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The Random-Access Memory Accounting Machine

II. The Magnetic-Disk, Random-Access Memory*

Abstract: The design features are described of a new large-capacity memory device having random access to information stored magnetically on rotating disks. The mechanical arrangement of an array of 50 disks is shown, and details are given of the pair of magnetic recording heads, which are spaced accurately from the disk surface by air jets. The access mechanism and the timing system for positioning the heads on the disk tracks are described. The total storage capacity of the system is 5,000,000 alphanumeric characters.

The IBM Type 350 magnetic-disk, random-access memory used in the RAMAC® System is a large-capacity storage device with relatively rapid access to any record. The information is stored magnetically on fifty rotating disks. The disks were chosen for the recording medium because they have a good volumetric efficiency for surface storage. In addition, they permit multiple access possibilities to any record. Magnetic recording was chosen because of both its permanence and ease of modification, while it still allows good storage density. Part of the unit is illustrated in Fig. 1.

The disks are mounted to rotate about a vertical axis, with 0.3-inch spacing between disks. This spacing permits magnetic heads to be positioned to any of the 100 concentric tracks which are available on each side of each disk. Each of these tracks contain 500 alphanumeric characters. Thus, the total storage capacity is 5,000,000 characters.

The reading and writing is accomplished with two magnetic recording heads. These heads are mounted in a pair of arms which can be moved vertically to the level of a selected disk, then moved radially to straddle it. The arms are positioned to the selected disk and then moved into the desired track by means of a feedback-control system. A unique arrangement permits one set of magnetic-powder clutches to provide the drive force for both positioning tasks.

The time to position the heads from one track to another depends upon the distance separating the tracks. The average access time, however, is about one-half second. The maximum is three-quarters of a second.

Disk array

The 50 disks, which make up the disk array, are the key to the layout and to the size of the memory device. A vertical shaft was chosen, as this more readily permits multiple-access mechanisms to be used. Theoretically, 20 access mechanisms could be installed. Up to the present time no more than three access mechanisms have been used. Mounting pads are machined on the upper and lower end castings of the array so that the access mechanisms may be bolted in place and removed easily for periodic servicing.

The disk shaft runs at 1200 rpm on precision tapered roller bearings mounted on a heavy, stationary vertical spindle. Since the radial runout limitations are less severe than with a magnetic drum because of the read-write head design, 0.001-inch runout is acceptable. The driving power is supplied by a conventional capacitor-start, induction-run motor. The large inertia of the disks requires a one-and-one-half horsepower motor to accelerate them to running speed in less than a minute, but the running power is less than one horsepower. Voltage variations of $\pm 10\%$ give less than 1% variation in speed.

The iron oxide coated aluminum disks are 24 inches in diameter and 0.1 inch in thickness. The thickness is required to maintain flatness during assembly and dynamic stability in use. The flatness of the disk is indicated by the requirement that there be no more than 0.0015 inch out-of-flatness in any two-inch distance on the surface. However, as much as 0.030-inch runout can be tolerated in total axial runout. The uniformity of the magnetic coating is indicated by the tolerance of $\pm 10\%$ on the 60 mv peak-to-peak signal at the outside track.

The disk-to-disk spacing is established by the disk

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Figure 1
Access mechanism of the IBM Type 350 magnetic-disk, random-access memory.

thickness and the clearance required for the magnetic heads to go between them. For practical reasons the spacing on this machine was set at 0.3 inch between disks 0.1 inch thick. Thus, the over-all height of the 50 disks is 20 inches.

A modified non-return-to-zero type of magnetic recording is used. The density of the recording varies inversely with the radius of the track. The density of the inside track is about 100 bits to the inch, and on the outside track this drops to about 55 bits to the inch. (This ratio of outer-track to inner-track radius was chosen as near to the optimum value of two as was mechanically feasible.) This recording density permits 500 characters, composed of 8 bits each, to be recorded on each track. With 100 tracks on each of the 100 sides, a total of 5,000,000 characters can be stored. An idea of the quantity of the storage can be conveyed by a few comparisons. This amount of storage is about the same as 60,000 80-column punched cards, or 2000 feet of magnetic recording tape recorded at 200 characters to the inch, with no space between records, or 940 single-spaced typewritten pages. It is interesting to see that the same number of tracks and track density on a magnetic drum would require a drum 13 inches in diameter and 42 feet long. Such a drum would have about seven times the physical volume of the disk array.

