6. Input-Output Devices for NBS Computers

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1. INTRODUCTION

The SEAC input-output equipment had a modest beginning with modified Teletype equipment which included a tape reader and keyboard for input operations, and a printer and punch for output operations. It was, of course, realized that there was much to be gained by adding magnetic recording devices to speed up the input and output processes, thereby putting the various parts of the machine in better balance. The requirements for this equipment seemed to fall in two classes. In one case data must be temporarily stored outside the computer but re-inserted later in the course of the problem. The other class requires a system of bringing new input to the computer and removing output. While there is an added convenience in having both of these features provided by a common system, the requirements are not entirely compatible. In the case of SEAC it was considered expedient to use separate types of equipment for input-output and overflow memory. The principle was to provide equipment that would make the computer a more useful tool but with emphasis on simplicity and reliability. For these reasons the reel-less tape drive for auxiliary memory was developed at the Electronic Computers Laboratory. Temporarily this was used as high-speed input-output but the reel-less method of tape storage did not provide the desired convenience. A cartridge loading wire recorder mechanism was chosen for high-speed input-output because of the great convenience this provides. The compromise here was in high-speed start-stop performance and the possibility of multichannel recording. In combination these two mechanisms provide a system with the desired characteristics.

To prepare input data, punched paper tape is used as an intermediate step. This makes the wire recording equipment simple as the wire can be moved continuously when the tape information is transcribed to the wire. The paper tape can be easily checked and corrected, eliminating the necessity for error-checking circuits on the keyboard.

2. INPUT PREPARATION

Figure 6.1. shows the complete input-output system in use with SEAC. Units A and B are used to prepare and check the punched tape. These units are Teletype apparatus with modified code and keyboard.

Unit C, called an "inscriber," comprises a punched tape reader, a drive unit for the magnetic recording wire cartridge, and control circuits for automatic transfer of the information from tape to wire. Counters control the tape reader so that the recording is put on the wire in blocks of eight words. Between these recorded blocks enough space is automatically provided to allow the computer sufficient time to acquire its next read-in instruction. Whenever the computer program requires that the wire be stopped and started between blocks, the counter is set to provide a much longer space.

Unit D is a punched-card-to-wire-cartridge converter that is now under construction. A machine (IBM Type 63) which converts punched card data to punched tape is commercially available but none is provided for the NBS computers at present.

3. MACHINE INPUT-OUTPUT

A modified Teletype apparatus (unit E) communicates directly with the computer and is used primarily for troubleshooting the computer or the program. The principle followed in adapting Teletype to SEAC was to avoid any modification to the basic mechanism that would affect its reliability. The code bars were reground and filled in, where necessary, to alter the code. Most of the function

