DESIGN FEATURES OF A MAGNETIC DRUM INFORMATION STORAGE SYSTEM

BY

J. L. HILL

Transcript of a paper delivered at the Association for Computing Machinery Conference, March 28 - 29, 1950, Rutgers University

Engineering Research Associates, INC.

ST. PAUL, MINNESOTA ARLINGTON, VIRGINIA

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MR. CHAIRMAN, MEMBERS OF THE CONFERENCE:

An essential element in making computers automatic is an internal memory mechanism. In the various computers which have been constructed or planned, this mechanism has taken various forms such as vacuum tubes, acoustic delay lines, magnetizable media, relays and punched tapes or belts. I am going to restrict my remarks to the memory mechanism known as magnetic drum storage in which the information stored takes the form of magnetized regions on the surface of a continuously rotating cylinder.

The experience of Engineering Research Associates in this form of storing data begins in August 1946, at which time we began a development program by attaching magnetic sound recording tape to the periphery of a small wheel and studying recording and reading techniques. A continuous development program is still in progress directed toward the improvement of this information storage mechanism. It is my privilege to bring you this report on the current status of development which represents the results of three and a half years' evolution. I should like to point out in passing that during this period several special purpose computing machines utilizing this storage system have been constructed and delivered. Each of these machines displays certain improvements over its predecessor which mark the progress of the development program. The features which I am going to discuss today are incorporated into a machine now in its final construction phase and due for delivery mid-summer this year.

The basic principle of the magnetic drum information storage technique is exceedingly simple: a minute area in the magnetizable surface is magnetized to saturation with one polarity to represent a stored binary ''1''. It is magnetized to saturation in the other polarity to denote the absence of a ''1'', or the storage of a binary ''0''. The problem assumes engineering proportions only when it is desired to select quickly and unfailingly certain of these minute areas and deal exclusively with them while at the same time minimizing the physical dimensions of each. By organizing the various functions which must be performed in a particular manner the problem becomes quite manageable. Dr. Arnold Cohen, in his article which appears in the current issue of Mathematical Tables and Other Aids to Computation, (January 1950, Vol. IV, No. 29) has described the organization of the storage system I am discussing. Since it is too early for many to have seen that article, I shall briefly summarize the significant properties.

1. The system operates parallel: All the binary elements of a single item of information are processed simultaneously.

2. The system operates asynchronously: Information to be stored may be impressed on the terminals of the storage system at any time, provided the system is not then executing a previously ordered operation. Or a reference to stored information may be ordered at any time the system is not likewise busy.

3. The system is selectively alterable: No erasing operation is required; the writing of new information obliterates that previously stored.

If we were to examine the surface of a magnetic drum we could expect to find a situation not unlike that diagrammed in Figure 1. The surface is divided into a number of relatively narrow bands which we shall refer to as tracks. Each of these tracks communicates with a magnetic head which is held stationary with respect to the revolving cylinder. Each track is divided along its peripheral dimension into rectangular areas which we term cells. Inside the boundaries of each of these cells a somewhat smaller area is magnetized quite

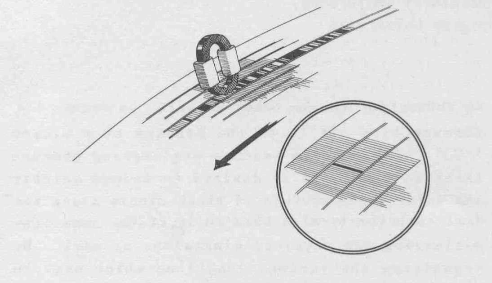

Figure 1. Storage of Binary Digits as Magnetic Marks

arbitrarily in one peripheral direction to represent a stored binary ''1'' and in the opposite direction to represent a binary ''0''. In the diagram the cell polarity is indicated by either a black or white marking.

By causing current to flow in the windings of the associated magnetic head in a particular direction and for a specific time, it is then possible to magnetize a cell to represent either a ''1'' or a ''0''. Cells so magnetized will, when moved rapidly past the same magnetic head, induce voltages in the head windings which have characteristics dependent on whether the cell then under the head contains a ''1'' or ''0''. By designing the external electrical circuits so that the voltage at the terminals of the magnetic head is sampled only when the desired cell is producing that voltage, it becomes possible to read the contents of any desired cell. The reading may be repeated an indefinite number of times without causing any deterioration of the cell's magnetization.

