. It is understood that in the center in which the microbes are suspended, the changes caused by the current — as increase in acid and alkalis — must also influence the vitality of the microbes. In this case the action of the current can be compared to that of sunlight, which, as has been determined, exercises through its chemical action on the center, a strong influence in retarding the growth of the microbes. As specially reductive of the activity of the bacteria were found to be the ions of oxygen and chlorine, in *statu nascendi* appearing in the center, which, as known, are among the strongest bacterodial agents. In fact, there are sufficient reasons in the physical-chemical properties of the current to explain the changes in the vitality of the microbes, which I observed in my experiments..

I will here take advantage of the opportunity to thank most warmly Dr. Bozzel, whose amiable and highly scientific advice greatly facilitated the execution of my work.

Involuntarily the question comes up, Does all this take place *in vivo* as *in vitro?* Certainly not with absolute accuracy, although according to the laws of physics, the constant current produces in the animal body, qualitatively as well as quantitatively the same phenomena as in the experimental tube. The difference is probably caused by the conditions of the medium. In the tube the current acts on a constant, homogeneous medium, and on a perfectly limited mass. In the animal body, however, these conditions do not exist. Here the current spreads much like a fan. The products of electrolysis are partly produced and assimilated by the surrounding tissues, and partly carried off by lymph and blood current. Therefore the acid of the center, *caeteris paribus*. will not reach the same degree of intensity as in the tube. From this it follows that the current in the animal body will not exercise full influence on the microbe inhabitants, as is done in the experimental culture. But we must not draw the conclusion therefrom that the action of the current in the animal body is necessarily weaker. It may even be more intense. This will depend on the conditions under which the life of the microbe occurs in the animal body. In the experimental culture, the microbes are left to themselves, and under conditions most favorable to their nourishment and rapid propagation. In the animal body, however, they must battle for their existence with the elements of the surrounding tissues. They are placed under the necessity to overcome here for their nourishment and propagation, the complicated resistance of the tissue cells, which represents a considerable antagonism to their activity. It is clear from this that it is much more difficult for the microbes in the animal body to resist the action of the current, than in the experimental culture.

Nor may it be forgotten that the passage of the current[11] increases the local nourishment of the tissues, and with it the resistance of the cells. This circumstance will also in its turn make the conditions of living worse for the microbes. Finally, nothing forces us to limit the therapeutical galvanization to 25 to 30 milliamperes. We can, according to circumstances, increase the current two or threefold. Here the local increase in temperature, which I took such great care to prevent in my experiments, is not to be feared. Such a phenomenon would even be very useful in this case for therapeutical purposes. In his excellent and exhaustive work: "Elements de microbiologie générale,"[12] Dr. Nicolle says: "It has long been known that the leucocytes require a certain degree of temperature, in order to develop their ameboid activity * * *. It is likewise known that the white cells greatly require

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[11] See my article: "Données biologiques relatives au traitement des inflammations aiguees par le courant continu." *Comptes Rendus* du Second Congrés international d'Electrologie medicale, à Berne, 1902.

[12] M. Nicolle: "Elements de microbiologie génerale," p. 198.

oxygen and that they invariably turn to the points richest in air. Heat and oxygen thus represent here two powerful exciters." Under these conditions the current appears, so to speak, as an exciter of phagocytosis, which under certain circumstances can render essential services to therapeutics.

From all that has been said above, it can be concluded that the action of the current on the microbes living in the animal body is identical to the one which I observed in my experiments. In this manner the importance of the current as a therapeutical agent in inflammations becomes considerably greater. The current not only increases the resistance capacity of the tissue cells against the harmful agent, but also acts in inflammations of a microbe origin directly on the microbes themselves, by reducing their vitality.

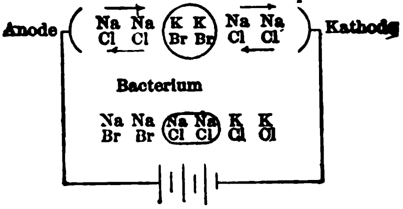
In the interest of scientific truth, I found it rational in my examinations to limit every experiment to a single period of galvanization. With a patient we can, however, repeat the application daily, and in extreme cases, two to three times daily. And after such repeated action of the current, the therapeutical effect must become considerable. My experiments proved that the generations produced by galvanized microbes have a less virulence than their generators. We must assume that also the microbe culture vegetating in the animal body will gradually generate weaker generations, following repeated galvanization. Their part as harmful agent must in this manner gradually lessen and finally disappear. At the same time the resistance of the cells attacked will increase up to their complete recovery.

All the above facts and observations offer new grounds to explain the favorable action of the constant current in inflammations. The clinical observations published by me and other authors may serve as direct confirmation of this. I intend, however, in order to fully clear up the question, to make further direct laboratory experiments and exhaustive clinical observations.

DISCUSSION.

Dr. T. PROCTOR HALL: The paper by Prof. Schatzky, which has been read, is, in my judgment, an excellent inspiration. We have theoretical views of things; we know certain things or think we know them, but we do not know them until we put them to the test of experiment. In this paper we have experiments detailed of considerable value. The illustrations were probably as successful as it was possible to make them, but without going still further and measuring the velocity of the ions, and we are unfortunate in this particular case. It would be impossible to eliminate entirely the polar effects, because some ions travel faster than others. There are two suggestions I would like to make regarding the paper. The first suggestion is that the current density should be given in these cases, rather than saying we had so many millimeters in the area of the tube. That would give us approximately thirty-three, which would give us the current density which was used in this case.

$$\text{Current Density} = \frac{\text{ma}}{\text{sec'l area}} = \frac{20630}{\frac{3}{4}} = 33$$



The second point to which I want to call your attention is the question of interpolar action of the electric current. Suppose the circle (indicated in the figure) represents one of the bacteria, and outside of it we have molecules, say of common salt, sodium chloride, on each side. There are in these bacteria toxines which produce effects upon the tissues, and it has been shown by a number of investigators that the toxines of bacteria become still worse when the bacteria are developed in solutions in which those toxines become more concentrated. On the other hand, when the toxines are eliminated from the bacteria as rapidly as possible, the bacteria become less virulent, and a steady action upon the ions will move them in the direction indicated.

The following paper was then read:—

ON THE ELECTRICAL PURIFICATION OF DRINKING WATER.

By PROF. JOHN W. LANGLEY, *Case School of Applied Science.*

This paper deals with the sanitary purification of water for domestic purposes.

Attempts to destroy bacteria by the direct action of electric charges did not result in any marked success. Milk was the fluid used and static charges as high as 150,000 volts from condensers of 1/7 of a microfarad capacity, were sent through 20 cubic cm in sterilized vessels, but the milk so treated soured only six hours later than a sample of the same milk not electrolyzed.

Substantially the same results followed the application of alternating currents of 500 volts having a frequency of 66 cycles for 10 minutes.

It has long been known that electricity had a lethal action on bacteria through the chemical changes produced by electrolysis. As long ago as 1892 work on the purification of sewage mixed with sea water was carried out on a commercial scale near Yonkers, N. Y. Here the chlorine produced from the salt in the water was the germicide, the electrodes being carbon and iron plates. This process has also been recently applied in England on a scale of nearly a million gallons a day; iron plates at both anode and cathode being used.

The most successful method of electrolysis for drinking water is by the use of aluminum plates as electrodes. A plant for this purpose is working commercially in Cleveland, O. The electrolyzer is a rectangular iron box. The aluminum plates are held in grooves in a slate lining. The application of 20 amp. at 15 volts, or 300 watts, in the form of a continuous current, produces sufficient electrolysis to purify 500 gallons per hour of Lake Erie water. The water flows in a continuous stream from the city supply through the apparatus. The action is to produce aluminum hydroxide which, as has been long known, combines chemically with the coloring matter, and most of the organic matter, and mechanically entangles all solid particles, including bacteria and fungi. The water issuing from the electrolyzer is milky from suspended aluminum hydroxide and passes to a filter filled with crushed quartz which arrests the solid matter. The effluent from the filter is colorless and of great brilliancy.

Chemical analyses show the albumenoid ammonia to be greatly reduced, usually upwards of 75 per cent, and is brought down well within the limits specified by the Michigan State Board of Health, which calls for a greater degree of purification than is generally called for by other States. The free ammonia is always increased, because of the electrolytic action changing a portion of the dangerous albumenoid ammonia (or of the nitrogenous matter which produces it) into the harmless free ammonia. The dissolved oxygen is increased and the organic matter which reduces permanganate of potash is diminished about one-half. No important change is made in the chlorine, but the temporary hardness due to bicarbonate of calcium is almost completely removed.

The action on the bacteria is very satisfactory. These are reduced on the average 97 per cent, and several analyses have shown a reduction of over 99 per cent. Moreover, those which pass the filter are of the harmless water-bacteria type, for in no instance in six months of continuous commercial operation has a single colon bacillus been found, though the lake water generally contains them. This result has been substantiated by weekly and semi-weekly bacterial tests.

The electrolysis evolves much hydrogen and a smaller portion of oxygen than the two-to-one ratio due to the composition of water. As the apparatus is under the city pressure, these gases are partially dissolved, so that the purified water is more fully aerated than the original lake water, which adds greatly to its palatability, and to its hygenic value.

DISCUSSION.

CHAIRMAN MORTON: In listening to this paper it might appear as being the best method of purifying water yet presented. A new chemical substance is produced in the water, and this is harmless in its nature. As to the matter of expense, it must add very materially to filter water after it has been treated. That is the only objection, I think, an engineer would make, namely that both electrical treatment and mechanical filtration are necessary.

No electrical method has ever been pursued in New York in relation to drinking water, but the health authorities have succeeded in keeping the water sheds free from pollution as far as possible, and it has been through the efficient service and watchfulness of the board of health that the death rate has been so greatly diminished.

On motion of Dr. T. Proctor Hall it was unanimously decided to invite the members of the American X-Ray Society to be present and participate in future meetings of Section H.

The following paper was then read:—

ROENTGEN RAYS AND RADIOACTIVE SUBSTANCES AS THERAPUTIC AGENTS.

BY DR. EMIL H. GRUBBE.

Every up-to-date member of the medical profession is doubtless aware of the great therapeutic value of radiant energy, and its unprecedented success in the treatment of certain diseases.

The X-ray has brought about a deep and general interest in all knowledge pertaining to physical therapeutics, and a vast literature is the outcome of this profound and universal study. On account of its novelty, physicians at first hesitated to use the X-ray therapeutically, but now, since clinical experience and testimony from the best professional sources have fully confirmed the claims made for it and have established it as a therapeutic agent of superior value, its use is rapidly supplanting many of the other older measures.

There is no doubt that the great question of modern pathology is the cause of cancer. The true pathology of this disease is unknown beyond the fact that cancer tissue is made up of cells which are either under or overdeveloped. Again, there is no doubt that the great question of modern therapeutics is the cure for cancer. The remedies which have been suggested from time to time are too numerous to catalogue. A remedy, however, which has been found to produce excellent results in nearly all cases, and cures in many, is the X-ray. The results obtained with this remedy have been of such good and marked character that it may be considered the most valuable measure in the treatment of this disease.

Up to the time when the X-ray was first used in malignant diseases, the treatment of these conditions was attended with highly unsatisfactory results. We may say, the introduction of the X-ray worked a revolution in the therapy of malignant diseases. Cases hitherto intractable have been cured in short order, and so well has this remedy maintained its reputation that at present it may be considered a specific in many of these conditions. We believe we are warranted in stating that it is the opinion of those who have had ample opportunity to observe all the various forms of treatment applied to malignant diseases, that the X-ray treatment, when scientifically given, is unquestionably the best for the majority of cases.

The exact mode of action of X-rays upon tissue is still to a large extent a matter of speculation, and must remain so until we arrive at some definite conclusion as to the exact nature of both the X-ray and cancer.

Soon after the discovery of the therapeutic value of the X-ray the writer began experimenting with fluorescent chemicals for the purpose of augmenting or increasing X-ray action upon the tissues of the human body. Entirely independently and even before we read of experimental work on the part of others, our investigations were under headway. It occurred to us that in the treatment of some cases, notably external lesions, by means of the X-ray, the therapeutic effect was too temporary or not powerful enough at the real seat of the disease. In other cases, particularly internal lesions, the results were not as satisfactory as we would like, due to the fact that the X-rays had to pass through a large volume of healthy tissue before reaching the diseased parts.

It has been known for some time that under the influence of X-rays many chemicals fluoresce. It has also been known that this fluorescence of chemicals produced an effect upon tissue similar to that following X-ray exposure, consequently, since by combination we get multiplied effects, this mode of treatment would have distinct advantages over the X-ray alone. Chemicals excited to radioactivity by means of the X-ray after being placed intimately in contact with the diseased parts, by either the injection method or external application, would, if successful, possibly prove valuable in many cases where up to this time, we had been considerably handicapped. There is no question that there is an enormous amount of energy stored up in these substances and this energy is made available through the medium of X-ray action. As the result of clinical observation and experiment we claim that by this method we can accomplish with a few exposures what could be obtained only after a great many sittings under the X-ray treatment alone.

Although we have spent several years (nearly six) in research upon radioactive bodies, and a long series of painstaking as well as painful experiments have been made, we shall confine ourself to one particular substance which we have investigated thoroughly.

The results of these investigations we give to the scientific world for what they may be worth.

We wish to present in an entirely conservative manner what may be reasonably expected from the application of the X-ray plus excited fluorescence in the treatment of malignant disease.

In our investigations there were found many substances which possessed pronounced fluorescing quality, but most of them also possessed disadvantages which could not be tolerated from a physiological standpoint. Strontium salicylate was selected as being the most widely applicable and at the same time least objectionable chemical. It has abundant fluorescing power and is extremely active chemically, producing a minimum amount of local irritation and altogether possessing comparatively few physiological disadvantages.

Strontium salicylate when chemically pure occurs in the form of fine white crystals, which are very soluble in water. The salt or a solution of the salt was found to be one of the most active fluorescing chemicals which we have examined. Although not very much used or mentioned in text-books as a therapeutic agent, this substance has very valuable properties, chief of which may be mentioned its sedative and antipruritic effects when used as a dressing on inflammed or ulcerated wounds. In addition it has a decided tonic action upon the whole system, but more especially upon the blood. It is also antiseptic and antipyretic. After the crystals or a solution of the same have been placed in contact with diseased tissue, the X-ray simply excites the chemical to action and all the interchange of chemical properties which result from this excitation is appropriated by the cells composing the tissue. It is as efficient internally as externally. It can be applied to the most delicate tissues, as it is perfectly harmless and non-irritating. This substance is particularly rich in ultra-violet rays and no doubt much of its therapeutic value is due to the fact that we can generate these rays within the tissues thus getting intimately at the seat of disease. The salt fluoresces irrespective of the vacuum of the tube used, that is a low, medium or high vacuum will serve to excite it. However, since the X-rays, like all remedies which are potent for good, also possess dangerous properties, we suggest that the technique cannot be too exact or too scientific. Our rule is to use a vacuum just high enough to penetrate the diseased tissue, but no more.

Of the two methods by which strontium salicylate can be introduced into the system and then made fluorescent by X-rays, local external application of the crystals is the simplest and safest. The subcutaneous method, on the other hand, is undoubtedly the most effective method, but it is not so simple or safe. Various factors determine the choice between external application and hypodermic injection. The latter is to be employed in serious cases and where it is necessary to act quickly and energetically and in all cases where the disease is beneath the surface and in internal affections. For the treatment of external or ulcerated conditions it is not necessary to inject the salt in solution. The fine crystals of the same may be freely dusted into the ulcer. When used hypodermically a saturated solution of strontium salicylate in normal salt solution is prepared. The latter solution which is also fluorescent under the X-ray will take up about 26 grains of the chemical per ounce, without precipitation. This fluid is heated to a temperature of 100 deg. F. just before using. We prefer to inject all around a growth if possible. The needle is introduced at the edge of the tumor, 5 to 10 drops of the fluid being injected. The needle is then withdrawn, another place selected and again 5 to 10 drops deposited, and so on until the growth has been well encircled. In ordinary cases the injections are repeated every other day, while in cases demanding heroic treatment, the injections may be resorted to daily, but always just before exposure to the X-ray. Clinical observation teaches that the dose is not of great importance. However, because the substance is practically non-poisonous we suggest using as large a quantity at one time as can properly be applied. Personally we have given 60-grain doses frequently without untoward effect. There have been but few cases in which we found any disturbance whatever, and since overstimulation is the only thing to guard against, the quantity which may be used in a given case depends upon the area of tissue to be treated. Patients do not suffer any inconvenience from the treatment. There is no pain except that due to the introduction of the needle, which is very slight.

Concerning the length of time during which this treatment can be administered we will say that it can be used indefinitely. We have one patient who has taken it for over six months consecutively without the appearance of any disagreeable symptom or sequelæ.

All cases treated receive the X-ray daily from the beginning, sittings lasting from 8 to 12 minutes, until dermatitis appears. We have employed this method in over 100 cases and although individual conditions have varied considerably and many forms of tissue have been under treatment, we have found few contraindications to its use.

An explanation of the action which takes place in the tissues under this treatment can only be theoretical. Therefore, we do not care to go into detail concerning this phase of the subject. In all probability its action is largely analogous to that of X-rays. The fluorescence in the tissues probably has a treble action. First, due to the fact that the rays given off are ultra-violet, they are bactericidal, or at least have the power of inhibiting bacterial growth; second, the irritating influence is such that nutrition is excited and stimulated; and third, granulations are excited and thereby rapid healing ensues. There is of course also the probability of the production of new chemical compounds in the tissues as fluorescence is developed. And we may even say that active chemical decomposition takes place and the effects of the nascent chemicals is made use of by the tissues in which they are liberated.

Of considerable importance is the fact that this chemical exerts not only a local action, but also a general stimulating and tonic action. In many cases it is of great advantage if a remedy can be used which will affect the general as well as the local conditions of the patient.

We must never forget that success of any treatment for a malignant condition does not necessarily depend upon the treatment *per se,* but to a very great extent upon the physical condition of the patient and also upon the particular part of the body affected by the disease.

To aid us in augmenting the recuperative powers of the system, we have in this chemical also its physiological effects. It is a decided stimulator of nutritive processes. It facilitates cellular change, removing diseased cells and causing the elaboration and replacement of healthy ones. We believe it has decided eliminative properties and for that reason it is of great value in aiding the system to throw off broken-down material, the absorption of which is always a dangerous element during X-ray treatment. In addition its sedative and anodyne effects are pronounced.

This combination treatment we have used for about two years. During the first year no special claims were made for its superiority as a therapeutic measure, although it was believed from the start to possess decided value as such. Now, with rapidly accumulating clinical evidence, we feel justified in claiming that it is a most efficient therapeutic agent.

Its field of application is very large. Indeed, the number of diseases which may with benefit be placed under this combined treatment is so large as to forbid even a casual notice of them all. Suffice it to say that it may be used in almost every condition in which X-rays alone have been found useful.

We shall not burden you with the reading of particular histories of cases treated. Instead we present a summary of all the malignant cases which we have personally treated by this method, classifying the conditions under headings which will be most readily understood. In the majority of the cases herein mentioned, pathological examinations of the growths were made by competent individuals previous to our application of this treatment. The diagnoses, therefore, were made with all the aids of modern medical science.

Lupus cases treated, 35; primary, 20; secondary (recurrent), 15. Results: Symptomatic cures in 28; died from intercurrent disease while under treatment, 2; stopped treatment before discharged, 5; average length of time under treatment, two months. The term "symptomatic" cures is used to denote cures which have not yet passed the three-year surgical limit. Of the above cases, the disease was located on the trunk in 8, on the head in 15, and on the extremities in 12.

Epithelioma cases treated, 27; primary, 18; secondary, 9. Results: Symptomatic cures in 18; died from intercurrent disease having no apparent connection with the epithelioma, 1; died from general infection, 3; stopped treatment before being discharged, 5; average length of time under treatment, two months. The disease was located on the trunk in 3; uterus, 2; head, 12, and extremities, 10.

Carcinoma of breast, cases treated, 12; primary, 3; secondary, 9; average length of time under treatment — primary cases one month, secondary cases three months. Results: Symptomatic cures in all primary cases and in five of the secondary cases; died from general carcinosis while under treatment, 1; stopped treatment before discharged, 3.

Carcinoma of the rectum, cases under treatment, 3; primary, 1;

secondary, 2; average length of time under treatment, five months. Results: Symptomatic cures in 1 secondary case and none in the primary case; died from general carcinosis, 1.

Carcinoma of the uterus, cases under treatment, 8; primary, 2; secondary, 6; average length of time under treatment, four months. Results: Symptomatic cures in 1 primary case and in 3 secondary cases; died from general infection, 2; died from concomitant disease, 1; stopped treatment for some other treatment, 1.

Tubercular gland cases under treatment, 14; primary, 10; secondary, 4; average length of time under treatment, three months. Results: Symptomatic cures in 7 primary cases and in 3 secondary cases; died while under treatment, 1; stopped treatment for some cause or other, 3.

Sarcoma cases treated, 2; 1 primary, 1 secondary. Results: The secondary case stopped treatment after three weeks due to financial difficulty. During the time he was under treatment there was a marked change in the growth as well as in his general condition. The primary case progressed very favorably indeed for two months and we were very hopeful of a symptomatic cure when the patient met with an accident from the effects of which she died a few hours later.

It is of special interest to note that in some of the secondary cases mentioned in the above list the usual methods of treatment yielded but negative results and we received the patients for treatment, therefore, without much hope for improvement; however it was surprising how many of these so-called "hopeless" cases were symptomatically cured.

Lest we be misunderstood we will say that when feasible, surgical measures should not be neglected in all malignant conditions. The X-ray treatment is indicated primarily when surgical measures are not applicable, or, when the diseased condition is inaccessible to the knife, and also as post-operative treatment.

In treating breast cases particularly we always expose the glandular region on the affected side for the purpose of stimulating glandular activity. In treating tubercular glands the chemical should be injected not into the glands but around them.

The results obtained by this method of treatment are certainly very satisfactory, for out of 101 cases we have been able to report 69 symptomatic cures. Most of those pronounced cured have been under observation for a period of from six months to two years; in only a few cases could the results be called unsuccessful.

We do not present this method as infallible, but if the X-ray is indicated in a given case, then we say the combination treatment will bring about results far superior to X-ray treatment alone.

We feel justified, by reason of the many favorable results, in saying that with this combination treatment nearly all malignant conditions can be arrested in their growth and in properly selected cases the majority can be cured. What we have said of this treatment is based upon clinical experience, and we feel safe in saying that it will bear a clinical test whenever properly administered. More clinical experience will no doubt add something to or change somewhat the present method of employing this remedy, but even as it now stands, it offers the profession probably the only approach to result producing treatment in some of the most distressing and fatal diseases to which human flesh is heir.

DISCUSSION.

CHAIRMAN MORTON: I can indorse and appreciate what the writer has said from my own standpoint, since I have had a large experience in this combined method of treatment. As amatter of fact, I think the method of saturating the entire human organism with a fluorescent fluid and then submitting it to the influence of X-rays, or of radium, had never been heard of until I published it more than two years ago under the name of "Artificial Fluorescence of the Human Organism and Its Use in Connection with the X-Ray and Radium." I have been deeply interested to see how, at this moment, interest is growing in this method, and this paper by Dr. Grubbé only confirms me in believing that it is one of the coming methods in the treatment of cancer and other malignant diseases. I shall express my views fully later on in a paper I have prepared.

DR. T. PROCTOR HALL: I assure you I appreciate thoroughly the paper Dr. Grubbé has presented. It is of very great interest to all of us, and I am sorry I have not had the opportunity of watching any treatments of this sort, so that I am not able to add anything to the discussion. Theoretically every claim in it is substantiated, and I am glad that clinically Dr. Grubbé has attained such excellent results.

CHAIRMAN MORTON: I would like to say this, that I think the effects claimed in the cure of cancer are remarkable. Sixty-nine out of 101 cases were at least symptomatically cured, and that is a striking record. I myself, personally, am in a position to know and to believe that this record is absolutely a just one. I should receive it without the slightest hesitation as correct, especially from what we may expect from this combined treatment or method of treatment. I have pursued that method now since 1900, and I have treated a large number of cases by it. I may safely say that by this method the percentage of cures of cancer is greatly increased. That, at least, is a very safe statement. I believe to-day that no case of cancer should be treated by the X-ray or radium which is not under the influence of some substance in the blood that may be excited to present a fluorescent condition. I believe fluorescent treatment is a great advance upon the X-ray or radium treatment alone.

Dr. GRUBBE: I want to say that my favorable list has been taken from comparatively simple conditions of epithelioma, lupus, and gland enlargements. If it were not for those three diseases I could not have made such a very extensive list, but part of the claim which I want to make for the list is that the improvement was brought about more rapidly than if the X-ray alone had been used. I believe that Dr. Morton will agree that the one feature that stands out prominently, more prominently than any other, is the rapid improvement under the combined fluorescent treatment with the X-ray. Those who use the X-ray treatment alone know that we may treat a case of epithelioma four or five months before we obtain any favorable result, but if by combining X-rays with other means the time should be saved only one-half, we should consider it a great practical advantage. From no other point of view than that of a reduction of the time alone. the treatment would have a field.

The following paper was then read:—

A CONTRIBUTION TO THE RADIODIAGNOSIS OF DISEASES OF THE HEAD AND BRAIN.

BY PROF. MAURICE BENEDIKT.

In harmony with rules of optics, we are obliged to suppose that any difference of penetrability or impenetrability of any substance in the path of X-rays should appear on the sensitive film used in photographing by means of such rays.

Every "shadow" must be intensified when a substance of little penetrability is in the path, and the shadow must become clearer if the light passes through a substance of the contrary quality. Every clear spot on the diagram must become darker, however, when in the line of the light there is a substance of less penetrability, and the spot must become clearer when a substance of greater penetrability is in the way. Experience appears to be opposed to this theoretical supposition, but in fact there exist merely different secondary conditions which seem to controvert the theory.

When we observe the human chest, it seems that almost all of the organs in the path of the light appear on the plate and produce a picture showing their positions.

As to the diagrams of the head, the general opinion exists that they show with rare exceptions only the morphological relations of the skull. This generally accepted view is fundamentally controverted by the fact that on excellent diagrams can be recognized all the air cavities of the skull, not only of the greater ones, such as the frontal, but also those of the ethmoid and sphenoid bones.

The optical effect upon the plate of the air included in massive bones and of that which separates two bones proves that the general opinion referred to is erroneous. This opinion seems the more erroneous since the cavities of the labyrinth also appear on the plate.

We can understand the appearance of the air cavities by the consideration that the Roentgen light is much diffused by passage through air. Therefore, parts containing air have the quality of brilliancy and in this way produce a strong effect on the plate.

When the mass of air is great, as in the chest-cavity or in the bowels, then this brilliancy has a clouding effect on the surrounding parts and blurs the diagram. Therefore, in the chest-picture the gristle of the bronchi is not seen and a distinct picture is not obtained of the aorta. For this reason also the diagram of the abdominal organs is blurred.

Fatty matter has this characteristic of brilliancy and, therefore, also blurs the picture in a high degree.

In two cases of extreme emaciation with distaste for food, the bowels being empty of air and there being no deposit of fat, I could see distinctly the abdominal organs and the kidneys, even with the screen alone. We must consider another quality of the Roentgen light, namely, that it is a whirling light produced by interruption of the electric current. For this reason lateral undulations enter in the direct rays and produce in the picture effects of lateral light. Therefore, the pictures become irregularly blurred. To prevent this effect, we must use diaphragms, the best being in the form of lead plates with relatively narrow holes.

There exist certain substances which seem little disposed to permit the entrance of lateral undulations and which conduct concentrated beams of Roentgen light, such as the brain.

When we examine a perfect profile diagram of the head we see the circumference of the skull from the upper nasal point to near the posterior point of the foramen occipitale magnum. We see also many details of the osseous base of the skull. The space between the osseous circumference and the osseous base is filled up in the negative by a grey, cloudy shadow which represents optically the mass of the brain influenced by the lateral walls of the skull. Every alteration of these walls, of the surface of the brain and of its interior, may appear in the diagram either as a shadow or as a clear spot. By a close study of the case we may decide if the osseous integuments, or the brain and its membranous integuments, or its interior are altered.

We may, indeed must, choose cases in which the pathological process and the localization are as clear as possible. This happens especially in simple traumatic cases in which the shock has no influence. I have communicated lately four such cases,[1] and in the

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[1] *Zeitschr. für Elektrotherapie;* von Kurella, Leipzig, 1904.

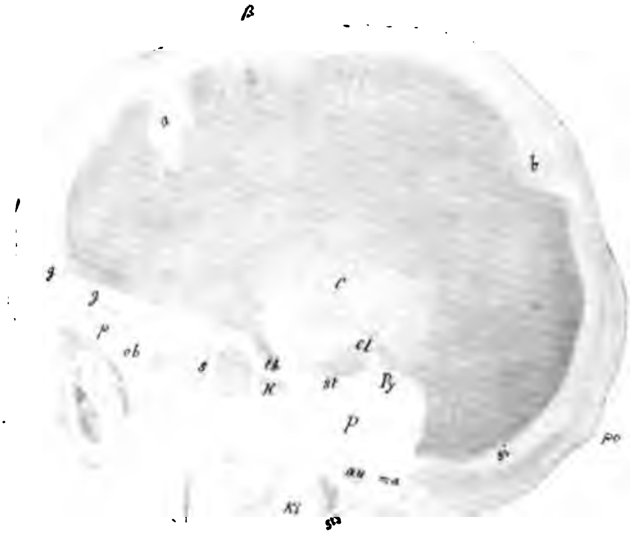
β
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FIG. 1.

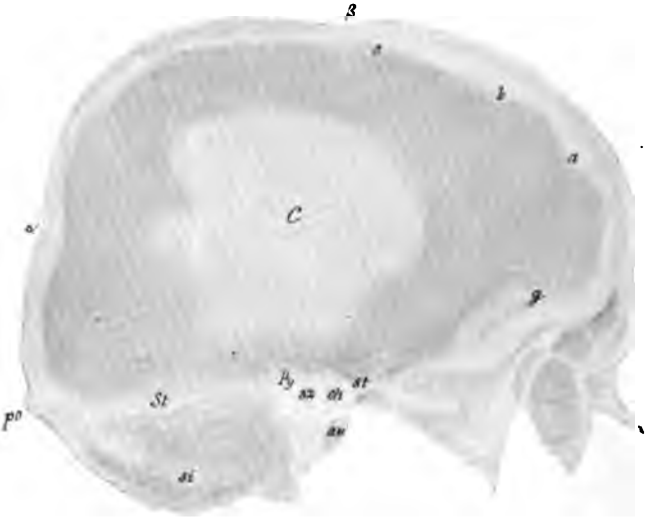
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FIG. 2.

present paper I wish to call attention to two others of such traumatic cases. In these the pathological process may be either simple bleeding or pachymeningitis, principally hæmorrhagica, if severe lesions of osseous parts are excluded. Another important morbid condition in such cases is the presence of abscesses. I believe that such a focus is more penetrable than the substance of the brain, because in the paper referred to as well as in the present one, the observed focuses were "shadows." I believe this excludes the presence of abscesses in such cases.[2] A third case belongs to those cases of epilepsy which are the effect of osseous stratification during pregnancy.

The focus of the lateral parts of the brain and of its interior give pictures so delicate that a reproduction by photography is impossible and we are obliged to resort to drawing. The figures in this paper are drawn from the sensitive side of the plate.

The impenetrable parts, which in reality appear clear on the negative, I shall call "shadows." The diagrams were made by Dr. Kienboeck. The special method is described in the paper already cited.

Before I pass to the discussion of the cases I will explain the radiographs of the base of the skull. It represents a severe case of ozaena, in which a congenital lack of the sphenoidal cavity exists. Fig. A is a photographic reproduction of a plate from the sensitive side by the use of a diapositive. The greatest difficulty in understanding the radiograph pictures of the base of the head arises from the appearance of the pyramid of the other side in the picture, though we have taken the greatest care in placing the medial plane of the head parallel to the plane of the photographic plate. This occurs for two reasons. The first is the natural asymmetry of the halves of the skull; the second is that the person photographed involuntarily turned his head so that the pyramid of the opposite side appears higher and behind the pyramid nearer to the plate. Rising from the frontal cavity are seen two shadows, which correspond to the highest edges of the roof of the orbital cavity *ob*. The base then continues to the sphenoid bone and we can recognize the outlines of the tuberculum *tb* and of the sella turcica *st* of the bone in question with the clivus *cl* behind. Sometimes we can perceive the ends of the alae minores *al*. Below

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[2] A traumatic case, in which the focus was more penetrable. "Zur Rœntgendiagnostik der traumet. Neurose." *Wiener Medic. Presse.*, 1903, No. 26.

the highest point of the pyramid, which I will call colliculus pyramidis *co,* we see some cavities, which can only be the cavities of the labyrinth *lb,* the canales semi-circulares, and in front of them the cochlea or the vestibulum. We can also perceive one or two cavities which are representatives of the meatus auditorius, *au,* internus or externus. But as the second pyramid appears also, we may see below the corresponding point *co'* traces of the cavities of the labyrinth of the other side.

The aspect of the second pyramid is shortened, so that the posterior part of it is not visible, and thus the picture of this pyramid may end in a sharp point.

Below the outline of the sphenoid bone we see the sphenoidal cavity *k* and in front of them the ethmoidal cavities *si.* Below are seen strongly marked the outlines of the upper part of the maxilla inferior and the teeth of the maxilla superior. I marked these outlines by means of a colored pencil on the glass-side of the original plate for better identification.

I will now pass to the description of the cases:

Case 1.— Kolar, M., engine-driver. On June 6, 1897, while leaning out of the engine, he struck his head against a lateral object. He lost consciousness, vomited and was confined to his bed for six days. He tried to resume his work, but could not continue. On Oct. 16 of the same year he came for the first time under my observation. He complained of violent headache, and his face had the rigid expression of a mask. Standing erect with his eyes closed he showed signs of static vertigo. Other symptoms were adynamia of the right arm with tremor when attempting to overcome any resistance. When moving either arm, he involuntarily moved the left leg. The tongue deviated in a slight degree to the right side. When his head was turned in the sense of the vertical axis, he felt a pain in the region of the atlas.

His hearing was defective on the right side and there was a cicatrix on his tympanic membrane. The whole head was very sensitive to percussion. The ophthalmological examination with the mirror and with the perimeter gave a negative result.

At first this case did not seem very serious, but I was not able to relieve him of his violent headaches. I applied iodine, franklinisation of the head, ice-bags, and "points de feu" without result. The trouble increased, and after the year 1900 epileptiform fits appeared with maniacal excitation. To give an idea of the excitability of his brain, I may mention that in the course of an ex-

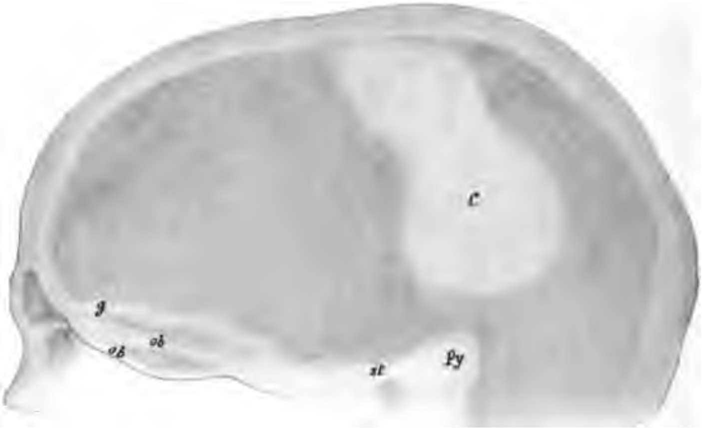

FIG. 3.

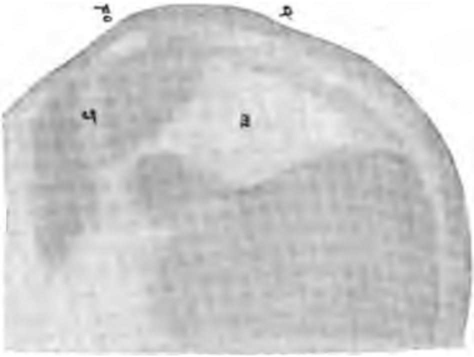

FIG. 4.

periment to measure the electrical resistance of his head with a current of 2 milliamperes, he was seized with spasms. Later I applied leeches and he bled for three days.

On Jan. 20, 1904, I had two profile diagrams taken with the Roentgen rays by Dr. Kienboeck. As the diagrams are too delicate to be reproduced for printing by photographic means, I had drawings of them made from the sensitive side of the plate. In this way the impenetrable parts appear clear and vice versa. I will recall that I call the clear parts "shadows" and vice versa. The drawing is made three-quarter size.

On the diagram of the right side (Fig. 1) is the "shadow" of the whole osseous circumference enlarged and the outline of the brain pressed in, as *a* and *b*. The frontal cavity is small, evidently through ossification of its walls.[3]

Instead of two narrow shadows of the bilateral uppermost edges of the roof of the orbita *ob,* such as we generally meet with, we see the whole spot *p* as a large shadow, in which we can distinguish a shadow *g,* which is evidently the lowest and most anterior part of the sinus longitudinalis. This large basal shadow $(p + ob + g)$ indicates a pathological process in the base of the anterior cavity of the skull, and certainly the same process which enlarges the shadow of the osseous circumference.

One sees a small focus *c* in the region of the central brain-lobes near the base. At *si* one sees the lowest and most posterior part of the sinus longitudinalis. When this part appears so distinctly, it may be a sign of a pathological state. Among other details visible are the ethmoidal cavities *s,* the sphenoidal cavity *k,* the exterior auditory canal *au,* and the sella turcica *st.* The arch, *tb,* marks the anterior part of the pyramid, *P,* of this side and one sees behind it a little elevation as representative of the highest point of this pyramid, which I call the colliculus pyramidis. Behind appears the elevation of the other pyramid, which reaches the point *cl;* its connection with *Py* is not distinct in the reproduction. One sees farther the processus mastoideus *ma,* the processus styloideus *sty* and the maxilla inferior *ki.* *β* marks the bregma and *po* the prominentia occipitalis externa.

On the left side (Fig. 2) we have nearly the same relations of the osseous circumference of the brain with the depressions of the outlines of the brain in *a, b, e.*

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[3] This cavity is not well indicated in the reproduction.

The frontal base which we have marked *p* on Fig. 1, is still more developed in the abnormal sense than on the other side. *g* marks the same part as in Fig. 1. Between *g* and *ob* nearly the whole spot is shadow, though not well marked in the reproduction. The frontal cavity is very narrow through the thickening of its osseous walls. At *st* is seen the anterior part of the pyramid of this side and the little elevation behind it. Below this elevation one sees the cavities of the labyrinth (*sz* and *ch*); the first may mark a semi-circular channel and the second *ch* the cochlea or the vestibulum. Behind this small elevation of the pyramid on this side appears the higher elevation of the pyramid of the other side *Py; au* marks the meatus auditorius externus, *si* the posterior and inferior part of the sinus longitudinalis, and *St* the sinue transversus.

An important feature found in this plate is a great focus, *c*, approximately in the auricular transversal section nearly 6 cm high and in its greatest breadth 5 cm, being 4 cm below the upper circumference of the brain, and having a zigzag-form. The posterior part of the sinus longitudinalis is marked by *si*. *β* marks the bregma, *α* the posterior end of the fissura sagittalis and *po* the prominentia occipitalis externa.

When we ask what pathological process we must assume in this case, the answer is a pachymeningitis, especially hæmorrhagica, with all its consequences, also of alteration in the osseous parts. The enlarged shadow of the osseous circumference is not principally the result of thickening of the bones, but is produced also by pachymeningeal deposits. The same will be the case for the enlargement of the basal shadow, *p*. The foci in both plates are produced with the greatest verisimilitude by peripheral pachymeningeal deposits on the lateral parts of the surface of the brain.

From the clinical point of view one could suppose here the existence of an abscess; from the optical point of view we have no such evidence.

Case 2.—Bornstein, Marcus, met with an accident Dec. 24, 1903, while entering a railway car not yet lighted. He fell over a trunk and received a contusion on the tibia and on the index of the left hand.

The nature of this accident seemed to point to a light lesion. To my great astonishment at the examination (Jan. 4, 1904) serious symptoms were found. Standing with open and closed eyes

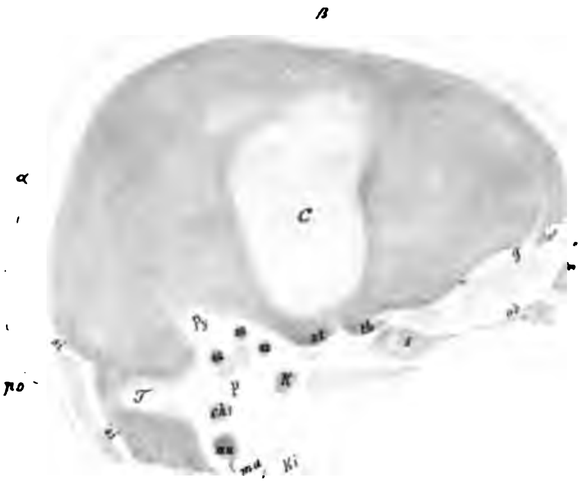

FIG. 5.

FIG. A.

the patient oscillated forward and to the left side. The supra- and infraorbital nerve of the left side were sensitive to pressure and the lateral frontal and temporal bones sensitive to percussion. In these localities the patient felt pains when he walked. The turning of the head excited pains, more toward the left than to the right side. The cervical and dorsal vertebræ were sensitive to pressure, the sensitiveness involving not only the processus spinosi, but also the lateral walls of the vertebræ on the left side. The pupil reflex was also feeble.

The plexus cervicalis superior and the muscles and bones of the left arm were sensitive to pressure, but this sensitiveness was not manifest in the nerves. The movements in the shoulder joint excited pain. The sciatic nerve and the n. cutaneus femoris externus of the left side were also sensitive to pressure.

The left arm and both legs, especially the left one, were adynamic. The patellar reflex was feeble, and especially on the left side. The left ear was more sensitive to the tuning-fork from the air and from the bones of the head. I was yet more astonished when Professor Reues found beginning bilateral papillitis n. optici. The range of vision was much diminished concentrically, and in the left eye there existed a complete defect of vision in an inferior and superior sector.

In this case the diagnosis was justifiable that there were serious anatomical intracranial lesions and, as the case was a recent one, also blood effusions. Radiographs confirmed this diagnosis as the following two figures prove.

I had two complete profile pictures made, but in the figures only the characteristic parts are drawn. On the right side (Fig. 3) there is a great focus, *c*, in the parietal lobe and extending into the occipital. The focus reaches approximately the base in the region of the pyramid. The pyramid of the same side is indicated by *st*, and that of the other side by *Py*.

On the left side (Fig. 4) there is a focus, *m*, which is situated in the upper part of the occipital lobe and occupies also a great part of the posterior position of the parietal lobe. This focus may have provoked the papillitis n. optici. *T* marks the sinus transversus (not well reproduced in the figure).

I will remark here that I have observed papillitis in a severe case of railway accident, with amblyopia, which disappeared in course of time, though to-day, after 20 years, there remains ataxia, a great number of other serious cerebral and spinal symptoms having ceased. In another case I observed a fatally progressive atrophy of the optic nerve. Both cases are published in my paper: "Spætsymptome bei traumatischer Neurose," *Berliner klinische Wochenschrift,* 1888, No. 52.

Case 3.—A lady in her thirtieth year experienced seven years ago, at the end of a pregnancy, partial convulsions in the right lower extremity. The next year, under the same circumstances, the convulsions were repeated, with the difference that the convulsions appeared also in the right lower extremity, then extended to the arm, and finally to the whole body, loss of consciousness ensuing.

These fits have persisted since that time and during recent months have become more frequent. The radiogram in profile showed on the left side (Fig. 5) a focus, *c,* in the region of the central convolutions, but not reaching the surface of the brain. On the other side there was no trace of such a focus. This focus corresponds completely to our knowledge of the extent of the pathological alterations in such cases of convulsions. The anatomical nature of this pathological alteration is undoubted and consists in osseous stratification (depositions) on the inside of the skull.

Fig. 5 shows an alteration of the base of the anterior fossa cranii. The shadow *g,* distinguishes the anterior and lower end of the sinus longitudinalis, ending in the large shadow, *p,* which identifies a stratification of the base in the region of .the crista galli and which joins with the shadow of the upper surface line of the roof of the orbita *ob.* This basal shadow is the effect of the stratification caused by pregnancy.