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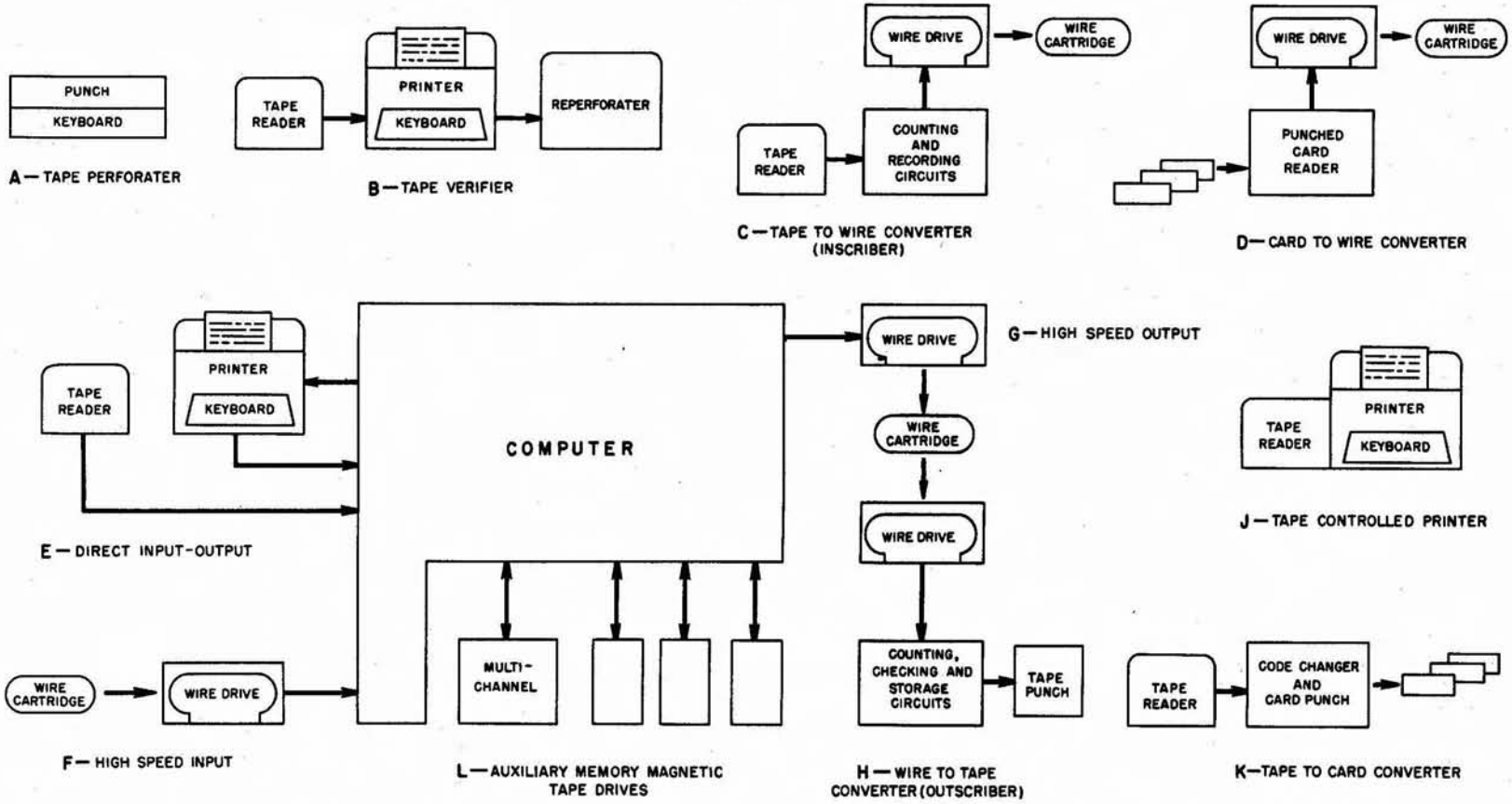

FIGURE 6.1. *Input-output and auxiliary units for the SEAC and DYSEAC systems.*

bars were removed, and those remaining were modified with respect to the code they recognize. A Teletype transmitter-distributor provides the timing signals to the computer for output printing at the standard Teletype rate.

A modified Flexowriter replaces Teletype equipment for DYSEAC input-output. The Flexowriter system comprises a punched paper tape reader and a punch built into an electric typewriter as one complete unit. Its operating rate is slightly higher, 10 characters per second as compared with 6 for Teletype. The Flexowriter also has the added advantage of being easily adapted to give such additional features as upper and lower case letters, 6- or 7-unit code, color change, and tabulating.

Teletype equipment is well suited to serial input-output as it includes distributing and collecting apparatus. The Flexowriter, since it is not designed to be operated over long lines, handles the units in each code character simultaneously on separate lines. In many types of computer circuitry, of course, this is a preferable arrangement. The Teletype machine in use with SEAC for some 3 years has proved quite reliable, and it remains to be seen whether Flexowriter equipment will provide similar reliability.

