Memorandum M-101

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From: E. S. Rich

Subject: Notes on Visit to Moore School, University of Pennsylvania on September 3, 1947

Date: September 9, 1947

1. Purpose of Visit

The purpose of the visit to the Moore School was to discuss the use of magnetic recording as a storage medium in electronic computers. The discussion on this subject took place with Dr. Chuan Chu and Mr. Sharpless. Mr. Joseph Chedaker also discussed some of his work on mercury delay lines used for high speed storage.

2. Magnetic Recording

a. Results of Research at the Moore School. Up to the present time, the research program on magnetic recording at the Moore School has been directed toward development of a satisfactory recording method for use with the EDVAC, so the results achieved represent a complete working system rather than the ultimate in the design of such equipment.

In the EDVAC, magnetic recording media are to be used in the input and output devices. The principle features of the magnetic recording system in these devices are as follows:

Recording Medium - Plated wire manufactured by the Brush Development Company.

Drive - Capstan drive coupled to an induction motor by a clutch system. Simple servos will be used to turn the feeding and take-up reels and maintain the proper amount of tension in the wire.

Heads - A single head design is used for the three functions of erasing, recording and playback. A single ring-shaped lamination of Mo-Permalloy has been selected as the best type of core for these heads.

Recorded Signals - Pulses are recorded at the rate of 2000 pps with a spacing on the wire of 40 pulses per inch. Positive and negative pulses are used to represent the two binary digits. A marker pulse of the order of a half-inch in length is recorded at the end of each word.

Wire Speed - A wire speed of 50 inches/sec is to be used in all operations in both the input and the output devices exept when reading information out into the printer. For this operation a speed sufficiently low so as to match that of the printer will be used.

The main considerations in the selection of the recording medium were the computer requirements, the recording performance of the magnetic material, and the availability of this material. Since information is to be fed into and received from the computer in serial fashion, a single channel recording such as may be obtained on a wire is sufficient. The performances of various magnetic materials were indicated by the results of tests conducted by Dr. Chu on several recording media. These results are shown in the attached table. Although the Brush Plated Wire does not give the highest resolution of pulsed signals, it was selected because it gives a relatively high output level, has very uniform magnetic properties, and is commercially available at low cost. Spools containing about 2 miles of wire are to be used.

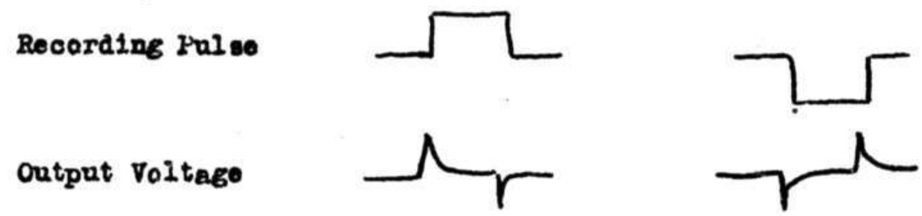
A clutch system to control the drive capstan is to be used for rapid starting and stopping of the wire. The clutch performance is such that the wire can be stopped and then brought up to speed again within the length of the recorded marker pulse.

A single head design for erasing, recording, and playback was decided upon so that recordings may be made for either direction of wire motion. A complete system will contain two such heads, one for erasing and the other for recording or playback. To reverse the recording direction, it is necessary merely to interchange the function of the respective heads by electrical switching.

The choice of 40 pulses per inch as the pulse spacing on the wire rather than a greater number which the table shows is possible was dictated by the necessity for reading into the printer at low speeds. The longer pulse length allows a higher level signal to be recorded and hence gives a higher output in the playback process.

A marker pulse at the end of each word is to be used so that the position of recorded information with respect to the playback head is known at all times. For the most part this recorded information is to be used in sequence, but if it is necessary to return to a previous word in the sequence this word may be located by counting the marker pulses. With the clutch system used, it was found that there was an optimum wire speed for most efficient use of the storage medium. Since the time required to stop and start the wire is a function of wire speed, the marker pulse length and hence the ratio of marker pulse length to word length is also a function of wire speed. Consideration of this factor resulted in the choice of the wire speed and the marker pulse length previously stated.