In the development of this storage medium, we have been making significant steps in the direction of decreasing the physical area occupied by the unit cells while at the same time improving our ability to deal with them as isolated individuals. In fact some of our recent improvements in technique have represented gains in both these directions making our present design standards even more conservative than we had intended. Our current design and production standards assign 1/80th of an inch peripherally by 1/16th of an inch axially to each cell. This means that in each square inch of drum surface there are 1280 cells each capable of storing one binary digit.

In order to reach a compromise between all the mechanical and electrical considerations, we have standardized on a peripheral velocity of 1600 inches per second in establishing the angular velocity of these drums. This corresponds to a velocity of about 90 miles per hour between the surface of the drum and the stationary heads, and precludes maintaining physical contact between the two. The distance between the polepieces of the magnetic head and the drum surface has been fixed at 0.002 inches, again a compromise between various mechanical and electrical factors; however this is a dimension not difficult to establish or maintain in the mechanical structures I shall show in later figures. The product of the cell density and the peripheral velocity yields the cell scanning rate, which is 128,000 cells per second. In other words, each magnetic head scans all the cells in its track at a repetition rate of 128 cells per millisecond. This corresponds to a cell period of 7.8 microseconds, during some fraction of which the cell and head are properly positioned either to record new data or to read previously stored information.

Figure 2 shows a block diagram of a complete typical storage system, and I would like briefly to point out the manner of operation. Across the top of the diagram the large rectangle represents the physical drum and indicates subdivisions into functional groups of tracks. Beginning at the left, there are two tracks for timing; one provides a series of timing pulses, and the second embraces the exact number of pulses to be used. The use of the second track eliminates a transient problem at the beginning and end of the wanted group of timing pulses.

The next subdivision contains the angular index tracks. These tracks are permanently recorded and provide at the terminals of their reading amplifiers a set of signals which express the angular position of the drum. These signals occur in a pattern which is unique for each cell period. To express the 2048 angular positions on the system shown here, 11 tracks are required.

The remainder of the drum surface is used for information storage, the capacity of this particular system being 122,880 binary digits. I might add that the physical dimensions of the drum for this

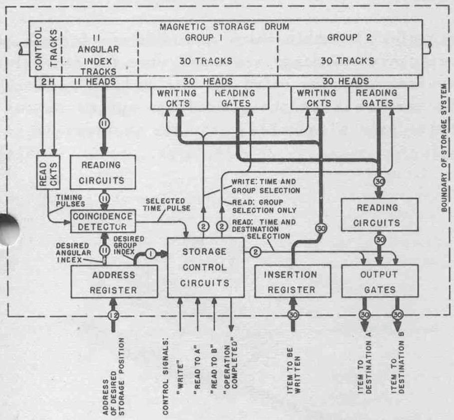

Figure 2. Block Diagram, Magnetic Storage Unit

system are 8-1/2 inches in diameter by 5-1/2 inches in length. The information tracks are divided into two groups of 30 tracks each to illustrate a feature which permits considerable design flexibility. This system stores items of 30 binary digits each and provides space for 4096 each items, half being in each of the two groups of tracks. The selection of the storage position for any of these items will therefore require first the selection of one of the two groups of heads, and then the selection of that angular position of the drum at which the desired 30 cells are in simultaneous communication with the 30 heads.

Although the diagram shows two groups of 30 tracks, systems have been built into some of our machines having as many as eight groups of information tracks. The number of tracks per group is a function of the size of the items to be stored; no limitations need be imposed on this value.

At the lower left, the block labelled "Address Register" receives a parallel voltage pattern from some external source and holds it until the storage reference is completed; this voltage pattern identifies one specific storage position, or address, on the drum. At the same or any subsequent time, one of the three wires which identify the operation is stimulated; for the moment let us presume that it is the wire marked "Write".

The item to be written or stored at the address held in the Address Register must be inserted into the Insertion Register in a manner similar to that by which the address was set up in its register. The output of the Insertion Register communicates with the writing circuits, so that when the writing is performed the operation will reproduce the contents of the 30 flip-flops comprising the Insertion Register in the thirty cells at the desired position on the drum.