Unit F is the wire drive that provides high-speed input to the computer. It accepts the cartridge prepared by unit C or D. All of the cartridge loading wire drives in the system are modifications of the mechanism of an office dictating machine. Figure 6.2. shows the input and output wire drives in the SEAC console. The wire is contained on two spools in a closed metal cartridge. This cartridge, shown in figure 6.3., carries a pointer traveling over a replaceable paper scale on which the data recorded on the wire may be labeled. These units can be switched to manual control so that the wire may be positioned to the data desired for input, and then switched to computer control so that when the program calls for input from this particular source it is automatically read in. Typical read-ins require only a few seconds, the speed of the wire being 120 times as fast as when it was recorded from Teletype tape.

A cartridge can contain about 14,000 words, which is enough to load the high-speed memory many times, and is the equivalent of over 7 hours of Teletype tape reading. Many programs may be put on the same cartridge, and a particular one can be located by use of the position indicator on the face of the cartridge. A device useful to the operator is a loudspeaker connected to the wire drive amplifier, which allows information groups to be located exactly. It also seems to give the operator a great deal of satisfaction to be able to hear something going on.

The mechanical part of the office dictating machine was purchased from the manufacturer unwired and without the associated electronic equipment. One modification required for computer input-output use is a change in the motor capstan size to produce the desired speed, in this case 8 ft/sec for both forward and reverse. The auxiliary equipment, units C and H, require a very slow wire speed, less than 1 in./sec, for transferring information to or from punched tape. For this application a second motor with gear train is mounted in line with the regular motor. The shafts are coupled by means of an over-running clutch so that either speed may be obtained by simply switching on the appropriate motor. Another important modification is the replacement of the recording head used in the office machine with a higher quality head. The mounting requires modification to fit the small space available, but this head produces a much cleaner wave form in the recorded pulses.

The cartridges as supplied for office use contain about 1,800 ft of stainless-steel wire (3.75 min at 8 ft/sec). This has been replaced with plated wire, which allows about twice the pulse packing. The recorder mechanism contains two oiled cork disk clutches operated by solenoids to engage the forward and reverse spool driving shafts. These solenoids are wired directly into vacuum-tube control circuits. The clutches require periodic cleaning, oiling, and adjustment to assure their reliable operation.

Considerable trouble has been encountered with the latching system for holding the cartridge into the wire drive mechanism. In many cases the latches became disengaged while the wire was running and allowed the cartridge to jump away from the spool drivers, usually causing the wire to break. Recently, the mechanism for engaging these latches has been modified in such a way as to eliminate this trouble. There is still occasional breakage of wire which is not explained. The plated wire, which gives better recording performance, is somewhat weaker mechanically and more brittle. Considering the great increase in operating efficiency offered by this system, the occasional trouble with

