PROLOGUE: March 12, 2010. Over the last 4.5 years I've received a variety of artifacts, documents, and papers from colleagues. Most were immediately given to the Legacy Committee archivists for storage in a designated LMCO area. Some, which I wanted to read, were filed at home for deferred processing. Last week, I opened my deferred processing file to look for a 'Goldberg' picture. After finding it, I decided to scan, do an Optical Character Recognition, and generate this paper for the web site April 2010 'Article for the Month'. The original paper document came from Don Weidenbach. At the bottom of page 209 is printed: "Reprinted from the *Proceedings of the National Electronics Conference* Vol. 3, 1947." The pages were numbered 201 through 209. The most surprising part is that there was a sheet with page '*#30'* on it stapled to the back of the document. That scanned sheet is followed by my observations about the document and that sheet. This 're-print' has been re-formatted for web use.

Editor: Lowell A. Benson; U of MN - BEE, 1966
UNIVAC to UNISYS employee, 1960=>1994

STORAGE OF NUMBERS ON MAGNETIC TAPE [PAGE 201]

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Abstract.-This paper describes a memory system for storing digital information on magnetic tapes. The tapes are bonded to the surface of an aluminum drum. Associated with each tape are three heads for reading, writing, and erasing magnetized spots on the tapes. This equipment allows numbers to be stored indefinitely, to be inspected as often as required, and to be removed when no longer needed. The system will store 200,000 magnetized spots on a drum 34 inches in diameter and 10 inches wide.

I INTRODUCTION

AN essential part of many automatic digital computers is a memory device, in which numbers may be stored for any desired length of time, and withdrawn from storage as required. The specifications for a memory device are dependent upon the techniques used in the remainder of the computer, and upon the type of problems which the computer is designed to solve. In general the memory will store one or more of the following types of information: (1) the original data of the problem, which may consist of measured values of physical quantities, known physical constants, or previously calculated tables; (2) the instructions for the operation of the computer, which may be changed automatically during the process of computation; or (3) the intermediate or final answers of the computation. Among the devices which have been used for number storage are mechanical counters, relays, conventional electronic tubes, punched tapes, punched cards, and acoustic delay lines. Currently under development are several types of electrostatic storage tubes and a number of methods for using magnetic wires and magnetic tubes. Each of these techniques has characteristics which are desirable for particular applications. However, the requirements for some applications are not readily met by any of the techniques now available, and new methods must be devised. For example, there are several problems of a statistical nature which require a memory having a capacity of several thousand numbers, and into which numbers can be readily inserted, deleted, or changed in value. For such an application the use of relays, mechanical counters, or vacuum tubes appears impractical because of the cost. Punched tape or punched cards could provide the needed storage capacity, but do not permit the values of the stored numbers to be changed easily. The features of magnetic recording offer attractive possibilities for problems of this type.

In the laboratories of Engineering Research Associates, a program has been initiated to develop a number storage system using magnetic tapes. This paper will describe some of the progress and results obtained in the early stages of this program.

II. PRELIMINARY CONSIDERTIONS [PAGE 202]

The most familiar application of magnetic recording is its use for recording of sound, where it is desired to record and reproduce faithfully the complex wave shapes present in speech and music. The requirements for this application, such as linearity, range, frequency response, and freedom from noise are well known. The requirements for a number-storage system are somewhat different. In digital computers numbers are usually represented by coded groups of electric pulses. Therefore, a number storage system must record and reproduce electric pulses. It is not necessary that the output voltage be a faithful replica of the input voltage. It is sufficient that the presence or absence of a recorded pulse be easily recognized. Therefore, the characteristics of linearity and flat frequency response are relatively unimportant.

A common technique for using magnetic tape for sound recording is to run tape from one reel to another at the slowest rate of speed possible, allowing it to slide past the poles of the recording or reproducing head. This method has several disadvantages when applied to a number storage system. It will become apparent later, that for use in a number storage system it is desirable to move the tape at a relatively high rate of speed, in some cases at the highest rate of speed obtainable. It is also desirable to run a number of tapes in parallel. These requirements cannot be easily provided by the mechanical techniques employed in sound recording, for the wear on the heads and tapes would be excessive, increasing the possibility of tape breakage and requiring frequent cleaning or replacement of the heads. Synchronizing the operation of a number of parallel tapes on reels presents an extremely difficult problem.