If one views more closely this master piece of Roentgen technics. a number of interesting details will be recognized. *s* points to the ethmoidal, *K* to the sphenoidal cavity. One recognizes under *tb* the tuberculum and under *st* the sella turcica of the sphenoid bone. Before *tb* is seen the shadow of the processus clinoidei alæ minoris ossis sphenoidalis. Behind it begins the pyramid of this side and below its elevation are seen the three cavities of the labyrinth *sz,* which may be the three semi-circular canals. Near *Py* is the elevation of the pyramid of the other side. The shadow *T* signifies the sinus transversus, and *si* the lowest posterior part of the sinus longitudinalis. *β* indicates the bregma, *α* the posterior end of the sutura sagittalis and *po* the prominentia occipitalis externa; *au* marks the meatus auditorius externus and *ch* may mark the meatus auditorius internus. These cases must not be confused with those of eclampsia intra partum, which are connected with albuminuria, and not with hysterical or epileptic fits intra graviditatem. The present case is a representative of a special form caused by osseous stratification on the surface of the central convolutions. We know that this anatomical process, which is common in pregnancy, shows very different degrees of intensity and localization, and has in general no clinical importance. Its involution varies greatly in intensity. When the involution is deficient, it may become serious, producing fits of epilepsy.

In my collection there are other plates of two cases of which I give a short description below.

The plates are dated 1902, the first May 20 and the other June 16. A comparison of these plates with those of the present day shows great progress. The difference between the second and the first pair is quite marked. The first pair shows an excess of dimensions, and they were taken without diaphragms.

In the second pair appear the small intracranial cavities. Both suffered from the above-mentioned form of epilepsy through pregnancy with isolated spasms on one side, with supervention of general spasm on the same, and on the other sides with complete loss of consciousness.

On the left profile picture of the first case (Kiesewetter) we observe first the whole osseous circumference enlarged. The same is the case with the base of the frontal cranial fossa. Within the frontal lobe there is a focus which does not reach the periphery and the inferior conical end of which nearly reaches the base. This inferior part of the focus incloses, in the form of a tiny island, brain-substance. In the parietal lobe is a great focus, which continues into the central lobe and reaches the base. The ethmoidal and sphenoidal cavities are unusually large, whereas the frontal cavity is very narrow.

On the right profile picture the osseous circumference, the shape of the frontal base and the dimensions of the ethmoidal and sphenoidal cavities correspond to those on the other side. In the frontal lobe there appears a focus and a second one in the parietal lobe, which sends a branch into the lowermost part of this lobe to the periphery. The shadows are not as sharp as in the plates taken later.

In the plates of the second case (Baruch), which are life-size, we see a very curious picture. The shadows by stratification seem to fight for space with the brain-substance, so that we see islands of brain-substance surrounded by shadows. We also see streaks of the pathological substance forming a network between the brain pictures.

The osseous circumference is enlarged only in single parts of the periphery, and some parts of this osseous circumference are so thoroughly penetrated, that we must suppose a secondary atrophy of those parts.

The plate is so perfect that we can see the cavities of the pyramidal and petrous portions of the temporal bone. The frontal cavity is very narrow; the ethmoidal and sphenoidal cavities are normal. On the left side the general shape within the brain-territory is nearly the same as on the other side, and on this side the form of network is still more decided than on the other. The osseous circumference is greatly enlarged in the occipital part and the shadow of the anterior and of the posterior parts of the sinus longitudinalis is very marked.

DISCUSSION.

DR. CHARLES R. DICKSON: As a delegate from the American Electro-Therapeutic Association to the International Electrical Congress, it is my pleasant duty to inform you that the American Electro-Therapeutic Association, immediately after hearing the addresses of welcome, and responses thereto, before proceeding to the transaction of any business whatever, in view of the historical nature of this meeting for the first time of a section of electrotherapeutics in an International Electrical Congress, decided unanimously to adjourn and attend the meeting of this section. A number of the members are, therefore, present this morning, and I would suggest that the courtesy of participating in the discussion be extended to them.

CHAIRMAN MORTON: In behalf of Section H, I assure you we appreciate the high honor and the delicate compliment conveyed in the adjournment of your meeting. In no sense could it have been conceived that these two meetings could be in rivalry, for the association meets annually and, like the brook, will go on, I trust, forever; while on the other hand this organization is an ephemeral matter, it rises and falls in one week. While I personally appreciate the compliment, I wish to impress upon the members of the American Therapeutic Association the fact that when they come here to join in our work, they are doing in the end the very best for the sum total for the advancement of our science, and that is the use and appliance of electricity in medicine. Therefore, I take pleasure in personally thanking the American Electro-Therapeutic Association for the compliment they have paid us and, I may add, the justice they have done themselves in adjourning to-day and being present at this meeting.

Dr. Wm. B. Snow: I wish to express my highest appreciation of this work. It seems that it can be truly said that it is the best work that has been done to this time. That we are able now to make diagnosis of brain lesion, and do it with the accuracy indicated on these diagrams, is one of the greatest advances that has been made in the use of the Roentgen ray. Dr. Benedikt's contribution is certainly a valuable one, and should be appreciated particularly by the neurologist who generally knows so little about the arts of radiography. The medical profession has not accorded this science due consideration, but such results will certainly rouse a latent spirit and dispel the apathy which exists. I wish to request that Dr. Benedikt be asked to give the technique which he employs in making these skiagraphs, as to quality of tubes, coils, and length of exposure. I feel that if such work can be done it should be done by experts everywhere. It but remains for us to appreciate and understand the conditions under which the work was done, to repeat these results. It only remains for the members of the profession who have the opportunity, to take up this work, not alone in the interest of diagnosis of the bony structures, but also to be able to diagnose inflammatory conditions and neoplasms. These skiagraphs have been taken from a part of the body which has been least studied; by the X-ray, a part of the body in which we have been least successful in obtaining results. We can but appreciate most highly the contribution made by Dr. Benedikt, in having shown so well what can be done. In closing, I would say that it is very unfortunate that the author is not here, and that there is no description of the technique in the paper.

Dr. Emil H. Grubbe: I also have been well pleased with the paper. Radiodiagnosis in cranial lesions has always been one of the subjects that has interested a radiographer most, if it has not interested the neurologist. We would hardly expect to have such decided results in making radiographs in the cranial convolutions as we have in making radiographs in other parts of the body. The reasons for this I need not mention; you all know them. I have had an extensive experience in radiography, but I had no idea that epilepsy, eclampsia, and other similar diseases could be diagnosed by means of radiography. I am also in a similar position with reference to the practicability of this subject as Dr. Snow. I would like to hear more about the technique, the particular method of making these wonderful discoveries.

Dr. D. R. Brower: We all know that Prof. Benedikt is thoroughly accurate and painstaking and has great scientific ability. He is one of the great neurologists of to-day, and his paper is to me an inspiration. I had given up the possibility of any accurate diagnosis being made by this method. I have had very many made, by very expert operators, and I have been fully convinced that they have not been a great aid to me in my professional work. I have still been hoping for better results, but there must be some peculiarity in the technique that Prof. Benedikt has devised that has enabled him to produce such pictures as we have here. His case of cerebral meningitis is a matter of easy diagnosis. I never have had satisfactory results in my experience with this method, but I must testify from personal observation to the exceeding painstaking of Prof. Benedikt's work, and I am glad to say that this thing alone has paid me for coming to the city of St. Louis. I shall go home feeling that a great contribution has been made to the diagnosis of the most intricate and difficult part of the nervous system.

Dr. T. **Proctor Hall**: Without attempting in any way to forestall anything that Dr. Benedikt will give of his technique, which I suppose he means to do in the publication to be issued by the Congress, but I think you will find a partial explanation if you will look on page 758 of his paper, about the middle of the page, where he says: "* * * lateral undulations enter in the direct rays and produce in the picture effects of lateral light. Therefore, the pictures become irregularly blurred. To prevent this effect, we must use diaphragms, the best being in the form of lead plates with relatively narrow holes." What he means is this, that from the anticathode in the tube we have diverging rays, and we also have rays coming from the walls, those disturbing parts he speaks of, constituting the disturbing rays. Now he says if you want to take a skiagraph of the brain what is needed is an arrangement of diaphragms which will only just permit the properly directed rays to reach the photographic plate. So with two diaphragms, one behind the other, almost all the disturbing rays can be cut off. Another plan that is adopted with these diaphragms is to attempt only a small part of the picture at once, and to secure this particular part with particular care. In that case, take a pair of diaphragms so small that you get only this part, placing one behind the other, and let a narrow beam of rays pass through and get a clear picture of that small part. That, I think, is the whole secret of his success.

Chairman Morton: I will add only a word or two to the discussion that has already taken place upon this excellent paper. I think there are quite a number of reasons why the pictures are so excellent. As we all know, there is a particular point in the life history of an X-ray tube when it does its best work. It is just as it is in the life of a man, a horse, or a country — there is a moment when its best work is done. I think I should want to select such a tube, an electrolytic interrupter, an eighteen-inch coil, and make a rapid exposure. In regard to this diaphragm method, at a subsequent time, when I have the opportunity, I will present another diaphragm which I think also adds very greatly to the clearness of the picture. But I really believe the fundamental reason of the success in the technique has been brought out in Dr. Hall's remarks in the use of the perforated lead diaphragm.

The following paper was then read:

STATIC ELECTRICITY IN CHRONIC NEPHRITIS.

A RECAPITULATION.

BY C. S. NEISWANGER, M. D., *Professor of Electrotherapeutics, Chicago Post Graduate Medical School and Illinois Medical College; President and Professor of General Electrotherapeutics, Illinois School of Electrotherapeutics.*

Original investigation, especially upon medical subjects, and where the results are almost phenomenal, is almost necessarily fatal to the finances and reputation of the investigator unless he be spared long enough to gain the company of sufficient support to strengthen his position.

The above subject, although not originally selected for this meeting, has been again chosen, partly at the request of friends, and we feel the more encouraged to do so because other physicians — notably Reed of Philadelphia and Hurd of Minneapolis — have in recent articles upon the subject, reiterated the writer's views.

How prone is the physician to criticise adversely the things that are new, and how inexplicable is human nature in general in this respect. The writer was forcibly reminded of this seemingly inate characteristic of all mankind when, eight years ago, he had the temerity to attack the old, accepted pathology of a recognized incurable lesion — chronic Bright's disease. And how nearly fatal it proved to his medical aspirations until, by persistent and extended clinical work, the dark clouds of adverse criticism are being replaced by the sunshine of honest investigation. Many letters are constantly being received stating the experience of other physicians in this direction and going further to prove the views of the writer.

It is not deemed advisable at this time to consider either the etiology, pathology or diagnosis of the disease under discussion, and only such pertinent points in the treatment will be given as will enable the physician to apply it intelligently. These are omitted, first, because the old are well known to every physician present, and the newer views of the writer have been almost constantly before the medical profession since their inception eight years ago; second, because they are not considered essential for the purpose of this paper, which is only a recapitulation.

A few points, although contained in former literature upon this subject, may be mentioned here merely as a reminder:

That chronic nephritis is more essentially a disease of central nervous impairment.

That one of the strongest proofs of this is the kind of persons afflicted. (See appended list.)

That the natural paths along which impressions are conveyed to the kidneys are through the splanchnics and spinal cord; and, when these tracts are impaired, the function of the kidney is correspondingly affected.

That the results of decapsulation show it not to have a place in the successful treatment of this disease, and that other operative procedures have been equally barren of results.

That the reduction of albumin obtained by strict diet has no clinical significance.

That the remedy indicated is one that will hasten the oxydization of waste products.

That static electricity is the logical remedy, because, by the evolution of oxygen, always accompanying this modality, it not only hastens the elimination of waste matter, but gives a better tone to the nerve centers affected by its vibratory action.

That static electricity is a powerful equalizer of the nervous forces, as is evidenced by its effect on the temperature, respiration and pulse.

That in all cases of chronic nephritis treated by the writer where there was mitral regurgitation or the hypertrophy which precedes it, the results have been almost entirely negative.

It was the intention to present at this meeting the reports of twenty consecutive cases, in which the diagnosis was made by experts, but on account of the length and similarity of these reports, it is only deemed advisable to present a summary of the twenty cases as follows:

Permanently relieved	12 or 60%
Partially relieved	2 or 10%
Failures	6 or 30%

The two cases that were partially relieved were still taking treatment and showing some improvement, but were finally lost sight of.

Although the results in 30 per cent were finally negative, two of the cases were so materially benefited after one month treatment that they were provisionally discharged. Both returned after the lapse of one year as bad as when first seen, and were not benefited by subsequent treatment.

In all the unfavorable cases the heart's action was characteristic of the advanced stages of the disease. Two had passed the age of 70, one was only 15.

Longest time between the discovery of the disease and presentation for treatment in all the cases was six years.

Of the twenty cases, seventeen were males, three females.

Five were physicians; four board of trade operators; three preachers; two housewives; one domestic; two traveling salesmen; one clerk in city hall; one jeweler; one laborer.

The treatment used has been the negative head breeze for 15 minutes, followed by positive insulation for the same length of time. The Morton Wave Current is alternately substituted for the head breeze. Treatments are given daily. After a few sittings the urea commences to increase, carbon dioxide is eliminated and albumin and casts decrease. The patient has a feeling of well-being, sleeps well and is free from pain.

If the results as stated in this paper serve to stimulate more extended research in this direction, the writer will feel amply repaid, and also be pleased to give more extended details — to any of the profession — than could be brought out in this paper.

DISCUSSION.

Dr. G. B. Massey: I am sorry that Dr. Boardman Reed is not here to discuss this paper, as I know he is making quite considerable use of static electricity in cases of this sort, and I think he will have something to say about it in a book which he is just getting out upon diseases of the stomach and intestines. Some five or six years ago my attention was called to static electricity as a means of diagnosing diabetes mellitus by a physician from Philadelphia, who quoted a report from a physician of Bordeaux, France, stating that the amount of sugar in several cases of diabetes mellitus had been reduced by static electricity. In the four cases reported there were no cures, but decided amelioration. I followed the directions very much as given by the doctor. This was before the Morton wave current had been devised. The application was a fifteen minutes' positive breeze to the head, not daily, but three times a week, and there were also sparks given the patient for some symptoms he had in the nature of neuralgia. I examined the percentage of sugar in the urine and found it was materially lessened, though ultimately not entirely gotten rid of; but the treatment was finally discontinued at the request of the patient as rather tedious, yet he felt that great good had been derived. The amount of sugar had been permanently lessened, judging by the remarks made to me by the patient recently, on meeting him some five years after the treatment.

Dr. W. B. Snow: Dr. Neiswanger's paper is certainly a record of results. I think, however, the conception of the *modus operandi* of the modality is a subject open to consideration. It seems to me that when we consider the action of static currents upon the system from the standpoint of their effects upon congestive processes, we have to take up the consideration of that feature with which we deal, in a low-grade inflammatory process.

I differ with the author in his idea as to the source of the action or method of action of the static current upon these congestive processes. When properly applied, the local vibratory action produces contraction of the blood vessels, and forces out the congestion, relieving the tension and making the circulation through the organ possible by relieving the local stasis. When we understand the uses of static electricity on that basis, as is daily demonstrated in our practice, the field of indication becomes very large. My own experience during the last few years with cirrhosis of the liver and nephritis, as well as with congestion of the prostrate gland and other glands of the body, has forced me to believe that there is no method in the field of medicine which offers so much for the local relief of congestive processes as the Morton wave current. Its application directly over the lesion, by a purely mechanical action, produces local drainage and relieves the congestion. That is undoubtedly the correct *modus operandi* of the static current. When we do recognize in it that action and apply it intelligently we get effective results. The field for the employment of static electricity will not be confined to the treatment of external affections in the future. Dr. Boardman Reed, to whom the author of the paper referred, uses this method also in some cases, substituting the static-induced current for the wave current. This substitution is only necessary when a machine of small capacity is employed, when it is desired to get an intense local vibratory action. The wave current is much to be preferred in all other cases, for the following reason that it produces, not only (1) local effect, but also (2) the effect of relieving the arterial tension, making it possible to lessen the disposition of a recurrence of the inflammatory process. This is the correct method as I understand it.

Dr. H. H. Roberts: I am sorry the author did not go into the etiology of the disease, because I think there are some parts of it which we should consider along the line of static treatment. Undoubtedly the static treatment does a great deal of good in this condition, but we should understand thoroughly the etiology of the disorder.

I believe the principal cause is from auto-intoxication, and the line of treatment should be along these lines. There is another source of electricity which produces marked effect in these cases besides the direct application of the static machine. In conjunction with the wave current, we should give special attention to the dieting and the digestive tract. If we will consider these lines, we will certainly be able to treat the case scientifically and with a great deal more benefit to the patient.

Down in Kentucky we have a great deal of nephritis, as many of our Kentucky Colonels are in the habit of partaking liberally of the extract of one of the cereals which is said to aid digestion, and incidentally to beget good fellowship. It naturally follows that we have a diseased digestive tract and that auto-intoxication effect follows. I therefore wish to emphasize that in the treatment of these conditions we will get far better results by giving special attention to the gastric disturbances rather than paying attention wholly to the nephritis.

Dr. **Wilcox**: I want to give my indorsement to static electricity, and also to the paper by Dr. Neiswanger. I know Dr. Neiswanger personally. I brought the first static machine to this city. I can indorse its application to many diseases of the kidney, especially nephritis. I had a case sent me by a cousin that was suffering with nephritis. I made an analysis of the urine and found the patient was in an exceedingly bad condition. I used the spark current. I do not use the negative in an inflammatory condition; I use the positive breeze. I use the spark more than I do the Morton wave current, and I know that it is beneficial in many diseases. I am a great believer in static electricity.

Dr. **Emil H. Grubbe**: This work of Dr. Neiswanger's was very interesting to me from the start. I have never been as enthusiastic over the method as Dr. Neiswanger, for the reason that I do not believe if we have typical organic Bright's disease or nephritis we will have any curative result from the application of the static current, the only effect being that of relief or temporary amelioration. It is a fact that we can reduce the inflammatory process; we can cut down the solids and do away with the albumen, but unless these patients keep up their diet and take better sanitary care of themselves they will have a relapse. I have had some very remarkable symptomatic cures, but I cannot let the patients get away from the prescribed diet, or in a little while they are back again for treatment. I claim that the static current has nothing to do with the production of organic changes in the kidneys. These organs are too far away to be much affected anyway. The effect is of course systemic rather than local, and for that reason I have always limited the treatment somewhat. I do not make any distinction between the polarity in the static treatment, for the reason that no one has ever been able to prove that there was any therapeutic difference. I simply wish to make the statement that the results are seemingly of a temporary nature, and if those patients are allowed to go back to work and eat and drink what they like they are likely sooner or later to develop the same symptoms for which the static treatment was given.

Dr. **S. H. Burch**: I have had under observation five cases of interstitial nephritis, accompanied by arterial sclerosis. In each of these cases I made five preliminary urinary examinations, and found the average percentage of urea to be from ½ to 1 per cent. These cases were treated both by means of the Morton wave current and the auto-condensation method of D'Arsonval. Each case received ten treatments first by means of the Morton wave current that caused an average increase of ½ of 1 per cent in the amount of urea excreted. The cases were then treated by means of auto-condensation, each receiving as before ten treatments. The latter modality caused no further increase in the amount of urea. In these cases twenty-five observations were taken by means of the sphygmomanometer, the instrument employed being Cook's modification of the Rivi Rochi instrument. It was found that the Morton wave current caused a decrease of blood pressure averaging 10 mm. This seemed very peculiar from the fact that 100 observations upon healthy subjects caused an average increase in the amount of arterial tension. Auto-condensation in these cases also caused a decrease of blood pressure. While all of these cases seemed to improve under these modalities, the cure was in each instance symptomatic, as a relapse occurred in every case after the treatment was discontinued for a time.

Chairman Morton: I am afraid I should not do Dr. Neiswanger justice if I should accept the theory that whatever would affect the kidney in the manner described would affect every other part of the human organism in the same manner. We know that the effect of static electricity is to produce an increase of metabolic processes. Urea, carbonic acid, water, etc., are increased. In other words, the reader of the paper relies upon the question of metabolic acceleration, so carefully explained to us by D'Arsonval, and these metabolic accelerations apply to all treatment alike; therefore it seems to me not impossible that the general form of treatment should have its due share of effect on the kidneys. But I am sure that Dr. Neiswanger will gather more imperative evidence, especially with the valuable aid of Dr. Boardman Reed and of Dr. Hurd, of Minneapolis. We must remember that in our personal knowledge we have known people whom we expected to die of Bright's disease years ago who are still alive and comparatively well, although continuously having a considerable quantity of albumen in the urine.

The following paper was then read:

THE THERAPEUTIC USES OF STATIC ELECTRICITY.

BY DR. WM. BENHAM SNOW.

That static electricity or Franklinism, so called, occupies a unique place in the field of high potential electricity is demonstrated, we believe, more positively in therapeutics than in any other field of employment. The methods of exciting this form of electricity are also unique, effecting the characteristic feature of the current evolved. In the electrostatic apparatus alone are involved the principles of the electrophorus and excitation by friction. By these methods are induced currents of very small quantity in conjunction with very high potential, which either, when discharged through the air or conducted through electrodes in contact with the body, produce a distinctly disruptive or resonating effect, or in other words, the oscillations physiologically have a clean-cut distinctly vibratory quality, capable of greater penetration and tissue oscillation, producing waves of vibration distinctly different from those derived from any other type of high potential apparatus. A comparison of the discharges from a Holtz machine having a given capacity of voltage and amperage with those from a Ruhmkorff coil operated by a current from a dynamo or powerful battery of the same voltage and current strength show marked differences.

It seems that currents having higher rates of frequency from the static source produce muscular contractions while currents of the same frequency from coils do not, i. e., they are capable of producing contractions under rates of frequency at which contractions from other currents cease. This statement is certain to be questioned. When it is recognized, however, that a current having the rates of frequency produced by the *static induced current* obtained from a powerful machine of modern type, employing a short spark-gap, in connection with the very small Leyden jars in common use, does not under any condition of speed cease to produce muscular contraction, either what has been recognized as a current of highest frequency by all observers has a frequency ranging below the rate at which muscular contractions cease, or this current is capable of producing contractions when employing higher frequencies.

It also seems that these static currents possess greater possibilities of diffusion, especially when administered from one side of the machine when the patient is insulated, capable in therapeutics of mechanically stimulating tissue activity to a greater extent than other currents having approximately the same frequency, potential and quantity.

Neither do other currents seem to have the same ability, the potential in each case being equal, of passing readily through poor conductors such as wood, nor of escaping to the same extent through the dielectric. That these observations are correct, the therapeutist who sees them demonstrated daily in his laboratory can affirm.

The qualities of electrical currents which make them valuable as therapeutic agents, except for the production of electrolysis, cataphoresis, and cauterization, are as follows: (1) Muscular contraction. (2) Intense local vibration. (3) General diffusion, with varied rates of frequency relatively influencing tissue oscillation and metabolism. (4) A current strength not likely to depress or unfavorably influence the delicate structures of the organisms. These qualities the static currents unquestionably possess to a greater degree than currents from other sources.

Muscular contraction influences local tissue metabolism and metamorphosis by effecting alternating contraction and relaxation of the muscular structures, thereby inducing activities, which overcome local stasis, induce activity of the circulation and an increased distribution of nutrition to the tissues throughout a region treated. At the same time, during administrations to a patient in a state of charge, contractions induce a greater activity of all of the metabolic processes, thereby promoting normal conditions. These effects cannot be obtained to the same extent with currents which lacking potential induce contraction of the mass of a muscle or group of muscles only by stimulating a motor point as is the case with the continuous and interrupted currents. A current to be effective must have such penetration characteristic of potential as to affect generally the muscular fibres, inducing distinct fibrillary contractions of the minute tissues in the area to be influenced by the electric discharges. It will be observed, therefore, that the quality of the currents which produce muscular contractions to possess the most far reaching and beneficial effect, when applied to inflammatory conditions, must be capable of great diffusion and be administered in such a manner as to *compel* such diffusion, i. e., with the patient insulated.

In order to effect the best results under the influence of muscular contraction, currents should be administered with a frequency adapted to the region and condition to be treated, the rates which will induce requisite degrees of stimulation or inhibition being observed. In other words, the frequency of oscillation and the duration of administration must be regulated to the conditions to be treated.

The effects of muscular contraction and associated vibratory impulses — mechanical in character — are invaluable in cases in which stasis is present, inducing, as they do, increased tissue metabolism and restoration of circulation, with the subsequent productions of normal conditions. The above facts place the static modalities in the first rank and offer a strong argument against the indiscriminate selection of coil currents of high frequency for the restoration of conditions of impaired metabolism, local or general, or for the relief of local stasis.

Local vibration induced by the static currents arises from two influences; the one referred to — muscular contraction — and the other, due perhaps partially to the impedance of the flow at the surface of the body as the current comes against the resisting integument, but without doubt mainly due to the attraction of surrounding oppositely charged capacities. The oscillations of the current are associated with a distinct sense of vibration of the surface of the body during an administration — synchronous with the spark-gap discharge.

It is impossible, we believe, to produce the same character of vibratory effect with any other high-potential apparatus. This effect depends largely upon or is markedly increased by the earth's capacity, as is demonstrated by altering the character of the grounding as to direct or indirect metallic connection during an administration. This same influence of the earth connection also markedly influences the degree of contraction produced. The above observations refer to the action in connection with the administration of the wave current. With the static-induced current distinctly marked local effects are produced beneath metallic electrodes at either pole.

The current of a static machine passed through a resonator in connection with a coil of the Tesla, d'Arsonval, or Oudin type ceases to produce the characteristic static effects, but becomes the same as coil currents.

Efforts have been made by some manufacturers of coils to produce effects similar to the static from coils, but so far the results have been unsatisfactory.

The general diffusion of the currents from the static machine seems to be more pronounced than from other sources of high-potential electricity. This is appreciated when comparing the effects from a Ruhmkorff coil having a spark capacity of 12 to 20 ins. and a static machine of like capacity. The discharges from the static machine will affect an individual either when insulated or standing near the apparatus, producing to a more marked degree the raising of the hair and the electric breeze than do the discharges from the coil. Other currents which are administered in therapeutics will not permit the administration of discharges of such spark length, nor, other things being equal, produce the manifestations of raising the hair when the patient is insulated, nor when administered to a patient insulated from one side of the source of energy the opposite side being grounded, will surround the patient with an intense vibratory field, as will the static wave current.

The current strength of the static discharges is remarkably small. In fact it is probably the minuteness of the quantity that permits the employment of the static currents for the production of many of the effects mentioned under the other headings explaining in a measure some of the results obtained. The diffusion of the static current of such very small amperage produces mechanical effects with a minimum of ionic interchange. It is this fact which eliminates all possibility of danger; for currents of large quantity and possessing power of great diffusion when passed through the tissues of the body are certain to produce electrolytic effects, and are destructive to cell life. With the static currents, the current flow is ample from a Holtz machine having eight revolving plates, 30 ins. in diameter to meet most therapeutic demands, the greater amperage of more powerful machines often producing unpleasant effects.

The effects and properties enumerated indicate the employment of the static modalities in the treatment of all conditions characterized by errors of metabolism, local or general. When it is appreciated that such conditions include all hyperæmias, passive and congestive, as well as conditions arising from excesses, lack of proper exercise, and malnutrition, the field for its employment, alone, or in conjunction with other physical measures, is seen to be very large. Their actions are mechanical, searching and serve as a *vis-a-tergo* for the re-establishment of normal activities and functions where destructive organic lesions have not intervened.

DISCUSSION.

Dr. H. H. ROBERTS: I desire to indorse Dr. Snow's paper most heartily, and I wish to emphasize one point brought out in regard to the use of the high-frequency current from the static machine. I think we get much greater effect from the high frequency from the static machine than that compared with the coil. Not only is the high frequency more powerful but there is much less pain produced from the static machine than that coming from the coil, and we can use a much larger spark-gap. It is certainly much safer to use the static machine and of greater comfort to the patient (which we should at all times consider) than the current which comes from the coil. I always use the static machine to produce my high frequency especially when I want a constitutional effect.

Dr. G. B. MASSEY: I agree quite entirely with the points made by the doctor, and I want to add that the earmarks of the paper denote a very earnest and painstaking worker. There are little points here and there that come only to the man that uses this method a great deal. One thing was mentioned by Dr. Roberts, the fact that there must be a lack of amperage with the higher voltages, comparing the static with the coil. The fact is there would really be a very little amperage with a great deal of voltage. Those things were pointed out by Prof. Jenks in his work. The doctor also noted that in the use of the static current the hair would rise which we would not find to be the case with coil currents. This is explainable on the ground that the surrounding walls are usually more charged with static machines than with coils, and this is a point I wish Prof. Jenks to take up; I would like to induce him to add another diagram to his excellent work on static modalities. A diagram of the conditions present in the indirect spark is not complete unless you show the room all around to be charged also. That practically does not happen with the coil current; you do not ground the other pole and you do not get that effect. What does grounding mean after all? A different electro-static capacity I should take it. I saw a statement in print two years ago of a man who said he had two earths to connect with. He claimed he was right, but his explanation was wrong, just as Dr. Snow was right, but his explanation was wrong. To my mind the explanation is simply this: One so-called earth is the gas pipe and the other earth is the water pipe; that is all there is to it. Here we have two electrostatic capacities imperfectly insulated and, you will find, having a different effect, as Dr. Snow insists in his book, from a circuit with but one set of pipes interposed as a ground.

SECRETARY W. J. JENKS: In the report which the committee on Current Classification will render to the American Electro-Therapeutic Association in a day or two, possibly to-morrow or Thursday, and which we hope may be read before the joint meeting so that the members of the Congress can also be present, this matter of capacity of the circuit in which the patient is placed will be considered somewhat fully.

It is sufficient to say now that there is but one earth to which, in the present state of existence, we can connect to form one plate of the condenser. The more perfect we make the contact with the walls, pipe systems, and all other objects that constitute that plate, the less resistance we interpose between the patient and that plate when the patient is on the insulated platform. The less distance we interpose between the patient on the one hand, and the floor where it makes the nearest approach to the patient, the conductors beneath the floor, and the walls of the room, the more we increase the capacity of the condenser. We can do the same thing by shortening the legs of the insulated stand, and we can do the same thing by cutting a sheet of metal and placing it under the insulating stand on the floor. In other words, we bring the plates of the condenser nearer together.

The bearing of this upon the capacity and the resulting discharge we shall try to make plain in our report.

CHAIRMAN MORTON: A few thoughts came to my mind while listening to this interesting paper. The most prominent thought is that it is a pity, a great pity, that we have not a better nomenclature for the various currents which we medical men are referring to as "high frequency," "static," "high potential," and so on. This is a work, however, which the committee is carefully doing for us and one which will be of the utmost value. We all admit that the current as ordinarily derived from an influence machine is simply a one-way current. It is a continuous current like the galvanic current.

But the "static induced current" has been a little bit misunderstood. In our second report it was stated that the static induced current produced a painful effect, and in the same report that Leyden jars of a half gallon were the ones employed. If the committee had employed small Leyden jars they would have found that the static induced current was not a painful current, but an agreeable current. The smaller the jars the greater the frequency. It is an absolutely painless current, and at the same time we obtain the utmost frequency that is consistent with the resistance that is put in the circuit.

DR. WM. B. SNOW: Dr. Morton referred to the differences between the discharges from a static machine and from the coil current in connection with the condenser. It is a demonstrated fact physiologically that when we hold a metal electrode or glass vacuum tube which is connected directly from the static machine, the hand contracts very sensibly with the passage of a short spark between the balls of the discharging rods, and as the gap is lengthened the muscles are thrown into complete contraction or tetanus. There is an absence of muscular contraction when connected from a coil or resonator in connection with a coil or static machine. That is the point which I wish to make clear, that the static current produces continuous local muscular contraction. To explain why this is so, I believe we have to consider the peculiar nature of the source of these currents, which when pronounced, with any apparatus which is distinctly electrostatic, differs distinctly in this particular from currents derived from other sources, or having an intervening coil, to damp out as it were the static characteristics. That was the main object of the paper.

Another point with reference to the frequency, which did not provoke discussion, but to which I wish to refer again, viz., that when taking the small-sized Leyden jars, used in connection with static machines, and placing them in connection with a 16-plate Holtz machine run at from 400 to 500 revolutions per minute, there will never be a time when holding the metal electrodes, one in each hand, that the current will cease to produce muscular contraction. Therefore, the general conception by scientists that at certain high rates of frequency the muscles cease to respond is not true of static currents, or the rates are distinctly lower. The idea that the output from a static is practically continuous and even in amperage and voltage may not be absolutely correct. On the contrary, it does seem that, other things being equal, the quality of the output varies with the resistance at the spark-gap.

THURSDAY MORNING SESSION, SEPTEMBER 15.

Chairman Morton: In calling the section to order this morning, I do so as recognizing the presence of the joint bodies of Section H of the International Electrical Congress and the American Electrotherapeutical Association. I need not say to you, ladies and gentlemen of Section H, and to you, gentlemen of the American Therapeutical Association, of the pleasure and honor I feel of presiding over this joint session.

Among the notable events connected with the introduction and consideration of the medical questions relating to the Electrical Congress has been the appointment of Prof. J. A. Bergonié, of France, as our honorary chairman. It is with extreme regret that I am obliged to announce that Prof. Bergonié cannot be present with us. His name has become a household word in electrotherapeutics. He it is who for twelve years in the *Archives d'Electricité*, published in Bordeau, France, has kept an accurate record of the advance in electrotherapeutics, and he has done it with absolute impartiality and fairness. I believe that Prof. Bergonié's journal will be recognized by every one of us as the most just exponent of the advance of electrotherapeutics in the last twelve years, and in that connection I am sure I express a sentiment which will meet with ready assent, and that is that the recent advances in the practical applications of electricity in medicine owe more to France than to any other country. I say this with no invidious distinction to our scientific brethren of other lands or of our own. I will say, particularly in this connection, that the high-frequency high-potential current, discovered and first put into practice in our land, has been developed to its present high degree of usefulness by French scientists and physicians, and though in Germany this current has not received extended consideration, we may not forget on the other hand what we owe to her in connection with the Roentgen ray and its splendid development in practice there.

We have the honor of having present with us to-day, M. G. de Nerville, as our first vice-president, and I can assure you, gentlemen, I believe you will extend to him a warm welcome. He comes to us from that beautiful France, not only beautiful as a country, but also beautiful in the exact science in which that land excels. He is not a medical man, but he is an engineer interested in the questions of standards and measurements and those deeper problems we must leave to experts like himself. But he comes here to welcome us as medical men, and as medical men we welcome him as an authority in exact science interested also in our medical questions.

I have the honor of introducing to you M. G. de Nerville.

VICE-PRESIDENT G. de NERVILLE: It is, to my regret, impossible to respond in English to the very amiable and for me altogether too flattering words, which the chairman, Dr. Morton, has addressed to me, and I ask your permission to express myself in my own tongue. I thank you very heartily for the honor you have paid to France in choosing, to preside over a reunion of such eminent and such illustrious men, as honorary president, a Frenchman, M. Bergonié, and myself, as vice-president. I am exceedingly touched and flattered by this honor. I regret more than any one the absence of Prof. Bergonié, whose high scientific reputation recommended him so well to your kind notice. As for me, I very modestly take this seat, to which I had no claim, for my studies and my work in electricity have not been directed toward electrotherapeutical applications. Nevertheless, this science which I know but too little has always greatly interested and attracted me. I recall, with pride, that upon the occasion of the First Congress of Electricity held at Paris in 1881, I had the honor of being attached as secretary to the section on electrotherapeutics. This recollection is very precious to me and I am deeply thankful to you for having, in so kindly choosing me as vice-president, attached me by a further bond to the beautiful science which you are developing.

At the request of Chairman Morton the following translation of Prof. Bergonié's letter was then read by Dr. Granger:

"My dear Dr. Morton: Owing to the state of my health I am forced to renounce the project which I had formed of attending the St. Louis Exposition and the International Electrical Congress accompanied by Mrs. Bergonié. I regret it so much more owing to the fact that the invitation had been made in such a charming manner, and I wish to thank you personally. I beg you, therefore, to accept my most sincere regrets and an expression of my everlasting gratitude."

MULTIPLE-ARC CONNECTION OF CROOKES TUBES TO ONE AND THE SAME COIL.

BY PROF. J. BERGONIÉ, *Université de Bordeaux.*

The multiple-arc connection of several Crookes tubes to the secondary circuit of one and the same coil has not been and can not be accomplished with the coils ordinarily on the market. This lies in the fact that the strength of the secondary current furnished by these coils is too small.

The series connection of two or several Crookes tubes would seem possible, *à priori,* in consideration of the very great lengths of spark supplied by the coils and the relative smallness of the lengths of the equivalent spark of the Crookes tubes giving useful rays. To a coil giving a spark of 50 cm, we ought to be able to connect in series two Crookes tubes having as spark equivalent 10 to 12 cm.

This series connection is a failure, as is the multiple-arc connection.

Having at different times suffered these failures and becoming imbued with the idea that, what was especially important for a Rhumkorff coil designed for the production of Röntgen rays, was not in the first place the length of spark, but the current strength which can be put out by the coil in the secondary circuit, I had constructed, as long as three years ago, by the firm of Gaiffe, a coil of the form and of the volume of the ordinary coils giving a spark length of 50 cm, but the secondary circuit of which, instead of being wound with wire 0.1 mm or 0.15 mm in diameter was wound with wire of 0.35 mm having a section five times larger. The construction was otherwise identical except as to this particular point. This coil fed by a Foucault interrupter gives, under the best conditions, a spark at most of 25 cm, but with a liquid or air-gap interrupter and using 120 volts, it gives at the best but a spark of

10 cm in the form of a large caterpillar—a real arc, the production of which can be prolonged without any damage to the coil.

This coil, fed as has been stated above, has been used for a year for the entire operation of the Röntgen-ray service of the St. André Hospital of Bordeaux, an extremely heavy service. We employ almost entirely Chabaud-Villard tubes with a cooled anti-cathode, as other tubes can not stand the strength of the high-tension current supplied for any length of time, which current measured with the new Gaiffe milliammeter frequently reaches 2 milliamperes.

I have furthermore found by an experiment repeated a hundred times that the employment of a Villard valve to stop the inverse wave produced by the coil upon the closure of the current by the interrupter is completely useless. Nothing seems to pass in the tube in the inverse direction, and the lighted zone of the tube is separated from the dark zone by as pure and clear a line as when a Villard valve is interposed.

It was under these conditions that I tried to operate two or several Crookes tubes connected in multiple arc to the secondary circuit of this coil, similarly to incandescent lamps on a lighting system. This experiment was crowned with complete success, and I have thus been able to connect as many as four Crookes tubes to the secondary circuit of this same coil, the four operating under perfect lighting conditions, and the coil taking 12 amperes at 130 volts.

These tubes connected in multiple-arc do not all need to have the same spark length—that is, send out the same rays. I was able to determine in fact, that some of them emitted No. 6 rays according to the Benoist radiochromometer, while a neighboring one sent forth No. 7 rays and still another No. 5 rays. Those with less penetrating rays were without a doubt more brilliantly illuminated than those with more penetrating rays. But this is the same phenomenon which takes place when a single tube is connected to the coil.

From this practical point of view, as has been confirmed by experiment, there is no doubt that with this special coil I can ordinarily secure simultaneous operation of at least two tubes. What has hitherto stopped me has been the difficulty in finding a simple bipolar switch for these three high pressures. The one I have had constructed is not very practical and is very cumbersome, but it has allowed of determining experimentally that when the circuit is broken at one of the tubes, close observation is required to notice any variation in the one which continues to operate.

In brief, the multiple-arc connection of two or more tubes to the secondary circuit of one and the same Rhumkorff coil has been practically established. For this a coil giving a spark of 10 cms is sufficient. It is necessary in order that this connection may succeed practically, that the secondary circuit of the coil be wound with much thicker wire than the wire ordinarily employed.

The chairman then requested the secretary to present the following paper:

SOME IMPROVEMENTS IN HIGH-FREQUENCY GENERATING APPARATUS.

BY. DR. GUSTAVE O'FARRILL.

If the two poles of an electric generator are connected by means of a conductor, a current will flow in the latter if a difference of potential exists between the poles. When the flow of current maintains the same direction, it is called continuous current, or if the direction periodically changes, alternating current. In the first case, the sign of a pole of the generator is fixed, and in the second case, it varies constantly. We call the period of an alternating current the duration of a complete oscillation made by two successive currents of opposite directions. The number of periods in the unit of time constitutes the *frequency* of the current and depends on the number of poles of the field of the dynamo and on the speed of the movable part, field or armature.

In industrial alternators a frequency varying from 40 to 150 periods per sec. is produced according to the different uses. If it is desired to obtain a high frequency, the number of poles and the speed of the movable part are increased. Tesla and d'Arsonval claim to obtain by this means and with more or less ingenious devices, frequencies of 10,000 and even 30,000 periods.

This enormous frequency of alternation is much inferior to that obtained by Hertz, and utilized by Tesla and d'Arsonval, by means of the oscillating discharge of condensers, with which the almost inconceivable figure of 1,000,000,000 periods is reached; that is, during a second the electric current goes and returns 1,000,000,000 times through the conductor.

The arrangement of the apparatus adopted by d'Arsonval to obtain this result is as follows: He connected the interior coating of two Leyden jars with the ends of the secondary circuit of a large Ruhmkorff coil and connected the external coatings through a thick wire solenoid. A ball detonator allows the discharge of the electricities of opposite sign of the interior coatings when the electric pressure is sufficient to overcome the resistance of the interposed layer of air.

If the discharge is produced under such conditions that

$$R < 2\sqrt{\frac{L}{C}}$$

(in which R is the resistance, L the inductance and C the capacity), then the discharge is oscillating; that is to say, the initial energy passes alternately from one coating to the other, transforming a part each time into heat, until it is all dissipated.

Mullin compared the oscillating discharge of the condensers to the oscillatory movement produced when two vases containing a liquid at a different level are suddenly brought together, when it is seen that the equilibrium is not established without various oscillations.

Now, as the external coatings of the condensers are connected by a conductor, the oscillating current of high frequency is established in the circuit formed by the balls of the detonator, the spark, the two condensers and the solenoid.

In order to thoroughly understand the production of the current in the solenoid it is necessary to consider: (1.) That the condensers interposed in the circuit of an alternating current do not interrupt it, as would happen with a continuous current, because with every inversion of the current the condenser is charged and discharged in inverse direction. (2) That the oscillating discharge cannot follow the secondary circuit of the coil on account of the high self-induction it presents.

Among the most notable properties of high frequency we must mention the increase in pressure, which reaches enormous magnitudes. It can increase to hundreds of thousands of volts. For such electrical pressures, the resistance of the metallic conductors is practically nil, the current circulates in open circuits and traverses space, forming electric waves which are reflected and refracted similarly to those of light.

For the purpose of increasing the currents of the solenoid, Tesla had the idea of winding about it another solenoid of thin wire, using liquid paraffine as a dielectric, and obtained induction phenomena which increased the pressure of the current.

It is likewise possible to obtain an increase in pressure in a more simple manner and with better results, by means of the Oudin resonator. Dr. Oudin modified the arrangement of the d'Arsonval apparatus and caused the current of high frequency to pass through a part of the solenoid, thus producing a very notable increase of the pressure in the remaining part of the same. He connects the external coatings of one of the condensers with one of the ends of the said solenoid, and the other external coating with a determined point of the coils and obtains at the other end a large and full brush discharge, which is increased if a capacity is brought near.

If the connection is made a few centimeters from one or the other side of the exact point for producing the said result, the length of the discharge is notably decreased; so that it is absolutely necessary to have a perfect adjustment between the capacities of the primary and secondary circuits of the solenoid and the strength of the current.

For the purpose of giving the current at the same time to the posterior and to the anterior part of the thorax of the patient, Mr. Rolland ordered two similar pieces of apparatus from the firm of Rochefort of Paris. Mr. Rochefort had the idea of constructing the apparatus with a single transformer and in this way discovered the bipolarity of resonators.

In order to obtain bipolarity it is necessary that the discharges produced by a resonator within a given time be of opposite sign to that produced by the other identical resonator; that is, similarly to what occurs in the Gramme ring to develop continuous current. These discharges are toward each other with the same energy as is observed in the discharges of electrostatic machines, and through all bodies, whether they be good or poor conductors.

