EDWARD WESTON AND HIS METER

C.N. Brown

Science Museum, London

Introduction

The most widely used instrument for indicating or measuring electric current or voltage is probably still the type with a pivoted moving coil carrying a pointer over a calibrated scale. With the enormous increase in the production of digital instruments it may not be correct to say that for much longer, but until recently there was nothing to compete with analogue instruments. Moving-iron and other types had their particular niches, but the moving-coil type was the most popular by a long way.

1988 is the centenary of the production of the first moving-coil meter, in the United States, by Edward Weston. It is not sensible to celebrate every possible centenary, there are far too many of them and most are not very important, but the moving-coil meter has played a very large part in electrical history, if not always a very prominent part. In its hundredth year it is worth spending a little time looking at its origins.

Edward Weston

Weston does not have the stature of an Edison or a Westinghouse, but he is a good example of an American engineer and entrepreneur. In fact, he was born in Britain in 1850, the son of a Wolverhampton carpenter and mechanic, and he did not become an American citizen until 1923. His parents wanted him to take up medicine and apprenticed him to a physician, but after receiving his diploma, and against his parents' wishes, he went to London to seek work in the sciences. He had been interested in science, particularly chemistry, from boyhood. Not finding anything suitable in London, he went to New York instead.

Life in America was not easy but he did find work, first in a photographic chemical company and then in the electroplating business, where his chemical skills enabled him to solve apparently intractable problems. He came to the conclusion that a dynamo was a better source of power than batteries, and began to design and build machines for electroplating with such success that, in 1877, some of his business associates financed the Weston Dynamo Electric Machine Company, with Weston as its general manager. Soon afterwards arc lighting began to become popular. Weston changed the name of the firm to the Weston Electric Light Company and began to produce arc lighting equipment, in competition with men like Charles Brush and Elihu Thomson. It was a profitable venture, and Weston, with his chemical knowledge, virtually controlled the manufacture of carbon electrodes. He also produced an incandescent lamp for a while. Litigation by the Edison company put a stop to this, but Edison had to pay royalties to Weston for one of his inventions, a material called "Tamidine" used for making filaments by an extrusion process. This was Weston's first real source of wealth. By 1882 the Weston company had been absorbed into the United States Electric Lighting Company. Weston became its chief electrical engineer. This company owned the Maxim incandescent lamp patents, and its counterpart in Britain was called the Maxim-Weston company.

In 1886 Weston resigned from the United States company, disagreeing with the way that it was being run. The company was so dependent on his patents that he had to be retained as a consultant, and the unpleasantness did not cease until fire crippled the company the following year. This was the time that Edison was going to the courts to suppress all incandescent lamps except his own, and Weston was in great demand as an expert witness, a role in which he excelled. Weston continued his work in a large and well equipped private laboratory in his home, which was now at Newark, in New Jersey. A need which Weston had felt acutely in his own work was for reliable and accurate measuring instruments, so he set about designing some. The first meter was finished in 1886, but he was so busy that he did not apply for a patent for two years. The application was granted on 6th November 1888.[1] At about the same time he set up the Weston Electrical Instrument Company. It was a private company and remained in his personal control until 1924, long after his counterparts such as Edison and Westinghouse had lost control of the companies which they had founded. In 1924 the company became incorporated, and his second son, also called Edward, took over direct control. Edward senior remained Chairman of the Board of Directors until his death in 1936.

Edward Weston was the recipient of many honours. In particular, he was a founder member of the American Institute of Electrical Engineers, now the IEEE, and its president in 1888-1889. His success in business was not without cost to his personal life. He worked obsessively, sometimes not leaving the laboratory for days on end. His wife never quite came to terms with the way he worked or with his success, and his relationship with his elder son was always strained. Weston was not unaware of these difficulties, but he could not change his character.

Moving-coil meters

The Weston meter was the first successful meter with a pivoted coil, but it was not the first moving-coil instrument. There are antecedents going back to William Sturgeon in 1824 and Cromwell Fleetwood Varley in 1856. There is also Sir William Thomson's siphon recorder of 1867, though the earliest version of that used a form of moving coil rather different from the one which became the norm. These can be regarded as the prehistory of the moving-coil meter because they did not lead to anything further, though the siphon recorder was a very successful instrument in its own right. The event from which a continuous history of moving-coil instruments can be traced is the appearance in 1881 of the Deprez-D'Arsonval galvanometer. The idea of allowing the coil to move originated with D'Arsonval, hence the instrument is often known by his name alone though both men contributed to its design and it was based on an earlier instrument by Deprez. Weston claimed that he had had the idea of a moving-coil instrument before D'Arsonval, but he did nothing at all about it until 1882, and then only sporadically.