The function of the Coincidence Detector is to compare the voltage pattern delivered to it from the Address Register with the continuously changing voltage pattern delivered to it from the reading circuits attached to the angular index tracks. At one angular position of the drum these voltages are identical, and the Coincidence Detector permits the timing pulse marking the center of that cell period to pass through to the block marked "Storage Control Circuits".

When the operation is writing, this "Selected Time Pulse" is routed out of this block to one of the two blocks marked "Writing Circuits", where it causes a writing operation to be performed in all 30 of the cells then adjacent to their respective heads. By writing with all the heads, no specific erasing operation is necessary. The writing operation itself obliterates the previously stored data. At the same time the writing operation occurs, a pulse issues from the wire marked "Operation Completed" to inform the external equipment that the information has been stored; simultaneously the Insertion and Address Registers are cleared.

Now let us presume that the operation is that of reading a previously stored item. One of the two possible destinations has to be selected externally to the storage system. In the case of either, the pulse arriving on one of the "Read" wires causes the "Selected Time Pulse" to pass through to one grid in each of 30 pentode gate tubes. The other grid of these gates is continually receiving the output of the block marked ''Reading Circuits''; this output is a 30-wire voltage pattern from whichever of the two groups of magnetic heads and reading gates has been selected. This selection is made by the same digit of the address which previously selected one of the two groups of writing circuits. Those of the 30 output gates which receive a voltage indicating the presence of a ''1'' in the cell at the desired address then permit the ''Selected Time Pulse'' or ''Sampling Pulse'' to pass through to become the output of the storage system and to actuate the external register connected to that line.

Returning for a moment to the operation of writing, Figure 3 shows one circuit by which it may be accomplished. The ''Selected Time Pulse'' is applied to both thyratrons on their control grid, while the information voltage from the Insertion Register appears on the shields to permit conduction to occur in only one. Whichever thyratron fires discharges the capacitor in its plate circuit through one of the windings of the head. It is the flux produced by this discharge which causes the cell to be magnetized. The two thyratrons produce flux of opposite polarity and therefore denote either a ''1'' or ''0''.

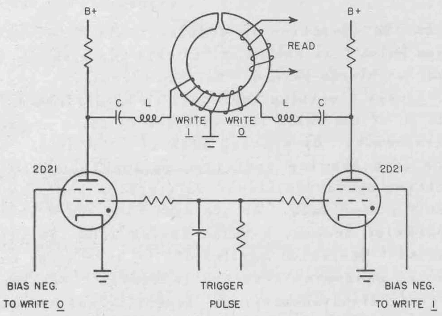

Figure 3. Writing Circuit

Although the magnetic structure of the head appears as a toroid in the previous diagram, the actual head structure in our latest design is shown in Figure 4. This unit has been partly cut away to expose the interior, and has been shown with an ordinary paperclip to permit some size comparison. Within a steel barrel and embedded in a plastic, the magnetic core structure can be seen to be somewhat the same shape as the paper-clip. At the left, this core extends out of the plastic to expose the magnetic gap which causes the flux to fringe out sufficiently to intersect the drum surface.

On a plastic bobbin which surrounds one leg of the core, three windings are wound, two for the writing function, the third for the reading function. The terminals of these windings appear as connector pins also molded into the plastic and ar-

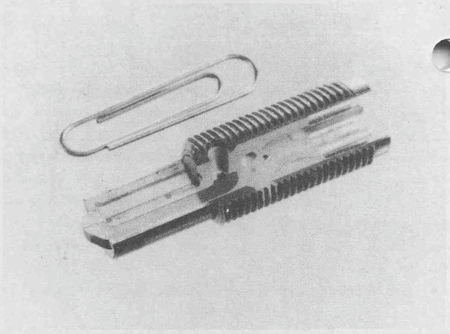

Figure 4. Latest Head Design

ranged to accept a conventional electrical connector. The hole through the core at the end opposite the gap is for a positioning fixture and functions only during the plastic molding operation. The external threads on the steel barrel engage with a positioning device to hold the head in relation to the drum surface; they also receive the screw ring of the electrical connector.