In order to obtain this result, Rochefort connects the poles of the transformer with two like jars connected back to back through their internal coatings, and connects the external coatings with the primary circuits of two Oudin resonators, in such manner that the high-frequency currents traverse them in inverse direction. Fig. 2a of the note sent by Mr. Rochefort to the French Electrotherapeutical Society perfectly explains this arrangement. (See Fig. 1.)

The currents induced in the secondary circuits will likewise be of inverse direction, and the polarity of the two ends of the solenoid will be of opposite sign.

Dr. Oudin is right in his affirmation that bipolarity really exists in simple resonators, because the point at which the application is made takes a potential of opposite sign to that of the current; but it cannot be denied that the potential with bipolar apparatus is much higher than with the simple type, because the length of the discharge is greater.

But to obtain this result, it is necessary to have between the capacities of the primary circuits of the resonators a perfect adjustment, which it is very difficult to obtain by the process of running one of the contacts over the coils.

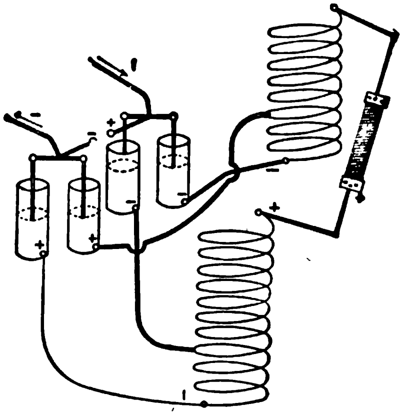

Fig. 1.

To overcome this difficulty in the endeavor, I came upon the idea of taking the coils from the middle of a single resonator as the common primary circuit, and the upper and lower ones as secondary circuits in order to obtain thus a perfect accord between the primaries. Fig. 2 shows my manner of proceeding.

The result was satisfactory, and since then I have had the pleasure of communicating it to Dr. Oudin, who kindly gave an account thereof to the French Electrotherapeutical Society, which directed the publication in its bulletin of a note on the subject, translated into French.

It might at first sight be thought that the modification devised by me of the Oudin resonator is nothing more than the union of two solenoids, which arrangement was made known by Mr. Rochefort in Fig. 3 of his note to the Electrotherapeutical Society, which figure I reproduce; but if the direction of winding of the wire is observed, it will be seen that one solenoid cannot be considered as a continuation of the other.

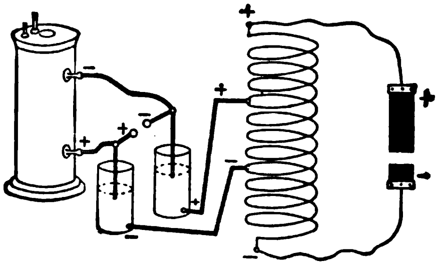

FIG 2.

In order to obtain bipolarity in an easier way, I form a vertical solenoid of a number of coils divisible by three; I take the third part of the middle as primary circuit, fix to the same the connections of the external coatings of the condensers and connect the free ends of the solenoid with thick and flexible wires which allow of making the therapeutical application at a distance from the apparatus.

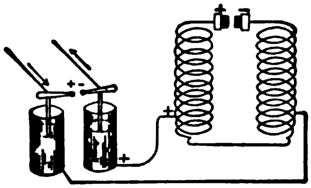

FIG 3.

If the ends of these flexible wires are brought opposite to each other, it is noticed that the discharge is larger at one of the ends; and when changing, by means of the commutator, the direction of the primary current of the transformer, the larger discharge is transferred to the other end, which proves that one of the poles is predominant.

If the discharges have different lengths, the capacities of the primary and secondary circuits being equal, we must infer that they are not identical. It is very probable that the same phenomenon will be found in the resonators as in the coils in which, upon condition that the currents are alternating in the induced circuit, one of them is predominant and fixes the poles.

The importance of this will be understood and also the usefulness through knowledge of the predominance of the poles for the utilization of the resonators, as well in wireless telegraphy as in electro-therapeutics — especially if, as is very probable, the poles be fixed.

If the balls of the detonator are replaced by narrow strips of tinfoil, leaving between them a small space, there is produced, at the moment the current is made to pass, an undulating and reddish spark which melts the strips connected with the poles of the coil. The distance between the ends of the strips being increased in consequence of the fusion, there is a moment in which the spark acquires an intense brilliancy, ceases to melt the metal, and the conditions of good operation of the resonator are automatically established. If the apparatus is continued in operation, an increase of the distance between the strips and consequently of the length of the spark will be observed; but more slowly and not by fusion but by volatilization of the tinfoil. Although the tinfoil melts and volatilizes at the ends of both strips, the consumption is more rapid in the negative strip. (Fig. 4.)

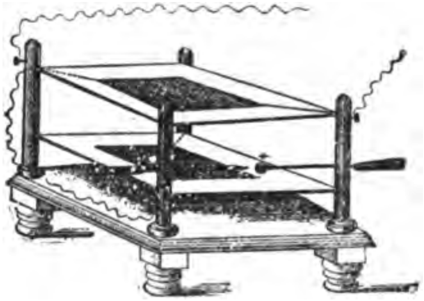

FIG 4.

Under these conditions there is an instant when the spark produces a musical sound, the pitch of which varies according to the rapidity of the breaks in the primary current. The discharge which escapes from the brush which I use for therapeutical applications takes on the appearance of a large violet crest visible in the full light of day and reproducing the sound of the detonator.

At the end of a certain time, the spark of the detonator becomes intermittent and then ceases completely, when the electric pressure of the condensers is insufficient to overcome the distance between the free ends of the strips, and it becomes necessary to re-establish the operation or bring the strips closer, or interpose a small insulated metal body in which the spark finds a point of support. By supporting the spark, it reaches a length of 6 to 7 cm, and the discharge attains its maximum strength; but it is absolutely necessary that the tinfoil strips have a regular thickness so as not to volatilize rapidly, or to substitute but one of the balls of the detonator for one of the tinfoil strips.

It can be proved that the positive pole is found in the end at which the discharge is greatest, by connecting the points of the solenoid with a Geissler tube which allows of distinguishing the poles. The negative ball appears then surrounded, as does also its handle, by a violet light, the positive one lighting up less. Although the phenomenon is not as clear as when the tube is connected with a coil, it is nevertheless sufficiently perceptible to distinguish the poles.

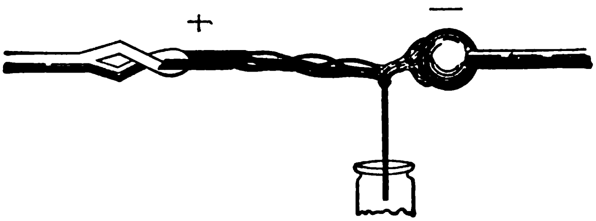

FIG 5.

Thus if we connect the external coatings of the condensers with the coils of the middle of a horizontal solenoid, and the internal ones with the poles of the coil, also horizontal, there will be established at the ends of the solenoid two poles of opposite sign to those of the coil.

In view of the fact that the positive discharge passes longitudinally over the negative, it is very probable that it has a more efficacious therapeutical action, especially in the operation on interior organs; and it should be preferred in the treatment of pulmonary tuberculosis.

In order to know when a current of high frequency is constant and has acquired its greatest strength, I employ an incandescent lamp, placed in a circular copper circuit of the same diameter as that of the coils of the solenoid, set up parallel to the middle coil. The fixed and brilliantly white light of the lamp indicates that the intensity of induction in the primary circuit of the solenoid is at its maximum.

To briefly sum up:

1. It is possible to obtain bipolarity of currents with a single solenoid, by taking the turns of the middle as primary circuit.
2. In the generation of high-frequency currents, one of the poles of the detonator predominates over the other, which is demonstrated by the greater consumption of one of two tinfoil strips.
3. The greater the length acquired by the spark of the detonator, the longer and fuller is the discharge at the resonator.
4. In order to modify the length of the discharge, it is not necessary to change the connections of the condensers with the solenoid, for the same result can be reached by changing the length of the spark.
5. There exists a predominance of poles in the ends of the solenoid, and that one is positive which gives the larger discharge.
6. Supposing the bipolar solenoid to be parallel to the coil of the transformer, then the poles of the same side are of opposite sign.

DISCUSSION.

CHAIRMAN MORTON: I simply wish to say, as a matter of record, and I am sure I express in a general way the opinion of every one here, that this method is an excellent, simple, and practical one, that deserves to be put into practice by ourselves as medical men. It is practical and extremely easy. You simply tap an ordinary resonator at two points and then the O'Farrill method is accomplished.

We will at once take up the program of the day, and we will give preference to the papers to be presented by the delegates of the American Electrotherapeutical Association, and I will announce as the first paper that of Dr. Herdman.

DUPUYTREN'S CONTRACTION, WITH INDICATIONS AS TO TREATMENT.

BY PROF. WM. J. HERDMAN, *University of Michigan, Delegate of American Electrotherapeutic Association.*

Acquired deformities of the hand may result from a variety of causes, taking their origin in the skin, the fascia, muscles, nerves, ligaments, joints or bones. Direct injury to a nerve or muscle or fascia may result in permanent contraction of the part affected. Severe burns or lacerations of the hand may result in cicatricial contractions that distort and greatly impede the actions of the hand, producing, at times, permanent disability. But a not uncommon disorder that affects the tissues of the hand is an affection of the palmar fascia, which, by reason of the peculiar deformity it uniformly occasions, and from the surgeon who, among the first, accurately described its pathology, has received the name of Dupuytren's contraction.

This disorder is rarely seen in persons who have not passed middle life, and, although cases have been found among women, it is in men that it is observed in the vast majority of instances. Slow and insidious in its onset, the first change that is noticed in the surface is a thickening or bunching of the integument in the palm of the hand in the line of one of the fingers, most frequently the ring or little finger. This elevated and hardened spot may be of the size of a small shot or split pea when first noticed, and upon pressure may prove slightly sensitive. It is commonly located as far forward as the third or distal crease in the palm. This little elevation may soon be followed by others of a similar character, either in advance or behind it in the same longitudinal line, or to either side and slightly in advance of the original spot. The effect of these formations is to moderately constrict and fix the integument of the palm and render it less freely movable over the subcutaneous tissue. Subsequently, in the line of the nodules, distinct bands begin to form underneath the integument. Usually a longitudinal one is first observed, which, upon an attempt at extension,

FIG. 1. DUPUYTREN'S CONTRACTION, UNTREATED.

FIG. 2. DUPUYTREN'S CONTRACTION, TREATED.

can be distinctly defined extending to the palmar surface of the first phalanx of the affected finger, and at times it can be observed to have an insertion as far forward as the second, or even the third phalanx. (Fig. 1.) Before the longitudinal band has become very prominent, lateral bands, taking their origin from the longitudinal one, can be observed running off to either side, inclining slightly forward, and being lost in the bases of the digits of the adjoining fingers.

This is the usual order of changes and the appearances observed as the deformity progresses; there may, however, be frequent variations from it. Instead of one, there may be two or even more longitudinal bands, while the transverse bands may be more prominent than the longitudinal ones. As soon as these bands become prominent, the patient finds it quite impossible to extend the bridled finger, and this attempt is in no respect more successful when the hand is flexed at the wrist upon the forearm, as is the case when the finger contraction is due to shortening of the flexor tendons. The degree to which the finger or fingers may be drawn down upon the palm varies much in different persons, and according to the duration of the disease in each case. In some cases there is but a slight impediment to the power of extension, while in others the contraction has steadily progressed until the nails of the fingers are buried in the tissues of the palm. It is remarkable that certain fingers are much more liable to this form of contraction than others. From statistics drawn from a hundred cases which I have been able to collect, some ten or twelve of which have occurred in my own practice, the following facts have been derived: The ring finger contracted 93 times; the little finger contracted 79 times; the middle finger contracted 45 times; the index finger 15 times; the thumb 9 times; the ring finger contracted alone, 18 times; the little and index fingers each, alone, 4 times; the thumb alone, never.

The most frequent combination was that of the ring and little finger, which occurred 67 times, while the ring, middle and little fingers were together involved in the contraction 17 times.

Usually it is only the first phalanx of the finger that is constricted so that the affected finger can be fully extended, except at the metacarpophalangeal joint. Yet in 7 cases it was found that the second phalanx alone was involved, while in 6 cases the contracting bands extended to all three phalanges of the affected fingers. There seems to be but little distinction as between the right and left hand. Out of 75 cases the right hand alone was involved 24 times, the left alone 13 times, both being involved 38 times. The right hand was affected therefore 62 times, the left 51.

When both hands are affected I have noticed a remarkable symmetry in the fingers involved, the only difference being the less degree of progress in the left. All observers have not, however, had this same experience, for some record considerable variation as between the two hands.

In order that we may clearly understand the mechanism of these contractions, it will be necessary for us to examine somewhat more in detail than the ordinary text-book description affords, the distribution of that structure in which Dupuytren found the pathological process take its departure, and to which almost the entire changes producing the deformity are confined.

Normal Anatomy.

That layer of connective tissue, which we term subcutaneous or superficial fascia, because of its uniform distribution immediately beneath the integument, varies in the amount and nature of its development owing to the function of the locality where it is found. The integument is more or less intimately connected with it by fibres from the connective tissue layer passing into and blending with the deeper layers of the derma. At times this union between the derma and the subcutaneous connective tissue is very slight, the connecting fibres few and slender and the underlying connective tissue itself open and lax, forming but an indifferent layer, sufficient only for the proper support of the lymphatics, blood-vessels, nerves, etc., that ramify in it, while the interstices between the fibres oftentimes contain cells stored with fat. In the more exposed regions, however, as the back of the arms, front of the thighs, etc., the integument and superficial fascia become more dense and thicker, and a closer union is observed between the integument and fascia, their connecting fibres being shorter, more numerous and stronger.

In such localities as the soles of the feet and the palms of the hands, where, by reason of the functions of these parts, greater density of these protecting coverings is required, we find the superficial fascia greatly increased in thickness, and its union with the overlying derma still more intimate, while the deposits of fat in its meshes form no longer a continuous layer, but are gathered in little pellets, occupying the interval between the numerous fasciculi which connect the skin with the underlying dense layer of fascia. The palmar fascia is usually spoken of as composed of a *central* and *two lateral portions*. The central portion is narrow above, near the wrist, where it is continuous with the lower margin of the annular ligament, and is strengthened by the expansion of the tendon of the palmaris longus muscle; it widens as it extends towards the finger. Opposite the heads of the metacarpal bones, its fibres, thus far uniformly distributed, are now grouped, to some extent, into four slips for the four fingers, each slip again dividing opposite the metacarpophalangeal joint, and the divisions passing one on either side of the flexor tendons, and being inserted, for the most part, into the sides of the first phalanx and glenoid ligament; but on careful dissection fibres are found inserted as far forward as the lateral and palmar surfaces of the second, and even of the third phalanx, while the removal of the integument in the attempt to trace these deeper fibres has severed the bands which served to unite the fascia to the skin throughout its entire expansion, which bands are found to be especially abundant over the ulnar surface of the palm.

Although the transverse fibres of the fascia forming this central portion are less numerous after the separate slips are formed for each finger, there is no complete interruption of them, and at the digital margin of the palm these transverse fibres form a distinct band stretching from the ulnar to the radial side of the hand. This band of transverse fibres gives form and strength to the web of the fingers, and constitute what the French anatomists term the "fibres of Gerdy." Some of these fibres stretch entirely across the palm, while shorter ones join two or more fingers only. The longitudinal fibres of the central layer of fascia freely interweave with the transverse fasciculi. The lateral portions of the palmar fascia are thin and less continuous fibrous layers stretching from the central portion over the muscles of the ball of the thumb on the one side, and on the other covering the muscles of the little finger and being continuous, both on the ulnar and radial margins of the hand, with the fascia of the dorsal surface.

Pathological Anatomy.

It can be readily seen from this description of the arrangement of the several portions composing the fascia, that any abnormal shortening or contraction of one or more of the longitudinal fasciculi of the *central portion* would result in traction upon the transverse fibres, the "fibres of Gerdy," and such of the fibres of the fascia as are inserted into the integument in the vicinity of the affected region. Slight contraction of the fascia would cause the little nodular bunches in the integument, while a more advanced state of contraction would result in the prominent longitudinal and transverse or crescentic ridges, with flexion of the first or even the second or third phalanx of one or more fingers, which are the characteristic appearances of the deformity when well established.

The opportunities for making a careful dissection and microscopical examination of these changes have not been many, but it seems to be the conclusion of Dupuytren, Goyrand, Adams and others who have studied the pathological histology that changes in the fascia alone may and does account for all the phenomena which these cases present.

In no case where dissection has been made is any record given of contraction of the flexor tendons, while in ten cases at least, it is especially stated that they were entirely normal.

Recently Nichols,[1] who has studied the histology of two cases in their early or developing stage, finds that the cellular and vascular elements are much more abundant at this period and that later the cells and vessels diminish, leaving the dense fibrous mass which has commonly been described. The hypertrophy of the fibrous tissues occurs especially along the course and in proximity to the small blood vessels. This author calls attention to the necessity for taking into account this fibro-plastic action and the abundant proliferation of connective tissue cells and their relation to their vascular elements in any attempt at an etiological explanation.

The skin, which to all appearances is thickened and hypertrophied at the seat of the ridges and nodules on the surface, and which has been assumed by many to be the real cause and starting point in the pathological changes, has been found, when freed from its attachments to the underlying constricting fasciculi, to be normal in thickness and microscopical structure. The apparent increase in its elements is wholly due to the density produced by the constriction and the absorption of the underlying deposits of fat, which no doubt atrophied by reason of the compression to which they were subjected. The changes, therefore, are thus found to be confined to the fascia alone, and consist in shortening and hypertrophy of irregular bundles which take their origin from the fascia and have an insertion quite variable, some in the skin of the palm or palmar surface of the digits, others into the ten-

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[1] *New York Medical News*, 1899.

dinous sheaths, while others are inserted into the bones of the digits, either laterally or as far as their dorsal surface. It is not necessary to assume, as some have done, that any of the normal fibres of the fascia are found distributed in all the localities where these thickened bands have been observed.

Diagnosis.

An accurate knowledge of the normal distribution of the palmar fascia and its manner of attachment to contiguous parts ought to prove a sufficient safeguard against any mistakes as to the tissues involved in this deformity, and indicate to the surgeon or physician the proper course to be pursued in treatment. Yet in certain of our surgical works of to-day, and not infrequently good surgeons, are erroneous opinions expressed both as to the pathology and treatment of this affection. The most common error that is committed in diagnosis is the assumption that the deformity is due to contraction of the flexor tendons, and treatment based on this assumption has not in a few instances proved disastrous, while, on the contrary, treatment has been withheld, by reason of this error, which might, if properly applied, have greatly contributed to the comfort and efficiency of many sufferers.

It is not necessary to dwell upon the differential diagnosis as between contraction of the flexor tendons and the palmar fascia, after the minute description that has been given of the anatomy of the latter, but it will suffice to say that at the point where the prominent ridges are observed in the palm in cases of fascia contraction, no such appearance could be produced by contraction of the flexor tendons, for the reason that they are so firmly bound down to the bones at this point by the strong fibres of their enveloping sheaths, that the most extreme flexion of the fingers never results in a prominence of the tendons. Again, contraction of the flexor tendons by reason of this insertion to the second and third phalanges of the fingers would primarily cause flexion of these phalanges, while in the vast majority of instances it is the proximal or first phalanx that is flexed in contraction of the palmar fascia, and no position of the hand will permit of its being extended.

Etiology.

In spite of the careful researches that have been made with the view of determining the etiology of this diseased condition, no very satisfactory conclusion has yet been reached.

Age, as we have seen, is an important factor, for in the vast majority of instances on record the deformity does not appear before the age of 50 years. In one of my cases the patient was 55, in another 65, another 73, while the others ranged between 50 and 70.

Sex also seems to play a part in the causation, since the deformity occurs in the male ten to one as compared with the opposite sex.

Occupation does not seem to have any share in determining the result, since the deformity has been observed in all conditions of life, the laborer, the mechanic, the shopkeeper and the professional man being affected with almost equal frequency. From this it would appear that the cause to which this deformity has been so commonly assigned, that is, a succession of mild injuries to the palm by reason of the manual employment in which the patient has engaged during the active period of life, can not be allowed much weight. Yet in some cases that have come under my observation I have thought that irritation from peculiar kinds of manual labor, such as caused frequent and undue pressure on the palmar fascia, if not the chief cause, may have acted in the rôle of an important accessory cause. My impression agrees with that of most observers also in that the greater number of those whom I have seen as sufferers from this affection have belonged to the professional class.

The majority of observers agree in the opinion that *a gouty or rheumatic state* is the more common etiological factor to be observed in these cases. In the records that I have been able to examine, in about 50 cases where the constitutional conditions were mentioned, gout was positively indicated in at least 45, while rheumatism seems to prevail with almost equal frequency. In my own cases, although in but one instance was the patient affected with decided rheumatic attacks, yet in all the rheumatic diathesis was well marked by occasional lumbago, muscular and joint soreness, and an excess of uric acid deposits in the urine. It is a noteworthy fact that the contraction much more frequently takes place over that region of the palm supplied by the ulnar nerve, and perhaps in the exposed condition of this nerve to rheumatic irritation, especially in the vicinity of the elbow joint, we may discover an important element in the causation. Neuritis of the ulnar nerve, in its course above the hand and in its palmar distribution as well, has been frequently noticed in the progress of this disorder, and the disturbed nutrition occasioned by the nerve irritation might well account for the onset of the subacute inflammation in the fascia. Adams calls attention to the frequent involvement of the expanded tendon of the palmaris longus in the affection, and cites this in support of the opinion that nerve irritation may be present as a cause in some instances, at least. In addition he claims that the facts of an evident hereditary tendency, the frequent occurrence of the contraction in both hands and the large preponderance of cases among the well-to-do and professional classes favors the view that the fibrous increase has a gouty or rheumatic origin.

My own experience convinces me that the preponderance of evidence as to the etiology of this disorder sustains the opinion that we have to do with a subacute inflammation of the subcutaneous connective tissue elements, resulting in a hyperplasia of these elements and subsequent cicatricial contraction of the new-formed tissue. The disorder seems to have a very close relationship to that constitutional state either rheumatic or gouty which by a slow process of nerve and other tissue irritation issues in subacute inflammation, distorts the nutritive process and creates deformities in the small joints and bones of the hands and feet.

I look upon these fascial changes in Dupuytren's contraction as but one of the expressions of a constitutional diathesis, nutritional or rheumatic in nature, in which an irritant present in the fluids of the body and due in all probability to incomplete metabolism, is the cause of subacute inflammation of the connective tissue elements. The nerve irritation if not antecedent to the connective tissue inflammation, a view to which I incline, is nevertheless an important factor in maintaining the hyperaemia that feeds the inflammatory process.

Treatment.

If the opinion here expressed as to the etiology and pathology of these fibrous contractions is the correct one, then the treatment of the local condition is but an incident in the proper management of such cases. A course of anti-gouty or anti-rheumatic treatment is indicated and should be maintained with the purpose of freeing the system from the irritating effects of the crude waste products with which the fluids of the body are loaded. Aside from the customary remedies for this purpose—I, in common with many others who are making daily use of the aid which electricity can render, employ it in cases of this nature with a view of bringing about a more complete metabolism in the products of tissue waste.

The electric energy is transformed into the chemical and mechanical forms of energy needed in the system to bring about this result, the tone of the muscular tissue is heightened, thus promoting more prompt and complete removal of effete products and the nervous action is stimulated. For this general stimulating, toning and transforming action the high-tension forms of electric energy seem best adapted, and it matters little whether these be obtained from the static machine, the Ruhmkorff or the Tesla coil, or from self-induction in the alternating magnetic fields after the method of D'Arsonval, Piffard or that employed by myself. The old-time methods of "general galvanism" accomplish the same result if they are persistently and faithfully made use of, but they are slower in effecting the required changes in tissue action and much less convenient in application. As for the local deformity, it can be dealt with in a variety of ways. (Fig. 2.) The surgeon has the choice of the subcutaneous method of severing the constricting bands, as strongly advocated and practiced by Adams of London, or the open method of dissection which Tubby[2] advises. It has always seemed to me much more natural and scientific to counteract these cicatricial contractions if possible by some method which will not repeat the very process of hyperplasia which has been the cause of the contractions in the first instance. A surgical injury no matter how aseptically and skillfully performed, is followed by the processes of repair, and a large share of these consist of an increase of connective tissue cells and formation of new cicatricial tissue from them which in many instances results ultimately in as bad if not worse state of contraction than that which first obtained.

We have in the action upon living animal tissues of the direct electric current of suitable strength a series of effects which seem to me is most admirably adapted to meet this tendency to cicatricial contractions in fibrous tissues. When the negative electrode conveying a current of this nature, of a few milliamperes strength. is brought into contact with the tissues, the alkaline constituents of the tissues are increased in the vicinity by electrolysis and the fluidity by phoresis. A softening of the new-formed tissue is thus brought about, its disintegration is favored, absorption of the excess takes place and a return to the normal amount of connective tissue belonging to the part is effected. This is a simple fact in the action of the direct current upon cicatricial tissue which

[2] London, *Lancet*, Jan. 12, 1901.

is of practical value wherever it is intelligently and skillfully employed and has a wide range of efficiency in many disorders which are now dealt with by surgery, in what appears to me. a most bungling manner. I refer especially to those disorders which are known as *strictures* due to inflammation, hyperplasia and subsequent contraction of the submucous connective tissue lining the various tubes and passages of the body such as the urethra, the Eustachian tube, the nasal duct, the uterine cervical canal and the like.

The hyperplasia of the palmar fascia with its subsequent contractions can be counteracted in this manner and the deformity prevented or removed—but it requires patience and persistency on the part of both physician and patient and faith and skill in the method. The cutting operation is more impressive, more spectacular, but if we keep in mind the ultimate result and the best interest of the patient the electric method has the most to recommend it.

There are, of course, accessory measures that it is advisable to employ both for the benefit of the constitutional and the local state, such as diet, hot baths, oily embrocations, massage, and, probably in some cases, properly adjusted splints with the view of maintaining moderate counteracting tension upon the constricting bands; but these are not in themselves curative.

DISCUSSION.

Dr. G. B. MASSEY: I thought the author was going to say he used puncture, but the plain negative pole and constant current were described. I would suggest that puncture might be tried, employing a curved surgical needle below or rather within the substance of the skin, using one-half or one milliampere under cocaine. This would make the action even more definite than described in the paper, although we might not get any better results. This is a rare condition. It is, so far as I have heard, not remediable by the knife operation. I have met several physicians who have this contraction and who have regarded it as inoperable, so that this paper is valuable in suggestion to us. It is a disease of no great importance, but one can readily see the annoyance produced by it if you cannot shake hands, or if a man cannot open his hands entirely to do any of the more delicate work that comes particularly to physicians.

CHAIRMAN MORTON: Of course, the principal value of this paper lies in the suggestion of a remedy for a hitherto practically inoperable disease. The technique employed is so simple that it admits of little debate, and I would suggest that those who use the Roentgen ray might find in it a remediable agent in reducing the cicatricial contraction.

The following paper was then read:

ROENTGEN-RAY DIAGNOSIS OF CALCULI.

BY RUSSELL H. BOGGS, M. D., *Delegate of American Electrotherapeutic Association.*

A scientific application of the X-ray in the diognosis of calculi has shown this method to be far superior to other means of diagnosis. Since the value of this method is so generally recognized in medical science, the question may now be asked, should a surgeon, under any circumstances, ask a patient to submit to an operation for calculi without first having a radiographic examination? According to the judgment of the leading surgeons, every case should be carefully examined by the X-ray, and the radiograph used as a guide for the operation. When such a procedure has been adopted by all surgeons, they will relieve themselves of a great deal of responsibility and the patient, frequently, of submitting to an unnecessary operation. Many times in the past, I have heard surgeons not only say that without the X-ray they could not have made a positive diagnosis, but that after the diagnosis had been made they could not have found the calculi in the urinary tract without the radiograph.

It has been said so many times that, unless the radiograph reaches the standard, no diagnosis should be made. But, still, many make a diagnosis from an unsafe negative and not only bring discredit upon themselves, but upon the application of the X-ray as well. It has been agreed upon by a large number of operators, that a plate, in order to make a positive diagnosis of a kidney-stone, should show every articulation, the spinous and transverse processes of the vertebræ, the outline of the last two ribs and the psoas muscles. A radiograph showing a gall-stone should show the outline and detail of the ribs, vertebræ, upper border of the liver and division of the bronchial tubes; and a radiograph to show a stone in the bladder, should show all details in bony structure of the pelvis.

The amount of knowledge gained from examining a radiograph depends entirely upon the experience of the operator. Too much stress cannot be laid upon the interpretation of the negative, otherwise small calculi composed of uric acid may be overlooked. Great care should be taken in making these radiographs, otherwise an imperfection in the plate might be mistaken for a calculus. This shows the necessity of taking two radiographs before making a positive diagnosis. The laity may be glad that nearly all the hospitals have realized that it requires more knowledge of medicine and electricity than the head nurse or some other inexperienced party possesses to make a careful diagnosis of calculi.

In my experience I have seen radiographs which did not come up to the standard, and a negative diagnosis had been made. In one of these cases, the surgeon was very positive from the patient's symptoms, that there was a stone in the urinary tract, but was undecided whether it was in the kidney or ureter. He sent the patient to my office for an examination. Two radiographs were taken in the usual way by placing one plate upon the other, and both negatives showed a stone in the pelvis of the kidney. On the other hand, many of you have seen a positive diagnosis made from a poor negative, and, of course, after the operation the surgeon and assistants had a very inferior idea of the X-ray. The radiograph should be up to the standard and then if the surgeon does not find the calculus, we can say it was due to lack of skill on his part and not the fault of the X-ray.

The difficulties in radiographing calculi are numerous, and practice is the only means by which this class of work can be done successfully. Many are continually asking, what exposure do you give, whose tubes and plates do you use, etc.? This all means very little. Every part of the work should be done in an accurate way, and a perfect radiograph will be produced.

An English writer states: "Personally, I know of no application of science in which the personal equation plays a more important part than in the application of the X-ray in medicine and surgery, and it, therefore, follows that it is exceedingly difficult to lay down fixed rules."

You can produce good radiographs by using any make of tube, if properly constructed, any make of plate, and almost any length of exposure. The exposure varies with the apparatus, size of the patient and may range any place from 5 seconds to 10 minutes. I prefer to make a short exposure and if the patient does not weigh over 150 pounds, usually I give from 15 to 30 seconds. By so doing, the patient can hold his breath and there is no movement of the kidney and the image is more distinct. How much the kidney moves during respiration is a question, but there is a certain amount of movement.

I will mention an instance where a uric acid calculus, scarcely discernible on the plate when an exposure of two minutes was given, was seen more distinctly when I had made a second plate in 30 seconds while the patient was holding his breath. Both radiographs showed the psoas muscle, but the stone was in the upper portion of the left kidney and partly obscured by the stomach. I believe the motion by respiration made the difference.

It has been well demonstrated that, with almost any induction coil, good work can be done, providing the technic is nearly perfect. However, variable inductance in the primary is of a decided advantage. There is a greater difference in the X-ray tube than any other part of the apparatus, and the variable inductance is an advantage when working with low tubes.

You will find tubes made by the same manufacturers, one with which radiographs can be made very quickly, while with another tube which appears to be identical, you will not be able to produce results no matter how long an exposure is given. I have purchased a number of tubes and have learned that the tube was largely accountable for successful or unsuccessful work, both in radiography or radiotheraphy, and the sooner the profession will learn that many of the failures are due to faulty tubes, the sooner the X-ray will attain its proper standing.

In radiography, I have always attempted to secure a tube which is focused to a point on the anode, which, when the internal resistance is low, will give sufficient penetration. I have usually found, when the light will penetrate the chest and show the bones very dark on the screen and the internal resistance of the tube is less than 2 ins., i. e., if it will not back a parallel spark of more than 2 ins., it may be considered a valuable tube. According to Ohm's law, the less resistance of the tube, the more current you can pass through it, and the more work will be done in a given time. In a high-vacuum tube, a larger amount of voltage is used to overcome the resistance. Then again, many use a tube which has too great penetration either to secure the best results or to do the work in the shortest time. It is only the rays that remain in the plate which are active.

The diagnosis of gall-stones by the X-ray has been accomplished by a number of physicians, and so far, I believe, no one claims to make a negative diagnosis, i. e., if the radiograph does not show a gall-stone the operator would not be positive that a stone was not present; while if the radiograph, made properly, shows a shadow, you can safely make a diagnosis of gall-stones. The reason why all gall-stones cannot be located by the X-ray is on account of the composition of certain stones.

In Thompson's "Practice of Medicine," there is the following classification according to the chemical composition:

1. Chiefly cholesterin.
2. Bile — pigment and calcium.
3. Calcium carbonate and phosphate.

"Every gall-stone, like a vesical calculus, is found to have a nucleus of such material as bilirubin, calcium, salts, or, exceptionally, a foreign body or micro-organisms. Around the nucleus the cholesterin is deposited in layers, which are both concentric and radiating. The external laminæ are brown, relatively hard, and composed in a greater part of calcium salt. In addition to the above fatty and bile acids, magnesium, iron, and copper are found."

When calculi are composed almost of pure cholesterin, they cannot be located by the X-ray, but if they contain sufficient mineral substances, the stones can be detected. At present, it cannot be stated what percentage of gall-stones can be located by the X-ray.

The only point in connection with the technic of making radiographs of biliary calculi I want to mention, is that the exposure should not exceed 30 seconds, while the patient holds his breath and then there will not be any movement of the calculi.

While it has been shown that a negative diagnosis in a case of suspected gall-stone is not always correct with a radiograph which has reached the standard, it is safe to make both a positive and a negative diagnosis of the stone in the urinary tract, providing the radiograph shows sufficient detail.

I have no cases of unusual interest of stone in the pelvis or substance of kidney which have never been reported, but I have located stones in eight cases in the ureter at its junction with the bladder. In two of these cases there was a stone on both sides in the same location, at the junction of the ureter and the bladder.

Five of these cases were referred by Dr. Buchanan, and, after the radiographs were taken and an examination was made through the rectum, in two of these cases the calculus could be felt very easily, and in one case, when the calculus was touched, the patient had pain in the region of the kidney. The history of this is so interesting that I shall report part of it.

Case 1. Mr. B. had been troubled with pain in his right side for some time and during one of these attacks, while in Philadelphia, called on a very prominent diagnostician and a noted surgeon who made a diagnosis of appendicitis, and told him that he must have his appendix removed within 24 hours. Fortunately, the patient refused to have this done, as there was certainly no appendicitis.

Case 2. Mr. G., age 25 years, had suffered with abdominal pain for more than two years. When in New York 12 months before coming for the X-ray examination, he had been operated upon for appendicitis. The patient most likely never had appendicitis, as the symptoms could have been all accounted for by renal colic.

Two radiographs were taken, one with a 15 and another with a 30-second exposure. Both plates were good and showed a stone in the left ureter, but the short exposure was the better. The patient weighed 145 pounds. He went to the hospital and Dr. Buchanan operated before the class of the West Penn Medical College.

The calculus was found in the first portion of the ureter. The patient made a good recovery and had hardly left the hospital when he had an attack of colic on the right side. Upon careful examination, the first radiograph showed a stone in the right ureter at its junction with the bladder. The patient went to Cambridge Springs and while there passed a calculus. Afterward, he returned to the Mercy Hospital and had the right kidney operated upon and a large amount of pus was found, following which he recovered. Another radiograph was subsequently taken which showed two small stones in the ureter at the junction of the bladder. These have not been removed, but the symptoms indicate that he will be compelled to undergo another operation.

Many surgeons have said it was unnecessary to make a radiograph to diagnose vesical calculi as they are so easily discovered by the sound. I have observed several cases in the past year in which the X-ray proved superior to the sound, not only in making a positive diagnosis, but also in showing the number, size and shape of the calculi. Then the surgeon is better able to decide which operation is indicated. It has often been said that there is considerable difficulty in radiographing small stones in the bladder on account of the bony structure of the pelvis, but so far, I have not found this to be the case, and in no instance have I failed to find a calculus where it was detected by the sound, and I have found stones which could not be located by the surgeon. A calculus of pin-point size in the bladder should be located by the X-ray.

In conclusion, therefore, no operation for calculi in the urinary tract should be undertaken without first having verified the diagnosis by an X-ray examination, but this examination must be conducted on as concise methods as the surgeon in removing the stone, with particular attention to technic, in order that the plate will always reach the necessary standard. After the plate has been made, it is essential that is is correctly interpreted. Two cases reported showed instances where a stone in the ureter had been diagnosed for appendicitis, and one had been operated upon.

It is a question whether the X-ray at the present time is of special advantage in the diagnosis of gall-stones, since a portion contain pure cholesterin which will not cast a shadow.

DISCUSSION.

Dr. T. **PROCTOR HALL**: In connection with the paper I wish to say that there is a possibility of platycytes along the line of the urethra. An examination of a case was recently made by Dr. Gregg, of Chicago, and a diagnosis of urethral calculus was made by very distinct shadows. Each one of those shadows represented a platycyte, and a number of cases have been found since. A diagnosis, even with the aid of the X-ray, should not be hastily made, but the result of the X-ray should be combined with other clinical data before making a positive diagnosis.

Dr. J. **SCOTT**: I agree with the author of this paper that all cases of suspected calculus should be examined by the X-ray, but I do not believe the ordinary operator is justified in making a negative diagnosis. If the X-ray showed a stone in the kidney or ureter, and we obtained this result on two or more plates, I think we could make a positive diagnosis. His suggestion that we should have a standard to compare our plates by is very important. I have had a number of surgeons tell me, "I have had X-ray pictures taken of suspected cases and not one has shown the presence of calculi, and I was almost positive they were present." They say the influence of this communicated to the patients discourages them operative interference, and from taking into consideration the other symptoms which are present. I think this work should be done only by men who are competent, men who will make a negative that will come up to the standard as given by Dr. Boggs. It also takes experience to interpret these negatives and to interpret the different shadows. It is easy to make a mistake.

Dr. G. C. **JOHNSTON**: In regard to the negative diagnosis of calculi, or the negative diagnosis of gall stone, I know of no operator who believes he can do it. The ability to make diagnosis of gall stones is in direct proportion to the skill and experience of the operator. When I first began to make diagnosis of gall stones I could make a negative diagnosis with equal facility, but now I cannot make a negative, I am glad if I make a positive. In applying one's self to the standard as set forth by Dr. Boggs, one is reasonably safe in making a positive diagnosis of calculi, but he wants to remember that the only positive things on earth are death and taxes. The fact that a surgeon does not find calculus when it has been shown by the X-ray the doctor says is due to the surgeon and not the fault of the X-ray. I believe that to be true. I have seen cases operated on by the surgeon without finding a calculus, but when he went back the second time he found it. I know one case where it was found *post mortem*. The X-ray cannot lie; it can be misinterpreted, but it cannot lie. I believe there are few men fitted to interpret a radiagraph. I prefer to interpret my own and I know Dr. Boggs does. The doctor says a great many cases of failure are due to faulty tubes, and by that he means tubes unfit for that line of work.

There is only one other thing I wish to call attention to. Just because a patient has a small stone in the ureter it does not follow that that stone must be immediately removed. I believe in the course of time it might become necessary, but if the surgeon is satisfied that the stone is there and it is a small stone, one that might possibly pass away, we should give it a chance to pass. But we know its location and if it gives any trouble at any time we can go after it.

Dr. MIHRAN K. KASSABIAN: I would like to call the attention of the section to the following important factors in the technique, viz., the time of exposure, process of development, correct interpretation of the negative.

The time of exposure, of course, will depend upon the degree of penetration of the rays and the thickness of the tissues. I prefer the short exposure with the tube of a high degree of vacuum, or penetration, for the reason that there will be no danger of production of a diffusion or secondary rays, which produce flat and foggy negatives and also because there will be less discomfort and movement of the diaphragm and abdominal viscera.

I believe that there is less danger of the rays penetrating the calculi in short exposures than in long exposures with low vacuum tube. I have experimented on the same patient with different tubes and found that a high vacuum tube with a short exposure gives more contrast and detail to the negative.

As to the process of the development of plates, I think that quite often the operator is uncertain as to the exact time of exposure, and the degree of penetration of his tube. These difficulties can be avoided by careful combination of the accelerator (sodium carbonate) and the reducing agent (metol and hydrochinon) and a dilution of the developer. The accelerator should be reduced in strength from one-third to one-half. If it is necessary later on, add more alkali. When the alkali is used in excess a fogged and flat negative is obtained, and less in contrast results.

The duration of the development is also important. Underdeveloped negatives have plenty of detail but the shadow of the calculus will be so faint that it may not be detected on the negative; *per contra* an over-developed as well as over-exposed negative will not show the shadow of the calculus.

The third point which is also most important is the reading of the negative. A positive diagnosis must not be made from a poor negative. Every small and large shadow should be accounted for. A properly diffused light should be used in reading and the suspected side should be compared with the supposed normal side. The skiagrapher should make his diagnosis from the negative only and not from the clinical or other symptons. In some favorable patients, and in soft negatives, the shadow of the kidney can often be detected. This will enable us to detect any neoplasm or abscess of the organ, both of which conditions show a widely diffused shadow.

In the Philadelphia Hospital, all within a month, I have had three cases which proved to be calculi in the pelvis of the kidney. The shadows were located just opposite the third lumbar vertabræ, one inch distant from the transverse process and three-quarters of an inch below the twelfth rib.

These small round shadows which are more frequently noticed on the left side and nearly corresponding to the lower portion of the ureter, occurring singly or in pairs, several years ago misled me, but subsequently an autopsy proved them to be phleboliths or vein stones. I certainly do not think that they are caused by sesamoid bones, as stated by the author. The intestinal tract should always be cleared before an X-ray examination in order to avoid any enteroliths appearing on the negative.

Chairman Morton: I would like to add a word which may be of interest to you. I made several usual X-ray pictures for stone in the kidney for Prof. Meyer of the Post-Graduate Medical School. We felt certain the stone was there and yet I could not get an affirmative picture. Prof. Meyer then put the patient on the operating table, opened him up and took the kidney out, laying it on the small of his back, and I placed a sensitive plate behind the exposed kidney. I took an X-ray picture and developed it. Prof. Meyer then incised the kidney and removed a calculus. This has never been published, and it is a contribution that may be added to radiography of calculus of the kidney.

Dr. Boggs: The stone was seen after the kidney was removed?

Chairman Morton: Before any operation whatever was made. As soon as we took the kidney out and laid it upon the small of the back, I placed a sensitive plate behind it, and made a brief exposure. I developed the plate immediately, while the patient was still under the anæsthetic.

Dr. Boggs: Did the plate show the psoas muscle and other necessary detail?

Chairman Morton: I do not remember that distinctly. It was about two years ago. With the best technique we could not get the stone. I only mention this to show that in cases of doubt a careful surgeon could call upon a radiographer for further assistance without delay and possibly with great advantage to the patient.

Dr. Wm. B. Snow: I wish to add but a few words to emphasize that which the discussion has developed. The particular work under consideration is the work of expert men with special aptitude for the work. I have been greatly interested in both the paper and discussion. The gentlemen who have taken part in this discussion have manifested a degree of familiarity with the subject and skill equal to that which would be found in any department of science. Those who will devote themselves to radiography, and acquire a thorough aptitude and technique in the matter of exposure and development, are the men who will succeed. It will probably never be possible for a large number of men to acquire an equal technique except they make it a thorough study associated with large practice. It is only those men who will give it the most careful and painstaking attention, and few surgeons interpret a skiagraph after it is taken, even by the most competent and skilled operator.

Dr. Boggs: I believe every kidney stone, unless it is a very small uric-acid calculus in an extremely large patient, can always be located by the X-ray if the radiograph shows the necessary detail.

I cannot agree with Dr. Kassabian about the high and low tubes. He says he uses a high tube, but it will not give the same amount of contrast and it is necessary to give a longer exposure with a high tube.

I will mention a *post-mortem* which was extremely interesting. It was a case that had been radiographed for vesical calculi. The patient had symptoms of vesical calculi, and the radiographs showed three small spots in the region of the bladder. A diagnosis of encysted vesical calculi was made. The surgeon opened up the bladder but was unable to find any stone and closed the wound. Six months afterward the man died of sarcoma of the pancreas, and they thought they would prove the fallacies of the X-ray diagnosis of vesical calculi. I had the pleasure of being present at the *post-mortem*. The pancreas and liver were sarcomatous and there were calcereous deposits in the omentum, and the three spots which showed in the bladder were found to be calcareous deposits from the disease.