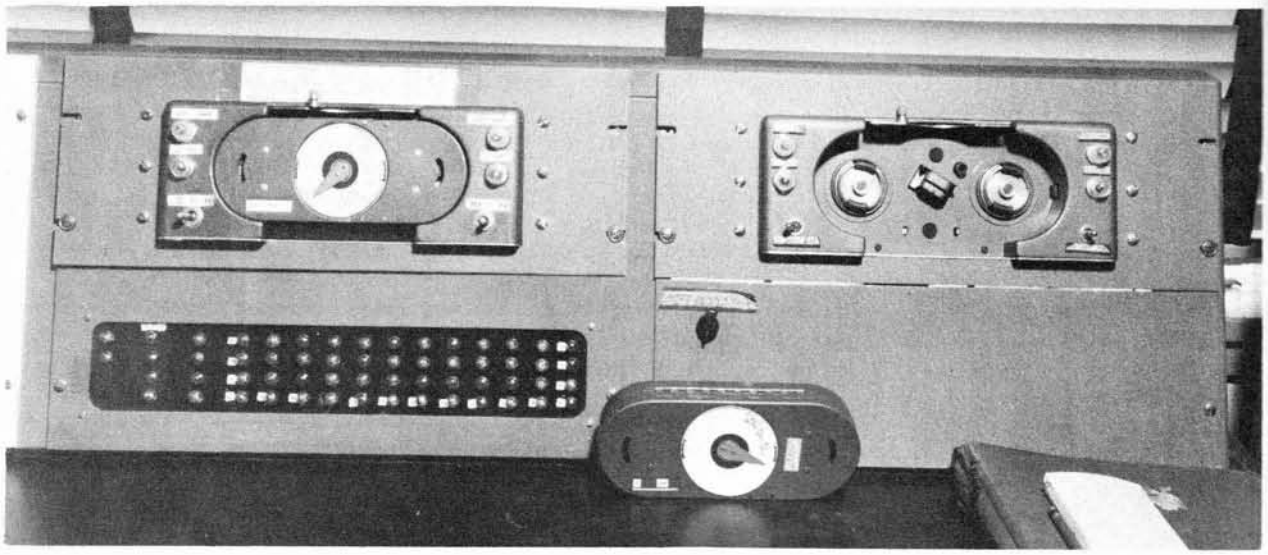

FIGURE 6.2. *SEAC input and output wire drives.*

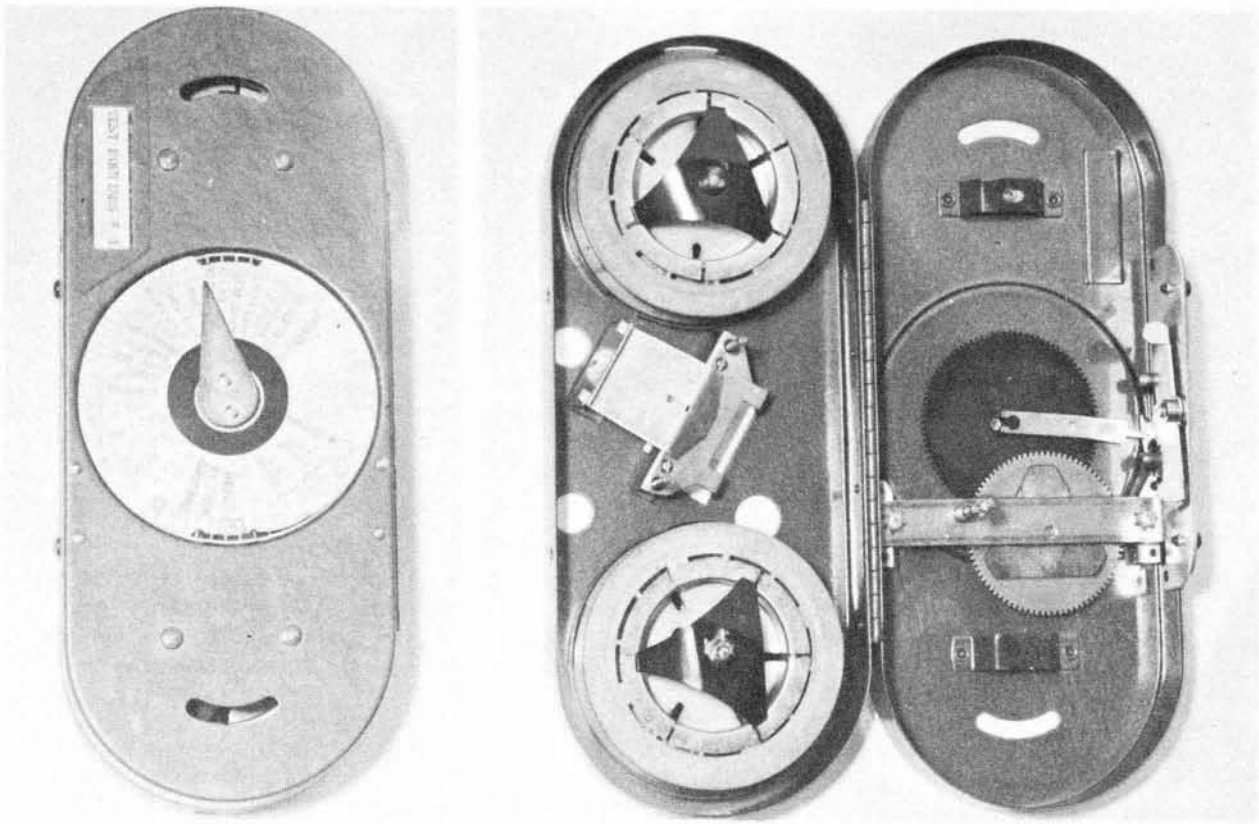