Now I should like to present a series of oscilloscope patterns which show quite clearly the mechanism of reading the information on the magnetic drum which will demonstrate the sound basis of this system of information storage. The first of these (Figure 5) shows the signal at the input to the first vacuum tube in the reading system which is caused by having written a single ''1'' in a continuous and homogeneous magnetizable surface. This surface has initially been saturated to the ''0'' polarity by the passage of a direct current through one of the windings of the head for a period of at least one drum revolution.

I call your particular attention to the vertical lines showing the sampling points of the cell in which the ''1'' appears and of the two immediately succeeding. These lines will be a part of each of the following pictures, and will serve to establish your time reference, since the cell now shown is the leftmost of three which will continue to occupy similar positions in the succeeding pictures.

The voltage wave shown in this figure is that induced in the reading winding by the flux variation

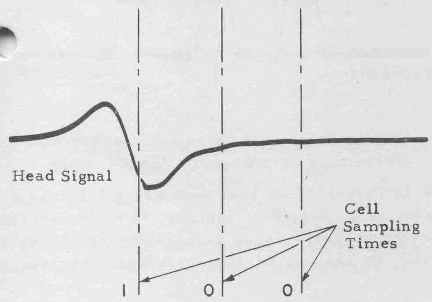

Figure 5. Signal at Reading Winding Terminals from Surface Previously Saturated to ''Zero'' State

occurring in the magnetic head when the poles of the magnetized cell pass by its air gap. It has an amplitude of four millivolts, peak to peak, at the low impedance terminals of the head winding and is stepped up in a thirty-to-one ratio transformer to present 120 millivolts to the grid of the first tube. Incidentally, this transformer and tube arrangement has been tested at the end of a fifty-foot wire connecting the low impedance windings of the transformer and head without appreciable signal attenuation or stray pickup. The wire in this case was unshielded two-conductor telephone wire.

Figure 6 shows the output from the reading circuits with the previous signal as input. You will note that the wave has been differentiated and shaped to a more or less rectangular form, and has a duration at maximum amplitude of approximately one half the cell period. The amplitude at this point in the circuit is roughly 50 volts.

Now I should like to call your attention to the short break in the trace in the approximate center of the first cell. This represents the location and duration of the sample taken in reading out this cell content. The relative durations of the top of the wave and of the sampling pulse, which is roughly 8 to 10 per cent of the rectangular wave, indicate the large margin of safety in the sampling technique. The visible portion of the notch in the voltage wave is due to circuit recovery after the sampling.

In Figures 7 through 11 we will follow the history of these three cells as each of them passes through the magnetization cycle caused by writing ''1's'' and ''0's'' alternately in each cell. Figure 7 shows the head voltage in the upper trace and the shaped voltage in the lower trace when a ''1'' is written in the second cell following the original writing. This time the sampling mark is present in the third cell.

Although the character of this head signal waveform would seem to prevent the further crowding of signals without loss of their identities as individuals, Figure 8 demonstrates how we are able to write and sample a ''1'' written between the

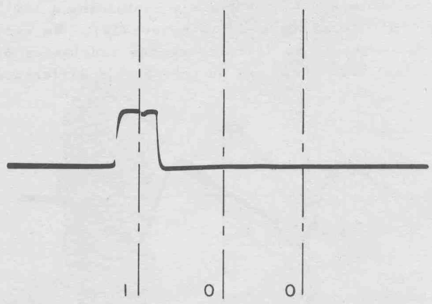

Figure 6. Shaped Signal Voltage Supplied to Sampling Gates with Sample Time Indicated

two previous ones. The patterns in this picture show the current standard cell density of 80 per inch, therefore the cell-to-cell distances represent 7.8 microseconds in time, or 0.0125 inches around the periphery of the drum.

In Figure 9 we have replaced the ''1'' in the center cell with a ''0''. Now you will note the sampling occurs when there is no voltage present, and the break appears on the baseline. Also note that there is a short voltage spike in the waveform which appears to be between the altered cell and the one following, but that it does not affect the validity of the sample.

In Figure 10 we have altered all three cells to contain ''0's''; instead of the smooth uninterrupted baseline you would expect, it would appear that there are ''1's'' between each of the cells and a spike after the third. This is caused by the circuitry which forms the rectangular pulses in the presence of ''1's'' attempting to do the same with the ripple voltage which remains after the altering operation. Since these voltage pulses occur entirely outside the range of sampling time, they are as ineffective in causing misinterpretation of the actual cell content as though they were not there!