In 1882 Deprez and D'Arsonval described what was to become the standard form of moving-coil galvanometer in which the coil is suspended between the pole pieces of a magnet by a metal strip, and there is a fixed cylindrical iron core (a tube in the earliest examples, but later solid) within the coil. Current entered and left the coil through the suspension strip and a similar, but loose, metal strip at the bottom. Attached to the coil was a mirror which reflected light from a small lamp on to a scale, to indicate the deflection.

Though by no means immune to changes in the Earth's magnetic field or other external fields, moving-coil galvanometers were not affected as much as the moving-magnet instruments in common use at the time. Also, they tended to be easier to use, though not as sensitive. Their disadvantages are apparent. The suspensions were delicate, they had to be level, and the lamps and scales made them awkward to set up and use. Most importantly, they were not amenable to calibration, so it was a tedious business actually to measure a current in milliamps.

Calibrated meters

With the spread of electric lighting, measuring rather than just indicating currents was becoming an important consideration. It was being tackled by people like Professors Ayrton and Perry, who had introduced, in 1883, what was claimed to be the first direct-reading meter for voltage or current. It was a polarized moving-iron instrument, developed from an earlier design which had a scale marked in degrees so that the reading had to be multiplied by a constant to obtain the current. The new instrument was fitted with a device to adjust the sensitivity to fit the scale, which was marked in amperes or volts.

A major problem with direct-reading instruments can be illustrated by a comment on the label in the box of one of the earlier Ayrton and Perry instruments in the Science Museum.[2] It reads "This instrument should be occasionally calibrated in accordance with the method described in the Instructions to detect change in the strength of the Horseshoe magnet". Another example is the "graded galvanometer", which was Sir William Thomson's attempt to convert a tangent galvanometer into something an electrical technician or engineer would find useful. It was patented in 1881. On the back of the control magnet of an example in the Science Museum[3] is painted a number indicating the strength of the magnet, in unspecified units, and the date that it was measured.

Permanent magnets deteriorated all too rapidly. They had to be treated very carefully, but even so any instrument relying on a magnet needed calibrating at regular intervals. Instruments using electromagnets were no better, because the hysteresis of even the softest iron made the meter readings dependent on previous treatment.

There were other problems as well as magnet instability. Meters tended to overheat, even if left in circuit only for long enough to take a reading, and this affected the accuracy. Also, scales were often not very accurate. This was particularly so if they were printed or engraved rather than individually calibrated, because there could be considerable differences between nominally identical instruments.

The Weston meter

The most important feature of the Weston meter was that it retained its calibration indefinitely, even when treated rather roughly. The key to this was obviously the magnetic circuit. Weston probably used the new tungsten steel for his magnets, but it is difficult to be sure because descriptions of the instrument do not go into that much detail and the introduction of the new material in about 1885 is not easy to document. The magnets were aged carefully before use, by magnetizing and demagnetizing them repeatedly, and the final magnetization was only to about two-thirds of the saturation value. There was a cylindrical soft-iron core and shaped iron pole pieces to give a narrow and uniform air gap. It is debatable whether the careful treatment of the magnet or the narrow air gap was the more important in keeping the magnetic field constant. Shaped pole pieces had been used in galvanometers by Deprez in 1884, but whether Weston knew this or introduced the idea independently is not clear. The use of shaped pole pieces was already common in dynamos.

Weston was obviously concerned to keep the meter as compact as possible given a scale length of about six inches. The shape and size are dictated by the arc of movement of the balanced aluminium pointer. Even the apparently simple task of designing and manufacturing the pointer required a surprising degree of innovation. The shape of the magnet, which was characteristic of these Weston instruments, was such that it fitted the largest possible magnet into the available space. The shaped pole pieces and cylindrical core meant that the coil moved in a radial magnetic field, which, in theory, made the scale uniform. Despite this, the early Weston meters had individually calibrated scales.