FIGURE 6.3. *Recording wire cartridge.*

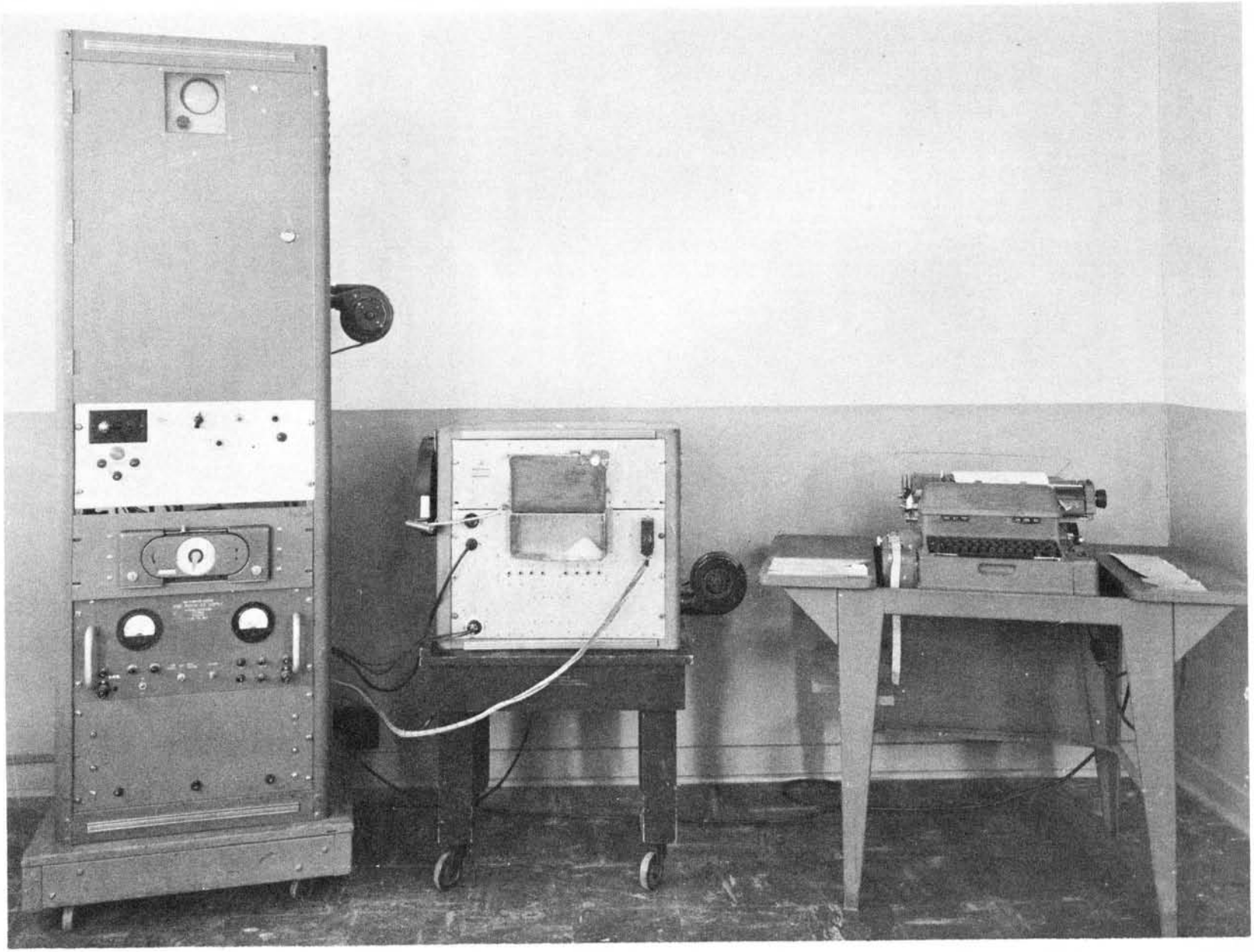

FIGURE 6.4. *Magnetic wire to punched tape converter and tape-controlled printer.*