Early in our experience we were quite concerned by this apparent inability to obliterate the effects of previous writing, and feared that it might in some way be cumulative. We therefore made a test on 1536 cells which subjected each to 50,000 cycles of alternately containing a ''1'' and ''0'' (that is 100,000 reversals). We were quite gratified to discover at the conclusion of this test that there was no perceptible difference

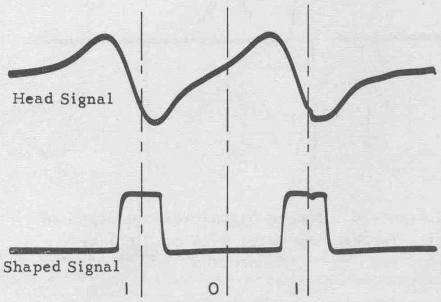

Figure 7. Signal Voltages from Surface Previously Saturated to ''Zero'' State

beyond that occurring in the first cycle which you have just seen. As you can see the total time during which a valid sample may be taken and still yield a ''0'' is roughly equal to the time duration of the ''1'' in the original waveform.

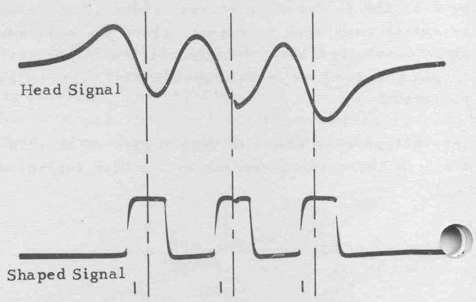

Figure 8. Signal Voltages from Surface Previously Saturated to ''Zero'' State

Now in Figure 11 we have restored a ''1'' in the center cell, and it is apparent that the sampling for its presence is as trustworthy as the original. By the use of this sampling technique we

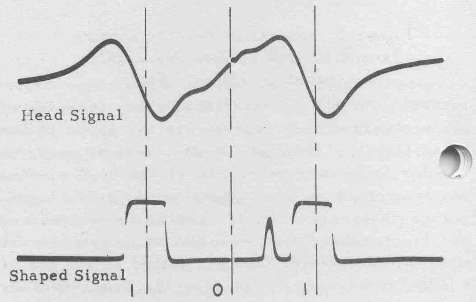

Figure 9. Signal Voltages from Alteration of Center Cell

have eliminated any signal-to-noise problem from the system.

Now let us progress quickly through some pictures of the hardware by which these storage systems are physically accomplished. Figure 12 shows an early model before we had developed our present head design and had satisfactorily tested our current cell density of 80 per inch. Figure 13 shows a laboratory unit, the one in fact on which the experiments were run which yielded the results

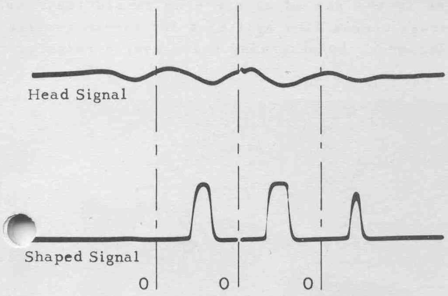

Figure 10. Signal Voltages from Alteration of All Cells

I have reported.

Figure 14 shows our present magnetic head and mounting system. An important feature of this

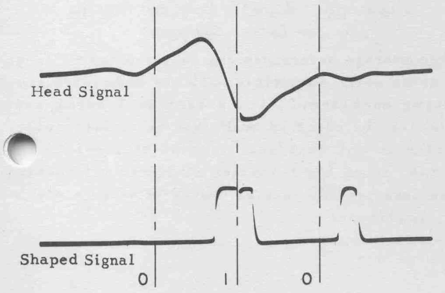

Figure 11. Signal Voltages from Restoration of "1" in Altered Cell

design is that an extremely fine vernier screw adjustment combined with a very rigid mounting is achieved without going to a thread pitch finer than 32 per inch or a fit more precise than commercial Class 2. The piece at the extreme left in this picture is an internally threaded insert which is pressed into holes in the cylindrical drum housing. This type of head mounting is extremely rigid and permits the maintenance of the head-to-drum spacing for indefinite periods without intervening mechanical adjustment. Another important design feature of this structure is that the heads are interchangeable. For example, material may be written on the drum surface by one head, which can then be removed and replaced by any spare head with no loss of performance. The replacement operation involves a simple adjustment of the radial clearance. Heads of this type have seen laboratory service for the past year and some units using this design feature have been in the hands of our customers for six months.