Having solved the difficult problem of making a magnet which would not deteriorate significantly, Weston made sure that the rest of the meter was crafted to a similar high standard. The coil was pivoted between two jewelled bearings and the control forces were provided by a pair of spiral springs wound in opposite directions. Pivoting the coil was an idea he had first tried in 1884. Steel springs could not be used so close to the magnet and moving coil, so Weston had had to use his chemical skills to devise and manufacture a suitable alloy. There had been other electrical instruments with pivoted movements, but not of this quality. Previously there had been little point because the accuracy and stability of the instruments did not warrant it. This was the watchmaker's craft, and quality, applied to an electrical instrument, and in a sense Weston's achievement was that he realised that this was worth doing. The pivoted coil and the hair springs made the Weston meter readily portable.

Another feature of the Weston meter that distinguished it from other instruments of the day was that the movement of the pointer was well damped. This was achieved by winding the coil on a copper former. Eddy currents were induced in this when it moved, producing a damping effect which was not quite critical but very close to it. Later, aluminium was used instead of copper. Weston had put a lot of effort into trying to eliminate eddy currents from the armatures of his dynamos, so he knew how to put them to good use when required.

Compared with other instruments the Weston meter had a high resistance, so it did not overheat. Also, Weston was ahead of his time in using the same basic movement with shunt or multiplier resistances to measure high currents or voltages. The resistances were built-in for the lower ranges and external for the higher ranges. In most other instruments the movement took the full current or voltage and it was much more difficult to avoid thermal errors. The german-silver wire previously used for resistances had far too high a temperature coefficient for the accuracy that Weston wanted, so he developed a better alloy, constantan, which was used in the early Weston meters. Constantan was not totally satisfactory because of its high thermoelectric e.m.f. against copper. Where this was a problem Weston made meters with thermometers and small adjustable resistances, but this was not an ideal solution. Weston solved the problem by developing an even better alloy, manganin, in 1893. This is another example of Weston's chemical and metallurgical knowledge complementing his electrical engineering skill.

There was another novel feature of the Weston meter. It was designed to be built on a production line basis, with interchangeable parts. The pole pieces, core, coil, and pointer, for example, were assembled into a single unit which could be detached easily from the magnet. The idea of identical, interchangeable parts would not have been so much of a novelty in the United States as in this country, where instrument making was still much more of an individual craft.

Both ammeter and voltmeter versions of the Weston meter were made right from the start. The earliest example in the Science Museum is a voltmeter, serial number 183, made in 1889 according to the calibration certificate in the lid of the box.[4] Before giving it to the Museum in 1935 the (British) Weston Electrical Instrument Company had checked the calibration. The accuracy was still within 0.2% of full scale over the whole range. The fact that it had retained such high accuracy for over 45 years gives some idea of the quality of the instruments, though it would have taken a very skilled user to achieve that precision consistently.

Weston was sufficiently confident of his meters to guarantee their performance provided that the seals remained unbroken, and at first he signed the calibration certificates personally. Close supervision of manufacture was easy at first because it took place in the laboratory at Weston's home, but the business soon outgrew the laboratory and it moved to a proper factory in 1890. Weston was said to place more reliance on his meters than on the tangent galvanometer.[5] This seems a strange statement nowadays, but the tangent galvanometer was the reference instrument for measurements of electric current. Weston had a large tangent galvanometer in his laboratory. In practice, it was inconvenient to use as an absolute instrument because it was affected by variations in the strength of the Earth's magnetic field, and thus also by any magnetic materials in the vicinity. The Weston meter was certainly more stable than that.

Introduction of the Weston Meter

One might imagine that such an important innovation would feature prominently in the contemporary press but in Britain the significance is apparent only with hindsight. The introduction of the Weston meter does not seem to have been noticed at all in the *Electrician*, but there is an article about it in the *Telegraphic Journal and Electrical Review*.[6] Contemporary textbooks do not seem to discuss the aspects of its design in any detail, where they mention it at all. Because of this, it is not possible to be certain about some of the finer details of its construction. It was said that Europeans at the Columbian Exhibition in Chicago in 1893 could not believe that Weston's shunt meters achieved what they did. Nevertheless, the Weston instruments were highly regarded by those who knew and used them. J.A. Fleming, in his *Handbook for the Electrical Laboratory and Testing Room*, published in 1901,[7] stated that, so far as continuous currents were concerned, no laboratory instrument fulfilled the conditions he thought important for a table ammeter so well as the Weston instruments. He was almost as fulsome about the Weston voltmeters.