Magnetic heads

Closely associated with the disks are the magnetic heads used for recording and pickup. Unlike drum heads, these heads must be of a minimum height. Refinements in design and techniques have brought this height down

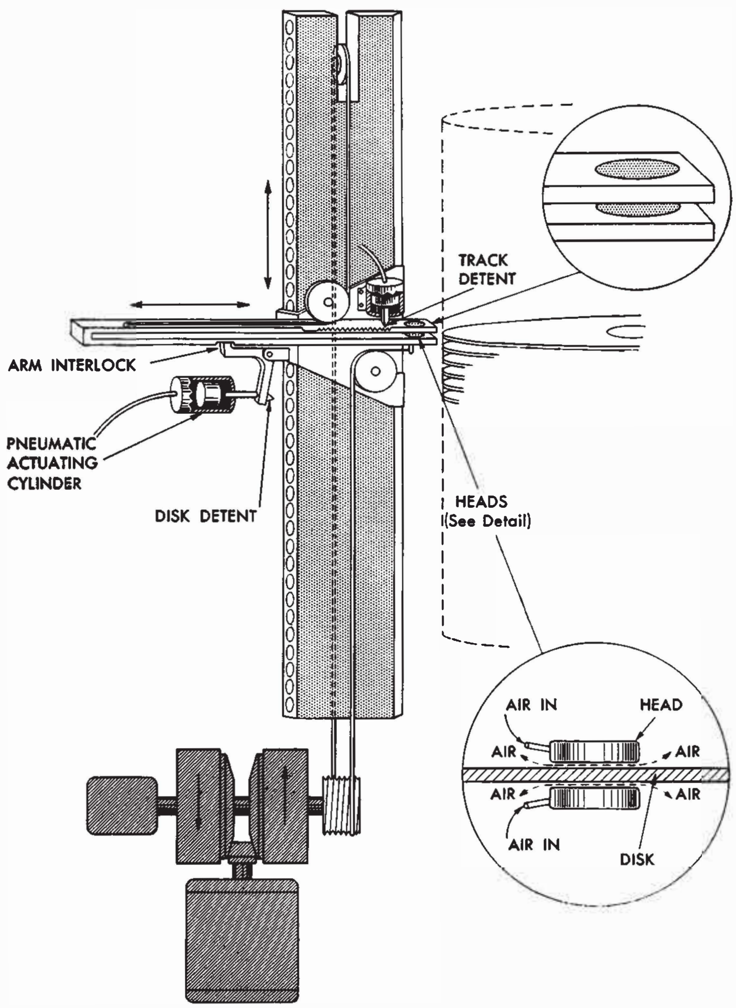

Figure 2

Functional diagram of access mechanism showing general scheme of vertical and horizontal positioning, interlock and actuator group.

to 0.2 inch. Binocular microscopes are used in the manufacture of these assemblies, which are potted in an epoxy resin to give durability and shock resistance.

The magnetic element consists of two distinct magnetic circuits. One circuit with its coil erases only, and the other circuit reads and writes. The erase gap erases a wider track than the following write gap records. This design allows reduced precision in radially positioning the heads, in that there are no magnetically disturbed track edges to contribute noise to the newly recorded track, which might not precisely coincide with the track previously written, perhaps by a different access mechanism.

The spacing of the heads from the disk is maintained by an air bearing obtained from minute air jets in an annular manifold surrounding the magnetic elements. Since the 0.001-inch spacing is held despite the axial runout in the disk, there is never physical contact between the heads and the magnetic coating. The head is horizontally constrained in a gimbal socket in the arm.

The use of compressed air in the magnetic heads and the access positioning detents requires a small compressor. This unit operates constantly, supplying air to a surge tank or by-passing it to the atmosphere, as necessary. Approximately 0.6 cubic feet per minute at a pressure of 50 pounds per square inch is used per access.

The read-and-write amplifier circuitry is quite conventional. The only variation from normal is the inclusion of an automatic gain control in the read amplifier. This feature is included to correct for input variations caused by variations in heads, disks and surface speeds.

Access mechanism

The access mechanism shown on the left in Fig. 1 is used to position the pair of heads to any track on the disk array. The heads face each other in a pair of arms. The arms move inward to straddle a selected disk during reading or writing. The arms, in turn, are held in a carriage for vertical motion to the desired disk.

The arms are guided, for radial motion, in bearings on the carriage. Within these bearings the arms are capable of about six inches of radial motion. The inner five inches position the heads over the disk recording area. When the arms are in their outermost position, the arms are completely outside the disks. The arms are in this position during vertical-drive motion.