Figure 15 shows the drum and housing for our latest equipment. This unit stores 400,000 binary digits and has 215 tracks. It has an overall length of 33 inches, and is 12 inches wide.

Our experience in the daily operation of equipment utilizing magnetic drum storage systems of this type seems to indicate that this system is well suited to the function of the internal memory for the kind of computing machinery this conference has been considering. Although further develop-

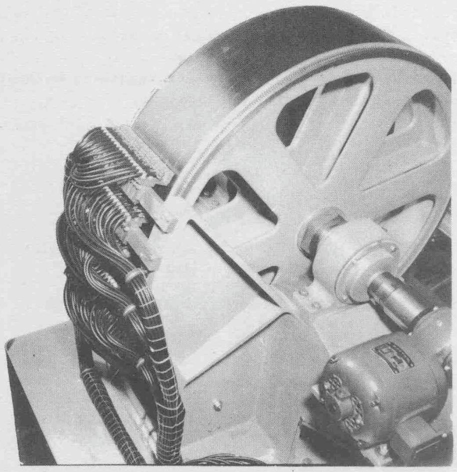

Figure 12. Early Model Magnetic Storage Drum

ment in the laboratories is already indicating advances in the art, we consider that the features of the system just described represent interim standards sufficiently high to permit their incor-

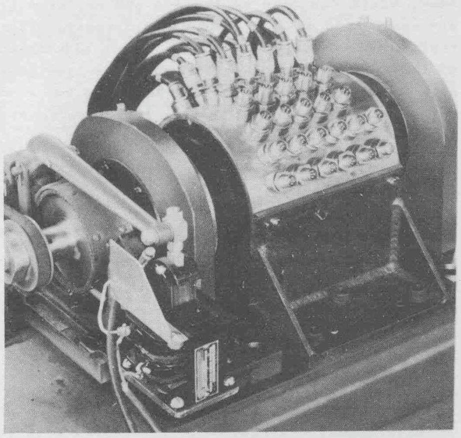

Figure 13. Experimental Magnetic Storage Drum

poration into today's computing machinery without any apologies for its performance.

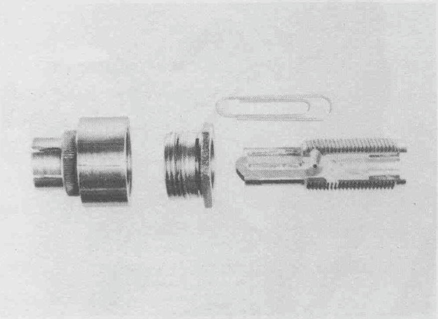

Figure 14. Present Magnetic Head and Mounting System

As a storage system with fairly large capacities,- 250,000 to 500,000 binary digits are reasonable figures,-it appears to combine the factors of storage capacity, bulk of equipment, and reference access time in what we believe to be quite satisfactory relationships. Although maximum access time is the period of one drum revolution, and average access time half that for random storage references, by observing a few simple rules or-

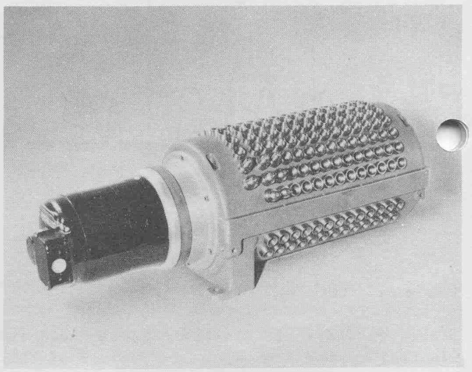

Figure 15. Magnetic Drum and Housing for Latest Equipment

dered storage references can be scheduled to occur at rates quite compatible with the associated computing machinery. Its property of being non-volatile, by which we mean that the stored information is not lost upon removal of power to system, makes the retention of stored information over long periods such as months or years a pleasant reality.