These objections can be avoided by bonding the tapes to the surface of a drum which can be rotated past the stationary heads, and by placing the heads a slight distance away from the tape surfaces. There can be no wear on the heads or the tapes, there is no danger of breaking the tapes, and mechanical synchronism for a number of tapes is obtained automatically. The drum can be driven by one motor, and no reversing mechanism, tape guides, or elaborate speed control is necessary.

Experiments using magnetic tapes bonded to a 5-inch wheel indicated that about 50 pulses per inch could be recorded and reproduced at a rate of 20,000 pulses per second, using commercially available tapes and heads, and separating the heads from the tapes by 0.002 inch. In these tests ring-shaped heads were used. These heads had two air gaps, one of which was adjacent to the tape, the other was diametrically opposite. The heads were oriented to produce longitudinal magnetization in the tape, by means of the fringing flux from the air gap. Before any recording was done for a test the tape was "erased", i.e., magnetized in one direction by energizing the coil of a head with direct current, and rotating the wheel. This procedure removed the effects of any signals previously recorded, and left the tape in a uniformly magnetized condition. Then, with the wheel rotating to give a surface speed of 400 inches per second, a series of electric pulses was recorded at a rate of 20,000 pulses per second. These pulses were applied so that they produced magnetization of the opposite polarity to the initial magnetization of the tape. The heads used for reading, writing, and erasing were identical, each having coils of 800 turns and working air gaps of 0.003 inch. The erasing current was 100 ma, the writing current had a peak value of 50 ma, and the reading voltage a peak value of 35 mv.

The characteristics of the heads are listed in Table 1. The core and coil assembly is shown in Fig. 1 and the head and mounting bracket assembly is shown in Fig. 2.

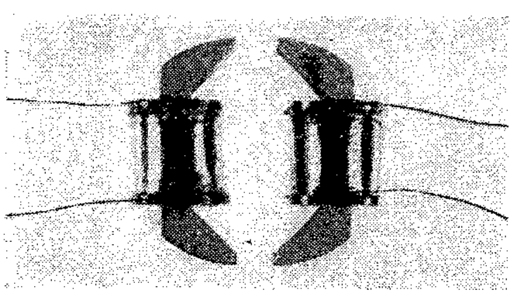


Fig. 1 – Core and coils for magnetic head.

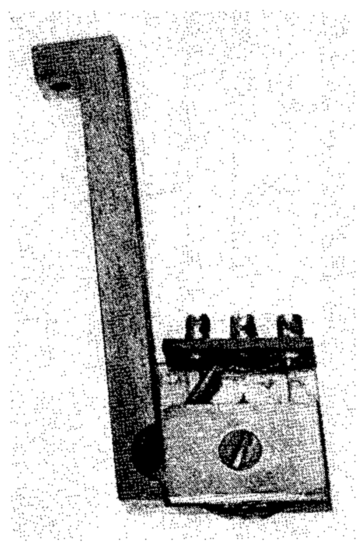


Fig. 2. Magnetic head and mounting bracket.

When the signals obtained from the reading head were viewed on an oscilloscope it could be seen that they were sufficiently well resolved to actuate pulse-shaping circuits. From the results of this preliminary test it was decided to continue the investigation on a larger scale.

TABLE I

CHARACTERISTICS OF MAGNETIC HEADS

Lamination thickness	0.014
Material	4-79 molybdenum permalley
Core thickness	1/8 inch
Wire	No. 36 Formex
Total turns	800
D-c resistance	24 ohms
Inductance at 1,000 cps	20 millihenries
Q at 1,000 cps	4
Front air gap	0.003 inch
Back air gap	0.006 inch
Writing current	50 ma
Reading voltage	35 mv
Erasing current	100 ma
Space between head and tape	0.002 inch

NOTE: The cores and bobbins were obtained from the Brush Development Co., and are the same as those used on their BK-919 head.

The tapes were Minnesota Mining and Manufacturing Co. Type SLlO012.

III. TESTS ON A LARGE DRUM

To test the feasibility of a system capable of storing a larger amount of information, a cast aluminum drum 34 inches in diameter and 10 ¼ inches wide was made. This drum was carefully heat-treated to minimize any tendency toward dimensional changes, and final machining was done With the drum on its own bearings and supported by the frame in which it was to be used. The initial eccentricity of the drum was 0.0007 inch. For four months this dimension did not change. After six months it has grown to 0.0009 inch. A sketch of the drum is shown in Fig. 3.