broken wire is tolerable. When the wire does break, the cartridge can be rewound with new wire, or the broken wire can be spliced and used if the spliced area is avoided.

As in the original operating system of the wire recorder, the engagement of the clutch solenoid closes contacts which start the motor. This gives an acceleration to the wire from standstill to full speed in approximately one second. Adequate gaps in the recorded program must, therefore, be provided to allow the wire to reach full operating speed before it enters the information area. This means that it is most efficient to use this device for input or output which requires few stops and starts between long runs of data. The output wire drive (unit G) is identical to the input unit. Both SEAC and DYSEAC have provisions for the use of several input and output wire drives, which may be automatically selected in the program.

4. OUTPUT AUXILIARIES

When a cartridge of wire has been recorded with computer output it is placed in unit H, called the "outscriber."[1] Here the wire is driven continuously at about 1 in./sec, and its information is transferred to a punched paper tape. Since this form of wire drive does not give quick start-stop operation, the use of a printer or card punch directly with the outscriber would require special provision for carriage return or card change. This could be done either by leaving large gaps in the recording at the expense of computer output speed or by providing a huge intermediate storage. The use of punched tape avoids these difficulties. The outscriber includes a shift register which both determines when enough pulses have been received to form a character and stores the information as the count progresses. A second register holds the information being punched as the first register accepts new information. Since the computer prints in blocks, it is easy to sense the gap in the recording between blocks and examine the shift register at this time. If the shift register contains information, an error is indicated and the wire automatically stops. The tape is produced by a Flexowriter punch operating at about 12 characters per second, the rate established by the wire speed and pulse spacing. Wires recorded on the inscriber (unit C) may be checked by reproducing punched tape on the outscriber. A second outscriber, now under construction, is based on the new Teletype punch which will operate at a speed approaching 60 characters per second.

The outscriber and inscriber are both designed to operate with either 4 bit or 6 bit binary coded characters. By using the 6 bit character, alphabetic information can be read in and out of the computer. The code for the letters is chosen so that the alphabet appears in ascending numerical order to facilitate alphabetical sorting. There need be no change in the computing machine to enable it to use both letters and numerals, but the input and output must be interpreted differently.

Punched tape may be converted to page print or punched cards. The printer now in use (unit J) is a modified Flexowriter. This includes a tape reader and electric typewriter operating in SEAC code. In the four-bit base-sixteen code used, the sign can be identified only by its standardized position in the word. A stepping relay counts characters so that at the sign position the code is modified. Another stepping relay counts words to control the carriage return. Figure 6.4. shows the outscriber and printer, units H and J of figure 6.1.

Two machines are provided for converting from punched tape to punched cards (unit K). One machine used a Flexowriter tape reader and relay code changer to operate a card punch (IBM type 24). The second machine is commercially available (IBM type 43) and is used practically unmodified.

5. AUXILIARY MEMORY

The equipment described thus far is concerned with the flow of information to and from the computer. Auxiliary memory requires a different form of external equipment which is provided by magnetic tape drives (fig. 6.1., unit L). A computer such as SEAC has a necessarily limited storage capacity in its internal high-speed memory. With many types of problems this is a serious limitation and requires that information be transmitted out of the computer for storage to be reentered into the computer later in the program. This means that the speed with which the storage and reentering can be accomplished is a major factor in the over-all operating speed. A common technique is to employ

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R. C. Haueter, Auxiliary equipment to SEAC input-output, Review of Input and Output Equipment Used in Computing Systems, Joint AIEE-IRE-ACM Computer Conference, S-53 (March 1953).

high performance servomechanisms to achieve rapid start, stop, and reversal of a magnetic medium in the recording device.