I believe in every place where we see a shadow on the plate we can safely say it is either due to density in the kidney or in the intestine.

On motion of Dr. G. B. Massey, the Section of Electrotherapeutics extended a cordial invitation to the American Neurological Association to be present and participate in its deliberations.

Chairman Morton: We shall now have the pleasure of turning to a most interesting, if not the most interesting, part of our program. With your permission, I am going to ask you to listen to the third annual report of the committee of the American Electro-Therapeutic Association on "Current Classification and Nomenclature, with Further Tests on Electro-Static Machines."

I will leave it to you to express your appreciation of the services of this devoted, tireless, and industrious committee. I take pleasure, gentlemen of the Section, in welcoming here for the first time Prof. Samuel Sheldon of the Polytechnic Institute of Brooklyn. He has worked many days and nights in our service in solving these intricate questions, because we have presented him problems that have puzzled brains like his and those of our distinguished secretary, Mr. Jenks, who has been his co-laborer. The services of Mr. Jenks have been rendered so willingly that I take pleasure in bearing this further testimony to their value. You have these two representative workers among electrical engineers with you to-day, and in listening to their report we have the great pleasure of testifying to them our great appreciation of the particular service they have rendered to all of us medical men.

I have the pleasure of introducing to you Prof. Samuel Sheldon and Mr. Wm. Jenks, who co-operated with him in the work of this report.

ELECTROTHERAPEUTIC CURRENT CLASSIFICATION AND NOMENCLATURE.[1]

This report opened with a paper on "Further Experiments with Electrostatic Machines" by Samuel Sheldon, Ph. D., professor of physics and electrical engineering at the Brooklyn Polytechnic Institute.[2]

The report relates to (a) the *efficiency* and *current output* of electrostatic generators of the Holtz and Toepler-Holtz types; (b) the *current characteristics* in circuits supplied from such machines; (c) the *circuit characteristics,* inductance, resistance and capacity; upon which the character of the current depends.

In the second report of this Committee, in describing tests made to determine the efficiency (ratio of output to input) of electrostatic machines, mention was made of the unreliability of the needle-point, gap method of measuring the voltages of such machines, because of changes in the character of the discharges. This unreliability has been further shown by the experiments which form the basis of the third report.

A strictly mechanical method of determining the efficiency of such machines was therefore devised, consisting, first, in operating one electrostatic machine as a generator, the mechanical input of which was determined by the method followed and reported by this Committee in 1903. The current from this generator operated a second electrostatic machine as a motor, the mechanical output of which was measured by a spring-balance absorption dynamometer. The generator was then made to operate a third electrostatic machine as a motor, the input and output, respectively, of which were likewise mechanically measured in the same

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[1] Abstract of the Third Report of the Committee of the American Electrotherapeutic Association on Current Classification and Nomenclature. Read at the Joint Meeting of Section H of the Congress and the abovenamed Association, Sept. 15, 1904. For full text of this report see *Journal of Advanced Therapeutics; Transactions* of the Association for 1904.

[2] See Second Report of this Committee, read at Atlantic City, Sept. 24, 1903; *Journal of Advanced Therapeutics*, Vol. XXII, No. 1, January, 1904, p. 24 et seq.

manner. Finally, the second machine, acting as a generator, also operated the third machine as a motor, and the input and output were measured. From the measured inputs and outputs the individual efficiencies of the three machines were calculated for different outputs. Tests of this character were made upon a Van Houten & Ten Broeck Holtz machine with 12 revolving 32-in. plates; a Waite & Bartlett Holtz machine with 12 revolving 30-in. plates, and a McIntosh Toepler-Holtz machine with 8 revolving 30-in. plates.

The results of these tests are given in Table I.

TABLE I.

OUTPUT IN WATTS.	EFFICIENCIES IN PER CENT.		
	Waite & Bartlett.	Van Houten & Ten Broeck.	McIntosh.
1	12.3	13.0	13.0
2	16.5	18.7	18.1
3	20.3	23.1	21.6
4	23.6	26.7	24.5
5	26.4	29.4	27.5
6	28.7	33.0	30.3
7	31.4	35.4	32.5
8	33.7	37.8	34.6
9	35.4	40.3	36.7
10	37.6	42.5	38.6
11	39.4	44.4	40.6
12	41.0	46.2	42.8

The tests show that, commercially speaking, electrostatic machines have much higher efficiencies than have been generally supposed. As will be seen from the above table, each of these machines has an efficiency over 40 per cent. The losses are due to friction in the bearings, the churning of the air by the revolving plates, and current leakage when the machines are operated at high voltages.

The tests of current output were made upon the three machines already specified; also upon a special machine made for Dr. Titus, of New York, having 16 revolving 32-in. plates; also upon a high-speed machine having 2 revolving 30-in. mica plates, made by R. V. Wagner & Co.

These measurements demonstrated the following conditions governing the strength of the current generated by disk machines of the Holtz or Toepler-Holtz type, when they are properly excited and operated:

1). The current strength is directly proportional to the speed of rotation of the plates.

2). It is directly proportional to the length of the collecting combs.

3). It is directly proportional to the distance of the centers of the collecting combs from the axis of rotation of the plates.

4). It is directly proportional to the number of rotating plates.

Let n = number of rotating plates;
l = length of one collecting comb, in cms;
r = distance of center of collecting comb from the axis of rotation of the plates, in cms;
V = speed of rotation of the plates, in revolutions per minute;
I = strength of the current generated by the machine, in amperes.

Then

$$I = a\ Vlnr\ 10^{-11},$$

in which a is a constant, and 10^{-11} is the multiplying factor for obtaining the value of the current I in amperes. For all practical purposes a may be taken as equal to 57, and the equation then takes the final form

$$I = 57\ Vlnr\ 10^{-11}.$$

The observed values of the generated currents, the current strengths calculated by means of the above formula, and the data employed in the calculation are given in Table II.

TABLE II.

NAME OF MACHINE.	V.	n.	l.	r.	I.	I.
					Calculated.	Observed.
McIntosh	400	8	11.90	28.4	0.000616	0.000649
Waite & Bartlett	380	10	10.06	31.0	0.000712	0.000725
Wagner	1,305	2	12.10	32.1	0.000576	0.000540
Titus	265	5 8	6.86 18.72	46.0 41.8	0.000495	0.000533
		5 7	6.86 13.72	46.0 41.8	0.000639	0.000672
		5 11	6.86 13.72	46.0 41.8	0.001180	0.001042
Van Houten & Ten Broeck	340	12	14.09	33.7	0.001090	0.000968

It is to be understood that this formula only applies to machines when clean and dry, and operating normally. At other times the current will be less than the amount indicated by the formula.

The strength of the current generated (which may be calculated from this formula, and also indicated when the machine is short-circuited through an ammeter) seldom or never represents, in strength, the current that is utilized by the physician, either in a patient or in apparatus. The inevitable leakage of current, both inside and outside the machine, the amount of which leakage varies greatly with the conditions of operation, materially reduces the percentage of the generated current which can be utilized. On the other hand, currents resulting from high-frequency discharges may have a value enormously greater than the current generated, and this is due either to storage capacity, as by the use of condensers, or to transformer action, as by induction coils.

The physician is probably more interested in ascertaining the qualitative characteristics of the current derived from an electrostatic machine, and particularly whether it be a direct or an alternating current, than in determining quantitatively its physical constants, as, for example, in the case of an alternating current, the exact frequency or wave shape.

In any given circuit the character of the current which will result from a sudden electrical disturbance, such as arises from the discharge of a Leyden jar, is dependent upon three factors, namely: the inductance, resistance, and capacity of the circuit.

If the inductance, in henrys, be represented by L; the resistance, in ohms, by R, and the capacity, in farads, by C, then the current will be oscillatory, provided $\frac{1}{LC}$ be greater than $\frac{R^2}{4L^2}$; or in other words, if R^2C be less than $4L$.

If $\frac{1}{LC}$ be equal to or less than $\frac{R^2}{4L^2}$, the current will be unidirectional.

If the current be oscillatory, the frequency f of the oscillations, in cycles per second, will be

$$f = 0.159155 \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$$

The inductance of a circuit is independent of its resistance, and depends only upon its geometrical shape, and upon the presence or absence of magnetic substance, and particularly iron.

Many circuits in the physician's work consist essentially of a single loop in the shape of a skewed and bent rectangle, the sides of which are made up of discharge knobs, rods, chains, connecting cords, and portions of a patient, as, for example, one arm and the leg on the same side of the body.

The inductance of such a circuit of course can be only approximately calculated; the approximation, however, is sufficient for the physician's purpose. At very high frequencies the inductance, in henrys, of a circuit consisting of a single conducting loop l cms long, and d cms in diameter, is expressed by the formula

$$L = 2\ l\left(\log_e \frac{4l}{d} - a\right) 10^{-9},$$

in which a is equal to 2.5 for a circular or square loop. If a be made unity, the equation gives the inductance of a straight wire of length l cms, and diameter d cms; if the loop be rectangular in shape, a will have a larger value than 2.5.

Changes in the diameter of the conductor do not materially affect the value of the inductance. For example, in a specified case, increasing the cross-section of the conductor 100 times reduces the inductance of the circuit only one-half.

The resistance offered by an ordinary solid cylindrical conductor, such as a metal wire or rod, to currents of very high frequency of the order of a million, or more, per second, is greater than that which is offered to direct, or low-frequency alternating currents. This is due to the fact that self-induction causes the major part of a high-frequency current to flow through the exterior skin of such a conductor, and permits the current to sink into the conductor to only a slight extent. Hence, the conductor, though solid, behaves towards such currents practically as though it were a hollow cylinder; and the conducting cross-section being thus reduced, the practical result is an increase of the resistance.

If R_1 = resistance, in ohms, per cm length of conductor for constant currents, or alternating currents of ordinary low frequencies;
f = frequency of a high-frequency current, in cycles per second;
l = length of conductor, in cms;
μ = average permeability of the substance of which the conductor is made (for iron = 900; for ordinary substances = unity);

then the resistance of the circuit, in ohms, to the high-frequency current will be

$$R = 0.000056\ l \sqrt{f \mu R_1}$$

As an example of the influence of high frequency in increasing the resistance, it may be stated that the resistance of a No. 10 B. & S. copper wire is ten times as great for currents of frequencies of a million per second as for constant, or low-frequency alternating, currents. With wires of larger diameter the increase of resistance will be still greater.

In many circuits employed by physicians the major portion of the resistance resides in a spark-gap, and the magnitude of the resistance of this gap is, therefore, in some cases the controlling factor in determining whether the discharge is oscillatory or not. Its value depends upon a large number of variables, among which are the length of gap, character and shape of discharge knobs, strength and duration of current, and the pressure, temperature and humidity of the atmosphere.

The maximum instantaneous value of the current which flows at any instant during a discharge between the knobs of a Holtz machine when its jars are connected in circuit, may amount to hundreds of amperes, and doubtless frequently exceeds 100 amperes. The time during which the strength of the current is so great is, however, very short.

The most important capacity that arises in these kinds of circuits is that of the Leyden jars. The capacities of the four standard sizes of Waite & Bartlett jars were measured by means of a ballistic galvanometer with the use of high voltages furnished by a Holtz machine. They were found to be, respectively, 0.0008, 0.0004, 0.00026, and 0.00008 microfarads. A measurement of the area of the outside conducting foil showed that there was an approximate capacity of a millionth of a microfarad per cm^2 of outside coating.

In general, the capacity of a condenser of this character, or of the plate form, is expressed by the following formula:

$$C = 0.000225\frac{An}{t}k$$

Where C = Capacity, in microfarads,

A = area of dielectric between two conducting plates, in square inches,

n = number of sheets of dielectric,

t = thickness of dielectric in mils,

k = specific inductive capacity of dielectric, as obtained from Table III.

TABLE III.

Air	1.0
Glass	3.0 to 7.0
Hard Rubber	2.2 to 3.0
Paraffin	2.0 to 2.3
Mica	6.6
Kerosene	2.0 to 2.5

Measurements were also made of the capacity offered by a man standing upon an ordinary insulating platform, and considered as one electrode of a condenser, the other terminal of the machine being grounded so that the floor and structural iron of the building constituted the other electrode. The capacity was found to be 0.00005 microfarad. When the man stood upon a hard rubber plate 0.25 inch thick, which was placed upon a brass plate constituting the other electrode, the capacity was increased to 0.0002 microfarad.

The second portion of the report was entitled [3] "High Frequency Oscillatory and Pulsatory Discharges," by W. J. Jenks and Chas. L. Clarke, members of the American Institute of Electrical Engineers, honorary members of the American Electrotherapeutic Association and members of the Congress. After summarizing the ground covered by the committee in the two preceding reports, and indicating that the statement now made by them was intended to be in the nature of elaborations of, and deductions from, the investigations of Professor Sheldon, these members of the Committee noted the fact that, so far as they had been able to ascertain, the laws governing the proper design of electrostatic machines have not heretofore been formulated in any publication. They then summarize the most urgent desires of the members of the Association as calling for more accurate information in the following particulars regarding high-frequency oscillatory currents:

a). As to the conditions under which they are present;

b). As to the manner of most effectively and certainly applying them;

c). As to the conditions under which they may be expected to change into low frequency or even into unidirectional currents, possibly without betraying to the operator the fact that such

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[3] In the diagrams, Figs. 1, 2, 3, 4, accompanying the second portion of the report, the + signs should be —, and the — signs should be +.

changes or any changes in the character of the current have taken place.

If the three factors, inductance, capacity and resistance, are known, the determination of the frequency by the formula given by Professor Sheldon is a matter of simple arithmetic. To secure oscillatory currents, the relations of these three factors to one another are, generally stated, as follows:

The resistance must be small; the capacity must be small; and the inductance must be large.

As an illustration, a case is assumed in which the possible value of these three factors are such as Professor Sheldon's paper has mentioned. Substituting those assumed values in the formula given by Professor Sheldon the following equation is developed:

$$f = 0.159155\sqrt{\frac{1}{0.000006 \times 0.00000000005} - \frac{500^2}{4 \times 0.000006^2}}$$

from which $f = 6{,}360{,}000$.

That is to say, the frequency of the current, under the conditions just assumed, will be more than 6,000,000 per second.

Now, further assuming that the resistance of the patient is increased to 900 ohms, all the other conditions remaining as before, and therefore that the total circuit resistance is 1000 ohms, we have

$$f = 0.159155\sqrt{\frac{1}{0.000006 \times 0.00000000005} - \frac{1000^2}{4 \times 0.000006^2}}$$

The second term under the radical being greater than the first term, the whole quantity under the radical is negative, and therefore the equation is impossible of solution, and the frequency can not be determined therefrom. Physically interpreted, this condition means that the current will not be oscillatory, but will be unidirectional in character, the oscillations existing when the patient's resistance was 400 ohms having been damped out by the increase of that resistance to 900 ohms.

A careful study of Dr. Sheldon's paper and the preceding examples will indicate that it is doubtful, to say the least, whether in many cases where the physician has been accustomed to think that high frequency is present, and has attributed his successful results to its presence, it has, as a matter of fact, been present at all. Direct-current high-periodicity pulsatory discharges might be easily confused with oscillatory currents of high frequency, and unfortunately we have, as yet, no instrument which can be applied, like a voltmeter, by the practitioner at any moment to distinguish one character of discharge from the other.

Hence it becomes important, especially at a time when extraordinary virtues and advantages are being attributed to high-frequency currents, to know how to produce them without uncertainty, even though we may not be able, without difficult experimentation, more or less assumption, and laborious calculation, to reasonably satisfy ourselves as to *how high* their frequency is.

The following suggestions may be of assistance. They are, so to speak, thumb rules:

1.) *Reduce the resistance of the entire circuit as much as possible relatively to the inductance.* To this end, remember that, as Prof. Sheldon has shown, the resistance offered by a conductor to the flow of high-frequency currents may be ten or more times greater than its resistance to low-frequency, or to continous, currents; and the conductor should be of liberal size, considering the maximum current to be carried. Remember also that, as Prof. Sheldon has pointed out, the greater part of the whole resistance may reside in the spark gap, which, therefore, should be as short as possible consistent with the production of effects of the desired intensity. Remember especially that the resistance of the patient may vary within wide limits, is difficult to determine, and without taking special precautions is liable to be high; therefore it should be made as low as possible by the use of large contact surfaces at the electrodes, moistened with a saline solution or equivalent means.

2.) *Keep the capacity of the circuit low relatively to the inductance.* Remember, however, that some capacity is absolutely necessary to the production of oscillatory currents, and that the strength of current, and massage effect upon a patient when so placed in the circuit as to constitute one condenser plate, are practically dependent in some degree upon the capacity. If in the treatment of a patient it is desired to simply pass the current through his body, *as a conductor,* without any other effect than that which will be directly produced by the current flow, the capacity of the circuit must be localized outside the patient (as, for example, in the Morton "static-induced current" apparatus, illustrated in Fig. C in this Committee's report for last year), and the patient forms simply a part of the conductor by which the outside coatings of the two Leyden jars are connected with each other. But if it is desired to subject the patient to massage effects due to the condenser action of alternate electrical charges and discharges (the current flowing in the patient in such application being merely a necessary incident of the treatment, and not considered as a part thereof) the capacity must be localized *within or upon* the patient, as, for example, in the Morton "wave current" apparatus, illustrated in Fig. F in the report for last year.

3.) *Increase the inductance relatively to the resistance, if for practical reasons the latter cannot be made very low.* The objections to increasing the inductance, if avoidable, are that it tends to decrease the frequency and strength of current, and therefore, in the application of the condenser massage treatment, tends to reduce the vigor and rapidity of the massage. The inductance may be readily increased when necessary by inserting a reactance coil in the circuit, consisting of a few turns of large diameter of heavy copper wire, with considerable space between neighboring turns, and without an iron core.

It is to be understood that in pointing out, as above, a way of obtaining oscillatory currents of high frequency for application to a patient, this Committee does not intend to express any opinion as to their therapeutic value, of which, naturally, the physician must be the judge.

These considerations as to practical and easy methods of securing high-frequency oscillatory currents, point to the great desirability of making numerous experimental measurements of the capacity and resistance of human subjects, under the conditions customarily present in general practice, and preparing a table giving the mean results of many tests.

Assuming that the rapidity of the cycles, or frequency, of oscillatory currents may have a vital bearing upon the therapeutic value of such currents, it becomes most important that the physician should know at what frequency, or between what limits of frequency, the best curative effects are to be obtained.

That the therapeutic effect of an oscillatory current may be related to its frequency is perhaps indicated by the difference between the physiological effects produced by a continuous current, or by an alternating current of the comparatively low frequency of 25 to 60 cycles per second, such as the frequency of the current from the ordinary alternating generator used in electric light and power-transmission plants, and the effects of a current of the undoubtedly high frequency of several thousands, aand even millions of cycles per second, such as the oscillatory current that can be produced by the apparatus of D'Arsonval, Tesla, and Dr. Morton, all of which were described in the report of last year; also by the apparatus of Prof. Elihu Thomson, of the Committee, described by him in a paper, entitled "Notes on the Effects of High-Frequency Electrical Discharges Passed Through the Body," read before the American Electro-Therapeutic Association in 1894, and published in the *Transactions* of the Association for that year, page 261.

D'Arsonval passed through two persons a high-frequency current of sufficient strength to bring a 1-ampere incandescent lamp, in series with them, up to a white heat, and through his own body a high-frequency current of "more than 3 amperes," without any other effect than a sensation of heat in the hands.

In the experiments by Professor Thomson, described in his paper above referred to, the current, passing through his body from hand to hand, had at times a mean effective strength as great as 1.5 amperes, as gauged by its heating effect upon an incandescent lamp, and produced no other physiological effect than the sensation of warmth at the wrists, which was felt because of the noteworthy generation of heat due to the comparatively high resistance localized at those points of the electric circuits. Physiological tetanus of the muscles was altogether absent. The reason for the absence of physiological tetanus with high-frequency oscillatory currents, and its presence with continuous currents, or electric light and power-alternating currents of the comparatively low frequency of 25 to 60 cycles per second, is not at present known with certainty. Some authorities hold that this absence is due to the fact that because of the high frequency such currents are compelled to flow practically on, or so near the surface of, the body that they do not penetrate to the nervous and muscular systems, as would a low-frequency or a continuous current, and therefore have no effect upon them. On the contrary, other authorities believe that the circulatory and nerve channels, compared with the tissues at and near the surface, constitute such superior conductors of electricity that the high-frequency currents flow therein to a large degree in spite of the tendency of the high frequency to force them to the surface, and that the presence or absence of tetanus is governed by the degree of frequency.

And it is this absence of tetanus, and the resulting harm, that constitutes the most obvious difference between the effects produced upon the living subject by high-frequency currents, and those resulting from low-frequency or continuous currents.

The line of demarkation between high-frequency and low-frequency currents, or the frequency at which tetanus begins to stop and immunity from tetanus commences, has not been clearly defined. Experiment has shown that at a frequency of about 10,000 cycles per second tetanus does not take place. But the line of demarkation for the physician's purposes has yet to be drawn.

Professor Sheldon has stated in his paper that the maximum instantaneous strength of the current which flows during a discharge between the knobs of a Holtz machine when its jars are connected in circuit, may amount to hundreds of amperes, and doubtless frequently exceeds 100 amperes. This is a fact that may be new to many physicians. It certainly is important for them to know.

An example has been worked out for the current flowing in a circuit which includes two Leyden jars, connected with each other in series, and each, respectively, with one of the prime conductors of a Holtz machine, as in the Morton "static-induced" high-frequency apparatus described in the Committee's report of 1903. The value of the constants of the circuit chosen for the example are such as are readily obtainable, and might be present in the use of such a machine, although doubtless differing in some respects from the conditions present when a patient is being subjected to treatment by the current from the machine. They are as follows:

For the capacity of two Leyden jars in series 0.0000000005 farad; for the inductance 0.000002 henry; for the resistance 100 ohms; and for the quantity 0.00006575 coulomb.

The quantity, or amount of charge, is based upon the assumption that the discharge knobs (each $1\frac{1}{2}$ ins. diameter) are 2 ins. apart, which calls for the charging of the condensers up to about 131,500 volts potential in order to break down the 2-in. air gap. The machine is assumed to deliver constantly to the circuit a current of one-half milliampere. With a current of this strength the jars will be charged up to the discharge voltage in 0.1315 second; and discharges will take place at the rate of 7.6 times per second.

Let f be the frequency, the formula for which has been hereinbefore given; Q the quantity; L the inductance; C the capacity, and

R the resistance, the value of an oscillatory current i at any time t is expressed by the equation

$$i = -\frac{Q}{2\pi f LC} e^{-\frac{Rt}{2L}} \sin 2\pi ft.$$

The maximum instantaneous value of the current is

$$i_{\text{max.}} = \pm \frac{Q}{\sqrt{LC}} e^{-\frac{R}{4\pi fL} \tan^{-1} \frac{4\ fL}{R}},$$

which is — for odd half-cycles, and + for even half-cycles. The time at which the current arrives at its maximum value is

$$t_{\text{max.}\,i} = \frac{1}{2\pi f} \tan^{-1} \frac{4\pi fL}{R}.$$

Applying the equations, it will be found that under the above conditions the strength of current produced by the discharge of the jars attains the very large maximum instantaneous value of 886.7 amperes, and does so in about one-tenth of a cycle, or complete oscillation, from the commencement of discharge. The current dies down to zero in one-half a cycle, then flows in the opposite direction and attains again a maximum instantaneous value, but this time of only + 15.3 amperes, during the second half of the first cycle, and dies down to zero again. During the second cycle the current does not at any time attain a strength of more than a small fraction of an ampere, so rapidly have the oscillations been damped down.

The frequency of the oscillations is 3,082,000 per second; and the length of one cycle, or time in which a complete oscillation takes place is 0.000000325 second.

This current curve is illustrated in Fig. 1.

It will be at once apparent from Fig. 1 that although the current is oscillatory, nevertheless it dies away so rapidly in the second half of the first cycle, compared with its strength in the first half of the cycle, that without sensible error it may be considered as a unidirectional, pulsatory current.

There is no term generally recognized in the electrical art as indicative of the *rate of pulsation* of a unidirectional pulsatory current analogous to the term *frequency* which denotes the *rate of oscillation* of an oscillatory current. For the purposes of this report the word *periodicity* will be so used; that is, to indicate the number of times such a current would pass through a *practically complete* pulsation or cycle in one second upon the assumption that the pulsations are repeated for that length of time, and one pulsation begins as soon as the preceding pulsation has *practically* ceased.

Theoretically a pulsatory current requires an infinite time to complete a cycle, but *practically* a single pulsation or cycle lasts only for an exceedingly short time. And the criterion adopted in this report as a practical measure of periodicity is the reciprocal of the time which would be required for a pulsatory current, having the assumed form of a sine half-wave, and of the same maximum instantaneous value as the true pulsatory current and practically pulsatory oscillatory current, to completely discharge the condenser.

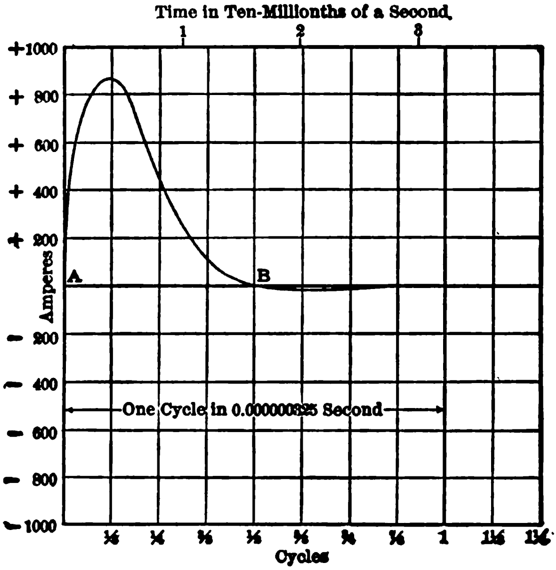

FIG. 1.

The duration t' of the above sine half-wave (which may be termed the *equivalent coulomb sine pulsation*) is given by the equation

$$t' = 1.5708 \frac{Q}{M},$$

and the periodicity p by the equation

$$p = 0.6366 \frac{M}{Q},$$

in which Q is the charge in coulombs, and M is the maximum instantaneous value $i_{\max.}$ of the actual current in amperes.

From these equations the duration of the equivalent coulomb sine pulsation of the current illustrated in Fig. 1 is 0.0000001165 second, and the periodicity is 8,585,400.

Hence, assuming the current to be pulsatory‸ and remembering that a pulsation takes place for each discharge of the jars between the knobs of the prime conductors, it will be of special interest to consider the intervals of time at which the pulsations follow one another, while the jars are supplied by the Holtz machine in continuous operation, and compare that interval with the duration of each pulsation. Since the discharges and pulsations take place once in each 0.1315 second, and a pulsation endures for 0.0000001165 second, the time interval between the ending of one pulsation and the beginning of the next pulsation will be 0.1315 second. The duration of a pulsation is, therefore, only about the 90/1000000th of 1 per cent of the time-interval between pulsations. If this ratio be expressed in terms of length, instead of time, it may be more readily comprehended. If the practical duration of a current pulsation, that is, the duration of the equivalent coulomb sine pulsation, be represented by a length of 1 in., the time-interval between successive pulsations (during which the jars are being charged) will be represented by a length of 92,000 feet, or 17.5 miles.

In addition to the fact that the current in such a circuit, under certain circumstances, may rise to a high value, the physician is specially interested in knowing its characteristics under the practical conditions that may exist when a patient is included in the circuit.

To this end, an example has been taken in which the arrangement of apparatus and patient is assumed to be the same as in the Morton "wave-current" application, described and illustrated in the Committee's Report for 1903. The several constants assumed for the circuit are based upon data given by Professor Sheldon, and are as follows:

Resistance, including the air-gap between the discharge knobs; also the patient, 500 ohms.

Capacity of the patient and floor (with walls) of the room, as the two plates of a condenser, 0.00000000005 farad.

Inductance due to the size and shape of the circuit in which the patient is included, 0.000006 henry.

The quantity of charge in the patient (based upon the assumptions stated in the case of Fig. 1) is 0.000006575 coulomb. The discharges will take place 0.01315 second apart, or at the rate of 76 times per second.

The results of the calculations give 170.8 amperes as the maximum instantaneous value of the current in the first half cycle, which is damped down to only 6.46 amperes as the maximum value in the second half cycle. The frequency of the oscillation is 6,360,000 per second, and the duration of one cycle, or complete oscillation, is 0.000000157218 second.

The current curve in this case is shown in Fig. 2.

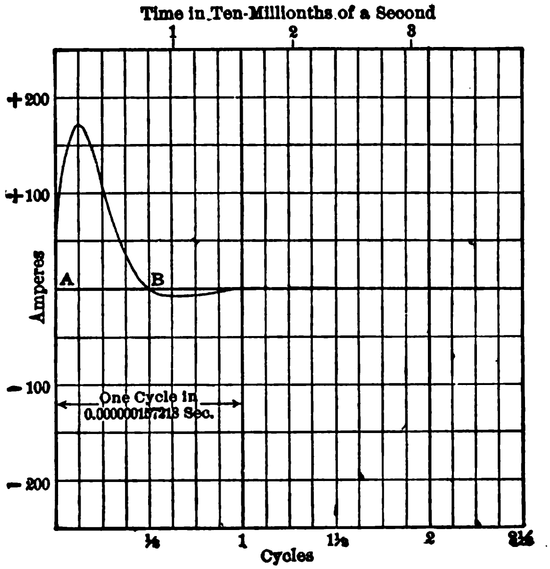

FIG. 2.

This illustration should prove of great interest to the physician. It shows that in the administration of the Morton "wave current" to a patient, the current may have a very large amperage, although for an exceedingly short time, and that while it may be oscillatory, and of extremely high frequency (at the rate of 6,360,000 complete oscillations in this case), nevertheless the oscillations may be damped down to such an extent, even in the first cycle, that the current is practically pulsatory in character, each pulsation practically enduring 0.0000000604 second, as measured by the duration of the equivalent coulomb sine wave, and having a periodicity of 16,553,000.

Considering then the current as a pulsatory one (with a maximum instantaneous strength of 170.8 amperes) flowing practically for 0.0000000604 second (that is to say, having a periodicity of 16,553,000 per second) and remembering that the discharges between the knobs, and also the resulting pulsations, occur only at intervals of 0.01315 second, or 76 times per second, we find that the duration of a pulsation is only the 460/1,000,000th of one per cent of the time-interval between pulsations, during which interval a comparatively negligible strength of current is flowing. • In other words, if the pulsations were plotted in a diagram on such a scale that the practical duration of one pulsation is 1 in. in length, the interval between the ending of one pulsation and the beginning of the next pulsation would be 18,000 ft., or more than 3 miles.

This example illustrates a case that may frequently occur in the physician's practice. The inquiry is therefore pertinent whether, after all, the therapeutic value of high-frequency currents depends upon their being oscillatory in character. Inasmuch as what have heretofore been called high-frequency oscillatory currents have probably been, in many cases, high-periodicity pulsating unidirectional currents, the additional inquiry is at once suggested whether the latter class should not be credited with as great utility as the former, particularly when it is considered that in the use of either class, the patient, in whole or in part, is alternately electrically charged and discharged.

In other words, is not the electrostatic machine, from the standpoint of electrotherapeutics, a convenient, practical means of producing a series of more or less rapidly variable effects, each of extremely short duration; and does not the greatest therapeutic value of the current from such a machine result from these rapid variations, especially those derived from condenser action, irrespective of whether the current of the discharges happens to be oscillatory and thus flows in alternately opposite directions, or is pulsatory and flows in only one direction? These are questions to which the physician may well give serious consideration.

In this connection, attention is called to the fact that the resistance of 500 ohms, assumed for the circuit in the present example, would have to be increased by only a small per cent to prevent the discharging current from swinging across the zero line, as shown in Fig. 2, and thus changing from a slightly oscillatory into a strictly pulsatory current.

A third example is given to illustrate the effect of reducing the resistance in increasing the amplitude of the current, prolonging the oscillations and increasing their frequency. In this example all the constants of the circuit and other conditions are assumed the same as in the last example, excepting that the resistance is reduced from 500 ohms to 100 ohms, although it is not now known to the Committee whether or not the resistance can fall so low with a patient in circuit, under clinical conditions.

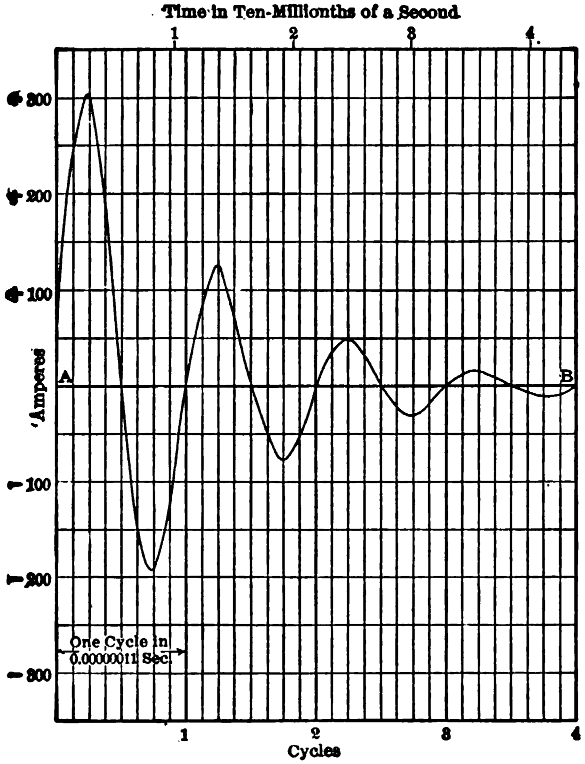

Fig. 3.

The results are shown in Fig. 3.

In consequence of this reduction the frequency rises from 6,360,000 to 9,092,500 per second; the duration of a complete cycle falls from 0.000000157218 to 0.00000011 second, and the maximum instantaneous value of the current increases from 170.8 to 304.4 amperes. By a comparison of Figs. 2 and 3 it will be seen that the decreased resistance causes less damping down of the current, so that the oscillations are greatly prolonged. With 500 ohms resistance the maximum value of the current in the second half of the first cycle is only a little more than 3 per cent of its maximum value in the first half of that period. With only 100 ohms in circuit the current would not be damped down to the same extent until it had made four complete oscillations.

But the duration of the four oscillations (0.00000044 second) bears only an exceedingly small ratio to the time between discharges (which take place at the rate of 76 per second) during which interval a comparatively negligible amount of current is flowing. Representing the duration of the four oscillations (from *A* to *B* in Fig. 3) as a length of 8 in. the intervals between successive discharges, that is, successive oscillations, would be 19,920 feet, or nearly 4 miles.

If $R^2 C$ becomes equal to, or greater than, $4L$ the current will cease to be oscillatory, and become wholly pulsatory, rising from zero at the commencement of discharge to a maximum value and then gradually dying away.

When $R^2 C$ *equals* $4L$ the resulting pulsatory current most completely discharges the condenser, and the current most nearly disappears in the shortest time. This is the *critical case* in which the current is just on the verge of being oscillatory.

For the critical case the current i at time t is

$$i = -\frac{Q}{CL} t e^{-\frac{Rt}{2L}};$$

the maximum instantaneous value of the current is

$$i_{\text{max.}} = -0.73576 \frac{Q}{RC},$$

and the time required for the current to attain its maximum value is

$$i_{\text{max.}\,t} = \frac{2L}{R}.$$

When $R^2 C$ is *greater than* $4L$, which represents the general case, the strength of the current i at time t is

$$i = -\frac{Q}{\sqrt{R^2 C^2 - 4LC}} \left\{ e^{-\frac{t}{T_1}} - e^{\frac{t}{T_2}} \right\};$$

the maximum instantaneous value of the current is

$$i_{\text{max.}} = -\frac{Q}{\sqrt{R^2 C^2 - 4LC}} \left\{ e^{-\frac{LC}{T_1 \sqrt{R^2 C^2 - 4LC}} \log_\varepsilon \frac{T_1}{T_2}} - e^{-\frac{LC}{T_2 \sqrt{R_2 C_2 - 4LC}} \log_\varepsilon \frac{T_1}{T_2}} \right\},$$

and the time required for the current to attain its maximum value is

$$t_{\max. i} = \frac{LC}{\sqrt{R^2 C^2 - 4LC}} \log_e \frac{T_1}{T_2},$$

in which

$$T_1 = \frac{2LC}{RC - \sqrt{R^2 C^2 - 4LC}}, \text{ and } T_2 = \frac{2LC}{RC + \sqrt{R^2 C^2 - 4LC}}.$$

In Figs. 1, 2 and 3 only the characteristics of the current, such as its frequency, strength and wave-shape during a single discharge, are illustrated. It is a matter of much interest and importance to the physician to understand not only the characteristics of the discharge current, but also the nature of the other electrical operations that go on in the circuit, both during the time the Leyden jar, or other form of condenser, is discharging, and also while being charged by the Holtz machine up to the potential required to produce another discharge.

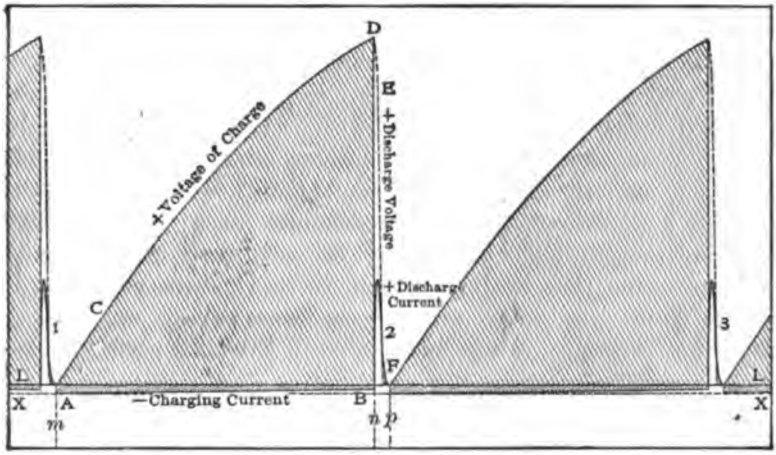

FIG. 4.

To this end the electrical operations which take place in the circuit (in which the body of a patient may be assumed as included) during the successive discharges of the jar and intermediate intervals of time during which the jar is being charged, are illustrated in Fig. 4, in which the curves 1, 2, 3, in heavy lines, represent three successive discharge currents. These discharges, as shown, are non-oscillatory; but they may be considered as representing oscillatory discharges substantially like the current-wave shown in Fig. 2, the negligibly small oscillation in the positive direction, below the zero, or base line, in Fig. 2, being omitted in Fig. 4.

Starting from the time *m* at which the negative discharge current 1 has practically ceased to flow, the relatively extremely small positive charging current *AB* begins to flow from the Holtz machine into the jar in the opposite direction. The accumulation of charge, or coulombs of electricity, in the jar, delivered to it by the continuous flow of the charging current, gradually, but with comparative slowness, raises its voltage, or the difference of electrical potential between its inner and outer coatings, and therefore between the discharge knobs of the machine, as shown by the curve *CD,* until finally at the time *n* the voltage has risen to an amount necessary to break down the resistance of the air in the gap between the knobs and cause a spark discharge to pass between them.

The gas in the path of the spark, heated to incandescence and rendered electrically conductive thereby, closes the local circuit, which includes the spark, Leyden jar, and also, say, the body of a patient, and the jar begins to discharge into the local circuit the stored electricity. The voltage which was slowly raised to the sparking pressure under the flow of the very feeble charging current during the time *mn* falls with enormous rapidity, as indicated by the dotted line *DEF,* and produces the relatively very strong discharge current 2 in the opposite or negative direction during the comparatively extremely short time *np.*

At the time *p* the feeble-charging current again begins to flow into the jar, and raises its voltage until another spark passes and another discharge current 3 flows in the local circuit. This cycle of changes is repeated so long as the Holtz machine is in operation.

As has been experimentally demonstrated by Prof. Sheldon, the Holtz machine generates a continuous current of constant though feeble strength, represented in Fig. 4 by the dotted line *XX.* But not all of the current generated will flow into a Leyden jar, because the voltage of the jar, in opposition to the charging current, causes a percentage of that current to leak off along other paths instead of flowing into the jar, and this leakage increases, and reduces the amount of current flowing into the jar, as the voltage rises, and also diminishes the rate of increase in voltage. These facts are illustrated in Fig. 4, which shows the diminishing strength of the charging current *AB* from the time *m,* when it begins to flow, until the time *n,* when it ceases to flow into the jar; and also shows by the curvature of the voltage line *CD* a reduction in the rate of increase in voltage as the latter increases in amount. If the charging current *AB* were of constant strength, the voltage would increase at a constant rate, and *CD* would be a sloping straight line.

During the time *mn,* in which the jar is being charged, the difference between the strength of the charging current *AB* flowing into the jar and the strength of the total current *XX* generated by the Holtz machine represents the current lost in leakage. During the time *np* when the discharge current is flowing out of the jar and in the local circuit the whole current *XX* generated by the Holtz machine flows through the discharge spark, but not through any other part of the local circuit. The machine is in fact then short-circuited through the spark gap.

In the examples illustrated by Figs. 1, 2 and 3, it has been assumed that a constant charging current of one-half a milliampere flowed into the Leyden jar, and upon this assumption the rate of charge and discharge of the jar was determined; also, the relative duration of a discharge and the interval of time between successive discharges. This assumption leads to results not at variance with the truth; for it would have been equally correct, and justified by the results of Professor Sheldon's tests, to assume that the strength of the charging current diminished as the voltage of the jar increased, but that its *mean or average strength* was one-half a milliampere.

It is to be understood that the curves in Fig. 4 are only illustrative of qualitative electrical operations, and are not so drawn to scale that the relative magnitudes of the operations going on in the circuit can be directly compared.

Assuming, as an example, that Fig. 4 illustrates a series of charges and discharges taking place under the conditions stated in connection with Fig. 2, then, in Fig. 4, the average height of the curve of charging current *AB* stands for one-half a milliampere. The maximum height of the discharge-current curve will then represent 170.8 amperes; the maximum height of the voltage curve, 131,500 volts; the time of discharge *np,* 0.000000078609 second; and the interval between successive discharges, or time of charging, *mn,* 0.01315 second.

Now, if the height of the charging current *AB* at the time *m* be one milliampere, *on the same scale the curve of discharge current should be 12,500 times taller than shown in Fig 4.* If the voltages were to be drawn on the same scale as the amperes *the* *voltage curves would have to be 2,922,222 times taller than in Fig 4.* As drawn in the figure, the intervals of charge, or time *mn*, are 20 times larger than the duration *np* of flow *of* a discharge current. Taking the distance *np* as the scale of time, the distance *mn*, or *time of charge, should be 8364 times longer than actually shown in Fig. 4.*

Do not these illustrations emphasize the importance of the question whether the therapeutic value of the prolonged oscillatory current is probably due, not to the fact that it is oscillatory, but to the fact that the patient is subjected to the intermittent action of current applications which alternately electrically charge and discharge the body, as one electrode or plate of a condenser, producing an electrical massage which is apparently of a profound character, acting upon each individual cell of the living tissues?

If so, may not the direct but pulsating current of high periodicity prove to be possibly as efficacious as the oscillatory current of high frequency, about which so much has been said and written?

In fact, may not the currents which have been used in many experiments, demonstrations and regular therapeutic treatments, derived from apparatus capable of yielding alternating discharges of high frequency, and hence assumed to be oscillatory, have been really direct discharges of high periodicity?

Of one thing we may be reasonably certain. The greatest value of the electrostatic generator thus far discovered resides in its ability to produce very high voltages with amperage so low that electrical and mechanical variations of inconceivable rapidity can be carried on in the human system, expending sufficient power to insure prompt changes, without the necessity of employing current flow so great as to destroy the delicate structure which it is the object of the treatment to repair.

DISCUSSION.

CHAIRMAN MORTON: You have listened to this extremely valuable report. I am sure you will agree with me that with the time at our disposal we shall not have time for its discussion. Such reports do us the most good when, on the long winter nights, we can study them at our leisure. Nevertheless, it would be unwise not to have some discussion, and if such is your pleasure I will call on you for discussion.

On motion of Dr. Wm. B. Snow the report was unanimously accepted and the committee ordered continued.