The Weston meters were expensive, high-quality instruments, ideal for the laboratory or test-room. There would have been no point in using them for many routine tasks. Even so, they do not seem to have been appreciated by engineers in Britain as much as they might have been. Perhaps there was an element of prejudice against them because they were "not invented here". Also, British engineers probably had a tendency to make do with cheap instruments. Weston meters seem to have been appreciated more in Germany. By all accounts, they were very popular in America, even though they were up to three times as expensive as other instruments. Competing manufacturers were said to buy Weston meters in order to calibrate their own. Naturally enough, other people tried to emulate Weston, but this proved impossible to do without infringing some of the many patents on features of the Weston meter. Weston was not a man to tolerate this. In the early 1900s the company had 64 suits in the courts at the same time, and in the end it won them all, even against such giants as Westinghouse and General Electric.

Initially, the sole agents for the Weston instruments in this country were Elliott Bros. In their 1895 catalogue[8] the Weston meters were advertised on a single page near the back, with a note that separate price lists were available on application. This was not an aggressive marketing strategy, but Elliott Bros. may have felt that the Weston instruments were to some extent in competition with their own, even though they produced nothing similar. In fact, there was nothing to compete with them at all for a number of years. The advertisement does note that Weston instruments were used by

Government Departments, the Post Office Telegraphs, various named electricity supply undertakings, manufacturers like Mather and Platt, and academic institutions like City and Guilds Institute and the University of Cambridge.

Later Developments

Weston was not content to rest on his laurels. A few years later, in 1892, he introduced an electrodynamometer instrument for use primarily on alternating current circuits.[9] It, too, was a high-quality instrument with a pivoted coil controlled by small springs. For years it was the best instrument of its type available. In Britain, one intriguing use for this instrument was in the Tinsley a.c. potentiometer, where it was used to set the current to the required value, much as one would use a standard cell balanced across a resistor in a d.c. potentiometer.

The company produced a large range of instruments. There were switchboard instruments, of course. The Weston station ammeter was probably more important to the company than the portable meters. It was a moving-coil meter operating across a suitable shunt, and as well as being accurate and reliable it was cheap to run, because it consumed very little power. Supply companies liked this feature because it saved them significant amounts of money. There were some problems with the switchboard meters. Many dynamos were so badly designed that they produced very large external magnetic fields. Weston had not allowed for this, if only because his own machines did not suffer from this fault. He had to alter the design of his meters, enclosing the movements in heavy iron cases so that they were not affected by strong magnetic fields.

The company always claimed that it made the best laboratory instruments available. In the Science Museum there is a Weston standard ammeter made in 1910.[10] It has a moving-coil assembly which looks very similar to that of the ordinary portable ammeters, but there are two magnets to give increased sensitivity, and a very long pointer. There is also a thermometer with its bulb inside the instrument, so that temperature corrections can be applied if required, and a spirit level, but no levelling feet. When last calibrated this instrument was accurate to 0.1%. Since the scale is marked with six arcs intersected by diagonal lines for ease of interpolation between the main divisions, it can be read to that sort of accuracy without difficulty. It has a set of shunts matched to it and marked with the same serial number. This type of meter was produced until at least 1925, but was eventually superseded by an even more sophisticated instrument which represents the ultimate development of the electro-mechanical measuring instrument.

The company did not rely on Elliott Bros. as British agents for very long. Instead, it set up a subsidiary in this country. It seems that instruments were not manufactured in Britain, because they all carry the name and address of the American company. The Weston Electrical Instrument Company first appeared in the London directories in 1906, at Ely Place, London, EC1. In about 1925 it moved to Great Saffron Hill, and later to Surbiton. It was wholly owned by the American company until 1936, when the British Sangamo Company bought a controlling interest. The two companies merged in 1938, to form Sangamo Weston Ltd.[11]

The moving-coil meter is not the only electrical instrument for which Edward Weston is remembered. There is also the Weston Standard Cell, introduced in 1892.[12] Weston appreciated the need for a good voltage reference source because he had felt it in his own work. For some years the Clark standard cell had been used as the standard of electromotive force, but it had a large temperature coefficient. Weston set about using his chemical skills to produce a much better standard cell. The Weston cell became the recognized standard at the International Conference on Electrical Units and Standards held in London in 1908,[13] taking over from the Clark cell. It is only now being superseded, by electronic voltage reference sources at one level and by superconducting Josephson junctions as the ultimate standard. Whether the moving-coil meter or the standard cell was the most important of Weston's contributions to electrical measurement is something which could be debated for a long time.