The drum is large enough to accommodate 40 magnetic tapes, each Y4 inch wide and 106.8 inches long. Let us define a "magnetic mark" as the impression made upon the tape when a single pulse is recorded, and a "cell" as the area of the tape required for a single magnetic mark. The results obtained with the small wheel indicated that 50 cells per inch could be used on a single tape. Therefore, 5340 cells can be assigned to each tape on the large drum, or a total of 213,600 cells for the entire drum.

Associated with each tape are three electromagnets, or heads, placed close together along the tape. When the drum is rotated the cells pass under three heads in succession. The first is a reading head, which examines the cells and produces an electric pulse for each cell containing a magnetic mark. The second is an erasing head which is energized by a direct current removing all magnetic marks in the cells which pass by. The third is a writing head which can insert magnetic marks in the cells if it is energized by a pulse of current at the proper instant. A newly written magnetic mark moves around with the surface of the drum and passes under the reading head about ¼ second after it was written. Between the writing head and the reading head there are always 5040 cells. Pictures of the assembled drum are shown in Figs. 4 and 5. In these/pictures there are only four tapes on the drum, two of these being placed side by side.

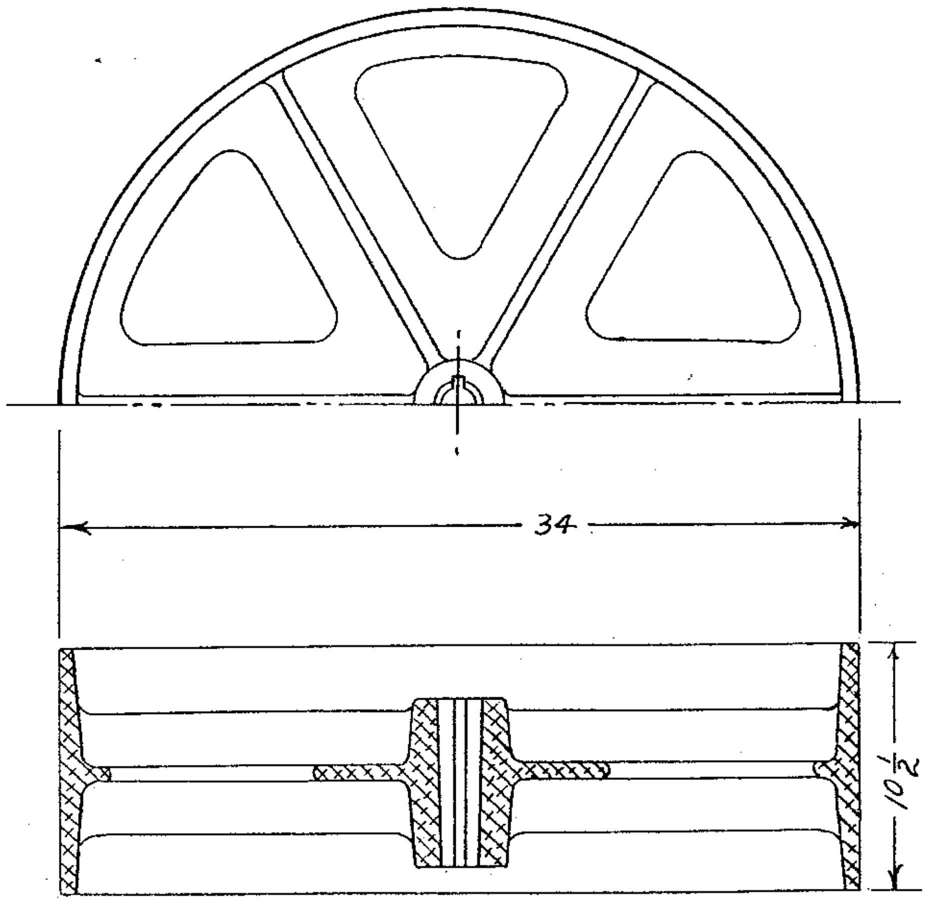


FIG. 3—Sketch of drum.

By connecting an amplifier between the reading head and the writing head, a magnetic mark can be automatically regenerated. As it passes under the reading head, a new mark will be written a few inches further along the tape by the writing head. Since the tape is always erased after it passes the reading head, the newly written mark is placed on a section of tape prepared to accept it.