A special circuit is to be used in the EDVAC for reading information from the wire. The details of this circuit were not discussed but the principle was stated. Because of the differentiating action of the playback head, the voltage generated in this head by recorded pulse signals has the wave shapes shown below. Both positive and negative pulses are



produced for a single recorded pulse. The reading circuit consists of flip-flops that are triggered by the first of the pair of output pulses but are insensitive to the second of these pulses. The use of an integrating circuit to obtain single output pulses caused too great an attenuation of the signal's to be practical.

b. High-Speed Pulse Recording. Dr. Chu stated that he hoped to be able to start a program of research on high-speed pulse recording in the near future. For this work he plans to use a metal cylinder plated with a layer of magnetic material for his recording medium. It is his opinion that heads cannot be in contact with the medium for operating speeds greater than about 10 ft/sec without causing excessive wear either of the heads or of the medium itself. A greater recording gap length is necessary when heads are spaced away from the medium so poorer resolution must be expected. For heads spaced 0.005" away, the number of pulses that can be recorded per inch might be about 75% of the number that could be recorded with the heads in contact with the medium. It was his understanding that the Institute of Advanced Study in conducting its research on this subject has obtained a recording rate of 50,000 pps with an operating speed of about 50 ft/sec.

3. Mercury Delay Lines

Mr. Chedaker demonstrated his equipment for high speed storage in the EDVAC using a mercury delay line and discussed some of the features of the line and its associated circuits. The delay line consists of a column of mercury 22 inches long and 3/8 inch in diameter contained in a glass tube with a quartz crystal mounted in each end of the tube. The "pulse packet" applied to the tube consists of two cycles of a 5 megacycle frequency generated by applying a pulse to a ringing circuit. In traversing the tube, the packet is greatly attenuated and is slightly spread out, i.e. it contains more than two cycles. The output voltage from the line has approximately the wave shape shown below.

Most of the attenuation occurs in the crystal transducers. There is a 30 db loss in each crystal and 6 db loss in the mercury column itself. The output packet is amplified, rectified, reshaped, and then fed back to the ringing circuit to cause another pulse packet to be sent down the delay line. In this way it may be retained as long as desired.

The 22-inch line produces a delay of 256 μs so that, for the one megacycle repetition frequency used in the EDVAC, 256 pulses may be stored in such a line.

4. <u>General</u>

Mr. Chedaker stated that they are looking for a better method of coupling between stages in the electronic circuits. In the delay line demonstration a considerable change in pulse wave shape was evident as the spacing between pulses was varied from 1 μs to 256 μs.

A small model of the EDVAC had been built up in the laboratory and was used for testing the various components of the computer. However, it was not operating at the time of this visit. It was understood that the design of the EDVAC has been completed and that the computer will have been constructed by the first of 1948.

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Results of Tests on Various Magnetic Recording Materials by Dr. Chu at the Moore School, University of Pennsylvania, (Operating speed - about 10 "/sec.)

Designation of Wire or Tape		Dimensions dia. of wires thickness of tape - mils	Weight gms/1000 ft.	Breaking Strength Pounds	Material	Magnetic Properties H_c	B_r	H_c/B_r x10^{-2}	B_s-H_s
GE Stainless-A	Wire	4	19.5	4	Stainless Steel	320	1800	17.8	
GE Stainless-B	"	3.9	19.0	3.9	Stainless Steel	*1	*1	*1	
GE Stainless-C	"	4	19.0	4.	Stainless Steel	30	7000	0.43	
GE Piano E	"	4.1	20.0	4.5	Steel	60	5300	1.13	
GE Cunife I-D	"	4.1	21.0	3.	Cu-Ni-Fe Alloy	65	2100	3.09	
GE Cunico No. 331	"	4.2	20.5	3.5	Cu-Ni-Co Alloy				
GE Cunife I No. 327	"	4.2	20.5	4.	Cu-Ni-Fe Alloy				
Nat'l. Stan. Cunife	"	3.9	20.5	3.5	Cu-Ni-Fe Alloy				
Nat'l. Stan. H_c=350 #3505	"	4	19.5	11.	Stainless Steel				
Nat'l. Stan. H_c=480 #3261	"	4	20.0	10.5	Stainless Steel	480	2200	21.8	
Nat'l. Stan. H_c=240	"	4	19.5	9.	Stainless Steel	240	2200	10.9	
Nat'l. Stan. H_c=180	"	3.9	19.0	10.	Stainless Steel	180	6300	2.8	
Swedish Tono-120-S	"	4.2	20.0	8.		700	200	350.	
Brush Plated Wire BK-913	"	4.5	27.5	4.5	Co-Ni Alloy on phosphor-bronze	220	9000	2.44	
Nat'l. Stan. Flat Stainless Wire		2x6	19.0	9.5	Stainless Steel	300	2500	12.0	
Brush Plated Tape		2.8 x 14.6	61.0	12.	Co-Ni Alloy on phosphor-bronze	220	9000	2.44	
Brush Paper Tape BK-914		2.3	149.	7.5	Synthetic Magnetite	115	400	29.	1220
Brush Paper Tape BX-29		2.2	144.	7.		115	760	15.	1680
Lear Paper Tape No. 11		4.1	183.	12.	Red iron oxide				
Lear Paper Tape No. 23		3.9	181.	12.	Red iron oxide	105	900	12.	2000
Lear Paper Tape No. 34		3.9	182.	12.	Red iron oxide				
German type L Tape		1.8	126.	6.	Synthetic Magnetite	85	100	85.	
Armour Tape No. 140		2.3	142.	5.		290	410	71.	680
Ind. St. Prod. Paper Tape - Stan.		2.7	161.	12.		210	*2	---	
Ind. St. Prod. Paper Tape - Hyflux		2.3	157.	10.		500	1000	50	2200