DR. WM. B. SNOW: I do not think words can express the gratitude we owe these gentlemen. The labor that has been expended and the remarkable skill in bringing out this valuable report places the American Electro-Therapeutic Association under obligations to them which will be difficult to repay. The shortness of time will not permit us to go into details in the consideration of a subject so technical, and, as Dr. Morton suggests, many of us, in order to realize and appreciate the technicality of the report, should give it very much study and close attention when the report comes to us in printed form. But we have before us a set of tables, principles, and laws that in our future study will give us a basis upon which we can form our conclusions and a method of doing more accurate and precise work. Personally, my conviction is growing more and more that frequency is not of so much importance in electrotherapeutics as potential. I think many of us are taking that position.

In reference to the administration of currents, personally I feel that the greater benefit is being derived from the lower frequencies, but that a high potential is indispensable, and that its penetration and the valuable mechanical effects we see and get we derive from lower frequencies.

I do not wish to take up any more time, but again wish to express personally my thanks to the committee.

Dr. G. B. **Massey**: Might not the greater pain experienced by patients from the direct spark (where the patient holds the conductor directly attached to one pole in the hand and the other conductor, attached directly to the opposite pole, is presented to the body), as compared with the indirect spark (where the conducting rod rests on the platform and the current from the opposite pole has to pass through two "grounds" of separate house pipes), be due to the direct sparks being oscillatory and the indirect ones non-oscillatory? The difference between the two is very marked, and not entirely due to their varying volume, for the indirect spark, being attached to the ground capacities, has much more volume, shown by a deeper contractile action on muscles, yet gives far less pain.

Prof. **Samuel Sheldon**: I do not know that I correctly understand the question. As to the painfulness or non-painfulness of the different kinds of sparks, it depends upon the current. Personally, I hardly feel qualified to speak upon the physiological side of this question. Still I have my own opinions on the subject. Pain seems to result from the action of the products of electrolytic decomposition upon the terminii of the nerves. The liquids in the cells of the body constitute the electrolyte and the decomposition products appear on both sides of the diaphragms which form the walls of the cells. The rate of development of these products depends upon the current passing through the cells. To fully understand the effect upon a patient, the amount of the current should be known and also where this current flows in the patient's body.

Dr. G. B. **Massey**: The point I am after is not cleared up yet. I know that the oscillatory current is much more painful than the non-alternating current, and I was wondering if the well-known fact that one of those circuits — that through the gas and water pipes, or the so-called indirect sparks — gave a less painful but deeper action, could not be explained by the theory that it was a non-alternating current, whereas the other is alternating.

Prof. **Sheldon**: If the oscillating current be painful, it is likely that there is a large amperage during the first oscillation of the discharge. If an endeavor should be made to send an amperage of the same magnitude from a continuous current source, the pain would be probably great and death might follow. The endurance of a patient toward continuous currents is to be reckoned milliamperes, while in these discharges it is possible to have, for an instant, 100 amperes.

Dr. G. B. **Massey**: I want to say, as one present at Prof. Elihu Thompson's demonstration of the passage of such enormous currents through his body, and also as having taken these currents through my own body, that I distinctly recall the remarkable lack of sensation other than a slight heat.

I can also corroborate the remarks concerning the use of the static machine as a motor. This was demonstrated in my office some years ago, a single-plate machine being run backward by a four-plate one when the driving gear and other sources of friction were removed from the machine that acted as the motor.

Dr. **Emil H. Grubbe**: I also wish to add a word of appreciation to the work of the committee. To those of us who are teaching the physics of static electricity the formulas given will have very much value. I had the pleasure some years ago of watching the work of old Dr. MacIntosh, the pioneer of the "friction" static machine, as he called it. At that time Dr. MacIntosh did all his work in a mechanical way. He simply constructed a machine according to his own formulation at that time, with nobody to aid him. I know if he were living to-day and present in the audience here and saw these formulas he would turn green with envy. These were the very things he looked for, but was incapable of working out by himself. I am disappointed in seeing the labors of the committee handicapped by the backwardness of the manufacturers of static machines. Here we are told we have a very small number of manufacturers of machines who were willing to exhibit their instruments in this test. Just lately several machines embodying new ideas have been put upon the market, and I would like to ask the committee to inquire about them for the purpose of obtaining more machinery to work with during the next year. I would like to have them try to see if they cannot get hold of two or three other machines. I would also like to ask the committee, if it has not already done so, and probably it is working upon that proposition, to investigate the relation of inductance to speed of the revolving plate; the relation which inductance bears to revolution, and also the relation of inductance to the size of the plates and the relative size of the stationary and movable parts. I believe many problems which now are considered theoretical will be solved if we can get some formulas relative to these principles. In my listening to the report I failed to find any mention made of the voltage in connection with amperage. However, some one just informs me that that matter was taken up in last year's report.

Dr. C. E. **Skinner**: I would like to ask Prof. Sheldon one question. I would like to know whether he would have us understand that the volume of current is increased in direct proportion to the speed with which the plate revolves. For instance, would two plates run at a speed of 1,600 revolutions a minute generate as great a volume of current as eight plates when run at a revolution of 400 per minute, other conditions being equal?

Dr. G. B. Massey: In connection with Prof. Jenks' remarks about the various qualities of these machines that may be selected by progressive manufacturers, in the direction of improvement, the question was asked whether we have to work out the problem of improving our current by increased speed or by enlarging the number of plates, and the remark was made that those questions had been largely worked out in connection with dynamos. The thought occurred to me at that time that in our work we have just one more element to consider among doubtless others, that is the effect of the noise made by a machine running at high speed on the nervous condition of the patient or patients in the adjoining room. This is a serious proposition; too high speed, if it is accompanied by an unpleasant, buzzing sound, tries the nerves of the operator as well as the patient. This is something that must be considered. We are willing to pay more money for our current if we can get rid of an objection of this sort. The additional cost required to run a larger number of plates would be offset by the advantage of lessened noise.

Dr. Wm. B. Snow: What relation does speed bear to the frequency and thickness of the spark that passes at the spark-gap? In other words, what bearing does speed have on the spark and the frequency of the discharge — speed vs. lower speed or more plates?

Prof. Sheldon: That has no influence upon the number of sparks; they are both alike.

I wish to add but a word. I do not know quite what the physician is after, but, if it be his desire to make an arrangement of apparatus in connection with the machine such as to produce high-frequency currents, then he should consider the formula just written upon the board, namely:

$$\text{Frequency} = 0.159\sqrt{\frac{1}{\text{Inductance} \times \text{Capacity}} - \frac{(\text{Resistance})^2}{4\,(\text{Inductance})^2}}.$$

To get a high frequency the first quantity under the radical must be large and the second must be small. To get the first one large, one must have both the inductance and the capacity as small as possible. One may have the capacity small, but if one endeavors to make the inductance small he gets into trouble. To make the second factor small the inductance should be large, as it enters as the square into the denominator of the second quantity. There is a particular value for the inductance to accomplish these results, but that is another story.

The following paper was then read:

SOME OBSERVATIONS UPON THE TREATMENT OF LUPUS VULGARIS BY PHOTOTHERAPY, RADIOTHERAPY AND OTHERWISE.

BY DR. CHARLES R. DICKSON, *Delegate American Electrotherapeutic Association.*

Until a comparatively recent period the treatment of lupus vulgaris had not been attended with brilliant results, and it remained for electrotherapy, as on so many other fields of conquest, to point the way to a more hopeful outcome.

This brief paper will not deal with the varied procedures of the past dignified by the name of treatment, nor yet with all the minute and interesting details of modern scientific technique in such happy contrast with former methods. No striking, novel, original theories will be advanced, but merely a few unpretentious observations particularly with regard to cases of long standing and unusual obstinacy, as a contribution to the literature of a subject which is deservedly attracting much attention at the present time.

In the treatment of lupus the X-rays scored their first therapeutic triumph, and a most notable one it was. To Finsen is due the credit for compelling the medical profession to recognize the therapeutic efficacy of light in affections of the skin and this led to the employment of the X-rays in the treatment of lupus, the result being that today phototherapy and radiotherapy are admittedly the most potent means at our disposal for combatting and conquering a most distressing condition.

Each method has its advocates. In America radiotherapy has claimed the allegiance of the greater number of investigators, probably due to the fact that nowhere has the static machine reached such perfection of development and use as here, and nowhere has more enthusiastic admirers, and for the possessor of such a machine the necessary X-ray apparatus involves but comparatively slight additional outlay, while the Finsen light is an expensive luxury, occupying much space and demanding more valuable time than the average practitioner can afford to give it.

Many very ingenious devices have been resorted to in the endeavor to overcome the difficulties which militate so seriously against the popularity of phototherapy. A form of apparatus which I have found of great service in many cases is a condenser spark lamp with iron electrodes known as the "ultra." It is used with the alternating current drawn from an ordinary incandescent lamp socket. The diminutive arc of this lamp emits comparatively few light rays but is very rich in ultra-violet rays as may readily be demonstrated. Being richer in the ultra-violet rays than the Finsen light it is more powerfully and more rapidly bactericidal and thus the time of exposure is materially lessened so that from 3 to 10 minutes only is required instead of the half-hour, hour or more of the Finsen lamp.

While the ultra-violet rays emitted by the iron electrode arc are of shorter wave length, more refrangible and are not so penetrating as the rays of greater wave length — the longer ultra-violet, violet and blue of the large Finsen lamps — yet they have a wide field of usefulness in lupus, and my remarks upon phototherapy will refer to this branch of the subject alone, demonstrating some of its possibilities.

The treatment of lupus vulgaris in its more aggravated forms is far from a simple process, many considerations are involved and much of the success will depend upon the skill, resourcefulness and patience of the operator, not to mention the faith and perseverance of the patient. Fixed rules cannot be laid down and yet there are certain preliminaries and adjuvants to treatment, attention to which may be of very material assistance and these apply to both photo- and radiotherapy.

The production of artificial fluorescence of the tissues by administering some fluorescing substance before raying as elaborated by Morton is an undoubted advantage. From 5 to 10 grains of bisulphate of quinine may be given one hour before each raying for this purpose. Many other substances may be similarly employed, fluorescin and others.

In very obstinate cases the internal administration of creosote in a form which can be tolerated and readily assimilated may prove of great value in hastening a cure and attention should be paid to the general condition of the patient if necessary.

The diseased tissues should be subjected to as little irritation as possible by manipulation in removing crusts or otherwise, and should also be kept as quiescent as possible in the intervals between treatment in order that extension of the disease may not be favored. If crusts or scales are present they should be removed before treatment if possible and the parts cleansed. For this purpose glycerin, to which has been added 25 per cent of oil of eucalyptus, may be applied but should it not soon cause loosening of the crusts further attempts at removal should be desisted from for the present and raying proceeded with, allowing the eucalyptus-glycerin to remain on. If the crusts are still adherent at the conclusion of the treatment they should be kept covered with white vaselin until the succeeding treatment when they will probably be found softened sufficiently to be removable by forceps or absorbent cotton.

The patient should avoid the use of water or of aqueous solutions for cleansing affected areas; if the skin is broken, the parts should be wiped off with vaselin instead and kept as dry and as clean as possible.

The eucalyptus-glycerin — varying the strength to individual needs, if necessary — may with advantage be applied to ulcerated or broken surfaces and a border of surrounding sound tissues before each raying in inveterate cases, it is quite transparent to ultra-violet and X-rays. In cases where the edges of an ulcer are healing very slowly, but the disease is not deeply seated, the application of a very thin layer of vaselin to the edges before raying has seemed to accelerate healthy granulation, and as white vaselin fluoresces a brilliant violet under the ultra-violet rays, while ordinary vaselin fluoresces a greenish blue and to a much less degree and moreover being of a yellow color absorbs the greater portion of the rays, the former is preferable. Creosote, oil of cloves and oil of cinnamon are opaque to the rays, oil of wintergreen fluoresces blue.

Rays of short wave length are absorbed and neutralized by those of greater length and the greater the disparity the greater the amount of absorption, hence the short ultra-violet rays are thus affected to the greatest degree by those at the opposite end of the spectrum, the long red orange and yellow. For this reason the removal of crusts before phototherapy is employed is especially necessary, for the color of the crusts, reddish or yellow, will not permit the action of the ultra-violet rays upon the parts beneath.

Blood on the surface or circulating in the capillary vessels has the same effect to a greater degree, and to counteract this effect the surface should be cleaned and adrenalin chloride applied to constrict the capillary vessels and drive the blood out of them, thus blanching the tissues, repeating the application as often as necessary during the sitting. The adrenalin may conveniently be added to the glycerin and applied before arranging the apparatus to be used, it will thus be afforded the few minutes necessary to its complete action before beginning operations, and raying should not commence until the parts are well blanched. It is rarely necessary to employ the adrenalin full strength (1/1000), in fact weaker solutions may be more readily absorbed. This blanching of tissues and removal of crusts is also of benefit in radiotherapy.

In phototherapy a lens of rock crystal is sometimes employed to press upon the parts to make them anæmic, and pieces of ice have also been used for the same purpose, but with the ultra-violet rays which act so powerfully upon the surface, pressure is to be avoided as far as possible as causing unnecessary irritation and more reliance is to be placed in adrenalin. Rock crystal and ice are transparent to the ultra-violet as to the X-rays while glass is opaque to both, a fact which is sometimes made use of.

If practicable, a margin of sound tissue about ¼ of an inch in width surrounding the diseased areas should be left exposed to the rays; all other sound tissue in their range should be shielded; in the case of X-rays thin sheet lead or the tinned lead composition known as "X-ray metal" may be used, stellate apertures being cut to correspond with the areas to be rayed, and the points turned back. For the ultra-violet rays the metal is also applicable, oiled muslin is likewise convenient, offering sufficient protection to sound tissue, the rays being absorbed by the yellow muslin.

The eyes of both operator and patient must especially be protected when exposed to either ultra-violet or X-rays. An exposure of a few seconds to the direct action of ultra-violet rays will provoke a very smart conjunctivitis or worse, and it must not be forgotten also that these rays are readily reflected by metal or even the skin itself. Large goggles afford a convenient protection, glass being impervious to both varieties of ray, but in the case of the ultra-violet it is safer to protect the patient's eyes with oiled muslin closely fitted to guard against reflected rays.

Where the skin is broken, ulcerated or crusted over, the affected areas and surrounding tissues should be kept in as clean and healthy condition as possible. Immediately after treatment the parts should be cleaned off with vaselin and a very thin layer of some emollient ointment spread upon fine gauze (or better still, on sterilized linen as being less irritating and more readily removable), this being applied to the crusted or ulcerated patches alone, carefully avoiding covering sound tissues which should be kept dry and clean. This dressing may be changed twice or thrice daily depending upon the amount of discharge. Where the discharge is slight the dressing may remain 24 hours or more. Should the tissues become sodden at any time the dressing should be discontinued until they recover their tone.

After experimenting with a number of applications which proved more or less unsatisfactory and were discarded in turn, the preference was given to compound thuya ointment. The indications were for a bland, emollient, antiseptic preparation of sufficient consistence to remain in close apposition to parts to which it was applied; something that would soften crusts, facilitate their removal and retard or prevent their reappearance, that would inhibit or antagonize the action of the bacillus and check extension of the disease, that would protect denuded surfaces, favor healthy granulation and cicatrization, be antiseptic in character while unirritating, readily absorbable and of such degree of consistence that while it could be spread without difficulty at all seasons in a thin layer, it would not be softened too freely by the heat of the body and flow over sound skin, but would keep the discharge and consequent crusts from the sound margins. Oil of thuya in vaselin (1/16) having afforded satisfaction as a dressing in some broken down cases of epithelioma which were being rayed, was resorted to in the lupus cases and combined in the same proportion with an emollient ointment consisting of lanolin (℥iii), white vaselin (℥v ʒv), white wax (℥ii ss), oil of pinus sylvestris (ʒiv), oil of juniper (ʒi).

If the discharge be very profuse a dusting powder may replace the ointment until the discharge is under control. For this purpose boro-chloretone or bismuth-formic-iodide will be found convenient and efficacious, but should be discontinued as soon as practicable on account of the tendency to form hard crusts.

Resinol ointment will be found of service in combatting the erythema of surrounding tissues. Lanolin is also useful for this purpose.

As between phototherapy and radiotherapy for lupus vulgaris, the former is to be preferred in cases in which it is applicable, but a combination of the two methods is to be commended.

In cases to which it is suited phototherapy possesses the advantage of requiring a less extended course of treatment; small circumscribed patches may disappear after two or three vigorous exposures. Better cosmetic results can probably be obtained by phototherapy, the extent and degree of action is more under control and reaction is less prolonged. It is the preferable method for indurated marginal areas such as the lobe of the ear or other parts liable to break down under vigorous X-raying, also where tissues are thin as the cheek and all other places where deep penetration is not required. For the eyelid it is the more commendable proceedure, and the lid will protect the eye better from the effects of a short ultra-violet exposure — four minutes being sufficient — than from a longer and more penetrating X-ray exposure. Also, there will be no fear of epilation of the lashes as would result from exposure to the X-rays and there is the same recommendation with regard to the brow, lip, head or other parts on which there is hair. Phototherapy is also of great value in toning up broken down tissue and promoting the healing of ulcerations.

On the other hand, radiotherapy is preferable when the area involved is extensive, as a larger portion can be exposed at one time with radiotherapy; also where greater penetration is required as when the tissues are tumefied, hypertrophied or pigmented, as in these conditions the greater proportion of the ultra-violet rays will be absorbed and neutralized before reaching the seat of the disease, and where much tumefaction, hypertrophy or pigmentation occur in a course of phototherapy, the treatment should be changed to radiotherapy at once or much valuable time may be lost. Radiotherapy is also more applicable where mucous membranes are involved not easy of access to ultra-violet rays such as the nasal mucous membrane.

Where there is fibrous or cicatricial tissue this may sometimes be broken down by vigorous but judicious X-raying, which being accomplished the rest may be left to phototherapy. Where there is ulceration this may be stimulated by radiotherapy and here again phototherapy resorted to if it is a suitable case.

Illustrative of these latter points the salient features of a couple of cases might be cited. In a man aged 70 years the disease had been present for 25 years and had undergone all the classical treatment, applications innumerable, curetting, excision, galvano-puncture et al. It was situated at the back of the neck toward the shoulder and was of ovoid shape, 2⅝ ins. in its longer diameter, 1½ ins. across, fibrous in character and with a much depressed cicatrix running down the central portion, around which lupus was much in evidence. The sites of galvano-puncture were the only locations where recurrence had not taken place. Ten exposures to the ultra-violet rays alone from 10 to 15 minutes each and seven more with the static brush discharge in addition showed that progress would be slow. All but the fibrous tissue was then carefully screened and it X-rayed at close range — from 4 to 6 ins. — on nine consecutive occasions for 15 minutes each with a fairly high tube, following each treatment with the brush discharge to the surrounding parts. This caused the fibrous tissue to soften and break down, and after 36 further exposures to ultra-violet rays all ulcerated patches had healed, leaving a surface almost level, very unlike the former depression. Some further ultra-violet raying was done as a precautionary measure as the skin was very thin where subject to pressure by the neck band of the shirt and showed proneness to chafe.

In another case, a man aged 55 years, the lupus was of 15 years' duration, involving portions of the forehead, brow, both upper and lower lid, cheek, ear, and all of the temple, running well into the hair; an area 4 1/2 ins. vertically and 2 1/2 ins. across, with all these tissues and those underlying immovably adherent to the bones beneath, inability to open the jaws wide enough to eat a banana, and marked flattening of the prominences of the brow and cheek denoting bone involvement. There was a crusted ulcerated portion measuring 3 ins. vertically, 1 1/2 ins. across the narrowest portion and 2 ins. across the widest. The ulcerated portion only was exposed to the X-rays for 15 minutes each on 10 succeeding days, the static brush discharge being used on the surrounding parts meanwhile. Twenty-four exposures to the ultra-violet rays followed, then the patient was allowed to return home and directed to continue a daily application of the ung. thuya co., the ulcer having become much smaller. Four weeks later the ulcer was 1 15/16 ins. vertically, 1/2 in. across the top, 5/16 in. across the center and 3/4 in. across the bottom. After 36 more ultra-violet exposures all ulceration was completely healed, and the skin and underlying tissues freely movable except a small portion over the malar prominence and outer part of the lower lid.

Cases may arise in which the X-ray after a prolonged course of treatment seems to lose its former good effect, or sometimes the parts become abnormally sensitive to it. In the event of either of these contingencies recourse may be had to the ultra-violet ray for a time until the parts recover their tone, when a return may be made to the X-ray.

In some patients the reaction after exposure to ultra-violet rays even for very short periods is so exaggerated that this form of treatment cannot be employed. Such cases should be exposed cautiously to the X-ray.

In a case of long standing which had been under the care of a great many physicians, and where a great many expedients had been resorted to in addition by the patient himself, the nose being the part involved, the X-rays effected a remarkable improvement for a time, then, seeming to lose all their efficacy and the case being at a standstill, more vigorous X-raying resulted in ray erythema. When this had passed off, an exposure to the ultra-violet rays of five minutes to each side of the nose caused a very severe reaction, erythema extending over the cheeks and eyelids, tumefaction of the tissues affected, very acute corryza with burning sensation about the nostrils and upper lip, lachrymation and pain. An ultra-violet exposure of the back of the neck for eight minutes on the same occasion to abort an incipient carbuncle of which the patient had had a number was eminently successful in attaining its object, but also resulted in blistering the neck quite extensively as from a severe sunburn, and the patient declared that he preferred the disease to the cure in this case. The neck had never been X-rayed. In the same case the application of adrenalin chloride was attended with such discomfort even in 1/10,000 strength that it had to be discontinued; it also intensified both ultra-violet and X-ray action very greatly. This case did better when the X-ray was returned to with short seances of eight minutes.

The advent of erysipelas in a part apparently cured may start up fresh foci of the disease to greater vigor than formerly and may cause the disease to spread and also to appear in parts hitherto free from it. In such cases the X-ray will be the preferable treatment.

The duration of exposure to either rays will depend largely upon the state of the skin, the size of the lupus, and the extent and degree of the reaction. Unless reaction is too pronounced daily exposures are preferable. From 3 to 10 minutes is the usual time for exposing one portion to the ultra-violet rays. X-ray exposures vary from 8 to 15 minutes with a fairly high tube not usually nearer than 6 in. from the part exposed. With the ultraviolet ray the lens of the lamp should be as near as possible to the part being treated.

When tissues are breaking down under X-raying, or erythema is becoming too marked, the brush discharge from the static machine is sometimes of assistance to restore tone.

In view of the fact that ultra-violet rays induce fluorescence, convert the oxygen of the air into ozone, cause chemical combination, give rise to oxidation and decomposition, possess a direct and vigorous bactericidal action, have a powerful effect upon capillary circulation producing not a mere transitory but a persisting dilatation of the capillary vessels promoting osmosis, influencing nutrition and favoring absorption, is it too much to expect that "photolysis" and "photophoresis" may open up fields of research as yet comparatively unexplored, and may come to mean much to suffering humanity, dealing with the power of light and more especially of the ultra-violet rays to break up medicaments into elementary forms or produce new combinations more absorbable and to carry such into the system as ammunition in the battle against disease, thereby on the one hand assisting the therapeutic action of light, and on the other hand utilizing the lytic and phoretic action of light to aid the therapeusis of external and internal medication?

DISCUSSION.

DR. EMIL H. GRUBBÉ: I am sorry that the author of the paper did not take time to read it to us in detail. It is not a very long paper, and he might have done so at the expense of very little more time, and we certainly could have discussed the subject much better. The author makes the following statement: "As between phototherapy and radiotherapy for lupus vulgaris, the former is to be preferred in cases in which it is applicable." Unfortunately he does not state what he considers an applicable case. Personally I do not prefer phototherapy to X-ray-therapy in any case of lupus vulgaris. I disagree with the author when he says, "In cases in which it is suited phototherapy possesses the advantage of requiring a less extended course of treatment." I have treated cases of lupus vulgaris with the one single X-ray treatment and have made them permanently well, never by phototherapy. Finsen's report with relation to this method should be considered very carefully. Although Finsen is not an X-ray enthusiast, he gives great credit to it. In my own work, the X-ray appeals to me more strongly, and I should always prefer the X-ray to phototherapy. The author also states the following: "In view of the fact that ultra-violet rays induce fluorescence, convert the oxygen of the air into ozone," etc. I do not believe that is a fact. We have no proof, so far as I have been able to gain any light in literature and by experiment, that the oxygen of the air is converted into ozone by the ultra-violet rays. It is a fact that metal substances may be decomposed in the tissues of the body, but that does not prove that oxygen may be assumed to take on an allotropic form.

Dr. Wm. Benham Snow: The last speaker I think made a serious mistake in stating that in any case the X-ray was better than the light. In my own experience I have seen cases where I came near having serious trouble from using the X-ray, but finally succeeded by resorting to light. In one case of lupus vulgaris of the ear, in which the lower portion was indurated, I should have expected it to come away if I had used the X-ray once more. In similar cases it is necessary to resort to other means than the X-ray or lose a portion of the tissue. In most cases, however, the X-ray is superior in the treatment of lupus vulgaris. Finsen was a pathfinder, but his method as a whole cannot now be rated as the best in the field in the treatment of most cases of lupus vulgaris. The endeavor to find our limitations in means and methods is certainly a commendable one, but when we have found them, the judicious employment of the best means is the course of the wise physician in all cases. The author spoke favorably of the use of the brush discharge. That modality is of advantage, but should not be used to the exclusion of the X-ray. There are often many ways to accomplish the same thing, and occasion arises where we can employ in some cases one to better advantage than another. For instance, a man who has an outfit for using the X-ray will use it, but he must know when to stop. Many have gone on raying to such an extent that they have postponed a prompt recovery. In an article published some months ago in the Journal of the Roentgen Ray there was an account of a physician in Dublin who had rayed for a lupus on the face forty times without a favorable result. He stopped the raying and it healed, and all evidence of the lupus promptly disappeared. If he had stopped raying sooner, it would probably have promptly healed. Nature was not given a chance to effect the healing.

Chairman Morton: With your permission I wish to say a few words, for I think we should get together as soon as possible on some ideas as to the technique in the treatment of these cases. I have long held a corresponding position, and published it too, that phototherapy as splendidly promulgated by Finsen, no matter how valuable it was as a pioneer, is now a bygone issue in the minds of most men in the treatment of lupus. It is my average experience with lupus that many cases can be cured in from two to four months. The Finsen method is tedious, the X-ray method rapid. I would like to make the remark that we may X-ray too much in cases of lupus. My own method of procedure is to apply the X-ray (three times weekly, medium tube, fifteen minutes exposure, nine inches distant from the target), until I produce a mild dermatitis in the neighboring sound skin. Having obtained a satisfactory dermatitis in this neighboring sound skin, I would advise a delay of treatment for ten or twelve days to see if the disease would not heal, and in two weeks' time one can be quite positive as to this. If it does not, then I repeat the same process until we have produced again a dermatitis in the neighboring sound skin. That technique I have followed right along and with success. I do not believe that powerful exposures are desirable. As to the use of the ultra-violet ray produced otherwise than by the Finsen light in lupus, I have no confidence in it whatever, owing to its non-penetrating quality.

Dr. A. M. **Baer**: In medicine we do not confine ourselves to one drug; we do not confine ourselves to calomel, or soda, or any other drug in the treatment of any disease, and at the present time I do not see why, if we have two or three electrical modalities in the office, we should confine ourselves to one line of treatment, either phototherapy, X-ray, or the partial discharge. It is a combination of all of them that gives our patient the best result.

Dr. **Charles R. Dickson**: In reply to Dr. Grubbé's criticism, I know it is an unsatisfactory way to present a paper without reading it all. A number of questions asked are answered in the paper. As to Dr. Grubbé's further criticism, I wish to state that the applicable cases are stated in the paper if he will read it in full. The paper does not deal with mild cases which can be cured with one application of the X-ray. Such cases may be cured by one exposure to the iron electrode arc rays. As to oxygen being converted into ozone by ultra-violet rays, I do not state this of my own personal knowledge. My authority is Dr. Leopold Freund, of Vienna, who makes the statement in his work, "Radiotherapy;" I have quoted him, and if he is wrong I have to apologize for him. Then as to the point about treatment with the Finsen light. The paper does not deal with the Finsen light proper, but with the vibrations of the iron electrode arc. The Finsen light takes in the longer ultra-violet rays, the violet, indigo, and blue. The spectrum of the iron electrode arc, as used in my cases, has very little blue or indigo, a little more violet and ultra-violet than the Finsen light, but in addition other ultra-violet rays much higher up in the spectrum, shorter and more rapid still, and it is these iron arc rays which are dealt with in the paper. No attempt is made to cover the whole field of the treatment of lupus, but only certain points that occurred to me in the treatment of a number of severe cases. The question as to the efficacy of the treatment is unnecessary when you read the first two cases cited, which I commend to your careful consideration. One case was under other treatment for twenty-five years, and was completely cured by the ultra-violet rays. The source of the ultra-violet ray in the cured cases was the alternating current, transmitted through a series of coils to a condenser below them, giving a so-called "high-tension, high-frequency" current; this is led to iron electrodes. As to the penetration of the rays, Freund says about one-third part of the rays of the present known ultra-violet spectrum are capable of penetrating to the lower layers of the skin, and the balance of them are absorbed by the epidermis. A carbuncle on the back of my neck had been treated surgically and the wound had healed, but, as frequently happens, two others appeared on the upper edge of the cicatrix. I applied adrenalin chloride solution to blanch the tissues, and two exposures to the iron arc rays completely aborted the carbuncle with no recurrence. In cases of foruncle, I have accomplished the same thing.

Dr. W. P. SPRING: I understood this was to be a joint session of the Congress with the American Electro-Therapeutic Association by courtesy of the Congress, but I would not have known that it was anything but a meeting of the American Electro-Therapeutic Association except by the badges, since all the papers that have been read have been read by members of the association. As one, I am anxious to hear from members of the Congress, and I wish to make a motion that we now hear Dr. Morton's paper.

The motion was duly seconded and, being put to a vote, prevailed unanimously.

Dr. W. P. Spring, vice-president of the American Electro-Therapeutic Association, then assumed the chair and called upon Dr. Morton for the reading of his paper.

FLUORESCENCE ARTIFICIALLY PRODUCED IN THE HUMAN ORGANISM BY THE RÖNTGEN RAYS AND BY RADIUM AND ELECTRIC DISCHARGES AS A THERAPEUTIC METHOD.

BY DR. WILLIAM JAMES MORTON, *Professor of Diseases of the Mind and Nervous System and of Electrotherapeutics, New York Post-Graduate Medical School and Hospital.*

The therapeutic method outlined in this paper and in previous publications consists in the saturation of the human organism in whole or in part with a medicine endowed with the property of fluorescence (or phosphorence) and in then submitting this patient to the action of X-rays or of the radium radiation or of high-frequency currents. It is, therefore, a combined treatment. I have termed it Artificial Fluorescence.

The sum total of the writer's object was to develop *light* within tissue, in the confidence that the well-known external effects of this agency might now be duplicated internally and especially in the expectation that certain wave lengths of the visible spectrum like the blue-violet and the yellow-green might exert specialized effects. But it is also and furthermore obvious that the wave lengths of the visible spectrum cannot be reasonably supposed to be the sole output and resultant of the absorbed energy of the X-ray and the radium radiations. Effects may, therefore, well be attributed to transformations into other wave lengths, as for instance, the ultra-violet, or even into the well-known secondary radiations, lower in wave length than the X-radiations, but still akin to them in their property of not being refracted and dispersed as are the violet and ultra-violet. These secondary radiations in their turn may set up fluorescence.

The main point is that by reason of the medicine administered to the patient a new set of radiations is set up within his tissues and that the most obvious of these radiations are light itself or closely akin to it.

In science it seldom happens that ultimate truth is arrived at all at once. Usually observations have preceded, a great number of experiments have followed, a final deduction has been made, and this itself may after all turn out to be wrong.

So it is regarding the subject of my paper, but certain it is that artificial fluorescence by radium and the X-radiations is founded upon a solid physical basis, applicable to living human beings, and that the clinical results obtained, at the least, increase the percentage of cures in many diseases.

Historical.

The steps leading up to the plan here presented of treating the entire blood system with a fluorescent substance and then submitting it to X- and radium radiations are few but most interesting. They relate to a local use of the fluorescent substance by hypodermatic injections or topical applications, and to the use of the Finsen light as an excitant. With these methods, I have had no experience since my object has been, not alone to affect superficial skin areas as in lupus, but rather to affect deeper areas like cancerous tumors, tuberculous glands, and tuberculous lungs, carcinoma of the stomach, and chronic diseases like malaria or general conditions like pseudoleukaemia. To accomplish this purpose, the medicine to be administered by the mouth must be harmless but also fluorescent, and a radiation must be used which is able to excite fluorescence deep within the tissues. Obviously, the Finsen light radiation would not furnish the penetration required and topical administration would not reach the diseases desired. I resorted, therefore, to the Röntgen ray and to radium.

Natural Fluorescence of Tissues of the Body.

In 1845, Prof. Brucke stated that the crystalline lens of the eye was fluorescent and the aqueous humour less so. In 1855, M. Jules Regnauld, using sunlight, found that the cornea fluoresced slightly, the crystalline lens highly, and the vitreous humour less so. In 1895, Setschenow of Moscow, in a series of careful experiments, corroborated these results. He observed that when the eye is brought into the focus of the ultra-violet rays, immediately the cornea and the lens begin to glimmer with a white-blue light. Dr. Henry Bence Jones (*Proceedings* of Royal Society, April, 1866, and "Lectures Upon the Application of Chemistry and Mechanics to Pathology and Therapeutics," London, 1867), not only repeated these experiments upon the media of the eye, but also, as a result of careful researches, made the very remarkable discovery that man and all animals possess in every part of the body a fluorescent substance resembling quinine. This substance he found to be an alkaloid and to be closely related to quinine. He named it animal quinoidine. Using a standard solution of quinine, 100 litres (equals 212 pints) of water, to obtain the same degree of fluorescence, he found that this animal quinoidine was present uniformly in extracts of the liver, heart, spleen, lungs, kidneys, brain, nerves, muscles, cartilages, blood, bile, and humours of the eye. The fluorescent substance did not disappear from lenses that had been kept for months in glycerine.

Using a spark from a Ruhmkorff coil as a source of light, Jones determined distinct fluorescence in a solution of one grain of quinine to 1,000,000 parts of water.

Dr. Chalvet, (*Gazette Hebdomadaire,* 2d series t.v. 1868), found that Dr. Bence Jones' fluorescent substance exists in various foods and even in wine and is, therefore, probably not of an animal but vegetable origin.

In 1868, Drs. Edward Rhoads and William Pepper, published[1] an interesting "Contribution toward our Knowledge of the Pathological Changes in the Fluorescence of the Tissues." They confirmed Bence Jones' results and then advanced the original idea based on an examination of the blood in a number of cases that "a close connection exists between the diminution of animal quinoidine and malarial diseases." They, therefore, gave quinine to increase the fluorescence of the tissues to its normal point.

In 1900, Dr. A. F. A. King of Washington, D. C., resurrected[2] these publications of Bence Jones and of Rhoads and Pepper, in connection with his theory and suggestion of placing malarial patients in the dark or in rooms with violet or purple window hangings. Dr. King bases his suggestion upon his belief that the sporulation of the plasmodium of malaria cannot take place in the dark but only in light and more especially in red light. This treatment corresponds of course to the red light or Finsen treatment of smallpox.

In 1900,[3] Prof. v. Tappeiner in conjunction with Dr. O. v. Raab tested the action of the fluorescent light of phenylacridin upon infusoria. Paramoeciae in an acridin solution of 1 in 20,000 died in sunlight in 6 minutes, in diffused daylight in about 60 minutes,

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[1] Penna. Hosp. Reports 1868.

[2] *Vermont Medical Monthly,* June 25, 1902.

[3] *Munchener Medicinishe Wochenschrift,* 1900, No. 1.

but if kept in the dark, they were alive after 6000 minutes, viz., after 100 hours. v. Tappeiner summarizes the results of his and v. Raab's experiments as follows (quoted from Freund, p. 519): "Light becomes highly injurious to paramoeciae in the presence of acridin, phenylacridin, eosin and quinine in solutions in which these substances in themselves (in the dark) are hardly if at all poisonous. This action of light is closely connected with the fluorescent quality of the substances named. The injurious power, however, lies not in the fluorescent light produced but in the process of its production."

O. v. Raab surmises that we have here a conversion of the energy of the light rays into chemical rays analogous to that of chlorophyll, which is also a fluorescent body, but with this difference that this conversion is the cause of death to the paramoeciae, whereas to plants it is the condition of continued life.

v. Tappeiner holds that this kind of light action comes into play with those animal organs, skin, retina, blood and lymph serum, which have the capacity for fluorescence. "He surmises, too, that the cause of the skin inflammation noticed by Wedding, in beasts fed on buckwheat, lies in the fact that substances get into the body which are capable of fluorescence."

v. Tappeiner concludes his article with the suggestion that fluorescing substances by being applied to the part and subjected to light may be employed in dermatology just as eosin and other fluorescing substances have been empirically employed for the last ten years in photography, viz., as "*sensitizers.*"

In 1901, H. Lieber of New York, made experiments with agar solutions inoculated with common mold and further experiments with grape and other fruit juices, and found that fluorescent substances like solutions of fluorescin, eosin, or rhodamin, arrested fermentation in every case as long as the solutions were exposed to daylight, but that the fluorescent substances had no perceptible effect upon the solutions when kept in the dark. These principles he applied to the preservation of food stuffs.

In June and August, 1903,[4] and later on,[5] the writer published his plan of saturating the entire system by administrations of fluorescent medicines and submitting parts or the whole of it to X and radium radiations, after, however, recording a series of

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[4] *Electrical World and Engineer*, June 20, 1903. *N. Y. Medical Record*, August 8, 1903.

[5] *N. Y. Medical Journal, etc.*, Feb. 13 and 20, 1904.

experiments upon patients from January, 1900, onward. In November, 1903, was published[6] the experiments of Dreyer upon "Light Treatment" by the method of "Sensitizing" tissues, already suggested by v. Tappeiner. This article, brief but most interesting and important, was a résumé of a report of investigations made to the Danish Academy of Sciences in April, 1903. Dreyer adopted the plan which has long been used in sensitizing photographic plates of adding to the bromide or chloride of silver solution, certain substances which are generally of a fluorescent nature. Infusoria, bacteria and animal tissues thus impregnated and submitted to the action of the Finsen light were affected by the green to orange rays exactly as without the use of the sensitizing agency they would have been affected by the ultra-violet rays. The importance of this plan is evident, for it is the red to green rays of the arc lamp which easily penetrate tissue, while the ultra-violet penetrate but very slightly. By the Dreyer sensitizing method the scope of the Finsen treatment for lupus, etc., would be greatly extended and simplified, the effect would extend more deeply, the area be more extensive, and the pressure device be unnecessary. Dreyer used principally erythrosin in a solution of 1 to 4000, a solution perfectly nontoxic, except under the influence of the arc-light radiation.

The following table is most instructive. Using a 30-ampere lamp, a quartz and water-cooled vessel, and erythrosin, different rays of the spectrum were tested and killed microbes as stated below.

COLOR FILTER USED.	Acting rays.	INFUSORIA.		BACTERIA.	
		Sensitized.	Normal.	Sensitized.	Normal.
Quartz	Entire spectrum. Ultra—Violet	10 sec.	100 sec.	60 sec.	80 sec.
Glass	Visible spectrum	10 sec.	9 min.	10 min.	10 min.
Solution, nickel sulphate	Red-orange Yellow Green, blue	10 sec.	13 min.	10 min.	10 min.
Blue glass, monochromic	Red, orange Yellow Yellow-green	10 sec.	70 min.	15 min.	Over 4 hrs.
Acid potassium, double chromic.	Red, orange Yellow-orange	10 sec.	110 min.	25 min.	Over 9 hrs.

The above table shows that it is the yellow-green rays to which the microorganisms are rendered sensitive.

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[6] *British Medical Journal*, November, 1903.

Dreyer also sensitized animal tissues by hypodermatic injections of erythrosin, so that the yellow rays, otherwise without effect, would now cause an inflammatory reaction such as is caused by the violet and ultra-violet rays.

Prof. Neisser and Dr. Halberstaedter (*Deutsche Med. Wochenschrift,* Feb. 18, 1904) review and amplify the work of Dreyer.

Neisser makes the following remarks as to the cause of the action:

1). The occurrence does not depend upon fluorescence, because there are sensitizing materials, which do not fluoresce, and fluorescent materials that do not sensitize.

2). The occurrence does not depend upon the absorption of certain rays, because there exists a number of fluorescing and non-fluorescing materials, which absorb the same rays, as erythrosin, and yet do not sensitize.

3). The process cannot be accounted for by the formation of toxic substances in the sensitizer during the illumination, because if one first subjects a sensitizing fluid to light, and afterwards puts microorganisms into the same, these germs are not killed.

In an article in the *Münchener Medizinische Wochenschrift,* May 10, 1904, Jesionek discusses the therapeutic applications of fluorescent substances in various diseased conditions after the method of Tappeiner just referred to. The skin was painted with solutions of fluorescent substances and then submitted to sunlight, concentrated by lenses or not. A solution of eosin was most commonly employed. In cases of carcinomatous growths parenchymmatous injections of 0.1 to 0.01 per cent solutions were used.

In July, 1904, in the *American Journal of the Medical Sciences,* Gunni Busck advocates exposing malarial patients to whom quinine had been first administered to sunlight, on the ground that quinine causes micro-organisms to be sensitive to light. The writer had already considered the possibility of this plan in his first publications and wrote: "As to sunlight as an exciting cause of fluoresence, it is to be noted that light passing through a red screen, as for instance the blood, fails to excite fluorescence, while the X and radium radiations readily penetrate this screen."

On the whole the fact is well established that quinine solutions when subjected to light exert a deadly influence upon some micro-organisms. Ullman has found that paramoeciae placed in solutions of quinine of 1 to 20,000 die only after standing about five hours in the dark, while they are killed in the course of eight minutes if placed in sunlight and under conditions which usually have no deleterious influence upon the paramoeciae.

What is fluorescence?

Fluorescence is the property which substances have of absorbing invisible or visible rays and giving out visible light. The fluorescent substance does not give out the same wave length as that which it receives. According to Stokes' law, it should give out a wave length of lower frequency, namely, the shortest wave length of the fluorescence spectrum is always of less refrangibility than the longest wave length capable of exciting fluorescence. Lommel[7] has shown, however, that solutions of fluorescin, eosin, and naphthalic red, do not conform to Stokes' law and Nichols and Merritt[8] in recent investigations show that rhodamin, resorcin blue, quinine, chlorophyll, and aesculin, also do not even approximately conform to this law. The fluorescence of quinine sulphate appears to be independent of the wave length of the exciting light.

Fluorescence and phosphorescence are much akin. The former lasts only so long as the exciting cause is maintained; the latter endures after the excitation has ceased. Substances like willemite exhibit both properties. According to Becquerel, fluorescence is only phosphorescence of short duration.

Sunlight, electric discharges, ultra-violet, the Röntgen and Becquerel rays, all excite fluorescence and phosphorescence. It is precisely these rays whose biological effects are now under discussion therapeutically, and the very pertinent question arises, is not the now familiar and ordinary curative effect of these various rays due to their common property of exciting fluorescence or even phosphorescence? Or put in a broader sense, is this curative effect not due to secondary radiations, invisible, as well as visible?

That the effects of the X-ray may be due to the fluorescence of the tissue elements themselves, is an opinion I have long held and expressed (*Medical Record,* Aug. 8, 1903). This opinion is also guardedly put forth by L. Freund in his incomparably excellent book on Radio-Therapy. On p. 336, he says: "It seems, moreover, not impossible that X-rays induce fluorescence in those tissue elements capable of this phenomenon, and that this process brings about chemical changes, especially in the cells. In this respect,

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[7] *Poggendorff's Annalen,* vols. 143, 159 and 160.

[8] *The Physical Review,* July, 1904.

those tissues which contain earthy matter would appear to possess some affinity to the bromide of silver gelatin, while other tissues which have no fluorescent capacity remain unharmed by the rays."

Goldstein (quoted from Freund), arguing that since Röntgen rays, when they impinge upon bodies, produce ultra-violet rays of very short wave length attributes to this ultra-violet light those biological effects produced in the deeper layers of the skin by Röntgen radiation.

Freund combats this view on the ground that biological effects are not produced in internal organs (heart, liver, etc.) where the Röntgen rays equally penetrate.