It will be noticed that each time a mark is regenerated it is moved to a new physical position on the drum surface, that is, it is moved forward from its previous position by a distance equal to the space between the reading head and the writing head. A difference in this space for two tapes will cause a corresponding difference in the physical shift of the magnetic marks upon the drum surface which will be cumulative for successive cycles of operation.

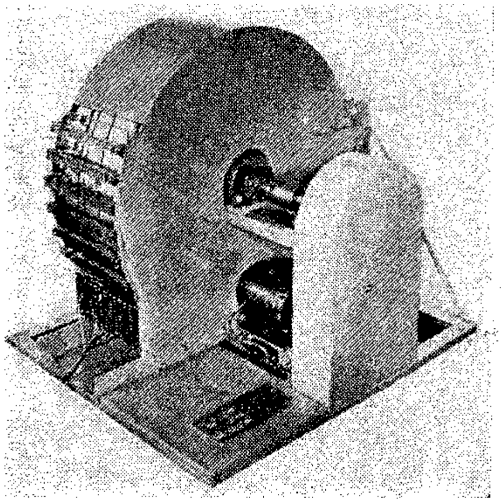


Fig. 4 – View of drum assembly showing head supports.

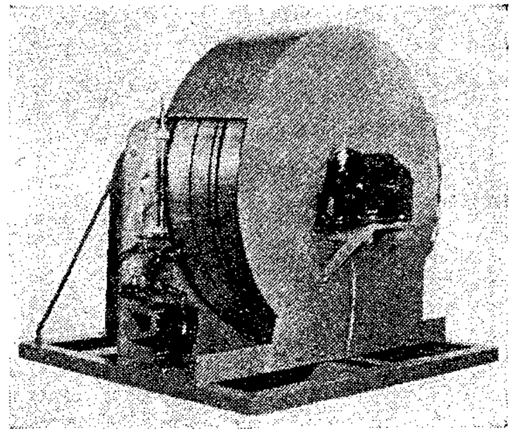


Fig. 5 –Drum assembly View showing intermittent advancing mechanism.

To insure synchronism of the signals from various tapes, timing signals are recorded on one tape, and these timing signals are used to operate gates in the circuits of all the amplifiers. Thus all signals which are read at approximately the same time are written at exactly the same time and the cumulative shift of the marks is prevented. A block diagram of the reading-writing circuit and the timing circuit is shown in Fig. 6.

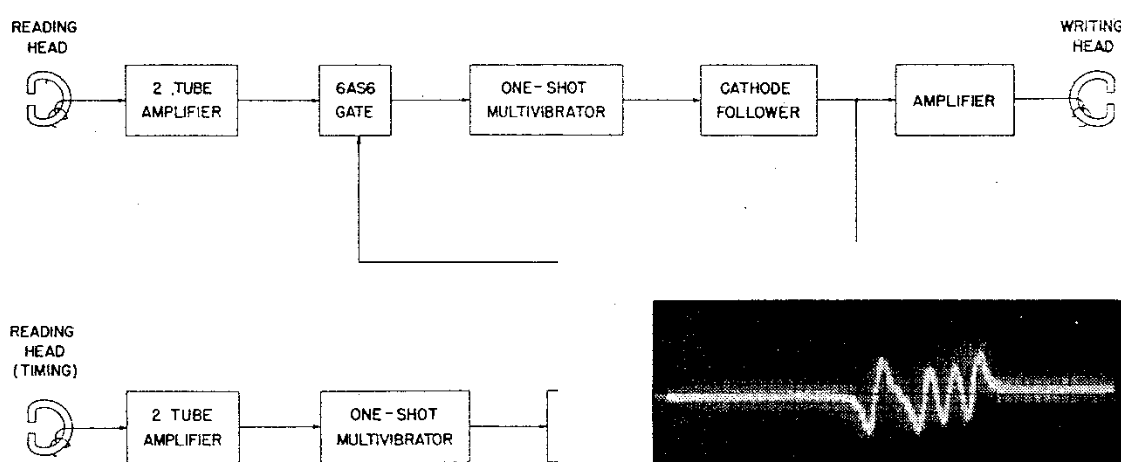
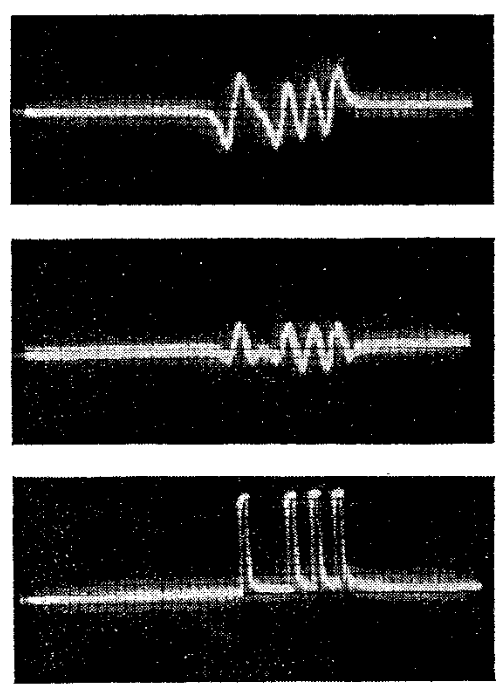