*1 - Almost non-magnetic

*2 - a few hundred gausses

Designation of Wire or Tape		*3 Noise Arbitrary Units	Output at Peak same units	Sine Wave Response Peak	Sine Wave Response 6db down	*4 Pulses per inch	*5 Rise Time	*6 Pulses per inch	*7 Sq. Wave per inch
GE Stainless-A	Wire	0.2	0.6	600	80-2000	120	750	67	60
GE Stainless-B	"	0.15	---						
GE Stainless-C	"	0.2	0.4	200(?)	100-300(?)	15	3500	14	16
GE Piano-E	"	0.3	5.0	500	100-1700	50	2500	20	30
GE Cunife I-D	"	0.25	1.4	800	50-2000	75	1250	40	40
GE Cunico No. 331	"	0.25	0.7	1000	150-2400	200	440	110	100
GE Cunife I No. 327	"	0.2	1.6	600	150-1800	---	550	90	85
Nat'l. Stan. Cunife	"	0.2	1.5	800	150-2900	180	500	100	95
Nat'l. Stan. H_c=350 #3505	"	0.2	0.8	800	125-3000	160	625	74	75
Nat'l. Stan. H_c=480 #3261	"	0.25	1.3	1600	350-4700	210	375	133	120
Nat'l. Stan. H_c=240	"	0.2	1.3	1200	200-4000	150	500	100	100
Nat'l. Stan. H_c=180	"	0.25	1.5	800	60-2600	90	1375	36	35
Swedish Tono-120-S	"	0.2	0.6	2000	600-6000		250	200	160
Brush Plated Wire BK-913	"	0.2	2.4	1200	200-4000	160	750	67	70
Nat'l. Stan. Flat Stainless Wire		0.2	2.0	2200	400-6000	300	251	200	210
Brush Plated Tape		0.2	1.6	1600	300-3500	280	292	170	160
Brush Paper Tape BK-914		0.3	2.6	1600	400-4000	240	250	200	160
Brush Paper Tape BK-29		0.2	5.0	1600	500-3100	230	310	160	170
Lear Paper Tape No. 11		0.3	9.0	1800	400-3400	250	310	160	180
Lear Paper Tape No. 23		0.2	14.0	1400	400-3400	230	417	120	130
Lear Paper Tape No. 34		0.2	13.0	1200	250-2600	230	520	96	120
German type L Tape		0.1	0.8	1400	350-4000	270	310	160	150
Armour Tape No. 140		0.15	6.0	2000	350-4000	280	210	240	200
Ind. St. Prod. Paper Tape - Stan.		0.3	2.4	1600	400-4000	250	250	200	170
Ind. St. Prod. Paper Tape-Hyflux		0.4	4.2	2000	500-4800	280	210	240	190

*3 - Noise figures doubtful because scope and amplifier noise is almost 0.2 units alone

*4 - Recorded 17.5 microsec. pulses in groups of 3-2nd pulse down 10%

*5 - 100 cycle sq. wave recorded microsec.

*6 - On basis of Time Rise

*7 - Calculated from sq. wave frequency at which E_o drops 10%