But many experiments upon the lower animals have demonstrated that profound lesions of internal organs are produced. In my own experience, I can never forget the peculiar, crispy, cartilaginous feeling of the cutting knife in a deep dissection for the radical removal of a carcinomatous breast, removed after three months of Röntgen treatment. Both the pectoralis major and minor were cornified as verified by subsequent miscroscopical examination.

But whether or not simple X-ray treatments produce in normal tissues either ultra-violet or fluorescent rays is not here the question. The possibility of such being the case is merely mentioned as constituting collateral confirmatory evidence. The writer's method, of course, is to permeate tissues and cells with a substance known by prior laboratory experiment to be actually fluorescent and known to retain this property when in the blood, and then to artificially excite this fluorescent quality in the combined fluids. The method itself is positive and demonstrable apart from theoretical considerations while its curative results are matters of clinical observation.

Certain it is as evident by foregoing statements that fluorescence and phosphorescence are natural properties of living animal tissues.

These two phenomena of light exist naturally in some infusoria, bacteria, insects, deep sea fishes, and as we have seen in the tissue of human beings. In the human being, as in the other living organisms mentioned, this fact must have a meaning since every function or ingredient of the organism means something. It is simply here a question if this intrinsic phenomenon can not be artificially utilized as a therapeutic measure.

Is the specific action of some well-known drugs due to their fluorescent properties?

As already mentioned, Rhoads and Pepper in 1866, acting upon the demonstration of the normal fluorescence of the blood by Dr. Bence Jones in 1866, presented the reports of twelve cases in which they claimed that quinine cured by increasing the fluorescence of the blood in cases of fever. In these cases they demonstrated a prior diminution of the natural fluorescence of the blood.

Dr. A. F. A. King of Washington, in his interesting article referred to on "Sunlight and Malaria" (*Vermont Medical Monthly,* June 25, 1902), argues that the malarial parasite is a naked amoeba, that red light promotes the vital activity of amoebae, while violet or purple restricts it; for instance *amoeba proteus* streams in the presence of red light, and ceases to stream in light from the violet end of the spectrum. The color of the light diffused through the blood is red, as one may see by holding the hand in front of a candle. Therefore, the malarial amoeba while thriving in red light, would thrive poorly or perish in light from the violet end of the spectrum. In this manner, he would explain cures of malarial fever by methylene blue, by Prussian blue, and by iodine, which last becomes in the stomach purple iodide of starch, and by quinine, aesculin and fraxin, all of which are "antiperiodics" in ague and fluorescent.

I would suggest another reaction which may have a bearing upon the curative and antiseptic action of the salicylates.

It is well known that the salicylates give a beautiful violet reaction with peroxide of iron. Supposing that salicylates are administered medicinally where is the peroxide to be found? In many diseases, most amenable to the action of the salicylates, there is a great destruction of the blood corpuscles with the formation of pigments in the organism. According to Hugouneng (*Gazette Hebdomadaire de Medicine,* etc., quoted from *Medical Record,* July 5, 1902) all of these pigments are rich in iron. Sometimes peroxide of iron occurs, probably from the destruction of Hematin, which chemically contains iron. Here, therefore, we may have another "color" explanation of the effect of the medicine administered.

Quincke (quoted from L. Freund) showed that haemoglobin gives off its oxygen more quickly in the light than in the dark. For this reason, light increases the oxidising power of the blood and correspondingly increases the processes of oxidation. The salicy-

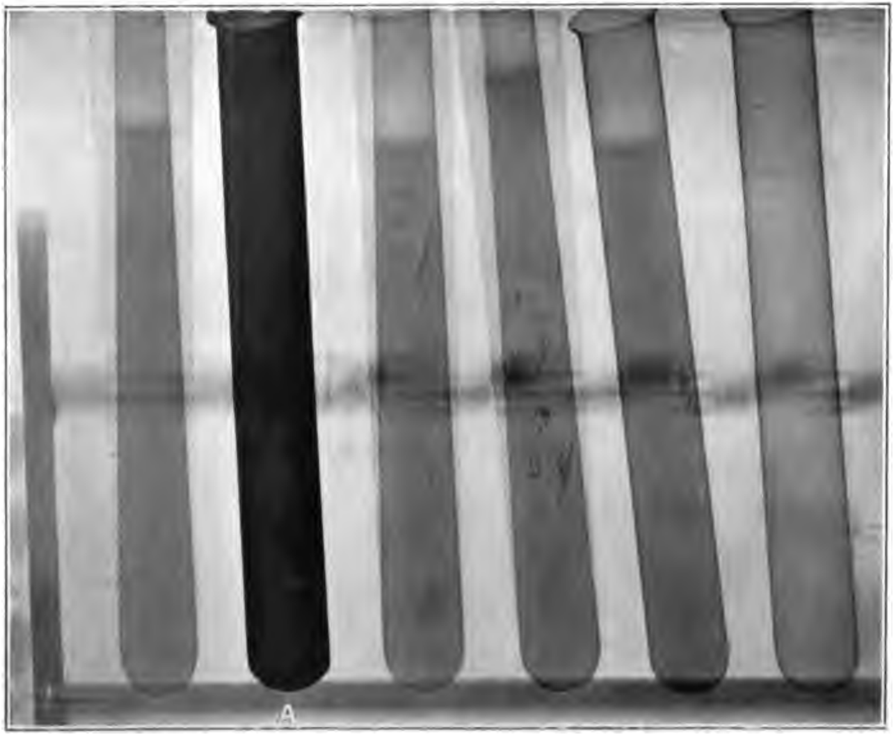

FIG. 3.—ILLUSTRATING ABSORPTION OF RONTGEN RADIATIONS BY FLUORESCENT FLUIDS OR FLUORESCENT COMPOUNDS, TUBES, ETC.

lates may, therefore, I would suggest, promote in this manner metabolic exchanges due to the violet light set up in the blood corpuscle by reason of a combination with the peroxide of iron set free in the decomposition of the corpuscle.

Fluorescence or Sensitisation?

The experiments quoted of Tappeiner and Raab and of Dreyer and Halberstaedter prove beyond question that some nontoxic fluorescent and nonfluorescent substances, under the excitation of the arc lamp radiation kill infusoria and bacteria and cause inflammatory reaction of tissue. This action is ascribed by them to a certain "sensitizing" effect of the same nature as occurs by the use of the same substances in photography.

What then is sensitization, especially in photography? The effect of light upon the sensitive material of photographic plates has long been familiar, but the nature of the reaction between the ether radiation and the sensitive material is not understood. It is not enough to claim that this reaction is simply a chemical one, and say that the chlorine or the bromine of the Ag Cl or AG Br is in unstable equilibrium and is jostled off of its molecular combination by the impingement of the radiation. This simple statement of the case is negatived by numerous objections. For instance, many substances added to the silver emulsions greatly enhance the amount of silver salts set free. Such substances are termed in photography, "sensitisers." Prominent among them are gelatin and eosin. It is, for example, a curious fact that the X-ray will not affect a collodion bromide of silver plate. We must, therefore, conclude that instability of the silver salt is promoted by the proximity and by some action of the gelatin. What the exact action of the sensitiser is, is not yet explained by chemistry.

The commonly received opinion is that by reason of the ether impulse a part of the bromine is separated from the silver and absorbed by the gelatin, and as throwing further light upon the process it is believed that the action of the sensitiser is to increase the capacity of the decomposed salt to absorb oxygen. Per contra, chloride of silver in a sealed vacuum tube and thus out of contact with oxygen, remains unaffected after months of exposure to light. But also, silver chloride free in the air, but unexposed to light, retains its white color. It would thus appear that both light and oxygen must be mutually present, and further appear that in some unexplained manner the "sensitiser" provides the oxygen.

From this point of view, it is pertinent to recall that Sir Oliver J. Lodge has suggested that the therapeutic valuation of X-radiation lies in production of ozone within the irradiated tissue. Granting this, a tissue impregnated with a sensitizer, would be richer in oxygen and we should thus simply enhance the effect of ordinary X-radiation. Against such a conclusion is the received fact that the X-ray produces no such pronounced action in deep as in superficial tissues, although it penetrates to the deeper tissues. L. Freund, as quoted, suggests that in the case of tissues rich in mineral constituents the minerals act as sensitizers.

These facts are all interesting, but they are not final—they explain, without explaining, and for the present I am content to believe that in fluorescence, namely, in light, or in the invisible radiations of the same nature of ether vibration we have a causation which is as fully explanatory of the effects in question as our present knowledge will justify. For this reason, I have preferred to term the method I have advocated "Artificial Fluorescence" of living tissue. Possibly, reasoning by analogy, we may draw the deduction that just as by the intervention of the fluorescent substance chlorophyll, the all-pervading agency of light, causes a supply of carbon to the plant kingdom, so, under the influence of the same light, intervening fluorescent substances cause a supply of oxygen to the animal kingdom.

Experiments.

Among liquid fluorescent substances may be named quinine, aesculin, fraxin, eosin, fluorescin or uranine, rhodamin, cochineal, copper potassium chromate, gentian, henbane, litmus, naphthalene red, paraffin, petroleum, vaseline, stramonium, tumeric, indigo, saffronin, paviine, magdala red, thalleen, resorcorufin and resorcin blue, and some salicylates. (Samples of each exhibited.)

It was quickly found that while the above substances were fluorescent to daylight, a great variation in their capacity for fluorescence existed when exposed to X and radium radiations. Some substances non-fluorescent to sunlight are vividly fluorescent to the X-ray and to radium, and vice versa. Among those most fluorescent to radium are quinine, uranine, fraxin, aesculin, and members of the petroleum series, like vaseline.

Experiments made with liquids in glass receptacles were valueless because the glass itself is highly fluorescent to the X-ray and radium. Radium radiations are on the whole superior to the X-ray

Figs. 1 and 2.— Skiagraphs of Normal Hand before and after Administration of Fluorescin.

in exciting fluorescence. Many fluorescent liquids absorb the X or radium radiations and therefore cast a shadow corresponding to the ordinary density shadow in radiography. This would seem to constitute a new sort of skiagraphy.

Applying this principle, I caused a subject, Dr. W. E. Deeks, to take twenty drops of a 1 to 30 aqueous solution of uranine, and one hour later submitted the hand to an ordinary X-ray exposure. The negative and print obtained when compared to a control picture of the same hand under the same conditions, except as to the dosage of uranine, gave an X-ray picture immensely superior in detail and clearness. This was especially true of the osseous structure and would lead one to suppose that certain portions of the bony structure when saturated with uranine, absorbed the X-ray to a greater extent than if the uranine had not been used. These pictures make an interesting addition to skiagraphy and are here exhibited.

A further interesting outcome of experimentation was the discovery of a new fluorescent liquid, fluorescing a very deep purplish blue so deep that when concentrated, it appeared almost black, but a drop of it added to a test tube filled with water gave a fluorescence as blue as that of aesculin. The observation arose in this manner: Test tubes in which fluorescing solutions of aesculin were allowed to stand during one or two weeks were found, themselves, to have become intensely fluorescent after being emptied and carefully washed out and dried. (See Fig. 3, A.) Such a test tube casts a shadow on a screen or gives a photographic print as dark as would ordinarily be caused by a piece of lead one-fourth of an inch in thickness. (Prints here shown.) It would seem that an aesculinate of silica or a silicate of aesculin had been formed. I have submitted some of this fluid to Prof. Bogert of Columbia University for analysis.

An analogy to the dark bones of the hand and the dark test tubes cannot fail to be noticed.

Granting the entire soundness of the physical facts of fluorescence as demonstrable by laboratory experiment, it is still important to know if the actual living tissue of a subject whose blood is impregnated with a fluorescent substance can exhibit fluorescence.

The following experiment demonstrates that such is the fact. Administering to the patient as above, twenty drops of a 1 to 30 aqueous solution of uranine, one hour later on, fold the lobe of the ear closely over an aluminum tube containing 20 milligrams of radium bromide of 1,000,000 radio-activity. If the experiment is done after remaining from 15 to 20 minutes in the dark, a faint glowing spot on the ear can be observed, not observable in a control experiment where uranine had not been employed. The same experiment may be made with the alae nasi, and perhaps preferably on the thin fold of skin at the junction of the fingers with the palm.

Radio-active water and fluorescent liquids administered conjointly.

Doubt has been thrown upon the possibility of radio-active fluids. There is no ground for this doubt. Such fluids promptly discharge an electroscope and retain this property for eight days if the fluid is kept in tightly corked receptacles. In a specimen furnished by me to Prof. Pegram of the Electrical Department of Columbia University, the radio-activity was at least one-half that of uranium oxide taken as a standard. If radio-active water is used to prepare fluorescent solutions, the fluorescence is highly augmented.

For this reason, I often administer to my patients under treatment by fluorescent fluids, a tablespoonful of radio-active water morning and night. (Radio-active water exhibited.)

It may be asked, But what effect has the radio-active water upon the living being? Demonstrably the water absorbs the emanations of radium and holds them for a considerable time, becoming now a secondary source of radiations similar to the original gamma rays. The charged water excites internal fluorescence.

Clinical Evidence.

In a combined treatment employing as I do the X-ray or radium, radio-active water and fluorescent fluids, which, where cure is effected, is the especial curative agency. I regard the fluorescent fluid as the basic agency and the radiations as excitants merely of the fluorescence. I regard it as essential, if one is to obtain the best results in the treatment of cancer, lupus, tuberculosis, Hodgkins disease, eczema, psoriasis, etc., etc., to administer fluorescent remedies. Whether these fluids act as "sensitisers," whether they allow of the production of more oxygen by ionisation as the X-ray and radium may act thus augmenting the action of the latter at deeper situations, or whether the fluorescent light itself acts as, I believe, does ordinary light and sunlight—these questions no one as yet can answer.

In support of the latter view, we may briefly summarize the action of light. Absorbed light in nature while usually transformed into heat, may also as has been said, be transformed into fluorescence and phosphorescence, may produce chemical effects as in photography, or in determining other chemical combinations, and may cause electric or mechanical phenomena.

Under the influence of light, plants absorb carbon and give out oxygen. They decompose the carbonic acid gas of the air by aid of the chlorophyll.

Physiologically, light acts upon the protoplasm and thus modifies vital processes. Its effect is both stimulating and irritating or destructive. According to Loeb (quoted from Freund) "light is not only an irritant in a physiological sense, but it actually infuses the organism with energy which is transmitted into other forms for the most part of a chemical nature."

That light kills some bacteria is now established beyond dispute by the experiments of a host of observers.

The effect of light upon animal organisms, including man, forms a most interesting chapter by itself. Light acts as a stimulus to the animal functions. Frog spawn in an opaque glass die—in transparent glass they develop normally. Darkness hinders and prevents the growth of many of the lower forms of animal life. Young mammalian animals, including children, develop more perfectly in light. Ciliary movements of epithelium in grown animals is modified by light. Light stimulates the action of unstriped muscular fibre and it stimulates pigment cells—it modifies the quality of the skin, reducing protoplasm to keratine, it produces intense inflammation of the skin. "The haemoglobin gives off its oxygen more quickly in the light than in the dark, hence light increases the oxidising power of the blood, and correspondingly the process of oxidation in the human body." (Freund.) And some observers claim that light modifies the oxidation of the tissues. Many experiments tend to show that light also modifies metabolism by direct action upon cells. Others, however, deny this. Experiments also show that light modifies the temperature, respiration and the pulse.

Applications in disease.

As to dosage, I employ quinine bisulphate, in doses of from five to fifteen grains daily, according to the natural physiological tolerance of the patient—fluorescin, a 1 to 30 aqueous solution, from

6 to 20 drops, three times daily, one hour after meals—aesculin, from 5 to 15 grains daily.

One patient, Dr. P. of Washington, D. C., has now taken in treatment of an extremely obstinate case of lupus, ten drops of the fluorescin solution, three times daily, during the last three months, and employing the X-ray, not only has his lupus healed over large areas, but also he has gained thirty pounds in weight in the three months. Both in hospital and in private practice, my cases of lupus heal more rapidly and get permanently cured by this method, and in less time than by any other method I have used.

I have ready to report six cases of tuberculous glands of the neck, two already subjected unavailingly to numerous surgical operations for removal, who are now perfectly well. One case of tuberculosis of the hip joint is making excellent improvement.

In tuberculosis of the lungs the method is giving good results, not yet ready to be reported upon in extenso.

In the case of the latter disease, in from one to three days after beginning treatment, a reaction occurs. The afternoon temperature in a recent case rose from normal to 103 deg. Fahr. The cough, night sweats and lassitude increased. Examination of the sputa at this time revealed an enormous increase of the number of tubercle bacilli. This reaction lasted about a week and then the temperature gradually fell to normal, with corresponding improvement in the other symptoms. The patient now entered upon a stage of steady gain in weight and comfort and personal appearance. The case is under most rigid observation by skilled consultants and will be reported upon later on.

It is interesting to observe that the course of events in this and other cases follows accurately that described by Dr. Chisholm Williams of London, England,[9] in his 43 published cases treated by him by high-frequency currents, and with such brilliant results. Of his original 43 cases he writes, "Three have died; the rest, 32, have had no treatment of any kind whatever for over 18 months. Eight cases had of an average two months' treatment, each since that time. This year none of them have needed treatment. The majority, who were workers, are performing their usual duties. The three deaths were due to pneumonia, tuberculous kidney, and lardaceous disease."

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[9] "High Frequency Currents in the Treatment of Some Diseases," London, Rebman, Limited, 1903, p. 173, p. 166.

Dr. Williams remarks further, "There is reason to believe that currents act in these cases in the following manner:

"Firstly on the tubercle bacilli themselves by making them pursue the same course as if they were under the X-rays. According to the experiments of Dr. Forbes Ross and Norris Wolfenden, in their paper on the 'Effects produced in culture of tubercle bacilli by exposure to the influence of an X-ray tube' (*Archives of Röntgen ray,* August, 1900), they observe that the bacilli rapidly increase in numbers and have a tendency to form clumps, then get small in numbers and shape, and take the microscopical stains very readily, but are pale in color." They say, in conclusion, "There is not the smallest doubt that X-rays stimulate them to excessive overgrowth, and only affect them adversely by attenuation from overgrowth.

Dr. Williams continues, "In my experience much the same process goes on under the high-frequency treatment. The tubercle bacilli, which are usually present in fair numbers, quickly begin to increase and after a few applications are greatly increased; they soon, however, form clumps and get misshapen, short and stumpy, and generally curved, and take the stain more readily than before. After a time they begin to decrease in numbers, and later, when the patient is obviously getting better in every respect, they may cease entirely, and may appear in the sputum after weeks of absence."

It should also be mentioned here that not only does the fluorescent method exert a direct remedial and curative action in phthisis, but it also has afforded me, and others to whom I have demonstrated it, a more accurate means of physical diagnosis as to the location and size and extent of pulmonary lesions. When one examines the thorax by the X-ray and the fluoroscope, first without the administration of fluorescin (or other fluorescible solution), and second after it has been administered, one is struck by the great difference. With fluorescin, the lesions are more easily distinguishable, they cast a darker and clearer shadow upon the fluoroscope which in its lighter portions is at the same time more brilliantly illuminated. In a word contrasts are greater and definition clearer. A skiagraph shows the same relative improvement in definition, as already pointed out in the illustration of the hand (Figs. 1 and 2).

In cancer I summarize only two cases briefly from my notebook.

They are typical of many others illustrating the superior efficacy of the fluorescent method over X-ray treatment alone.

Case 1, Mrs. E. E. A. Jan. 28, 1904. Six years ago a tumor in the right breast and a gland in the axilla appeared. The entire breast was removed by Dr. W. E. Brown, and pronounced carcinomatous. Cancer returned and extensive surgical removal was resorted to. Cancer again recurred and patient resorted to the use of the X-ray but to no avail.

Four months ago the right arm began to increase in size and grew quite large. She then came to me.

Present condition.—Brawny oedema of right arm, a lump nearly an inch in diameter, of stony hardness within the axilla, induration in the scar tissue, extensive induration at the pectoral fold, infection of the lymphatics of the skin, and a few skin nodules, enlarged glands above the clavicle and the personal appearance of carcinosis. She had lost flesh, and was sallow, pale and anaemic.

The patient was put upon quinine and X-ray combined. By March 1st, the swelling of the arm subsided. Owing to the difficulty of getting the X-ray into the axilla, radium bromide 20 milligrams of 1,000,000 radio-activity in two aluminum tubes were employed, placed directly upon the hard axillary tumor, one hour daily, for a month. A radium "tan" was established and the skin peeled off several times.

May 26th. No sign of disease remains. The cachexia has disappeared. Patient has regained her normal weight and is discharged to await events.

This is the first case in which the clavical glands were involved, in which I have seen a recovery.

Case 2. Mrs. L. E. W., July 12, 1904. About five years ago had the right breast removed by the "plaster" process, on account of a tumor about the size of an orange. Five recurrences have ensued, each one in turn treated by the same method.

Present condition. An open ulcer about 3 in. long and ¾ in. wide is situated in the center of extensive and widely infiltrated edges of surrounding tissue. A small, hard tumor in axilla, also enlarged glands.

Treatment. Fluorescin and X-ray combined, usual technique and radium, high intensity as in Case 1.

July 27th. Ulcer already almost healed.

Sept. 8th. The indurations surrounding the cicatricial tissue, the enlarged glands, and the small hard tumor in the axilla are fast disappearing. The ulcer is long since completely healed.

Oct. 15th. Patient returns home today. Careful examination reveals no infiltration and absolutely no sign of her former disease can be found.

Dr. A. Beclère, of Paris, reports in *La Radium* of July, 1904,[10] a case of cure of osteo-sarcoma of the superior maxilla, recurrent after having been twice removed surgically during a period of three years. "Synchronously with the X-ray treatments and half an hour before their application, were administered, 50 cgm of the bichlorhydrate of quinine as recommended by Dr. Morton, of New York." Beclère considers that the details of this case may fairly be considered as indicating that the quinine through its property of fluorescing when subjected to the influence of the X-ray may have been a factor in producing the cure, but is not ready to commit himself positively upon this point without having observed more cases. The reviewer continues, "The case is certainly very important, as the cure of a malignant process involving bony tissue by radiotherapy alone, is at present almost, if not quite, an unparalleled event."

I am glad also to note that Dr. R. C. Kemp of New York, following my suggestion of the use of fluorescent solutions in diagnosis and treatment, has demonstrated its value as a means of determining the position and size of the stomach.

Dr. Solomon Solis Cohen, of Philadelphia, has brilliantly verified the value of the method, employing a special stomach lamp of his own construction. I have found that the illumination is increased by the use of radio-active water and also that no technique as to fluids and bicarbonate of soda is of special value. A simple solution of fluorescin in plain water (1/8 of a grain of fluorescin to a pint) is all-sufficient to produce a vivid illumination when the stomach lamp is introduced. Doubtless many other applications similar to transillumination of the stomach will follow the method of the internal use of fluorescing solutions I have outlined.

Among cases in which I have found the method useful are carcinoma and sarcoma, lupus, Hodgkins disease, tuberculosis and phthisis, eczema, psoriasis, and also in many nervous affections and insanity.

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[10] Quoted from *Archives of Electrology and Radiology*, September, 1904, p. 355.

SUMMARY AND CONCLUSIONS.

1). The excitation of fluorescence within tissue is a species of phototherapy and dependable upon the same basis for curative effects. The term sensitization is not accurate, for it is not known what the term means. There is no proof that fluorescent substances make the cells or other microrganisms vulnerable to the exciting radiation.

2). What the fluorescent light lacks in intensity is compensated for by propinquity to tissue.

3). The methods of Tappeiner (1900) followed by Dreyer (1903) consists primarily of superficial applications or of parenchymatous injections submitted to the action of sunlight or to the action of the electric arc light.

4). The method here outlined consists of a medicinal saturation of the entire blood system with a fluorescent solution and submission of the parts or the whole of the patient to the Röntgen and Becquerel radiations, and to electric discharges.

5). The method naturally includes filling cavities with fluorescent solutions as well as using them medicinally.

6). Following the suggestion of the use of fluorescent solutions in diagnosis and treatment, the method has proved of value in determining the position and size of the stomach and other cavities of the body.

7). This method is not of the same category as "*sensibilitization*" by Dreyer's method, for the process and the results are different.

8). This method permits of a deep effect by the fluorescent excitation of the absorbed medicines which is not an effect due to the X-ray or radium radiation. The effect is probably due to the fluorescent light.

9). This method permits of an improvement in skiagraphic effects and of fluoroscopic examinations.

10). The thoracic cavity presents upon the fluoroscope a degree of illumination far beyond that produced by the X-radiation alone. The method is useful in tuberculosis of the lungs, and in other cases of tubercular deposit, as well as in cancer, malaria and other diseases referred to in this paper.

DISCUSSION.

Dr. Morton: Some one in the course of discussion has asked me to explain this matter more fully. The procedure is most simple. Take quinine, for instance. Simply administer to a patient quinine up to the point of his physiological limitations. Some patients get along with five grains, some with seven and one-half, some with ten, daily. I increase the dosage according to the patient's natural tolerance. Thus, no matter upon what part of the body you turn the X or other radiation your fluorescence is excited. Secondarily, the whole patient may become irradiated — the entire body may have fluorescence set up within it or this effect may be confined to a single part. If the case is a carcinomatous breast or a sarcomatous ulceration, fluorescence is set up at that point. Perhaps you saw in a recent issue of the Archives of Electrology and Radiology there is reported a cure of osteosarcoma by the use of this method, and the physician, Dr. Beclère, in reporting the case is inclined to believe that if he had not used this method the osteosarcoma would not have gotten well. I too am of the same opinion. I have a case of osteosarcoma of the femur under treatment by this method that it getting along very well.

Or again you give a solution of uranine, one part of uranine to thirty parts of water, and give five drops three times a day in a tumbler full of water one hour after eating; increase the dose every few days up to twenty drops, according to the toleration of the patient. Within twenty minutes after the administration of the uranine the urine becomes intensely fluorescent, and while the patient is taking this fluorescent preparation the urine remains thus fluorescent. The uranine is not changed in passing through the system. I began in my clinic in New York to treat an ulcerating sarcoma as large as a man's head, and immediately with the use of the fluorescent preparation and the X-ray treatment the frightful odor ceased and the tumor diminished in size, but we did not, however, save the patient; she died of general infection.

Dr. C. E. Skinner: I would like to ask Dr. Morton whether there is any one substance that he prefers uniformly to any other, and if he selects some one of the fluorescent solutions to suit different conditions?

Dr. Wm. J. Morton: It has been my practice now for some years to treat cases of carcinoma by the quinine method and the X-ray, and then later on I used radium in the same manner. Radium causes a brighter fluorescence of quinine than does the X-ray, and in cases of carcinoma is superior to quinine. Another beautiful fluorescent substance is called aesculine. The dosage of aesculine is about 10 grains daily. But one does not need to give more than five grains daily to entirely fluoresce the whole body when the exciting radiation is applied. Five grains of aesculine will give a general fluorescence of the thirteen pints of fluid in the human body. I have made no special differentiation, except that I use quinine in certain cases and aesculine in certain cases. I have no definite knowledge as to the difference. These three fluorescent substances are to be recommended because they have absolutely a non-toxic effect, and if one will confine himself to these three, namely, quinine, fluoresicin, or uranine and aesculine, he will do very well. Dr. Grubbé mentioned yesterday the use of strontium salicylate; this is also a good fluorescent preparation. I would like to ask Dr. Grubbé what dosage he gives.

Dr. **Emil H. Grubbé**: I have used this chemical because it is more fluorescent than anything I have ever used. It is fluorescent, particularly in the violet portion of the visible spectrum, and by examination I am also able to prove the existence of a large proportion of ultra-violet rays. This substance is also non-toxic, and in some cases I have given sixty grains daily for several months. My method differs from Dr. Morton's in that I do not saturate the system. I have applied the method in a limited manner compared with Dr. Morton's. I inject the solution in cases of tumor by the hypodermic method and just before I apply the X-ray. In treating ulcerated conditions I dust the substance in the form of crystals right into the ulcer and then apply the X-ray. I am pleased to hear that Dr. Morton has discovered a method for using fluorescent substances to aid us in radiography; this to me is very interesting, and as soon as I get home I shall put into practice some of the things I have learned here. To me this paper is extremely interesting since I have worked with fluorescence in connection with the X-ray quite a good deal. I have been considerably handicapped by having to do this work myself. Dr. Morton has so many able assistants and he has been able to gain much more knowledge than the rest of us. I know it will stimulate me to more activity, and I hope everybody who has an X-ray outfit will get hold of some of these fluorescent substances and begin investigation on his own behalf.

Dr. **Morton**: I wish to thank the gentlemen for the close attention they have given to the paper and the discussion. In relation to the point about peroxid of hydrogen, it is at least, I think, an interesting suggestion, bearing upon color effects in the blood. The destruction of the hemoglobin is accomplished with a considerable production of peroxid of hydrogen, and if salicylates are administered as in the usual manner we may possibly have a violet or blue-colored medicine acting by reason of this color alone. This, however, is a consideration quite apart from fluorescence artificially excited.

(Continuation of Discussion on Friday.)

Chairman Morton: I wish to take a few minutes of your time to present to you in continuation of yesterday's paper with a specimen of radio-active water, drawn from a tank used in my office. The bottle is tightly corked and the water will retain its activity for four days, and will lose it gradually until the end of the eighth day; it is quite easy to make a continual fresh supply.

I would also like to pass about an interesting method for the application of radium. In my hand I hold a celluloid tube or rod. In its plastic condition it has simply been rolled in a salt of radium. The radium salt has become incorporated in the surface of the celluloid and the celluloid has then hardened; the particles of radium salt are now retained very close to the surface, much as a fly is retained in the well-known amber specimens. The radium salt can thus be preserved without deterioration, and in this shape it can be applied to cavities where otherwise it would not be easy to apply it. We first received our radium in glass tubes, but that would allow only the escape of the Gamma rays which correspond to the Roentgen rays. Then we received it in aluminum tubes, and that would allow only the escape of the Gamma and Beta rays. But by this method we obtain some of the Alpha rays which constitute about 90 per cent of all. In this connection it is important to note that the effect of radium is due to a surface action. For instance, if we should take a glass of radium water and place it under the electroscope it would have no more action on the electroscope than if we took a flat section of the same water of the thickness of paper and placed it under the same electroscope. Therefore, radium water or a radium salt spread out secures surface action and we gain nothing by using a solid mass. In other words, if this were a solid rod of radium it would produce no more ionizing effect upon the air, nor any greater effect upon the patient's lupus or cancer, than if, as in this instance, it is simply spread upon the surface. It is the recognition of the surface action of the radium that lends importance to this new invention. It is the invention of Mr. Hugo Lieber, of 25 West Broadway, N. Y. City, and I think it becomes of considerable interest in our radium application, in that it reduces the price and increases the facility of usage.

Undoubtedly most of us have seen the Albers-Schöenberg compressor in the exhibit of the German educational department at the World's Fair. It is an expensive apparatus, but an effective one, and you will see skiagraphs in the exhibit of Siemens and Halske that are most beautiful taken with the aid of this Albert Schöenberg compressor. To-day we have seen the application of the same idea by Dr. Beck. I will also show here an apparatus of my own; it is simply a piece of aluminum plate from one-sixteenth to one-fourth of an inch thick and six inches in diameter. It is extraordinary how little influence a sixteenth inch plate of aluminum has upon the penetrating capacity of the X-ray. I strap this disk around the body, taking up the slack every few minutes until I have acquired great fixity of the part, whether of the hip or kidney region, the abdominal region, the shoulder region, etc. Pictures obtained by this compressor diaphragm of aluminum are very clear and distinct, and from the fixity obtained during the taking of the skiagraph it makes it a very convenient device. I have used it since the first beginnings of skiagraphy but have never published the idea, and to Schönberg surely belongs the credit of promulgation of fixation in skiagraphy.

I pass the disk around as an exhibit. In its edge are cut slots for the use of bandages or the disk itself may be set in a flat brass ring, the latter slotted for the bandage or strap.

Dr. Carl Beck: I simply want to give our esteemed chairman credit for his pioneer work. I am sorry he did not work his idea out more elaborately some years ago, because he would have been the Albert Schönberg of this country. The principal was conceived by him long before Schönberg. After that Walter had the same idea and later Schönberg worked it out. I have seen the whole plant of Siemens and Halske in Berlin, and the apparatus they sell there, and I can only corroborate that it is the greatest outfit I have ever seen anywhere. I have seen most of the plants in this country, and I believe that is the greatest and the most valuable outfit which exists. Nobody interested in skiagraphy should fail to see it. I believe with the compressor alone a valuable picture can be made. If a man understands the technique perfectly he is able, by giving the patient a careful position and by estimating the degree of vacuum correctly, to get a much better picture with a simple apparatus than the man who is not skilled in skiagraphy with elaborate means. I hope Dr. Morton will elaborate his ideas still more.

A LARGE FIBRO-SARCOMA TREATED BY ROENTGEN RADIATION.

BY DR. CLARENCE EDWARD SKINNER.

Probably no one subject has ever excited a greater degree of interest in the minds of medical men than the discovery of the beneficent influence which the Roentgen ray exercises upon malignant disease. It has now been demonstrated thousands of times, it has been studied by hundreds of scientists, yet our positive knowledge of the rationale of this influence is still practically nil, and a large proportion of our colleagues are still skeptical as to whether such a power is actually inherent in the X-ray so as to be utilizable for the attainment of practical curative results. This is especially true with regard to deeply-located malignant processes and we are obliged to admit that with regard to this particular class of cases, there is much to justify skepticism; the failures are much more numerous than the successes. Occasionally, however, a case is encountered in which effects of profound significance are observed, as regards both rationale of action and the demonstration of its curative power, and it is because of some striking clinical phenomena obtaining in the following case and bearing upon these points that I call it to your attention.

The patient was brought to me in January, 1902, from the Memorial Hospital of New York City where she had been for some months under the care of Dr. W. B. Coley, whose description of the case up to that time, as it appears on page 767, Vol. XXI, of the "Twentieth Century Practice of Medicine", is so succinct and complete that I quote from it as follows:

"M. J. H.—, female, aged 34 years, was referred to me by Dr. Maurice H. Richardson of Boston, on April 19, 1901. The patient had a well-marked family history of malignant disease. She had been operated upon three years before for what was regarded as a fibroid tumor of the uterus; tubes and ovaries also were removed. No microscopical examination was made. Two months previously she had first noticed a hard tumor in the lower part of the abdominal wall in the region of the cicatrix. There was no pain, no discomfort, but rapid increase in size. When the patient came under my care, physical examination showed a tumor, the size of a cocoanut, in the lower part of the abdomen, filling up the entire iliac fossa, extending nearly to the umbilicus, and two inches beyond the median line to the left. The tumor was very firmly fixed and seemed to involve the abdominal wall. An incision was made under cocaine and a portion of the growth, which infiltrated all the muscles of the abdominal wall, was removed for microscopical examination, which showed it to be fibrosarcoma. The erysipelas toxins were used for ten months. During the first two months the growth decreased more than half in size, and for a long time thereafter, while there was no decrease, there was no distinct growth. Later on, the influence of the toxins seemed to have become lost, and there was a slow but gradual increase in size. In January, 1902, the tumor was growing rapidly, and at this time the abdomen had the appearance of that of a woman seven months pregnant."

Three points are established by Dr. Coley's description. First, that a large deeply-located abdominal tumor was present, which was inoperable and malignant in the opinions of two of the ablest surgeons in the United States; second, that these opinions as to malignancy were confirmed by microscopical examination of excised portions of the tumor; third, that in spite of thoroughly applied treatment along approved lines, the tumor was rapidly growing and entirely beyond control.

The measurements of the tumor when I began to apply the X-rays in January, 1902, were 10 ins. from side to side, at the level of the anterior superior spines of the ilia, 8 ins. vertically in the median line, and about 5 ins. anteroposteriorly in the median line. Estimation of the last-mentioned diameter is based, in addition to the gross appearances, upon observations made by Dr. Coley when the last excision for microscopical examination was done in December, 1901, the incision having been carried down to the peritoneum in the median line; I was assisted in the determination of the other two by Dr. C. A. Bevan of West Haven who brought the case to me and who has watched it most carefully throughout. The anterior surface of the mass was evenly convex, somewhat more prominent on the right side than on the left, of a stony hardness throughout, firmly adherent to the overlying skin and firmly adherent to the os pubis. The patient weighed 128 lbs., was rapidly losing flesh, markedly cachectic, and so weak that the ascent of a flight of half a dozen stairs was an herculean task; she complained of sensations of pressure in the abdomen, and disturbance of the intestinal and bladder functions was present. In a word the general condition was bad and growing rapidly worse. Pain had never been present.

The X-ray applications were begun Jan. 28, 1902, and were all administered by means of a Truax improved tube giving rays of high penetration and backing up a spark of from 4 to 6 ins., excited by a Morton-Wimshurst-Holtz influence machine having 12 32-in. revolving plates, for the first seven months, and by a machine of the same type having 16 revolving plates 32 ins. in diameter for the rest of the time. The anode was placed 9 ins. from the patient's skin and the duration of the application was 15 minutes; the tube was focused upon the middle of the anterior surface of the tumor at one seance, upon one side at the next, upon the other side at the next, and so on treating these different areas successively. That the rays penetrated clear through the growth was demonstrable by the fluoroscope when the treatments were applied to the sides of the tumor, the rays being visible in considerable volume upon the opposite side. One layer of thin toweling only was interposed between the source of the rays and the patient's skin, and the face, chest, and thighs below the level of the pubis were shielded by tin foil gauge No. 22.

During the first two weeks she received six treatments. At this time an area 5 ins. in diameter on the anterior median surface of the growth had softened very noticeably to the depth apparently of about an inch, the skin had become freely movable over this area, the patient's general condition had markedly improved, and the impairment of intestinal and bladder functions had decreased to a very considerable extent. The sensations of pressure in the abdomen, of which the patient had complained bitterly before treatment, had nearly disappeared, she felt greatly improved generally, and had gained 3 lbs. in weight.

To make a long story short she received forty-six applications up to June 5, 1902, a period of 125 days, being an average of 1 radiation every 2.7 days, when the following conditions obtained; the antero-posterio diameter had increased to such an extent that the distance between the anterior superior iliac spines, measured over the tumor, was 15 ins. with the patient lying flat upon her back, instead of 13¾ ins. which it had been when treatment was commenced; the vertical dimension of the tumor had increased on the right side but had decreased on the left side to the extent of about an inch so that the growth was now irregular in outline, its longest axis running diagonally from the upper right hand border about the level of the gall bladder, to a point just to the left of the os pubis. Three or four times since treatment was commenced she had suffered from attacks of sharp prostration accompanied by febrile movement and circulatory acceleration which had lasted for from three to seven days, the last one, which was more severe and of longer duration than the others, having occurred in May. These attacks were probably toxaemic in nature. Aside from these attacks her general condition was very good, she was eating well, sleeping well, constantly gaining in strength, and could walk moderately-long distances without difficulty. If it had not been for this improvement in the general condition I think I should have discontinued the treatments at this time as the increase in the size of the tumor did not tend to reassure me as to the ultimate outcome.

On June 7 I sent her to her home in Massachusetts for a 10 days' vacation and when she returned a marked change had taken place. All traces of the toxaemia which were present when she went away had disappeared, she walked with the sprightly step of health, there was a good color in her face, and she reported herself as feeling better than for many months. The most striking change, however, was in the tumor; it seemed to have decreased in size about 20 per cent and the patient had found it necessary to shorten her waist bands and the fronts of her skirts to keep them from dragging on the ground. We resumed the treatment with new courage and considerable hope.

From June 17 to September 3, 1902, a period of 78 days, she received 31 radiations, an average of one every 2.5 days. Her general health continued good, her strength steadily increased, and the tumor slowly but steadily lessened in size. During the latter part of August she consulted me as to the advisability of resuming her occupation of teaching school which had been interrupted for a good deal more than a year, saying that she then felt amply able to do so and was getting very tired of having nothing to do. It was decided that she should resume her position tentatively, returning to the sanitarium every week or two for further treatment.

This line of management was followed out until April 25, 1903, a period of 234 days, during which she received 46 radiations or an average of practically one every five days. On several occasions during this period when she was able to stay but a day, she received two treatments in 24 hours. Slight erythema was induced several times which always subsided kindly before the time of her next visit; the skin and subcutaneous tissues had assumed a brawny, leathery consistence, and slight evidences of toxaemia of two or three days' duration but not severe enough to interfere with her daily duties, had appeared three or four times; the tumor had continued to decrease in size, the process of diminution being particularly rapid for several days following each toxaemic attack.

From April 25 to August 29, 1903, a period of 127 days, she received eight treatments, an average of one every 15.8 days. Following the application on April 25, she suffered for six days from a sharp attack of toxaemia accompanied by slight soreness of the growth, which was followed by a very marked lessening in size. Her weight at that time (August 29, 1903), was 139 lbs., and the tumor was no longer noticeable when she was clothed.

Early in September, 1903, she developed an area of necrosis as large as a silver half dollar 2 ins. to the right of the median line and just above the upper border of the pubis, which was accompanied by very severe pain for two weeks and by fairly constant but gradually-subsiding pain for six weeks more; the ulcer required over three months for complete healing and presented a variation in appearance from the ordinary X-Ray ulcer in that no white gangrene was present at any time. It appeared first as a dark-colored scab projecting slightly above the surface of the skin; later pus formed under this scab. When the scab was removed and the cavity washed out the same condition would recur after a few hours. The cavity was about one-quarter of an inch deep with abrupt edges.

She received her next radiation on November 25, 1903, although the ulcer was not yet healed. The tumor had diminished rapidly while the burn was in process of evolution although no radiations had been given, and presented at this time the appearance of a disc-like mass about 3 ins. in diameter and an inch in thickness, lying to the right of the median line and just above the pubis from which it had now become detached. It was not sensitive to manipulation. The skin over the whole abdomen was mottled dusky red and brawny in consistence; the latter characteristic seemed to extend for some distance into the subcutaneous tissue.

From this time until May 20, 1904, a period of 185 days, five radiations were given, being an average of one every 37 days. The patient's weight had increased to 147 lbs., and *the tumor had entirely disappeared.* She was examined by Dr. G. N. P. Mead of Winchester, Mass., at that time, and by Drs. Bevan and Coley in July, all of whom had had the patient under observation not only while she was under my care but for long periods previously, and all of them confirmed the result of my own examination as regarded the entire disappearance of the growth. A spindle-celled sarcoma, 10 ins. in the horizontal from side-to-side, 8 ins. in the vertical and 5 ins. in the antero-posterior diameters, which was inoperable, had resisted every measure applied for its relief, and was rapidly developing lethal symptoms in the person of its victim, was entirely removed and the patient restored to a condition of unimpaired usefulness and apparently perfect health, by 136 applications of X-rays of high penetration from a tube excited by a static machine, the treatment having extended over a period of 849 days, being an average of one application every 6.2 days.

Prominent among the conclusions deducible from this case are the following:

First, Roentgen radiation sometimes brings about the entire disappearance of large, deeply-located malignant neoplasms, which have been proven to be hopelessly lethal in their tendencies under any other management, and simultaneously restores the patient to apparently perfect health.

Second, the fact that it sometimes accomplishes this result, taken in connection with the size of the malignant mass in the case just cited, demonstrates that the lack of satisfactory influence which attends its employment in so many cases is not due to weakness inherent in the remedy itself or to mere thickness of the tissues intervening between the pathological focus and the source of rays, but to some at present undetermined factors which it remains for us to identify and which, it seems justifiable to hope, we may some time in the future eliminate.

Third, there is probably a direct and intimate connection between systematic toxaemia and the disappearance of malignant growths under Roentgen radiation, as indicated by the uniform occurrence of sudden diminution in the size of the tumor immediately following each onset of toxaemic symptoms during the later course of this case.

Fourth, the application of the Roentgen rays to a malignant growth belonging in the same class as the one I have just described, should be persisted in as long as the patient's condition will permit, even if no benefit is observable. It will be remembered that no material effect upon the tumor was demonstrable in this case until after the radiations had been systematically and regularly carried out for six months.

Two other points to which I desire to call your attention are that the rays employed were of a high degree of penetration, and that the tube producing them was excited by a static machine. The belief is prevalent that the rays from a given tube are identical whether the tube be excited by a coil or a static machine. I am not as yet sufficiently well supplied with observations bearing upon this point to feel justified in making any positive statements in reference thereto, but I wish to place myself upon record as believing that there is a vast difference between the therapeutical effect of the rays derived from a tube excited by a static machine and those derived from a coil-excited tube, and that the difference between the rays derived from these two sources will sometimes constitute the difference between success and failure in the management of deeply-located malignant processes.