FIG. 6—Block diagram of r



In Fig. 7 are shown three oscillograms which illustrate the operation of the circuit for a duration of time sufficient for five cells to pass under the reading head. Magnetic marks were present in the first, third, fourth, and fifth cells, but there was no mark in the second cell. The upper oscillogram (a) shows the voltage at the coil of the reading head, the center oscillogram (b) shows how the signal is modified by a *RC* coupling circuit having small time constant, and the lower oscillogram (c) shows the signal at the output of the amplifier.

The signal-to-noise ratio is 10 or better at the coil of the reading head. The predominant frequency of the noise is much lower than the pulse repetition rate, possibly about 500 cps. The small time constant coupling circuit discriminates against the noise more than the signal, so that the signal-to-noise ratio at the grid of the first amplifier tube is much higher than 10.

Fig. 7. Oscillograms of voltage at the reading head, voltage at the grid of the first amplifier tube, and output

The initial recording of signals on the drum is accomplished by preparing punched tapes having the desired patterns of marks and spaces, and using a tape reader to transfer the information to the drum. This operation is facilitated by the use of a gear, having 534 teeth, attached to the same shaft as the drum. This gear can be engaged by worm to which is attached a 10-tooth ratchet. When the ratchet is advanced by one tooth the drum rotates 1/5340 of a revolution, or approximately 0.020 inch at the periphery. By advancing the ratchet on signals from the tape reader, the .drum can be moved intermittently, in synchronism with the movement of the tape, at a rate of about 8 steps per second. Holes in the tape are recorded as magnetic marks on the drum.

After the desired information has been recorded on the drum, the worm is disengaged and the drum rotated at 225 rpm. Signals can then be repeatedly read, erased, and rewritten on the same track at a rate of 20,000 pulses per second, as described above. However, during the time that the drum is gaining speed the erasing and writing circuits must not be allowed to operate. A single mark is placed on one of the tracks to indicate the end of the recorded information. When the drum has reached full speed, a switch is operated manually which starts the operation of a control circuit. This circuit detects the passage of the single mark, and starts the operation of the erasing head and the writing circuit at a time when no recorded information is passing under the reading heads. A strip across the drum comprising 300 consecutive blank cells per tape must be reserved for this purpose.

Two test runs have been made in which continuous erasing and rewriting was done on one tape for 15 hours without a failure. During this time the drum made 200,000 revolutions, so that each cell passed under the heads 200,000 times. The total number of cells passing the heads was 10^9. The pattern recorded on the tape was 1 mark, 1 space, 3 marks, 15 spaces. This was repeated all around the tape.

This drum has been in constant use for 4 months, serving as a laboratory instrument. It has been valuable as a generator of various trains of pulses for testing purposes. During this time there have been no failures attributable to the system.

IV CONCLUSIONS [PAGE 208]

The apparatus described would not be sufficient for a computer memory system except possibly for some very special cases. In general, additional circuits would be necessary. A counter would be needed to count the marks on the timing track, and thereby indicate at every instant what cells were under the reading heads. Associated with this counter would be a coincidence circuit to indicate when the counter had reached a position specified by signals from the control system of the computer. A signal from the coincidence circuit would operate gates in the reading-writing amplifiers to cause signals to be taken out of the storage system, or to be inserted into it.