For SEAC a system was devised to solve quickly and economically the problem of overflow memory without the use of servomechanisms. As seen in figure 6.5., the device for moving the magnetic tape comprises a capstan turning continuously and a jam roller which may be moved into contact with the capstan by means of a solenoid. The complete tape drive mounts two of these capstan assemblies rotating in opposite directions with the recording heads between. The tape hangs loosely over the capstans and is accelerated to its running speed, typically 5 or 10 ft/sec, when the jam roller is engaged. The total acceleration time, including the solenoid lag, is about 5 msec. Individual motors (dual-speed hysteresis) drive each capstan and are so mounted as to allow easy replacement by motors of a different speed. The capstans are of smooth stainless steel and give very little friction against the loose tape. The jam roller is simply a small ball bearing with a nylon tire pressed on it. The solenoid which moves the jam roller about 0.010 in. is adapted from the coil of a short telephone type relay.

The units now in use with SEAC employ single-channel bipolar recording with a-c erase on 1/4-in. tape. The tape is stored in a "tank" where it falls in random loops from the capstan as seen in figure 6.6. This tank is formed by the space between two plates separated by slightly more than the tape width. Separate tanks are used to receive the tape from each capstan, with the ends of the tape prevented from passing through the mechanism. There is no tendency for the tape to twist parallel to the faces of the tank and therefore no opportunity for snarls to form in the tape. The SEAC units can be operated with up to 3,600 ft of tape in a tank 19 in. wide and 3 ft high. A single tank may be used with the tape spliced into a continuous loop, but the use of more than about 400 ft in this way has proved difficult. The use of wider tape and multichannel systems is entirely feasible. At the present time the tapes are run at 5 ft/sec and recorded at 110 pulses per inch. The tapes have been run satisfactorily at 10 and 15 ft/sec, but at the present time the SEAC cannot handle pulses as fast as these speeds would present them. The amount of information that can be put on a tape depends on the manner in which it is recorded. When it is required that the tape be able to stop between blocks of information, enough blank space must be provided for it to do so. This space is provided in the recording operation by delaying the recording until the tape has had time to move sufficiently. At most, SEAC can record or read eight words per instruction. If the program calls for more than eight words at a time, there is no point in leaving the blank space every eight words. Only enough space is needed to allow the machine to compute the next read-in instruction. The system is designed so that the programmer may state in the instruction whether he wants the longer space provided or not. Recording without these spaces is called "compressed" recording. Using the compressed recording 12,000 words can be recorded on a 600-ft tape; uncompressed, 8,000 words. The same compressed recording system is used on the output wire units, where the long start-stop time makes it even more effective.

One trouble encountered in the use of these reel-less tape drives came from the strong tendency of the tape (acetate base) to acquire an electrostatic charge as it passed through the drive mechanism. Such a charge can be strong enough to cause the tape to stick to the tank near the top until it backs up into the mechanism and is damaged by a sharp fold. This trouble is completely eliminated by the use of a tape now available with an evaporated aluminum film on the back surface. If Lucite is used for the tank, it must also be treated to prevent the accumulation of static charges on its surface.

Another problem arises from the presence of flaws in the magnetic tape. Commercially available tape has many small imperfections in the magnetic oxide coating which are quite undetectable in ordinary audio work but which cause loss of one or more digits of information in pulse work. With multichannel apparatus there are several systems for avoiding these flaws, but since we are operating a single-channel system, an attempt was made to improve the tape surface mechanically. The Electronic Computers Laboratory developed a technique that is quite effective in eliminating flaws from ordinary tape. The serious flaws are caused by nodules of the oxide that project above the normal surface and lift the tape away from the head. They may be removed by passing the tape surface across a properly shaped scraping blade. This technique has been successful only with the product of one manufacturer, since the physical characteristics of the flaws vary with the manufacturing method.