The carriage, during vertical motion, slides on a vertical "way," as shown in Fig. 2, a functional schematic. At each of the 50 disk positions a detent hole is provided in the way. A pneumatic-detent piston is energized upon arrival at the desired disk. This detent, by means of a mechanical linkage, controls an interlock which frees the carriage and locks the arms for vertical drive, and frees the arms and locks the carriage for radial drive. The arms are capable of being freed only when the carriage is positioned properly at a disk, and the carriage is capable of being freed only when the arms are completely outside of the disks. Thus, a safe interlock is provided to prevent mechanical damage to the disk array.

The driving force is provided by a pair of magnetic-powder, motor-driven, counter-rotating clutches. These

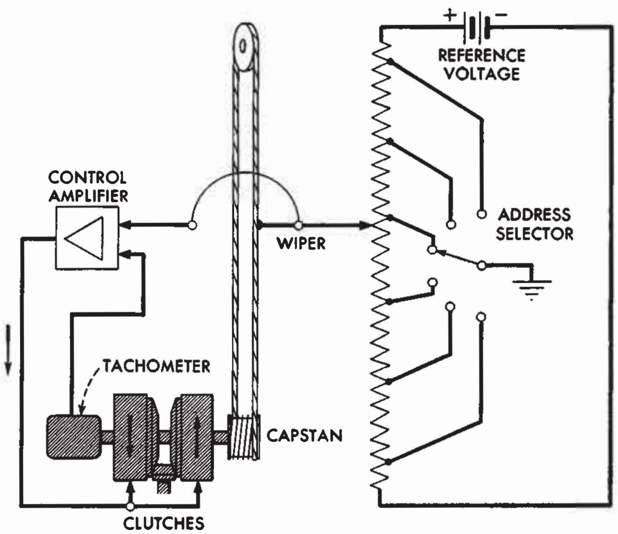

Figure 3
Functional schematic for either horizontal or vertical positioning by access mechanism.

clutches have a common output shaft, on which is located a drive capstan. A small steel cable connects the drive capstan to the arms through a system of three pulleys. When the arms are locked, the carriage is free and the clutch torques result in vertical-drive motion. Similarly, when the carriage is detented, the arms are free and the same clutches control radial motion. In addition to the detent for locking the carriage, a detent is provided to position the arms accurately to the selected track. These detents greatly relieve the positioning requirements of the position-feedback controller.

The clutches are controlled by a null-seeking, feed-back-control system. Position signals for the radial and the vertical drives are obtained from potentiometers on the carriage and on the way, respectively. Figure 3 is a functional schematic which is intended to illustrate either radial or vertical positioning. An electrically-floating voltage supply feeds the potentiometer element. Taps are located uniformly along the potentiometer element. The desired address is established by grounding one of these taps with an address-relay tree. An error voltage is seen by the potentiometer wiper unless the wiper is positioned at the selected tap. Through the control amplifier, the clutches are controlled to position the wiper to make the error voltage zero. The tachometer is used to stabilize the feed-back loop. A d-c control system is used with relatively large voltage on the potentiometer to eliminate any serious drift problem.

A group of relays are used in a logic network to guide the access mechanism in positioning. The logical decisions are based primarily upon the condition of the carriage detent, whether the carriage is at the correct disk and whether the arms are at the correct track.

Self-clocking system

To greatly relieve the accuracy required in positioning the head along the track, a self-clocking system has been incorporated instead of a timing track. The tolerance with this system is such that limited movement of the head along the track can occur while reading or writing. Reading or writing with different access mechanisms is also facilitated by this system.

The clocking system is composed of two timing oscillators. Their operation is such that one oscillator is on while the other is off. In writing, one oscillator runs continuously for timing the entire record. In reading, the oscillators are controlled by the recorded bits. Each bit read switches one oscillator off and the other on, thus resynchronizing on each bit. Since there are at least 2 bits per character, including the space bit, an oscillator never runs more than 7 bits at a time. Thus, the effects of a difference between oscillator frequency and read bit rate are greatly reduced. When an oscillator is turned on, it always comes on with the proper phase. The combined output of the two oscillators feeds the bit ring used to determine bit position within the character.

In a system such as this, the frequency of the oscillators relative to the disk speed is important. With the present arrangement a tolerance of at least one per cent is permissible. This tolerance is easily met with the large inertia of the disk array, the motor voltage-speed characteristics and the oscillator stability.

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