The read-erase-write system has a fundamental weakness in that a momentary fault in the reading-writing amplifier can allow all the marks in the associated track to be erased, because they are always erased after they have been read, and are ordinarily rewritten in a new position. If the writing operation is interrupted, the marks will not be regenerated and will be lost. The results of the tests made with this system indicate that this situation will occur very frequently. However, an additional factor of safety can be obtained by eliminating the erasing operation. Tests have shown that by applying pulses of the proper polarity to the writing head, the effect of a previous mark can be made negligible. Therefore, instead of a continuous erasing process, marks may be selectively erased. The use of this technique would permit a mark to remain in the same cell for an indefinite length of time unless a specific command was received to cancel it.

It is beyond the scope of this paper to make a comparative analysis of the two erasing methods. The continuous-erase system was selected for investigation because it provided a means of making a large number of tests with a minimum of apparatus.

Two important characteristics of a computer memory are the storage capacity and the access time. The storage capacity is the amount of information which may be stored, and the access time is the lapse of time required to insert or withdraw a number in a particular cell.

The factors affecting access time can be expressed in a simple equation:

$$C = H\,T\,R$$

where

C = total number of cells
H = total number of heads
T = maximum access time in seconds
R = scanning rate in pulses per second

The drum described above has a capacity of 200,000 marks, and an access time of ¼ second. There are three possibilities for designing a system having improved access time: (1) by using more cells per inch, (2) by increasing the tape speed, and (3) by using shorter tapes or more heads per tape, thus decreasing the number of cells to be examined by each head. The maximum number of cells per inch which can be used depends upon the spacing between the heads and the tapes, the width of the front air gap in the head, and the resolving power of the pulse shaping circuits. The maximum tape speed will be limited by either the mechanical limits of moving the tape, or by the response of the heads to high frequencies. The recent development of pulse transformers for pulses of very short duration make it appear that heads for high frequencies can probably be made to operate successfully. The extent to which the number of cells per head can be reduced depends upon the required capacity of the memory and upon the number of amplifier tubes which can be justified.

V. ACKNOWLEDGEMENT [page 209]

The writer wishes to acknowledge the contributions made by J. L. Hill, S. M. Rubens, and R. L. Perkins to the technical part of this work. He is indebted to W. F. Winget for assisting with the manuscript.

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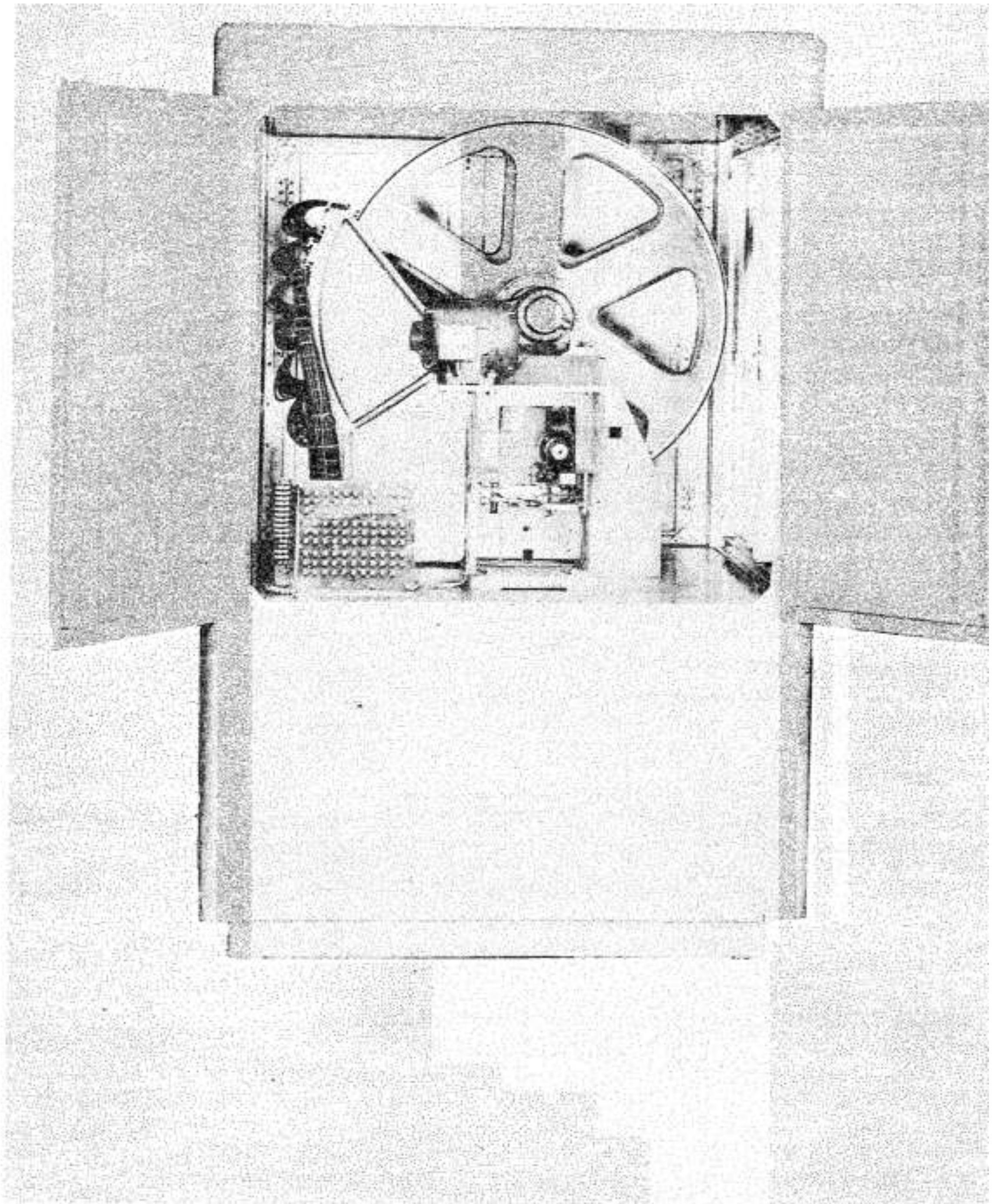
Vol. 3, 1947.