I am aware that the question of recurrence in this case still remains to be eliminated but for the solution of that problem the future history for several years only is adequate; but even if the growth recurs tomorrow, the present fact remains, that a woman whose condition was such that she was absolutely useless and hopelessly doomed to early death three years ago, has been for two full years restored to a condition of unimpaired usefulness in an arduous walk of life, to a condition of unimpaired comfort in living, and to a degree of apparent general good health as great as, and a body weight that is greater than she had ever attained in her life before, and that all of these conditions have been obtained solely and entirely through the instrumentality of the Roentgen ray.

DISCUSSION.

DR. EMIL H. GRUBBÉ: I do not care to take up too much time, but the paper is one which is really a landmark of the subject. I cannot allow it to pass by without comment on two points which I consider of very great importance. First the matter of pushing the treatment. You will note that Dr. Skinner did not stop the treatment. You will note that Dr. Skinner did not stop treatment even though he had burned the patient; he continued the treatment while the burn was slowly healing. After that his results were obtained. Even after we find we have toxemia present we must increase the application of the X-ray treatment, and we must use adjuvant treatment to aid the X-ray in its destructive and eliminative work.

Dr. W. B. SNOW: I wish to report a case of sarcoma that came under my observation, which is rather remarkable. This case had two months' treatment by the Coley fluid preceding the treatment by the X-ray. In this case the results from the Coley fluid were far more successful than in the case just reported. It was an abdominal tumor located in the muscles just below the umbilicus. I did not see it in the early stages when it was about one-half as large as a human head. It had been reduced to the size of a small orange, when the patient was sent to me by Dr. Grad who followed it with me. After the first application of the X-ray there was a violent reaction. It finally broke down and discharged freely from the surface, and gradually disappeared. It is now two years since the treatment was discontinued and the patient remains well.

Dr. C. E. SKINNER: I fail to see how anything in this case which I have had the honor of reporting could be construed as commendatory of the toxine treatment either applied alone or in combination with the X-ray, as far as ultimate results are concerned. The tumor decreased temporarily under the influence of the toxines at first, but for several months before she came under my care the toxines had lost their power. The tumor was rapidly growing; was larger than before the toxines had been administered, and she was given them in such large doses that her condition was a matter of the gravest concern to the attending physician on several occasions because of their effect. He could not benefit her any more because the toxines had lost their power and the tumor was gaining on the patient in spite of them. In some cases the toxines are unquestionably a good thing, but as they were not administered in conjunction with the X-ray, I do not consider that they played any part in producing the favorable outcome of this particular case.

In reference to using the static machine tubes on a coil, there are some static tubes like the Truax that you cannot excite with the coil. There are others, however, with which you can use the coil, and if you do not employ too high an amperage the anode does not burn out. I have a number of static tubes through which I use the coil current right along, but I have to watch the amperage and keep it down with a rheostat so that the anode does not get too hot. With this precaution many static tubes can be safely excited with a coil current.

FRIDAY MORNING SESSION, SEPTEMBER 16.

The Section was called to order at 10 o'clock by the chairman, Dr. Wm. J. Morton, who announced the first paper on the program by Dr. Kellogg, to be read by Dr. Monroe.

ELECTROTHERAPEUTICS IN CHRONIC MALADIES.

BY DR. J. H. KELLOGG.

For more than thirty years I have devoted myself to the study of physiologic therapeutics and the practical application of natural and rational measures in the treatment of chronic disease, and have endeavored to correlate into a practical system the various curative forces comprised under the terms hydrotherapy, kinesitherapy or medical gymnastics, active and passive, thermotherapy, phototherapy, and electrotherapy. Each of these classes of curative measures is a complete system and presents resources which may be made available in almost every form of disease, acute and chronic. There is perhaps no disease or morbid condition in which hydrotherapy may not render some substantial service. The same may be said of phototherapy, electrotherapy and all other classes of natural curative agents. Nevertheless, a careful study of each of these classes of therapeutic measures renders clearly apparent the fact that each one has its special province.

This is particularly true of electrotherapeutics. There are cases in which electricity will accomplish what can not be so well and quickly done by any other means. Even in these cases, however, the best results are often attainable only when hydrotherapy and other physiologic means are employed in connection with the application of electricity. For example, when electricity is employed for the relief of pain, its effect may be greatly enhanced by making just previously an application of heat, as by means of a very hot fomentation. The fomentation moistens and congests the skin, and thus increases its conductivity while lessening the sensibility of the cutaneous nerves so as to increase their tolerance of the electric current, thus rendering possible the application of a current of maximum strength. Heat has also a specific effect to inhibit pain, thus contributing in a marked degree to the desired result. By this combination of the hydriatic and thermic effects of a fomentation with the special effects of the electrical current, results are often obtainable which can not be attained with either measure alone. I have for many years practiced the application of heat in connection with electrical application by placing over the electrode a rubber bag filled with hot water, or a flannel cloth wrung out of hot water.

On the other hand, when it is desired to secure the stimulating effects of electricity, as, when the purpose is to excite muscular contractions, a cold application just preceding the electrical application is of very great value by increasing muscular excitability. Every one is familiar with the fact that cold water is likely to cause cramp in swimmers. This is a very pronounced example of the effect of cold water acting through the thermic nerves in exaggerating muscular contractility, even to the degree of producing spontaneous tonic muscular contraction. The cold application may consist of a compress wrung out of cold water, or rubbing the part with ice. The application should not last more than three or four minutes. It should be accompanied with rubbing. By this means it is possible to secure contraction in muscles which do not respond to an electrical current that the skin will tolerate. I find it especially useful in the application of the sinusoidal current to the abdomen and back for gymnastic purposes. Vigorous cold rubbing is also of great service as a preparation for electrical application in cases in which muscular degeneration has taken place to such a degree as to lessen susceptibility to electrical stimulation. A long chapter might be written on the correlation of electrotherapy with hydrotherapy, but the special purpose of this paper is to call attention to a few practical points in connection with the application of the galvanic and sinusoidal currents.

In relation to galvanism. I desire especially to emphasize the necessity for using currents large in amount or of long duration. Nearly thirty years ago I spent some months with Dr. George M. Beard, who then stood foremost in this country in electrotherapeutics, and since that time have made very extensive use of electricity in the treatment of chronic invalids. I was not very long in recognizing the correctness of the suggestion made by Dr. Beard to me as I was leaving him. He said, "Doctor, if you expect to get definite results from electrical applications, you must be sure that your patient has faith; otherwise the application will do him no good."

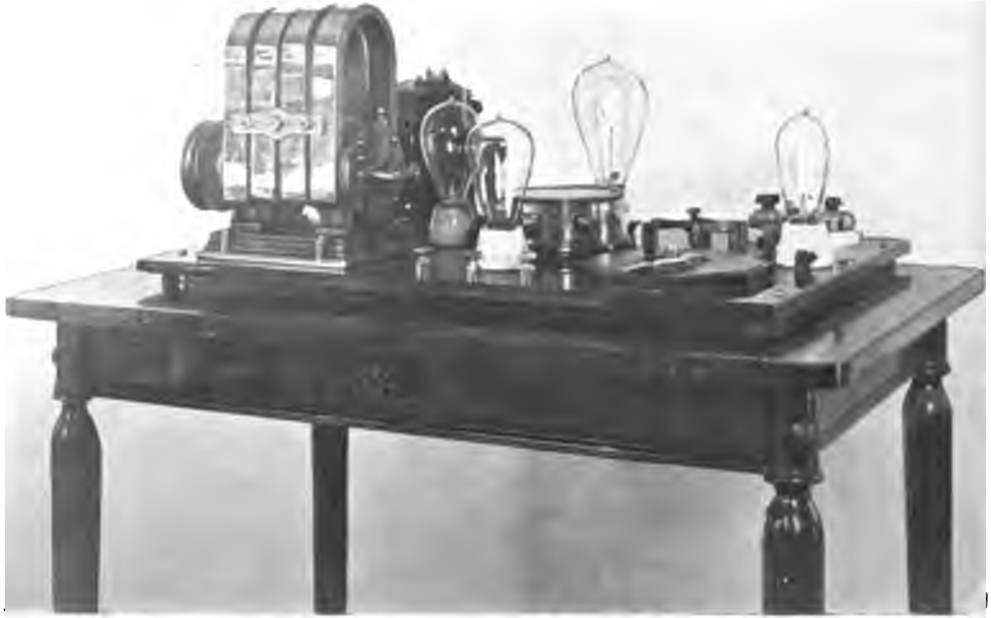
The introduction of the milliammeter and other instruments of precision into practical electrotherapeutics made possible the employment of current in larger quantity, so that results more tangible than mere psychological effects became possible. Some sixteen years ago I became convinced of the necessity of using currents of larger volume and longer duration, and I immediately began to see results such as I had not before observed. For example, applying one large, well-moistened electrode over the abdomen, and the other, the positive, to the back of the neck, and applying a current of forty to sixty milliamperes, I have observed in four or five minutes evidence of very great increase of glandular activity in the fact that patients were compelled to use their handkerchiefs freely on account of the profuse flow of saliva. I thought it reasonable to suppose that other glands within the sphere of action of the current were likewise influenced. Observations which I have subsequently made have convinced me that the activity of the gastric and intestinal glands and the kidneys may be powerfully influenced by strong galvanic currents passed directly through the body. For many years it has been my practice to employ daily in cases in which I wished to influence the abdominal viscera currents of forty to one hundred milliamperes by means of large clay electrodes applied to the abdomen and the lumbar region. I have seen most excellent results from galvanic applications of this sort. I would not like to dispense with this means of treatment in dealing with gastro-intestinal disorders, and in cases of malnutrition accompanied by emaciation. I have also found it useful in various forms of visceral congestions and neuralgias.

About twenty-years ago I began applying electrical current of smaller quantity during a prolonged period, say one to ten hours. A convenient method is to make the application at night, binding the electrode to the affected part and allowing the current to pass during the entire night while the patient is asleep. In a building lighted by electricity this is easily arranged, by employing some simple form of rheostat, taking the current from a lamp socket. The rheostat must be constructed so that it can not be easily disturbed, so that when it is once adjusted, the amount of current can not be increased. Four to ten milliamperes, the quantity differing with the size of the electrode, may be applied by this method during a whole night without any ill effects, and often with most excellent results.

The idea of making a prolonged application of electricity is by no means new, as it has been exploited by quacks and charlatans to an unlimited extent in the form of electric belts, electric armor, etc. My undertaking was to make an application of a known quantity of the current during a definite but prolonged period and with a definite purpose. I have found the result so valuable that, in equipping the new main building of the Battle Creek Sanitarium, I took care to have an extra socket in each room as a provision for utilizing the house current in this way. I believe that much more may be accomplished by this mode of electrization than has heretofore been realized, especially in the use of the galvanic current. I am preparing a more extended account of my observations with this method for publication in another paper.

Some twenty-one years ago in experimenting with all the different forms of electrical apparatus which I could obtain, and electrical currents from different sources by different methods, I made use of a simple magneto-generator at that time used for ringing of bells of telephone systems. I was much impressed with the fact that this generator, when operated slowly, produced exceedingly energetic muscular contractions, and without painful sensations unless the contractions became so violent as to be painful.

I first described the effects of this current in a paper read before the American Medical Association in 1888. Four years later, some nine years after I discovered the peculiarities of this current, d'Arsonval, of Paris, presented, at a conference of the French Society of Physics, a paper in which he described the effects of an electrical current to which he applied the term "Sinusoidal." He obtained this current from a small magneto-electric machine, modeled after the machine of Clarke. I saw at once that the current which he had studied was identical with the one of which I had been making use for several years, and with the aid of my electrician, I constructed an electrograph by means of which I was able to make graphics which agreed exactly with those of d'Arsonval. These graphics with others obtained from different forms of electrical apparatus may be seen in connection with a chapter contributed by me to the "International System of Electrotherapeutics" (F. A. Davis Company, Philadelphia.) Dr. Jacoby has briefly described my apparatus in the first book of his "Electrotherapy," constituting Vol. 1 of "Cohen's System of Physiologic Therapeutics" (P. Blakiston's Son & Company, Philadelphia). Dr. A. E. Kennelly later designed an excellent alternator for producing rapidly alternating sinusoidal currents which could not be well improved upon.



VIEW OF APPARATUS.

In my own use of the apparatus I have found the current produced by slowly rotating the armature of the machine of fully as great value as that produced by rapid alternations.

After many experiments, I have arrived at the conclusion that for practical purposes the ordinary power generator, such as I have here on exhibition is, on the whole, perfectly satisfactory, (see cut). The current produced is sinusoidal though the curve is not perfectly regular, but in practical use I have not been able to see any essential difference between the effects obtained from it and those obtained from a machine producing a more uniform curve. The apparatus is well made and is durable, as I have demonstrated by several years of hard usage, and is of low price.

In a paper read eleven years ago at the third annual meeting of the American Electrotherapeutic Association, I described the effects of the slow and rapid currents obtained from this apparatus, as follows:

"In the use of the sinusoidal current from my apparatus, different effects are observed, according as the machine is rotated slowly or at a high rate of speed. When rotated slowly and connected with sponge electrodes held one in each hand, vigorous contractions are produced in each arm, and in alternation, nearly all the muscles of the arm seem to participate in the contractions. When one electrode is placed in contact with the feet and the other held between the two hands, the muscles of both extremities are made to contract vigorously. The contraction is spasmodic rather than tetanic in character, as when the faradic current is employed. By proper adjustment of the current, strong muscular contractions may be induced."

During the eleven years that have passed since this paper was written, I have continued, as during the ten years previous, the use of both the slow and the rapid currents, and with increasing confidence in their value. The rapid current I have also used in connection with the full bath, the so-called hydro-electric bath. The slow current, which in making prescriptions I designate as S. S. (slow sinusoidal), I find exceedingly valuable as a means of exercising weak, undeveloped, or partially degenerated muscles. A great number of chronic invalids have extremely weak muscles and recovery is impossible without proper development of the muscular system. Sometimes exercise is impossible because of the extreme degree of muscular weakness. In other cases, exercise can not be taken because of the weak condition of the patient's nervous system. Voluntary exercise requires the use of nerve centers and nerves as well as of muscles. In certain forms of neurasthenia, great exhaustion results from even slight muscular exertion. In such cases the sinusoidal current employed as a means of general muscular exercise, is of the highest value. The application is painless to the patient, requires no expenditure of muscle or nervous energy, and the patient's muscular system can be made to do a tremendous amount of work in a very short time.

A moment's calculation will give something of an idea of the large amount of work which the muscles can be made to do in a short time by this method. With a current alternating five times a second, ten strong muscular contractions can be produced each second, as the muscle contracts with each alternation of the current. There will be six hundred contractions each minute, and in ten minutes, six thousand contractions. One or two minutes' application to any part of the muscular system is usually sufficient to secure the required amount of work.

The slow sinusoidal current is of very great use in the treatment of obesity. In fact, I find it almost indispensable in the treatment of patients who have become so obese that they can not exercise, or who have cardiac complications making any considerable amount of exercise impossible. By prolonged applications, repeated two of three times daily, the patient's muscles can be made to do as much work as though he had walked several miles. Very strong currents are required, as very vigorous contraction continued during a considerable period (five to fifteen minutes), are necessary to produce effects akin to those of voluntary exercise. Local applications of the sinusoidal current are of very great value as a means of removing local accumulations of fat.

Another important use which I find for the slow sinusoidal current, is in the treatment of spinal curvatures due to muscular weakness, especially lateral curvature, single and double scoliosis also in those cases of posterior curvature of the upper portion of the spine, commonly called round shoulders or flat chest.

An indication for the sinusoidal current, which I regard as extremely important, and in which both the slow current and the rapid current may be advantageously employed, is in the treatment of enteroptosis, a malady which is almost universal among American women, and extremely common among business and professional men. Since Glenard called attention to the significance of this condition, the great evils which arise from prolapse of the abdominal viscera through irritation of the sympathetic nerves as well as the derangement of the functions of individual viscera, I have given much attention to this matter, carefully noting the position of the viscera in every case; and, after observing many thousands of cases of chronic disease in all forms, I am compelled to say that weakness of the abdominal muscles and resulting displacement of viscera is a prevailing condition among chronic invalids. The slow sinusoidal current is, of course, an exceedingly appropriate measure for exercising any part of the body which needs special development.

The work accomplished under the influence of the sinusoidal current is not merely mechanical. The effect is entirely different from that of mere passive movement. A simple experiment will easily demonstrate this. If the temperature of the skin covering the calves of the legs be taken for each leg by means of a surface thermometer, and then a sinusoidal current be applied for a few minutes to the motor point controlling the posterior tibial muscles of one leg so as to throw them into vigorous intermittent contraction, a marked difference of temperature will be observed. In an experiment made for me by one of my students under my direction, the temperature of the active leg was observed to rise 3.2 deg. F. in 10 minutes. The elevation of temperature must have been the result of the increased amount of blood flowing through the part, and of thermogenic activity in the active muscles. By extending the application to all the larger groups of muscles in the body, effects may be produced capable of influencing all the bodily functions to a most pronounced degree. The most important of these effects may be briefly summed up as follows:

1). *Increase of Metabolism.*

The muscles are the principal seat of the thermogenic process. Associated with the muscular tissue is a large amount of thermogenic tissue, so-called. In the muscles are stored up large quantities of glycogen. Oxidation of this thermogenic tissue is constantly taking place under the influence of the thermogenic centers. Simple brushing of an electrode over the skin with an electrical current of some sort which produces a slight tickling or prickling sensation, accomplishes practically nothing for the patient. Physicians as well as patients become disgusted with the inefficiency of such electrical applications, and rightfully come to look upon them as a means of appealing to the patient's imagination, or, possibly, simply a method to replenish a hungry pocketbook. Multitudes of physicians have spent considerable sums of money in supplying their offices with electrical apparatus which may have ceased to use within a few weeks after installation, simply because of the barrenness of the results and of their inability to see a rational basis for the applications made.

The sinusoidal current rests upon a solid foundation of positive effectiveness. Its influence upon metabolism may be accurately measured. A simple bathtub calorimeter affords a simple means of determining the amount of increase of tissue activity produced under the influence of the current. The amount of heat generated by a person in a bath at a temperature below his body may be measured by noting the amount of heat communicated to the water.

A subject placed in the calorimeter for 20 minutes communicated to the water of the calorimeter 46 calories. The sinusoidal current was then turned on with sufficient strength to produce general contraction of the muscles. At the end of another 20 minutes it was found that 61 calories had been added to the water, showing that an increase of 15 calories had occurred, that is, it was found that the patient had produced 32 per cent more heat. The increase in heat production was at once appreciated by the subject in a relief from chilliness from which he had previously suffered very much. The combined effect, that is, the thermic influences of the water—the temperature of the bath was 86 deg. F.—and that of the sinusoidal current, increased the heat production from the normal rate 1.8 calories per minute to 3.05 calories, nearly double the normal rate. At this rate a bath of 30 minutes duration would consume an ounce of sugar. If a patient, then, is found to have 60 grams of sugar in his urine, one might expect to consume the greater part of it by a sinusoidal bath of 30 minutes duration twice a day; and this, I find in actual practice, can be done.

2). *Increase of the Peripheral Circulation.*

There are few chronic diseases in which visceral congestion is not an important part. The pale or sallow skin of the chronic dyspeptic is a plain indication of a spasm which exists in the peropheral vessels, and as a necessary consequence, visceral congestion.

The application of the sinusoidal current to the abdomen alone is sufficient to produce great relief in a large class of neurasthenics who suffer from a great variety of distressing symptoms as the result of congestion of the portal system, and consequent irritation of the sympathetic centers. In the writer's opinion, the majority of neurasthenics are suffering from this cause. Neurasthenia must be looked upon not as a disease but as a symptom. The writer was acting as assistant to Dr. George M. Beard, in the department of nervous diseases in the Demilt dispensary, New York city, taking careful records of patients at the time when this lamented genius was collecting the data which he later published in his work on neurasthenia, and during the years which have elapsed has had opportunity for observation of a great number of neurasthenics. Careful study and consideration of the subject long ago led me to the fixed belief that neurasthenia can not be in any proper sense regarded as a disease, but only as a symptom, like dropsy, albuminuria, glycosuria, cough, anemia, and other similar pathological states. The pathological foundation of neurasthenia differs in different cases, but in a large proportion of cases it is unquestionably located in the abdominal region, and consists in a disturbance of the sympathetic growing out of passive congestion or stagnation of the portal circulation. This is in probably the majority of cases the result of weak abdominal tension, which is, in turn, the result of weak abdominal muscles.

By the application of the slow sinusoidal current to the abdomen vigorous intermittent contractions of the abdominal muscles may be produced, and as a result their tone may be increased so that through compression of the abdominal veins the stagnated blood is pushed along; the half-asphyxiated viscera are cleared of their toxin-laden blood; the sympathetic centers receive a fresh, invigorating blood-supply; the diaphragm is strengthened, and hence the breathing is reinforced, the blood better aerated; the heart's action is invigorated; metabolism is encouraged, and every vital process is improved.

The rapidly alternating sinusoidal current which I designate in prescription as S. R. (rapid sinusoidal) is applicable in neuralgia in all parts of the body. It is of great value in relieving coccyodynia, spinal and intercostal neuralgias, and particularly the paresthesias from which neurasthenics and other classes of nervous invalids often suffer to a distressing extent.

In concluding this paper, I wish to put myself on record as believing that much of the prejudice against electrotherapeutics is due to the fact that electricity is so often exploited as a cure-all. Most of the works on electrotherapeutics which have been published recommend this agent for almost every malady flesh is heir to. This is certainly an error. Electricity properly applied is capable of accomplishing wonderful things therapeutically, both when applied exclusively to conditions in which it is specially adapted, or in conjunction with other measures, in conditions in which it is a useful supplementary remedy. The great merit of electricity as a curative agent lies in the fact that it is a physiologic remedy. As such it belongs to a family of noble remedies which is in recent times rapidly coming into better recognition, remedies which utilize the great forces of nature, those which are active in the production and maintenance of living beings. None of these great natural agents, heat, light, electricity, etc., should be employed exclusively. The proper correlation of these physiologic agents in such a way as to give to the sick man the best possible chance for the recovery of health constitutes the true art and science of rational medicine.

DISCUSSION.

Dr. Emil H. Grubbé: I make use of sinusoidal currents, but from what I have heard of the subject in this paper I would not feel very competent to comment upon the author's work. I wish to pass remark upon two points which precede his discussion of the sinusoidal subject. The author claims to use from four to five milliamperes of current for many hours. That is, the patient is connected with the electric device and he is asked to go to sleep. It is not reasonable to suppose that the patient would be taking continuous galvanic treatment of from eight to twelve hours. Personally, I have never tried that procedure, but it seems to me it would be a very dangerous method, and would be applicable only where the application is made to the extremities of the body. I should hesitate to apply four to six milliamperes for as much as one hour to any vital part. Then there is also the danger of accident to be considered. Another thing strikes me very forcibly; the author uses ancient, dirty methods of applying electricity. There is no doubt that the day of the sponge electrode, the clay electrode and others of a like nature should be relegated to the past. We are very apt to be cleanly when we hold ourselves up as surgeons, but we forget to observe that aseptic rule when we come to electrotherapeutics. We might as well be clean as dirty for it is cheaper Personally I believe it would be much better if we should dispense with those ancient electrodes and use something better and handier and cleaner. The method I have used is a towel moistened with water and use that as the constant electrode, a plate of block tin placed over this and connected to the circuit; but the clay, sponge, and other electrodes of a similar nature should never be applied to tissue directly.

The following paper was then read:

PHYSICOTHERAPY OF NEURASTHENIA.

BY DR. J. A. RIVIÈRE.

Neurasthenia, as was justly perceived by Beard, is a want of nervous energy, "nervous depression," a fatigue accompanied by loss of nervous power, "nervous exhaustion." It is no doubt weakness which predominates in the syndrome of Beard, but irritable weakness, "irritable debility," requiring successively cerebro-spinal stimulants and sedatives of the nerve-cell, precisely dosed, so as to raise the forces and increase the nerve-tension. It is important to avoid abuse of nerve-stimulants, every artificial excitement being speedily followed by correlative exhaustion.

If physicotherapy[1] renders signal services in the cure of neurasthenic cases, it is precisely because it applies itself to the probable cause of the evil, to the *nutritive trouble of the nerve-elements.* By re-establishing the normal influx of the neurones, the nerve-dynamism, we restore the inhibitive influence of the brain over the spine, we minimize the reflex power of the latter, and the disordered exaggeration of its automatism; "moderating action over the whole of the weakened and over-excited nervous system" such is the therapeutic formula which strictly applies to Beard's disease. The whole of physicotherapy should then be put in contribution; we must remedy the weakness of the vasomoter center, the lowering and, above all, the variability of the vascular tension, the diminution of the nutritive activity of the cells, characterized by the dyspeptic troubles, the phosphaturia, the digestive leucocytosis, the muscular atony, the visceral ptosis, the hepatic congestion and insufficiency, etc.

Patients suffering from Beard's disease are the most refractory to pharmaceutical treatment. They are the most frequent victims of that medicinal poisoning so well described by Hayem and con-

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[1] See "Physicotherapy, its Indications, its Advantages," by Dr. J. A. Rivière. A communication made at the Fourteenth International Medical Congress, Madrid, April, 1903.

stantly deplored by enlightened physicians. We owe especially to Weir Mitchell and to Professor Raymond a better comprehension of the true treatment of neurasthenia, which is based, at present, on rigorous applications of physical agents.

Let us review briefly the most useful applications and begin with hydrotherapy. The douche of short duration with broken jet, on the spine and trunk, followed by the foot-douche and dry rubbing, is one of the best tonics for increasing the rate of forces in the case of people who are "fagged out", who have "no back-bone", who need a mild reaction, capable of restoring their nerve-energy and will, of dispelling their anguish, scruples, and insomnia, of stimulating the peripheral circulation, and of generally increasing the lowered arterial tension. In case of marked arthritism, not an uncommon thing with neurasthenic patients, we should be satisfied to employ the Scotch douche applied by means of the spray; in this way there will be no risk of increasing the painful irritability.

Carbonic acid gas baths have remarkable advantages as tonic sedatives especially if they are not taken too hot (34 degs. C. on the average) nor of too long duration (20 minutes at the most). A few baths of CO_2 literally transform some people who are depressed, devoid of physical and mental vigor; we see before our eyes, so to speak, the continuous renewal of their nervous and intellectual energy, the restoration of appetite and sleep, the remarkable improvement of the gastro-intestinal atony and of the muscular weakness, often so persistent. This action, powerful and sustained, of the CO_2 bath, makes it one of the most active and thorough agents of nerve-cure. Arthritic subjects are those who benefit mostly from this mode of treatment.

The CO_2 bath remedies, in fact, the gastro-hepatic auto-intoxication which is the principal cause of this strange sensation of morbid fatigue, the origin of the greatest nervous discomfort and especially of the great cephalic irritability. Thanks to the titillating and galvanic influence of the gas on the innumerable nerve-tufts of our external envelope, we obtain a derivative effect on the cerebro-medullary centers, an increase of gastro-intestinal peristaltism. a complete unblocking of the portal circulation; in short, a sort of *re-education of the vaso-motor centers.* By acting on the peripheral capillary circulation, the CO_2 bath modifies also the mechanical distribution of the blood, re-establishes the muscular force, increases the general metabolism and the proliferation of the hematoblasts, favors oxydations and the elimination of toxins. This really amounts to the anti-arthritic influence.

Mecanotherapy and massotherapy apply principally to the gastric dilatation, to the constipation and to the oliguria of neurasthenic subjects. Methodical massage acts as does the *re-educating* exercise, compensatory mecanotherapy, rational gymnastics, by combating the muscular atrophy and rendering the joints supple in arthritic subjects as well as regulating their nerve-influx and their general reflex mobility. Amyosthenia (which sometimes extends to the unstriped muscle-fibre) is the chief cause of the gastric dilatation of the nervous dyspepsia and of the general hypotension; the mecanotherapy and massotherapy apparatus, when properly combined, remedy this diminution of muscular function as well as the circulatory and glandular sluggishness.

The digestive troubles, so important in neurasthenia that for some authors they attain the dignity of being the *pathogenic* element in the disease; the alternatives of fatigue and excitment with great loss of strength, the morning depression (due to insufficient storage of energy and the loss thereof during sleep) all these symptoms call for a treatment by massotherapy, by vibrotherapy, by kinesitherapy, all excellent methods for the restoration *ad integrum* of the molecular nutrition. Abdominal hydromassotherapy working on the abdominal nerve-plexuses acts like a powerful moderator of the hypochondriac reflexes coming from the solar plexus, that " abdominal brain " as Bichat named it. Melancholia, " the blues ", loss of interest in life, are symptoms referred from antiquity to pathological modifications of the great vegetative system, and the modern study of neurasthenic conditions has only confirmed these results of the experience of our ancestors.

The method of vibration and massage is also very valuable to remedy spasmodic phenomena, of secondary importance, no doubt, but very disagreeable to patients. Such are cramps, twitchings, fibrillary contractions, dysphagia, trembling, dyspnœa. Giddiness and tachycardia are more within the pale of hydrotherapeutic agents. The last-mentioned symptom is particularly attenuated by cold applications to the precordial region, by Chapman's bag, etc., etc. Hyperesthesia, paresthesia, and diverse algies often so capricious, dysesthesia (numbness, tingling) yield to well-devised massotherapy. We thus increase the circulation of the blood and lymph, we improve the nutritive condition of the skin and muscles, we stimulate the osmotic phenomena of the nerve-cell. It is thus an excellent treatment for local neurasthenias, such as Professor Huchard has defined, and a most active remedy for the reduced vitality of the neurones in cerebro-spinal debility.

However it is certainly electrotherapy which renders the greatest services in the treatment of neurasthenia, and those that are the most speedily appreciated. It holds, and will long hold, the first place for modifying nerve-nutrition and harmonizing nerve-reactions. Even as a measure of prevention, electricity can be used to save certain nervous subjects (or patients of neurotic heredity) from falling into neurasthenic exhaustion. There exists in fact a prodromal period of neurasthenia, as there is a premonitory period of consumption. It is, therefore, the business of the sagacious practitioner to make an early diagnosis and thereby enhance the chances of a profitable cure.

All the modes of electrotherapeutics, faradisation. voltaisation. franklinisation, and even magnetism have been utilized from the time of Beard until now. But the use of alternating high-frequency currents, auto-conduction, the sofa-condensator, the resonator, etc., are remarkably favorable in arthritic cases, in which these agents improve the oxydations, whilst they regulate the arterial tension.

These currents, which the genius of d'Arsonval has applied to the treatment of the sick, have always the effect of regulating the general circulation, of raising the nerve-potential, when it is lowered, of restoring sleep, calm and appetite, as the regretted Apostoli used so well to say. These marvelous effects are obtained, in our view, by the series of oscillations which these currents impart to the nerve-cells, and which result in *bringing back the neurones to their physiological orientation.* What takes place in the conductibility of the neurones is exactly the same as in the Branly's tube of filings applied to wireless telegraphy. It is well, however, to make short applications and to favor frequent elimination during the course of treatment, by means of abundant diaphoresis, thermo-luminous baths (of which we shall soon speak), diuretic drinks, laxatives; sometimes a little calomel mixed with bicarbonate of soda, in the way we have often indicated.

The electrostatic bath, with the electric douche or cephalic "souffle" is much used against cerebral depression, insomnia, paresia of the limbs, headache "en casque." Frictions and the negative "souffle" may be used for regions affected with neuralgias or simple hyperesthesia. The static bath has a double effect; it is a sedative and it regulates the nervous system; when well handled it will conquer the most persistent pains, those of the sacral, and similar regions of pain. It increases also (though in less degree than the high-frequency currents) the nutritive exchanges, retarded or perverted by arthritic influence, whilst it obtains from the nerve-substance a better balanced incitability. The neuralgias and nerve-spasms which resist the static bath generally yield to the faradic current.

Electrotherapy should also be preferred to hydrotherapy in cases when the reactions are slow to manifest themselves, when rheumatic irritation is prompt, and the respiratory organs sensitive, also in the numerous cases of neurasthenia with diminished circulation of the skin or subject to giddiness or cardiac spasm. It is perhaps for this reason that for the female sex electricity represents the treatment to be preferred.

Franklinisation should also always commence by short sittings so as not to make too strong an impression on the patient by an electric energy which may upset the system, and cause a certain uneasiness, thereby interfering with the continuity of the treatment; "patience and moderation," such should be the invariable motto of the therapeutist in physicotherapy as well as in pharmacology. For the great general depression with pronounced myosthenia, nothing is so valuable as the bipolar high-frequency effluviations. It is also the treatment to be preferred in sexual neurasthenia, when we wish to combat impotence and anaphrodesia in the male, or utero-ovarian atony with dysmenorrhœa in woman.

By the harmonization and the regulation of the central nervous system, a state of equilibrium is communicated, so to speak, to the whole of the living organism, complex as it is. By storing up the nervous influx in the cells, by insuring their trophic integrity, by favoring the temporary functional hypertrophy of the neurones, and their more direct contiguity, methodic electrotherapy visibly restores the disturbed vitality of neurasthenic subjects. Science, it is true, has not yet explained by what chemical process, by what vibrations of the molecular order, the energy of the neuroglia and the power of the cellular connections are *remade* and regenerated, whilst the fatigue and nervous exhaustion are abolished. The analogies of the electric and nervous currents, which seem to obey the same laws (Helmholtz), explain why electric treatment which brings back the good conductibility and the proper orientation of the neurones precludes paresthesia, delay in the transmission of sensibility, fusion and accumulation of sensations, polyesthesia, synalgies, errors and perversions of localized sensations (abnormal sensations of hot and cold, tingling, pricking, numbness) which torture the minds of neurasthenic patients, whilst they portend to them graver objective disturbances and serious lesions. Headache and neuralgias as well as reflex pains of sympathetic derangement, central or local algies (peripheral or visceral) affecting the stomach, the intestine, the heart, with irradiations, are eminently (and almost exclusively) the proper domain of electrotherapy.

Static baths and high-frequency currents ward off acute or emotional attacks, diminish the intensity of localized surface-pains, obliterate the stigmata of neurasthenia, and that species of fixed sense-images " analogous in the domain of sensibility to monomania in the intellectual domain " (Blocq). I could mention several cases of glossodynia, of obstinate rachialgy, of impotence, of ovarian or lumbo-abdominal neuralgia, cured in neurasthenic subjects in a few weeks, thanks to the gradual return of the fundamental nerve-equilibrium. In these cases of local algies it will be found proper, as the lamented Blocq advised, to *mobilize the pain,* which modification is in fact a palpable demonstration that the disorder is no grave lesion; a good means of obtaining this result is to faradise the painful surface with the electric brush, taking care to frequently repeat the applications which should not last longer than ten minutes at most. I have also obtained good results from radium, from X-rays, from violet light, and even from localized heat.

In case of pronounced spinal irritation with sacrococcygeal pain or pain at the back of the neck, alternatives of hot and cold, stiffness, numbness, cephalic troubles, I am absolutely convinced that electricity, when well handled, can keep away the specter of tabes or of general paralysis. The fixed idea of a grave condition, the state of anxiety, of psychical obsession which readily characterize neurasthenic debility and which influence the mind to the extent of disorganizing all nervous synergy, disappear gradually, by the reactional compensation that electricity brings to the cerebro-spinal system. Normal vitality is awakened gradually, without violence, by the physiological action of the *sole physiological tonic,* by the recharging of the living accumulator and condensator. The cerebral activity is no longer interfered with, the memory becomes more retentive, the judgment more confident, reason less timorous, the will more energetic and not so listless. The neuropath is a transformed being.

An excellent adjunct to electrical treatment is radiotherapy. The vibrations of the red rays are well borne and contribute to raise the strength and to regulate the sensibility. The thermo-luminous baths (as I amongst the first applied them in medicine) possess a radiotherapeutic activity analogous to that of the solar rays, that is to say *vivifying and productive of* well-being and repair. The blue light is soothing, etc. The thermo-luminous method, anti-acid and eliminating, increases also the nervous potentiality of neuroarthritic subjects, relieves their circulation, invigorates their cells, favors nervous reserve and cerebro-spinal tension, removes the spasmodic tendency, and puts in order the nutritive assimilation for the greater advantage of the renovation of the blood and tissues. We thus reach by means of the centripetal neurone the suffering cortical center. We draw off the nutritive waste, the parent of rheumatoid pains, of lassitude, of cryesthesia, of insomnia and of abdominal congestion; for, in my opinion, auto-intoxication is the cause and lesion of nervous depression. This requisite elimination is done especially by white light, which procures an excellent diaphoresis at a low degree of thermality, thanks to the improved radio-luminous vibrations obtained by our divers apparatus.

I might complete this exposition of the physicotherapeutic treatment of neurasthenia by describing certain accessories, such as hydro-electric baths, which I especially reserve for anemic and neuralgic patients and for patients showing some grains of sugar or some centigrams of albumen in the urine; continuous currents most useful in the treatment of muco-membranous colitis and of constipation which so frequently follow in the train of Beard's disease; improved vibratory electric massage which I apply in the cure of different visceral algies; the vibrating helmet and platform for cerebro-spinal neuralgia. Certain particular indications are met with by ozonotherapy, phototherapy, and radiotherapy. We cannot apply any well-defined, fixed or immutable treatment, any cure *ne varietur* to the mobile, ever varying, manifold and subtle manifestations of neurasthenia. There must be a reasonable and wise co-ordination of the different physical agents, utilized in accordance with the hierarchy of the symptoms, the study of the reactions of cellular life, of personal differentiations, and (why not say the word) the more or less conscious intuitions of the practitioner.

SUMMARY AND CONCLUSIONS.

1° The symptomatic and pathogenic complexity of the malady of Beard makes it necessary to have recourse to all the numerous resources of physicotherapy.

Success in treatment belongs to the physician who can utilize according to circumstances all the physical agents and who has the greatest *command over his apparatus,* that is, knows exactly what to expect from them.

2° Just in the degree that pharmacy is untrustworthy and dangerous, is physicotherapy adequate and profitable to neurasthenic conditions. The most powerful curative means are the cold or Scotch douche, the CO_2 bath, mecanotherapy and massotherapy, kinesitherapy and vibrotherapy, of which we have described the principal indications. As to electrotherapy, it assuredly occupies the first place for the cure of nervous exhaustion.

3° All the modes of electricity can be utilized, but those acting most energetically on the general condition are high-frequency currents, electrostatic baths, faradization, radiotherapy, thermo-luminous baths, hydro-electric baths, etc., etc. All these applications (which ought to be watched and dosed like medicines) should always remain within the exclusive province of the medical man.

4° I think that I have proved that no fixed form of treatment can be applied inflexibly to such a multiform and subtle disease as neurasthenia. By knowing how to reason, to co-ordinate, to vary, to leave off, to reapply, with judicious care, the physicotherapeutic agents domesticated by science, we shall realize the most difficult, the most complete and the most lasting of cures.

The following paper was then read:

RECENT ADVANCES IN RÖNTGEN-RAY DIAGNOSIS.

BY DR. CARL BECK, *Professor of Surgery in the New York Postgraduate Medical School and Hospital.*

The greatest advance made in Röntgen-ray diagnosis during the last few years is marked by the methodical use of the diaphragm. It is possible by these means only to reproduce the structural details of thicker portions of the body well, thus preventing serious diagnostic errors.

In his first publications Röntgen himself called attention to the fact that the air, while irradiated, sends effective rays in all directions, and it has been known since the early Röntgen era, that there are secondary rays emanating especially from the wall of the Röntgen tube, which cause diffusion in the body, and while the rays penetrate a thin organ like the hand, directly, throwing most definite outlines of the bones on the photographic plate, thick portions, like the pelvic region of a fat individual, reflect the rays. During exposure, in other words, each muscular portion affects the plate individually, thus diminishing the contrast.

The fact that soft tubes are least apt to diffuse the rays would obviously suggest their use, but their small power of penetration makes them unfit for representing thick layers.

Now, this observation, that the currents are unidirectional, sometimes even the whole of the tube becoming a source of the Röntgen rays, gave an impetus to the construction of lead diaphragms, which do not permit a larger amount of light to pass than the reproduction of the area to be traversed requires. Thus the injurious secondary rays were kept off, the effective cone of light only being projected on the plate.

The original diaphragm, devised by Walter, simply consisted of a sheet of lead into which a hole was cut, the diameter of which was about two inches. This was traversed by the rays emanating from a tube which was placed above. Besides the rays from the target those emanating from the tubal wall passed the hole in the diaphragm, whereby a considerable amount of diffusion was still produced.

To obviate this, tubular diaphragms were constructed which permitted the passing of the focal rays only, while those emanating from the tubal wall were excluded.

It was on this principle that Albers Schoenberg devised his compression-diaphragm, which prevents diffusing of the ray, as well as motion of the object to be exposed, by its compressing arrangement. The great drawback of this apparatus, however, is its large size and the extraordinarily high price.

These considerations gave me the impetus to construct a simple tubular diaphragm—at first using an ordinary piece of a stove pipe, with the aid of a tinsmith, a rather crude arrangement, but one answering the purpose perfectly. Droell, of Heidelberg, made it more elaborate for me (Stellrohrblende) and the Kny-Scherer Company, of New York, perfected it still more. The arrangement could be made so simple that the expenses for the whole appliance are still very low and within easy reach of everybody. It consists of a simple movable tube provided with a screw attachment which permits of fastening it to any table or footstool (if used on the floor). In order to shift the tube upward and downward it is inserted in a metallic ring, by which it can be screwed tight in the position desired.

The patient is placed underneath the tube after having it raised sufficiently. Then it is adjusted to the region to be examined by pressing it so far into the tissues as the patient is able to tolerate without discomfort. If the desired position is attained the tube is fastened by the screws. It is evident that perfect immobilization of the exposed area is thus obtained, which is of special value in obstinate children. At the same time the compression of the soft tissues diminishes the absorption of the rays and lessens the distance between plate and tube at the same time.

A wooden stand may be erected above the upper margin of the tube in order to hold it *in situ,* but it is safer to fasten the tube in a separate tube-holder, although it is somewhat troublesome to focus it. The diameter of this tubular diaphragm is 4 ins., a size which answers nearly all purposes. For minute work, however, it is preferable to employ a larger size for calculi and a smaller one (3 ins.) for children.

With the aid of the tubular diaphragm the exposed area must show its normal size and structure and tissues, like thick tendons and fasciae, must be recognized and the individual layers of the skin, fat and muscle differentiated.

Of two skiagraphs taken by me at the same day on the same patient, one would probably be called a good one if the other were not seen. The former, which is taken in the ordinary way, shows the bones of the shoulder well in general, but the displacement of the scapular neck, caused by a fracture, is but indistinctly noticeable, while the small skiagraph, taken with the diaphragm, shows the condition well. The structural details are thoroughly represented. Of two other skiagraphs representing an osseous cyst in the inferior maxilla of a man of 38 years, one shows the translucency of the cyst and the dark outlines of its cortex before operation, while the other shows the bone after removal, the contrast being more pronounced therefore. Still, without the diaphragm, the regular outlines of the cortex would not show so distinctly.

The disadvantage of the tubular diaphragm is that only small areas can be shown at a time. This disadvantage is felt the least in the representation of joints, while in examining for concretions the tubular field may miss the seat of the suspected area.

If, for instance, a calculus is suspected in the urinary tract, it is not certain, beforehand, whether it has situated in the kidney itself, or in the renal pelvis, or in the ureter. Therefore *a priori* an area must be included in the skiagraphic plate, which is bounded by the eleventh rib and the crista ossis ilei on one side and by the vertebrae and the anterior axillary line on the other. Into each corner of the plate a wire letter is placed for localization. If only faint outlines are obtained, their relations to the wire letters photographed on the plate as well as to the bone structures are made out. Then it can be estimated at what region the diaphragm should be adjusted best to attain marked outlines.

If, while there is strong suspicion of the presence of a stone, the large plate proves to be negative, the whole area must be examined by the diaphragm by separate exposures, five to six different exposures with the tubular diaphragm sometimes being indicated under such circumstances. This is, of course, very troublesome, but, in view of the great importance of a correct diagnosis, there is no way out of it. Similar views apply to the skiagraphy of biliary calculi.

In this manner, sometimes small-sized renal calculi can be made visible which would have escaped ordinary routine examination.

I have been able to show traces of calcareous deposits in a kidney which were produced by a tuberculous process.