Conclusion

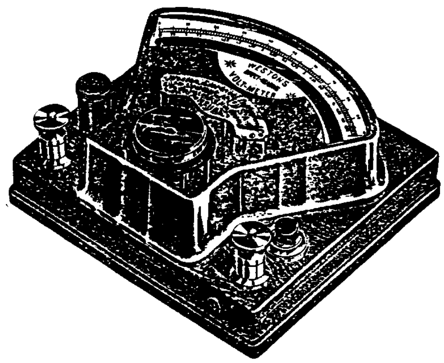
The small, portable ammeters and voltmeters remained one of the Weston Electrical Instrument Corporation's basic products for many years. A few years ago the Science Museum acquired a late example from an Admiralty Research Establishment.[14] The case is plain black plastic instead of mahogany and brass, but the movement is very similar to those made in 1888. The card with the meter shows that it was calibrated in 1951, and that may well be the year of manufacture. No doubt there were many improvements over the years, but the longevity of the basic design is a tribute both to Weston's insight and to his skill in a number of different fields. Edward Weston's meter is an example of fine mechanical and electrical engineering but it also owes much to his chemical knowledge, to his business acumen, and to his tenacity in the law courts and in all aspects of his work.

Discussion

A number of additional points were made in discussion.

Mr. Bamford pointed out that the pivots of a moving-coil meter are among the most highly stressed of all mechanical components. They operate close to the yield point of the metal. This is necessary to minimise friction and so maintain the sensitivity and accuracy of the instrument. Weston must have paid a great deal of attention to the design and construction of the pivots of his meter.

Mr. Clifford said that calibration of meters is still a problem with meters of reasonably high accuracy. Scales are less uniform than theory suggests, and there are still significant variations between different examples of the same instrument. The cause may be variations in the permeability of the iron used to make the pole pieces. One manufacturer has overcome the problem by printing a range of slightly different scales and fitting the one which, on test, best matches the characteristics of a particular instrument.



One of the first Weston voltmeters

Bibliography and References

The source of much of the material used in this paper is *A Measure for Greatness. A short biography of Edward Weston*, written by David O. Woodbury and published by McGraw Hill, New York, 1949. Other sources include the entry for Edward Weston in the *Dictionary of American Biography*, Supplement Two, edited by R.L. Schuyler, New York, 1958, and the obituary in *Engineering*, vol. 142, 1936, p. 276. Other specific references are given below.

The origins of the moving-coil galvanometer and of other instruments mentioned in the paper are described, with references, in *The Development of Instruments to Measure Electric Current* by J.T. Stock and D. Vaughan, published by the Science Museum, London, 1983.

1. United States Patent No. 392386, 6th November 1888. The corresponding British patent is No. 6569 of 1890.
2. Science Museum Inventory No. 1953-121.
3. Science Museum Inventory No. 1909-158.
4. Science Museum Inventory No. 1935-322.
5. See reference 9.
6. *The Telegraphic Journal and Electrical Review*, vol. 24, 1889, pp. 204-206.
7. J.A. Fleming, *A Handbook for the Electrical Laboratory and Testing Room*, The Electrician Printing and Publishing Co. London, 1901.
8. *Elliott Brothers, 101 & 102 St. Martin's Lane, London, W.C., Manufacturers of Electrical, Optical, Engineering and Mathematical Apparatus*, Catalogue No. E.4., 1895. (Copy held by the Department of Physical Sciences, Science Museum, London.)
9. *The Electrical Review*, vol. 30, 1892, pp. 7-8.
10. Science Museum Inventory No. 1980-79.
11. See *The Electrical Review*, vol. 120, 1937, p. 37, and vol. 123, 1938, p. 223.
12. The Weston cell was granted a United States patent on 4th April 1893. The British patent is No. 22482 of 1891.
13. See *Electrician*, vol. 62, 1908-09, p. 104.
14. Science Museum Inventory No. 1982-1485.