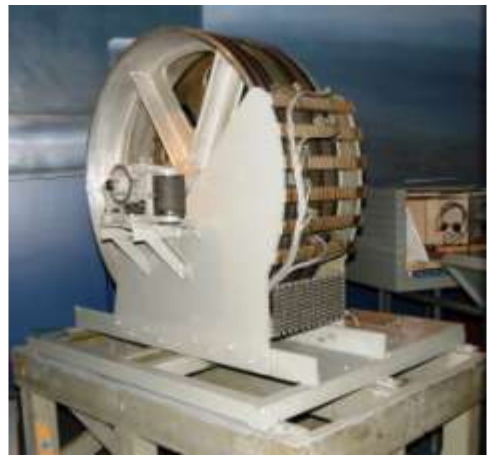


Goldberg Computer *Memory*
Magnetic Drum

30

Observations by the Editor:

1. Somewhere out there is a document that has 29 pages in front of a page 30 figure labeled Goldberg Computer.
2. Mr. Coombs uses the word 'computer' in his introduction then twice in his conclusion – leading me to believe that he knew where this drum technology was headed.



3. Figure 4 and 5 closely resemble the Drum presently at the Minnesota Historical Society, although the MHS doesn't have the shrouds over the 'spinning' wheel.
4. The Figure 3 physical design sketch looks like the 'Goldberg Computer' drum picture.
5. The original paper appeared in a 1947 Vol. 3 issue – Assuming that volume 3 was the third quarter and that the drum had been running for four months when the article was drafted means that the initial operation had to have been either early 1947 or late 1946.
6. Page 95 of Capt. David Boslaugh's book "*When Computer's went to Sea*" states that John Coombs presented a paper on magnetic drum storage techniques at the November 1947 National Electronics Conference. Obviously it was this paper. The same page states that the Goldberg drum was a 24" size.
7. There is another 'early' computer identified on page 95 of Capt. Boslaugh's book which preceded ATLAS –

   "By early 1949 Atlas design and fabrication was well enough along, especially its magnetic drum memory that it appeared feasible for CSAW to steal a march in time. During a 4-month period the CSAW engineering staff built 6 bit electromechanical relay versions of the Atlas arithmetic, control, and input/output units, then integrated these components with an Atlas magnetic drum memory to test the logic design and begin training programmers. [257, p.490]. CSAW engineers used the relay-based computer, which they named ABEL, to verify Atlas logic design, after…".

   To me, this reads as if there was a 6-bit stored program computer operating in mid-1949, before BINAC (9/49) and SEAC (5/50) and maybe before EDSAC (5/49)! The '[257, p.490]' is a book by Tomash.
8. Comments from others?

LABenson; BEE, 1966 – U of Minnesota