This gave me the impetus for trying experimentally to what extent destructive processes in the kidneys could be represented by skiagraphy. In the case mentioned the calcareous foci were recognized by the use of the tubular diaphragm as a light and disseminated shadow in contrast to the shadows of renal calculus, which cast a darker and more confluent shadow. The diagnosis was corroborated by nephrectomy.

When no calcareous deposits exist in association with tuberculosis, skiagraphic representation seems to me to be absolutely unreliable with our present means.

One of the tuberculous kidneys removed showed a large cavity at the upper and a smaller one at the lower pole when it was bisected. The skiagraphic experiment illustrated the proportional degrees of translucency which was naturally more marked at the upper pole. When the same kidney was skiagraphed through the abdomen the translucency failed to show. Therefore, I feel convinced that this translucency could not be demonstrated through the living body.

During exploratory nephrotomy, translucency could be recognized by a small fluoroscope surrounded by sterile gauze, whereby the foci might be located before dividing the renal tissues. It is to be expected that with the better construction of Röntgen operating tables more fluoroscopic information can be obtained during the process of a surgical operation.

In conjunction with the diaphragm apparatus must be used to estimate the degree of the vacuum of the tube. For this purpose various skiameters were advised. Lately the chromoradiometer of Holzknecht has much been spoken of. While this certainly represents an ingenious construction, it seems to me that for the practitioner in general the osteoscope, described by me in No. 32 of the *Berliner Klinische Wochenschrift,* 1903, answers the practitioner best. Its principle consists in using the skeleton instead of sacrificing the living extremity of physician or patient.

For this purpose the bones of the forearm and hand are fastened to a sheet of pasteboard or similar translucent material. By being inserted in the frame of a fluorescent screen this can be moved to and fro, so that the phalanges, the carpus or the elbow can be studied. To make the apparatus more compact, besides the hand only the epiphyseal ends of the forearm may be utilized, and when the hiatus between the eminentia capitata and the radial head is distinctly shown on the screen of the osteoscope, sufficient contrasts can be expected on the plate.

The elbow is a better guide than the wrist, if permeation of thick tissues is to be considered. Just as in the living carpus the bones of the osteoscope appear black, if a soft, and light gray, if a hard tube is used. The handle of the osteoscope is surrounded by a shield of lead, so that the hand is perfectly protected while holding it. It is no small advantage of the osteoscope that only one hand is needed for manipulation. The bones of the apparatus may be hidden under black muslin or pasteboard. By attaching a tapering box to the frame, like the one used with the fluoroscope, the osteoscope can also be used in a light room.

If the hand used is protected by lead gloves, which I show, and the other hand is also needed, it should be similarly protected. As the wrinkled and shrivelled hands of physicians, who use or employ this method frequently, demonstrate, the danger of continuous exposure is not sufficiently appreciated.

The sad experience of one of the assistants of Edison, whose arm had to be amputated on account of non-observance of such precaution, should serve as a timely warning for many.

Up to date four cases of epithelioma, which developed after the unrestricted daily use of the Roentgen rays, are reported in the State of New York. This observation speaks in favor of the irritation theory of cancer and is unfavorable for the parasitic etiology.

Discussion.

Dr. Emil H. Grubbé: I am very much interested in this simple diaphragm. I have used the complex arrangement of Albers Schönberg and have discarded it entirely because it is too complex and impractical. The instrument was recommended largely for the purpose of allowing us to diagnose conditions such as renal calculi, and I have tried to use it for other purposes also, but I find I can, with the technique I use, make better radiographs without than with it. The fact that we make these pictures for surgeons necessitates our using something more than the small picture which the diaphragm allows us to make. A surgeon wants to see something more than a picture three inches in size on the plate. Dr. Beck is fortunate in being both the surgeon and radiographer. I am asked to make pictures on plates 14×17 inches. We have not advanced sufficiently to convince the surgeon that he must look on the scientific side of the subject alone. I am interested in this diaphragm because it is simple, and it is also cheap. We can have them made in different sizes, and we might have them larger than the one exhibited. I should prefer them two inches larger in diameter; then possibly I could convince the Chicago surgeon that a large plate is not necessary. There is no question but what more detail could be brought out in pictures by this method. I would like to ask Dr. Beck to give us more of the detail, tell us more about the construction of it so we may be safe in the exclusion of the stray rays. The author mentions in his paper that he has not seen the shadows of kidneys on plates. I had on exhibition, at the Roentgen Ray Society meeting, a plate 17×22 inches which showed the outline of the kidney perfectly. The technique used was a very low vacuum tube, an amperage of about 30, and a 36-inch coil. The exposure was a snapshot, the interrupter used was a dip mercury turbine, and the exposure was made in the time it required to open and close the snap switch. I believe it can be done even in heavy individuals; the picture I made was one of that sort, the woman weighing 150 pounds. We had also a picture of the bony structure of the chest and neck on the same plate.

Chairman Wm. J. Morton: I welcome the remarks of the reader in regard to the very high importance that the X-ray occupies in the diagnosis of surgical injuries. I share with him my wonder that American surgery, ordinarily so advanced, has been so backward in recognizing the value of the X-ray in surgical diagnosis. It has happened to me time and time again that distinguished surgeons have brought to me injuries of the elbow, of the shoulder or about the ankle, and have diagnosticated a dislocation, or perhaps fracture. I have taken the X-ray picture, and the diagnosis has proven to be absolutely wrong. We all, of course, make mistakes. At the same time we should encourage procedures which reduce our mistakes to a minimum. Surgeons themselves know the difficulty of diagnosis, and, therefore, they should extend to radiography a warmer welcome. I think I can tell you why this has not been sufficiently and generally done. Unfortunately, in this great and free county of ours, it is the same in science as it sometimes is in athletics, a "go as you please" match, and it makes no difference how accurate, how conscientious, or how careful an operator like the reader of the paper may be; it makes no difference how conscientious I may be in my work, there are hundreds of others whose position in science is about the same as that of the climb-the-pole electricians and who are advertising themselves all over the country as competent X-rayists. These are the men to whom some surgeons are sending their patients to have X-ray pictures taken. A surgeon has such a picture made and the person who makes it, as I have known myself, reports that the picture does not show anything, while the fact is that the negative is valueless; the surgeon goes home and condemns the X-ray diagnosis. This is one estimate of X-ray diagnosis in America, perhaps a little too strongly stated, and, therefore, we need just such an apostle of light as the reader of the paper to teach to surgery its duty in this matter, because any criticism of that sort comes with good grace from a surgeon when it might not come with equal grace from others.

The question was brought up as to whether the kidney is shadowed in the ordinary X-ray photograph. I have had pictures in which I have been able to distinguish the clear outlines of the kidney. I have had many others where I could not distinguish that outline. It depends largely upon method, namely, upon a "soft" tube, a strong current, and a "snap shot."

In regard to the osteoscope, the trouble with most of the methods of judging of the intensity of the X-ray is that they depend too much upon the fluorescent quality of certain salts, and this fluorescent quality varies, so that when the fluorescent measuring instrument is at one point to-day, in a week or two weeks, or in a month or two months, according to the condition of the atmosphere, according to the temperature or on account of exposure to the light the chemical has lost its activity, and so your judgment is continuously at fault. In taking a picture of the kidney my own practice has been, as I am sure it is also the practice of the author of the paper, to use a lead diaphragm with a perforation, and in connection with that I also use an aluminum compressor which I will show later on. The best method of all is, I believe, to have the patient hold his breath while a quick exposure is made. To my mind this skiagraph of the shoulder exhibited by Dr. Beck is a most delightful picture. Do I understand that it was taken under the same conditions as that of the hand? (Dr. Beck: Yes, sir.) Certainly there is a remarkable difference in favor of Dr. Beck's diaphragm, and an interesting thing is shown here, viz.: While there is no true reflection of the X-ray, there is still a scattering effect from the sides of the metal tube which plainly has concentrated the rays at certain points. The particular diaphram here shown will give an excessive accumulation of the X-ray around the edges and greatly to the advantage of the contrast shown in the picture. We have all seen in using radium doubtless the same deflection of the radiation from metallic surfaces and impression upon the negative.

I congratulate the reader of the paper; for it is just such papers that are most welcome. I will add, in the interest of accurate diagnosis, and especially accurate diagnosis by aid of skiagraphs, that I believe that if the reader will resort to the method I have outlined here at this session, of administration of fluorescent substances he will add to his diaphragm effect, and thus step by step we shall acquire a skiagraphic art that is far beyond anything we know of at present.

Dr. **Emil H. Grubbé**: We forget all about the instrument of Dr. Beck in determining the relative condition of the vacuum tubes. If so much depends upon the stability of the fluoroscope I would like to hear from Mr. Friedlander, who is a manufacturer, upon that point.

Mr. **R. Friedlander**: I wish to congratulate Dr. Carl Beck upon his paper and dare say that his apparatus demonstrated here for the purpose of obtaining better results in skiagraphy is the most practical and simple one I have ever seen.

I did not come here prepared to take part in the discussion of any papers, and consequently I do not know exactly on what subject the doctor wishes me to speak. We are using a barium platino-cyanide screen in order to obtain the best results in fluoroscopic work with the X-ray. The crystals have been heretofore too large, and consequently they would in course of time absorb a good deal of air and moisture and deteriorate in value. I presume you have found the same conditions in your experience. This is due in my estimation to the fact as stated before, that the crystals are too large, and to get smaller ones they must be recrystallized. I happen to have some samples with me of the crystals we used at present in making screens. They are now so fine you can almost dissolve them in solution and thereby receive fluorescent fluid, in fact you could get the same principles in fluorescence that have been shown here by Dr. Morton. The same thing can be accomplished by the sulphides of calcium; it depends upon how small the crystals are. In making a screen, it is necessary that the crystals be equally divided. The smaller and finer the crystals used, the better results we get and the longer the screen will last.

Dr. CARL BECK: Of course, I would like to say much more, but I am afraid I would be misunderstood in reference to my special colleagues, the surgeons. Our esteemed chairman said that any criticism of surgeons came with better grace from a surgeon than from an electrotherapeutist or a neurologist. I feel that distinctly, because I do not think it would show good taste for a surgeon to criticise his confrères, but I am quite sure I may be pardoned for calling attention to our errors, including my own, for the very reason that it is for the greatest interest and benefit to us all. If, as Dr. Morton has alluded to, the Röntgologists will not educate the surgeons up to where they ought to stand, they will never be as effective as they ought to be. It seems to me it is absolutely necessary that every surgeon should understand enough about skiagraphy himself to be able to understand all the apparatus, and especially to recognize the picture, because he has to educate his own eye to read what is on the skiagraph. I am opposed to having pictures furnished to the surgeon; he must know himself what he wants. Some years ago my friend Prof. Gerny, from Heidelberg, visited me. He is one of the greatest surgeons to-day. When he looked at my apparatus and I told him it was my opinion that every surgeon ought to have an apparatus, he just smiled, but did not say anything. Last year when I visited Prof. Gerny at Heidelberg one of his assistants said to me, "You did not do me any good when Prof. Gerny visited you. When he came back from America he put up a laboratory and I am the fellow he picked out to do the work." Two weeks ago he wrote me that he has not time to do all the work himself, but he could see he could not do good work unless he supervised it himself. How wrong and how right Dr. Grubbé is! I take my cases out of practice. I want to show you what I can get out of skiagraphs. I do not want to enter into technical details. You are the men to work that out. I can show my views best by reporting the following case: A man of forty years of age sustains an injury and his arm become paralyzed. A surgeon of national reputation examined him. I do not report this case in order to criticise the surgeon, because the symptoms shown were such that any one might commit an error. The surgeon found a fracture of the middle humerus, and I have to give him credit for having put that humerus in the best shape possible, my X-ray photograph taken two years afterward showing that absolutely. The arm became paralyzed eight or nine weeks after the fracture was sustained, while at the time of the injury there was no symptom of any interference with the nerve. Now the surgeon (and that was the first point in his error) concluded that the radio-spiral nerve was impacted and, therefore, he advised an operation. The patient submitted to it. the operation was done and the nerve was found intact. If the surgeon had taken an X-ray picture he would have found that he was perfectly successful in putting the fracture in shape, and if it was in good condition it was not likely that there was an injury of the nerve there. He did not think of any other fracture, but unfortunately he advised this patient to go to an X-ray photographer and have a picture made. He advised the patient to have a skiagraph taken above the elbow, as he wanted to see the particular area around the humerus. The X-ray picture was taken accordingly by an electrician and it did not show anything abnormal, and the surgeon was astonished that the paralysis still continued. Two years after that the gentleman came under my observation and I found that there was a dislocation at the head of the radius and a fracture of the ulna, which made the most extensive displacement. This, on account of the swelling, was not discovered at the time the fracture was sustained. The fact that the surgeon wanted a skiagraph of the humerus only shows that he did not think there was any trouble at the elbow. If the surgeon had done that skiagraphic work himself he would have been puzzled at finding the humerus in good shape and he would surely have examined other parts of the arm and the proper therapy could at once have been instituted by him. The Roentgen rays are of such great importance that we cannot do without them. Of what enormous importance it is to make a differential diagnosis between osseouscyst and osteosarcoma which gives the same symptoms. The differential diagnosis between osteomychtis, rheumatism, syphilis, and kindred diseases are all things of the greatest importance, and while I do not believe you can make the diagnosis simply by the X-ray, it is a most valuable adjunct to the other methods.

As to diaphragms, it is true, it would be most desirable to have pictures five feet long with all the details shown; it would indeed be a consumation devoutly to be wished, but this is so far a technical impossibility I absolutely deny that without a diaphragm you can get so distinct a picture as this one here (indicating), and if a surgeon is made to understand that he cannot get so distinct a picture unless he is satisfied with a small area he will put his request in different shape. What advantage is it to the surgeon if the ribs are shown, if the clavicle is shown, or if a larger piece of the humerus is shown? That is no benefit to the surgeon in this case, in which we want to see the fracture of the neck of the scapula. This small portion of the shoulder is sufficient for him. So the surgical knowledge and the X-ray knowledge must be combined, and if both parties work different ways, they will never get any satisfaction out of it.

The question of diaphragm-skiagrapy was raised with reference to the skiagraph of the kidneys. I did not say it was not possible to make a picture of the kidneys, but that it was rather rare, and from a practical point of view the method which gives a good picture of the kidney and nothing else is not of much advantage.

As I said before, the very frequent fractures of the lower end of the humerus have been a constant source of dissatisfaction to the surgeon. But recently a surgeon published a record of fractures and said, "We have given up the idea of a perfect restoration, even with the X-ray; it is impossible to get a good articulation of a fracture." Koenig, the great old German surgeon said, "How desirable it would be to get an exact anatomical representation of a joint." Now, we have reached that point most decidedly and we can do it, especially with this diaphragm. I have made many skiagraphs of the elbow, and I have written a text-book on fractures which was published nearly five years ago, in which you will find some good pictures of fractures, although none was taken by a diaphragm. I did not publish my bad pictures; it would not have been any advantage and my bad pictures were in the great majority. My diaphragm has the advantage of keeping the extremities absolutely tight, which would be impossible in little children by the ordinary method. In cases of spina bifida the spinal column can be distinctly shown with it and a hiatus is well represented.

The experiments of Dr. Morton have interested me very much. I do not know of any place where I would rather speak of this subject than where Dr. Morton is present. I do not believe he gets enough credit for his work. He gave the first demonstration of the X-ray in New York, and it is the pioneers that ought to be honored since this method has become so very important. I have been interested in seeing his pictures of the hands and his experiments with fluorescents, and I have no doubt the subject will be further developed so that we may be able to utilize it much better in practice.

Let me conclude by alluding to a simple case in practice. The first case which Dr. Morton showed was a case of a needle in the hand. It was an unfavorable case to show. I remember in former years when people came to my clinic a girl would tell me she had a needle in her hand. I would palpate the needle, make an incision, find the needle and take it out, and that settled it. Just as often, however, I was not sure whether it was there or not. Frequently it took me an hour to ascertain whether it was in the hand or not, and the poor girl had to be tortured a whole hour just to find that sometimes it was not there. Often in the excitement they forgot whether it was pulled out or not. When I was a young assistant my chief gave me the case of a young lady who said she had a swelling on her finger, but gave no history. I thought it was a case of arthritis induced by an injury of some kind. There was no history of the presence of a needle, so we excluded that possibility. I immobilized the finger, but there was no improvement. I looked up my text-book to see what I could apply to the case, but all in vain. After two or three months' treatment my chief said to me one day, "There is a slight possibility of the presence of a foreign body," so I cut down and found a needle. I was very much ashamed at the time; it took me three months to get down there. Nowadays we would look at such a case with the fluoroscope and that would settle the question at once. In my clinic in New York a little fellow came in complaining of pain in the region of the ankle. I examined him thoroughly and found his calcaneum showed slight swelling, but there was no history given of any injury. I skiagraphed him and found to my great surprise a very large needle in his foot which he had carried two years, having been in different clinics in New York city. Some of the surgeons spoke of ulcer, sarcoma, and the question of syphilis was mentioned, and while not claiming credit for knowing more than the other surgeons, I examined him with the X-ray, thinking I might find something there, and as soon as the diagnosis was made the needle was taken out. It is significant that the surgeons who saw the case gave an opinion. Although I did not know any more than the others I was a little more careful in expressing mine, having found out many of my mistakes through the X-ray before.

I wish to give you these illustrations because they are depictions from true life. You ask me how it is that this man gave no history of a needle in his foot. I can understand it theoretically, but know nothing of the facts. We must reckon with the stupidity of people. This boy, who was a dwarf, was asleep, there was a violent knock at the door, he became terrified and fell down, and he undoubtedly fell on a needle which broke. Probably by walking the needle was driven somewhat deeper into the tissue.

We cannot dispense with the X-ray any more, and not only every surgeon, but every physician must sooner or later add it to his equipment. If he will not do it he will be left behind and his neighbor will do better work than he can do.

The following paper was then read:

THE CATAPHORIC DIFFUSION OF METALIC IONS IN THE DESTRUCTIVE STERILIZATION OF CANCER AND TUBERCULOUS DEPOSITS.

BY DR. G. BETTON MASSEY.

The medical world has but slowly realized the full meaning of the modern demonstration of the germ origin of certain diseases. In tuberculosis, cancer and syphilis, for instance, not to mention other analogous affections of less importance, modern research has shown that we have primarily a single nidus of infection, where a germ colony of extraneous origin has succeeded in implanting itself on, or within, the human host, often in a most accessible location for complete eradication, yet the physician is apt to content himself with inadequate methods for its local destruction, relying too much at times on the corelated fact that depressed or disordered vital chemistry has permitted the foothold of the disease to be established, and depending too much, particularly in tuberculosis, on what might be called physiologic sanitation for a reversal of the soil conditions that permit the continued presence of the disease. Such an attitude is singularly like the old house-to-house sanitation when an epidemic disease has appeared at a port. No one could object to the sanitation, either civic or physiologic, but our modern health authorities now recognize the necessity for a more strenuous treatment of the affected individuals or infected port by isolation and prompt destruction of the imported germs.

We must adopt a similar attitude toward the primal site of infection in an individual in whom a germ colony has become lodged. To employ the knife, necessarily opening the avenues of local and systemic distribution at the cut edges, is most unscientific. Nothing but complete and destructive sterilization of the germ colony in situ, while erecting simultaneously a barrier to the operative dissemination of the infected cells, can fulfill the scientific indications of the problem.

An electric modality, the constant current, is herewith called to the attention of the Congress as the most effective agency for conveying germicidal chemicals into and throughout such a germ colony, and clinical details of a large number of cancers so treated will bear me out in the claim that, if the colony is overwhelmed by a sufficient dose dispersed throughout its extent, complete eradication of the infected cells may be secured, with the erection of an effective quarantine of the surrounding tissues.

As the result of many experiments the writer has selected mercury and zinc as the materials which, when ionized and dispersed within the tumor, will best meet the indications. The process may be best understood by a brief narration of the practical details of such an application, taking a major application to a cancer of the breast under an anesthetic, as a sample:

ZINC-MERCURY CATAPHORESIS IN CANCER.

The patient lies on a large dispersing pad, made preferably of clay and as large as the whole dorsal surface. This pad is electrically connected with the negative pole. After anesthesia has been secured, small pointed electrodes of zinc, heavily coated with mercury, are connected with the positive pole and thrust into the peripheries of the growth. The current is now turned on, to a strength, approximately, of 200 milliamperes to the electrode. In a few moments, a whitish area of necrosis will radiate from each point, and from all portions of their contact with the growth, the several areas finally meeting, when the whole growth will become devitalized, softer and inodorous. The devitalization thus produced is so directed from time to time during the application, that the whole base of the growth, as well as its mass, will be included in this area of complete necrosis and sterilization, its edges subsequently becoming a line of demarcation when the slough separates, some 21 days later. Beyond this area of complete destructive necrosis of all tissues, a zone of infiltration will be found, in which a less dense diffusion has resulted in the death of lowly organized wandering malignant cells without necrosis of the tissues. This surrounding zone of parasitic sterilization will be found to be a most important feature of the practical application of the method, for no other surgical method offers a similar destructive agency against the yet latent migrant cells that surround all actively growing malignant tumors.

The electro-chemistry of this process invites the particular attention of an audience of this character. It is evident that in the electrolysis that occurs in the body electrolyte with a current that sometimes reaches 1500 or 1600 milliamperes, maintained an hour or more, large quantities of oxygen, and considerable chlorine, are dissociated, ionized and discharged against the zinc and mercury. The metals thus attacked are eroded deeply, temporary salts form in a dissociated condition, the metallic cations being propelled from the electrodes radially throughout the growth, forming ever changing relationships with the oncoming anions. That these mercury and zinc cations give up their charges as soon as the living tumor tissue is met, in the immediate neighborhood of the electrodes, is evident by their action on the tissue, which turns a grayish-white color. This necrosing action must be that of normal atoms, with full powers of the nascent condition. It is possible that this is so only when the chemicals are developed in considerable mass of concentration.

In practice, it is found that no material amount of these chemicals gain entrance into the bodily circulation, even when 1½ amperes (1500 milliamperes) have been used for three hours in a large growth, the chemicals draining away with the discharges, or remaining within the slough when it separates. Their action at the living tissue edge, when driven in, tends to coagulate the capillaries and lymphatic spaces, forming a barrier against any kind of absorption, whether of germs, cells or chemicals.

The fact that appropriate electrodes, with slender conducting shanks, may be so shaped and insulated as to convey the current harmlessly to the seat of disease, at a distal portion of such body-cavities as the nose, mouth, throat vagina and rectum, and there develop the cations, indicates a peculiar adaptation of this remedy to germ colonies in these situations.

Such is the major application of zinc-mercury cataphoresis in the treatment of cancer. It is practically a major operation, and will at times cure the disease at once. The minor application varies from this in the absence of general anesthesia, the use of but one active electrode made of thinner zinc, and in the usual necessity for frequent repetition until the growth has been removed piecemeal, if the case is of such moderate malignancy as to permit the minor method to be used successfully. The details of the minor method are somewhat similar to those employed in the treatment of tubercular foci, which will be described next:

ZINC-MERCURY CATAPHORESIS IN TUBERCULAR ADENITIS.

The minor method of zinc-mercury cataphoresis is an office application, employing the constant current of ordinary voltage and the usual dispersing pad. The active electrode is a sliver of zinc, cut from a sheet of zinc, such as can be obtained from stove dealers, a long-handled pair of surgical scissors being usually equal to the task. The sliver is about 1½ ins. long, and ⅛ in. wide at the base, tapering to a sharp point, which may be made sharper by a little filing. It is attached to a conductor of slight weight, to prevent being dragged out of position, by twisting the bared end of a sufficient length of No. 32 or 30 copper wire about its base and clamping the base when turned over tightly on the wire. The electrode is now complete if it is wished to cauterize a tract through the unbroken skin into the tubercular gland; or, if a sinus already exists, the edges of the sinus may be protected and the action confined to the diseased structure beneath, by coating the instrument with fused sealing wax to a point near its tip.

Having placed the patient on a couch with the indifferent negative pad on the abdomen, the electrode is coated with the quicksilver, an opening is made through the skin with a tiny bistoury, or Hagedorn needle, under the chloride of ethyl spray, and the electrode thrust into the opening. A current of from 1 to 3 milliamperes or more is now gradually turned on and maintained for 30 minutes. The burning sensation may be greatly lessened by placing a drop of saturated cocaine solution at the point of entrance of the electrode, the cocaine being diffused locally with the other cations.

A tiny white slough will be found to be the result of the application. It is to be repeated thrice weekly, until the center of the growth is thoroughly sterilized, when the opening is allowed to close, leaving a scar no larger than a pin head.

This treatment is followed by a complete cure in from six to a dozen applications to each affected gland, and it has been invariably noted that the patient regains a good color during the treatment, followed by subsequent robust health.

DISCUSSION.

DR. GRANGER: My intention is not to discuss Dr. Massey's paper, but to add further testimony to the observation he has made and the results he has obtained. I had the pleasure of meeting the doctor two years ago at New Orleans, and at his insistence I did some of this work. The twelve cases which I treated by mercuric cataphoresis were unselected ones. My aim in treating all cases which applied to me was to acquire the necessary technique and experience, to thoroughly test the possibilities of the method, and to find out what palliation, if any, could be offered to those hopelessly inoperable patients, in whom the disease is so far advanced that nothing more than a very temporary palliation can be hoped for.

But if we can destroy the odor and prolong life in such cases we can feel that we have accomplished something. There was one case of the recurrence of the disease in the pelvis six months after a hysterectomy. There was a cauliflower growth in the vagina. I had postponed operation three weeks, and within that time the growth filled the vagina and came down into the vulva. The patient was anæsthetized and the current applied and the odor disappeared completely. The patient died two months later. If the patient can stand the anæsthesia for an hour or two he can be relieved of all pain and odor. Twenty-five per cent of the cases I saw were either on the tongue or palate, and you can very readily see that it would be very difficult to use the ordinary straight electroxdes on the tongue or in the mouth, as the mouth has to be kept wide open, and in any case of anæsthesia it would be more difficult, so I gave the instruments this shape. When these are anchored in the tongue they will remain there and two or three can be put in at the same time. Taking this as the upper jaw (illustrating on the blackboard) and this the lower, the instrument was inserted this way (indicating) and driven into the growth. The instrument was introduced in this direction (indicating) so that the periphery of the whole growth was circumscribed. This patient was seventy-three years of age and I was afraid I could not continue the treatment until the growth was destroyed. I thought if I could cut off the circulation in that growth it would slough off even if it was not destroyed. Another point I noticed, and that was the selective action the current has on the malignant tissue.

Dr. W. B. Snow: The facts have been stated and there is little to be added. It seems to me that there cannot be too many ways of coping with cancer. In Dr. Massey's method we have a means of reaching cases where other means frequently fail. In many of my own cases the X-ray has not accomplished all that could be desired, yet a great degree of success has been obtained, and I feel, as I have frequently said, that any additional means of overcoming these difficult problems strengthens our hopes, and in the one under consideration, we have a very valuable one.

Dr. Charles R. Dickson: I have had some experience which apparently was profitable to the extent of prolonging the life of a man who was suffering from a large fibro-sarcoma of the neck. I referred the case to Dr. Massey for treatment, but unfortunately before it could be completed secondary hemorrhage brought the career of the patient to a close. It was a case in which we hoped to obtain good results, although the disease had made great progress. It was a case which illustrated the possibilities of treatment, in that we had such an enormous mass to deal with, it being one of the largest tumors of the neck I have ever seen. The man was sent to New York for advice, but those who saw him absolutely refused to operate, and there is no doubt that cataphoric treatment prolonged his life very materially. In minor cases we also get good results. For instance in epithelioma of the lip and epithelioma of the eyelid, there is no doubt that cataphoric treatment holds out wonderful possibilities. It is certainly worth our while to investigate.

Chairman Wm. J. Morton: I have followed for a long time with close attention Dr. Massey's advancing steps from one point to another in the demonstration of this method of attacking cancer. There is no doubt, as another speaker remarked, that in incurable diseases there should be a possibility of recourse to as many reasonable methods of treatment as possible. We all know that in the treatment of many such diseases there exists a multitude of remedies; probably one not much better than another. So it is with cancer, and as long as cancer stands in that position I am sure that Dr. Massey's procedure will receive our respectful attention. There is only one point in my mind I wish to speak of in regard to this procedure, and that is this, that it is undoubtedly a destruction of tissue by caustic action. That is to say, the positive pole is manufacturing, by aid of the electric current, in the patient's tissue a new chemical substance, which we know in the case of zinc is oxychloride of zinc, and in the case of mercury is oxychloride of mercury, both destructive caustic agents. Around the neighborhood of the needle appears at once a white area, extending more or less according to the strength of the current, and according to the distance apart of the two electrodes. There is no such action with the negative electrode; it is only the positive which exhibits this caustic action. If we could claim a selective effect of the electric current upon cancer tissue and lupus tissue, then we would certainly have a very important advance made, but I hardly see how our electric current can distinguish between sound tissue and diseased tissue, or between sound blood cells and diseased blood cells, and again in such a case it would not be necessary to use "soluble" electrodes. Platinum needles would suffice as in the Parson's method. We come back, therefore, to the treatment of cancer by caustics, and it must be admitted that some of the operations performed by caustics are entirely successful. I believe there has been too much prejudice against a caustic, because it has not always been retained in the hands of the competent surgeon, but I know some surgeons in New York who have been using it with great success in the extirpation of cancer of the superficial types. In many cases we would prefer the use of the knife, and so would most surgeons, but the patient prefers the use of the caustic, although it makes a deformity greater than the knife, but such is the dread of the knife on the part of many patients that they desire to do anything almost rather than submit to it. I do not think this sentiment should be encouraged. I simply wish to submit this idea, namely, as to whether this procedure is not rather a caustic action than an electric action. It certainly has been carried to an extreme degree of perfection by Dr. Massey.

Dr. G. B. Massey: Our chairman is entirely right in his statement that the caustic action is a very essential part of this treatment. But the difference between electrochemical cauterization, a cauterization by which chemicals are driven into the tissue of the cells by electric osmosis, or whatever process it is, is very vast, indeed, from that of putting a caustic upon the surface. There is also a very great difference between this method and the usual method of applying caustics. Cataphoric sterilization can be done at once under an anæsthetic instead of the patient being compelled to suffer for six or eight weeks under the application of caustics. There is another difference, too, involved in the question presented by the chairman, and that is whether this method does discriminate, or exercise a selective action between cancerous and noncancerous tissue. A surgeon standing before the patient with knife in hand does not expect that knife to select the work to be done, but he trusts his trained fingers to place the knife in the right place, and so you must select the place where you wish to put your electrodes. But beyond that, there is a selective action due to the electric current alone, and that is owing to the increased conductivity of the tissue that is made up of cells that are better conductors, yet of less vitality, contrasted with the normal tissue by which it is surrounded. The selective value must not be depended upon alone. You must put your electrode where it will do the most good, and depend upon the selective action of the current to make your work more successful.

There is another point that was alluded to by Dr. Morton, and that is the lesser scarring. I should say there is greater ease of removal, with lesser scarring and lesser pain than attends the knife operation. Any of these points will be held to be true by one who has seen this operation under ether. It takes mass effects to teach sometimes, and it requires mass effects here to show this method to advantage. The advantage of this method over the knife is illimitable when we take into consideration the living germs that we may sow in the tissue with the knife. And this is, of course, its main advantage. But the cosmetic effect is vastly superior to the most beautiful knife operation also. Without skin grafting, a large wound usually heals up as a V- or Y-shaped scar of no greater length than the finger, the skin appearing to extend inward over healthy granulations with a linear cicatrix at the center. The cosmetic effects are distinctly better. The feeling of comfort to the patient after she is put to bed is also an important factor that is secured by this method, the comfort being much greater than by the knife operation. I have had a patient who received a current of 1500 milliamperes sitting up in bed in the hospital reading the newspaper the morning following, though this patient succumbed later to the only risk associated with the method: secondary hemorrhage. The cause of this lack of pain is probably the obliteration of nerve endings in the area of the current action. The ends of the nerves and the vessels are all sealed up; there is no sensation unless you find it in the live, healthy tissue beyond the diseased tissue. Where the growth is small, and the action extends unnecessarily far beyond its edge, we may have small pain during the twelve hours following the application, but this is usually slight. and no medication is required.

A paper by Dr. G. G. Burdick, of Chicago, was then read by title in the absence of the author.

RADIATIONS IN THERAPEUTICS.

BY DR. GORDON G. BURDICK.

The remarkable discovery that the X-ray had remedial qualities excited the greatest scientific interest among physicians, and led a few representative members of the medical profession to spend considerable time and money developing latent possibilities of this method of treatment. The poor, inefficient apparatus we had in the earlier days which developed a ray of a very low penetrating power, quickly conquered many obstinate skin diseases, and at the present time, in the hands of experts, it has become a specific in many cases of infectious skin diseases.

As the apparatus improved in quality and we began to transform more energy, we obtained a richer ray of greater penetrating power. Other workers came into the field and began to report the cure of diseases situated beneath the skin, and also the cure of a number of skin diseases that seemed to resist former radio-therapeutic treatment.

The extraordinary interest taken in this line of treatment by physicians stimulated manufacturers to further efforts to improve their apparatus, with such success that the later investigators in this field are convinced that the ray has no effect upon disease, and that the earlier reports of cures were overdrawn.

This dangerous condition of thought will eventually cast discredit upon the most valuable method of treatment ever brought before the medical profession if something is not done to correct the faulty technique used by different operators. It is hardly to be expected that as important a method of treatment could be left to nurses, or be used by men who know nothing of physics or electricity and be successful.

Radiations are forms of motion in the surrounding medium, derived from various sources of energy, having different periods and detected by various means. The lower periods have been used for centuries, for various troubles, such as the application of heat and cold as a local application; cold retarding atomic motion, while heat accelerates.

We find that metabolism is modified by imparting different forms of motion to its atomic structure. Cold retards motion, consequently the cells are not active; secretions are diminished or stopped and waste is retarded; while by slowly increasing the period, we find that atomic motion becomes rapid, secretion and excretions are increased, the capillaries dilate and a greater supply of blood is brought to the part in order to protect the cells from destruction.

If we increase the period so that the thermometer registers 115 degs. the motion becomes so active and so general among the atoms that disintegration begins and liquefaction will insue, causing a destruction of the cells. If we now increase the period as determined by the thermometer, we find that we lose penetration. The local action becomes so active that superficial destruction of tissue takes place, and a burn results. We now know that the limit of periods that the human body can safely stand when determined by the thermometer is 120, for with a higher period we lose penetration.

We are unable to use any of the other forms of radiation until the frequency is increased to that which the human eye can detect, as light. And then we find that the eye will respond to a greater number of frequencies; this we call the spectrum. We know now that it would be impossible for life to exist without the frequencies noted in the visible spectrum, that all plant and animal life is capable of transforming the energy of light, and using it for heat, light and chemical actions as may be required by their respective structures.

Until the discovery of the X-ray it was not known that higher frequencies could be produced that would have chemical power.

It of course was known, but excited little comment, that the magnetic lines of force would pass readily through the human body. It is true some observers attempted to use them in the treatment of disease, but with indifferent success, as it was found that the body could transform only a small amount of the energy used in the apparatus, so the method of treatment was abandoned for a number of years, until the development of the X-ray apparatus made it possible to secure more rapid frequencies, by the inventions of numerous types of rapid interrupters, until at the present time the frequency of about 60,000 a minute is reached, and we find that the body can transform enough energy from the magnetic lines of force to modify its nutrition in a wonderful way. It is theoretically possible to increase the periods sufficiently high to give the magnetic lines of force a chemical action. It is only a question of proper apparatus.

Beyond the visible end of the spectrum, about three octaves of frequencies may be detected by means of the bolometer and by the fluorescent effects upon certain salts, and by means of its chemical action. It seemed incredible to scientists when Roentgen announced that he had detected a new radiation that was capable of passing through the human body and affecting photographic salts. Considerable skepticism was experienced until it was verified by different observers.

Extensive experimenting has determined that from an ordinary X-ray tube radiations pass off, having different periods, and having characteristics that vary with its periods. We know that there is emitted from a tube a radiation that is transformed by certain crystals so that it will be visible to the human eye. It is also known that a radiation is sent off, having chemical qualities which is capable of affecting a photographic plate; it has certain penetrating qualities, will pass through small thicknesses of aluminum and may be carried through the human skin. This radiation passes about 4 ins. from the tube, it is extremely rich in chemical effects; has a destructive action over certain bacteria, and is the ray used in the treatment of infectious skin diseases. Many tubes do not give off this ray, owing to its being absorbed by the thick walls of the tube. As a general proposition it can be accepted as a proven fact that this ray cannot pass through glass 1/20 of an in. in thickness.

The great majority of the modern tubes will vary in thickness from one-tenth to one-twentieth in thickness, consequently are worthless in the treatment of diseases of the skin. The small cheap tubes are usually more valuable for this class of diseases than the more elaborate type upon the market, manufacturers have vied with each other to produce a tube that would endure the hardest kind of usage and stand the energy from the heaviest type of apparatus, and have only reached this point by increasing the thickness of the walls of the tube, until at the present time it is a problem to obtain a tube that will allow enough energy to escape to make a good skiagraph of the human trunk.

A halt must be made to this alleged progress, or radio-therapeutic treatment will pass into oblivion. The true chemical ray, called the X-ray proper, is of value from a radio-therapeutic standpoint only when absorbed. It is capable of imparting motion to the human cells and bringing about chemical changes only when the ray is allowed to come to rest within the tissues. If sent with great velocity, motion is imparted, but the body is only a conductor; it transmits energy, but none is absorbed.

Let us reason by analogy for a minute. If we have a glass lens, we may transmit a beam of sunlight all day and the lens will remain at about the same temperature as the surrounding objects; but let us coat the back of the lens with lamp black and immediately the lens is brought to a very high temperature. To prove that the same energy passes through the lens in both cases we may cut our lens in a convex form so as to bring the rays of light to a focus, and we find that the temperature is raised, not at the lens, but at the focus, where the rays are conveyed and arrested, while with the lamp black the energy is arrested and absorbed at the lens.

The same principle holds true in radio-therapeutic treatment. The operator should have an exact knowledge of the precise depth he wishes the ray to pass, so by adjusting the vacuum of his tube, or varying the electromotive force, upon a tube of a suitably low vacuum it is practicable to pass the ray to the exact depth and have all of its energy absorbed and at the place where we wish the work done.

I well remember in the earlier days, soon after getting my powerful apparatus installed, I had occasion to treat a young man who had a severe burn from hot water upon both the chest and back, which became infected with lupus. I decided to try the chest first as it was in the worst condition. After three weeks' treatment I found that the condition was apparently getting worse upon the chest, and had about decided that it was not a suitable case for the X-ray, when he called my attention to his back, which had given him no trouble since he had taken the treatments. Upon examination I found that the back was in a fair way to recovery, while no relief was had upon the chest, but the phenomena interested me, and I continued to treat him in the same manner until the back was well. This matter puzzled me so much that I turned the man around and sent the ray through the body to treat the chest, when much to the astonishment of all, the chest began to get well, and a steady progress was noted until recovery was complete.

It took months of experimenting to solve the riddle, but when it was done difficulties connected with the treatment began to melt away, and we found that it was possible to do work with some degree of certainty.

My experience has developed a technique that is absolutely reliable, and has brought order out of chaos, that exists in this field of work. I reduce my tubes below the line, so that no X-ray is given off while the tube is connected in series with the machine, and then by raising the electromotive force of the apparatus by means of the spark-gaps, I can cause the corpuscles in the tube to travel at any desired speed; so that we can get any desired penetration that we may wish to use in any case. The higher the electromotive force, the faster the corpuscles travel, and the greater the degree of penetration we will have, so that it is possible to get anything from 1/8 of an in. to 8 ins., by increasing the spark-gap from 1/4 of an in. to 1 in. upon each side of the tube.

Chairman Morton: Now, gentlemen, somewhat in a mournful sense I see we have reached the end of this session of Section H of the International Electrical Congress. All the thanks and congratulations and compliments to ourselves have been said, and there remains almost nothing to add on my part, except that I should be glad to entertain a motion tendering a vote of thanks for the assistance and service — the successful service — of our secretary. He is not one of the medical fraternity, but he has given up most arduous labors in one of the greatest electrical businesses in New York, and has come here to work with us, and day in and day out he has worked with us. I know we all feel grateful to him for his services as secretary as well as for the invaluable work he has performed on the committee with Prof. Samuel Sheldon.

Dr. G. B. Massey: I wish to move a vote of many thanks to the efficient secretary who has done so much to help physicians to understand the agent that this Congress is called upon to study. Of course, we can only thank him officially for what he has done here, but in so doing I trust he will consider that we thank him for the many other things he has done for the medical men in connection with this subject.

The motion of Dr. Massey was numerously seconded, and unanimously prevailed.

Secretary Wm. J. Jenks: I thank you for your expression of appreciation. It has been a great pleasure to me in the last twelve years to attempt to absorb some of the ideas of physicians and surgeons which bear upon the branch of science to which I have been giving now more than thirty years. The work of the present Congress has proved to be a most pleasant form of recreation. This has been due in large measure to the entire harmony of policy and action which has existed in this, as in many other joint efforts, between our honored chairman and myself. It is interesting at this time to recall that Dr. Morton was the first electrotherapeutist whom I was privileged to know, and it was through his kind introductions to other electrical specialists that I was asked to read in 1894, just ten years ago, what I believe to have been the first paper on the needs of electrical medication from the standpoint of the electrical engineer ever submitted to a body of men of your profession. By that paper and resulting work in the development of special meters adapted to your needs, I was able to inaugurate that active co-operation first in this country and afterward abroad, between the medical fraternity and the electrical engineers, to the results of which some of you have referred in terms which give me more credit than I deserve. Nothing could now be more pleasing than to hear thus directly from those who have closely followed that work, their conviction that in this latent effort, for the success of the Congress, I have been measurably useful.

Vice-president M. G. de Nerville then took the chair.

Dr. Charles R. Dickson: It is my pleasant duty, although words fail me to express it properly, to move a resolution which it seems a pity should be done in such a formal way. I know that each of us, from the bottom of his heart, feels that a vote of thanks should be tendered to the chairman of this section, Dr. Wm. J. Morton, for the able manner in which he has presided over this meeting, and for his way of going about securing the success of this section under very great difficulties and disabilities, and I know that for what has been done on this historic occasion all will be delighted to think that to Dr. Morton we are indebted for the success of Section H of Electrotherapeutics in connection with this International Electrical Congress. I would like to say more, but am sure that anything I have left unsaid will be ably supplied by Dr. Massey.

Dr. G. B. Massey: Mr. Chairman and Members of the Section: I rise to second this motion, and while by no means an orator, I wish to say that I have been long interested in electrotherapeutics, and for a long while I have felt that the chairman of this section has graced electrotherapeutics with his wonderful personality and his vigor of investigation, and no one was more pleased than I to hear that he had attracted the attention of the International Electrical Congress toward this particular department and its work, and has succeeded in bringing about an international discussion of the subject.

The motion being put to a vote, the resolution was unanimously adopted with applause by a rising vote.

Chairman Wm. J. Morton: I can only say, Mr. Honorary Chairman and Gentlemen, I am very certain that I do not deserve all the good words that have been said of me. All I have ever tried to do is to work hard and to do my duty as plainly as I could see it. I confess to a love of electrotherapeutics, and I confess to doing my best to promulgate the use of electricity in medicine. It is for the reason that I have been so long fighting this battle of electrotherapeutics against long odds that I appreciate highly the remarks made here by the three speakers who have preceded me. Time was, and that not so long ago, when it required great moral courage for a regular physician to take up the practice of electrotherapeutics. That day has passed. The advent of the Roentgen ray, its therapeutic achievements and the newer theories of the part which electricity plays in the constitution of matter and in the processes of biology has forced a tardy and reluctant, but at the same time respectful, attention to electrotherapeutics. I thank you, indeed, for your kind words, and I can only say, as I have said before, I have simply tried to do what one ought to do.

I will close this meeting by saying that I think I express the sentiment of every one present when I say that we feel a warm pleasure in the presence here of our honorary chairman. We have already welcomed him from the bottom of our hearts, and he has responded most gracefully. Our greeting and his reply is already a matter of record, and I can only say to those who came here to take part in our proceedings, and to those who have left their sections to be present with us, I can only say to them, and to the honorary chairman and to you all, almost in the words of Shakespeare,

"Parting is such sweet sorrow,
That I shall say, good-bye, till it be morrow."

The section then dissolved.

ROLL
OF
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International Electrical Congress
ST. LOUIS, 1904

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