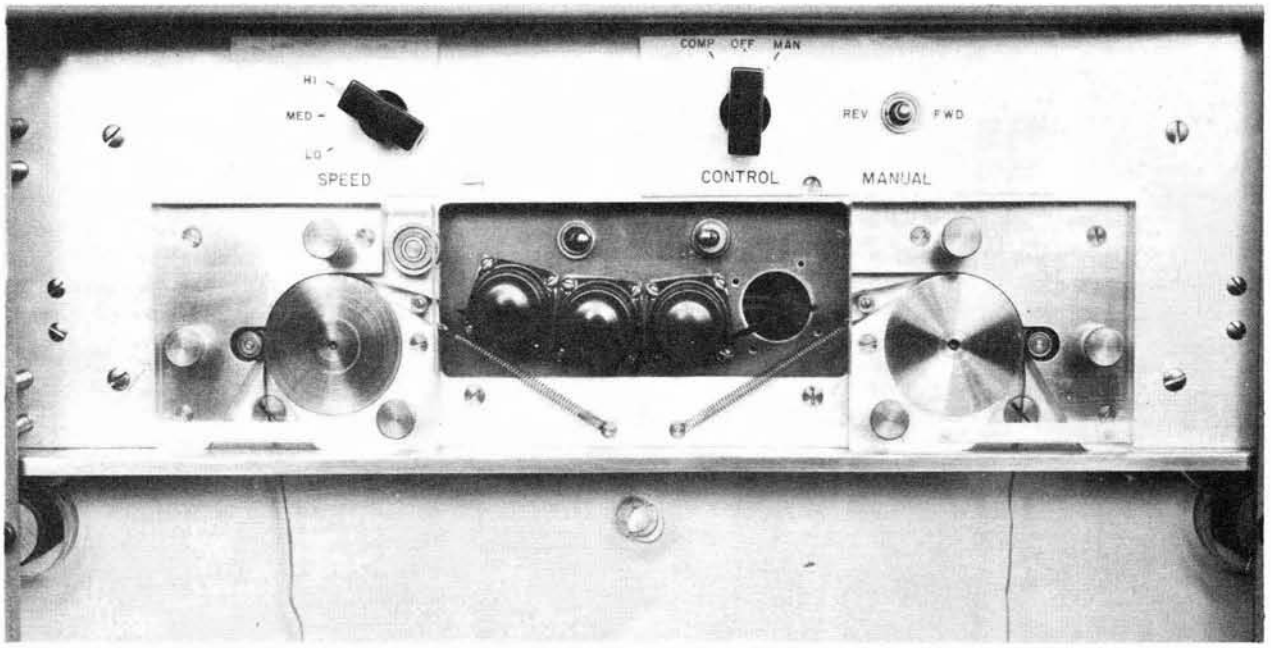

FIGURE 6.5. *Tape drive capstan and jam roller.*

FIGURE 6.6. *Auxiliary memory tape drive.*

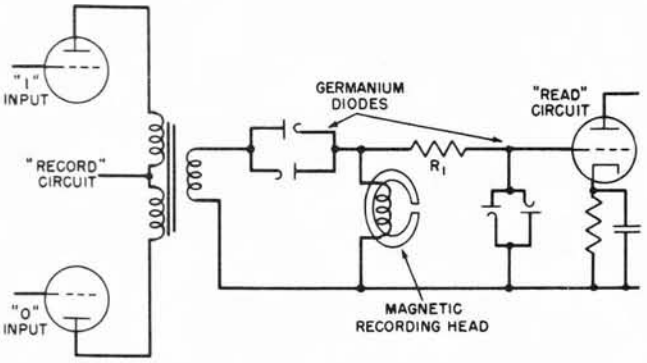

FIGURE 6.7. *Recording and reading circuit.*

A third difficulty arises from the use of plastic tape with this storage method. If a 1,200 ft tape is left immobile in the tank for a day or so, it develops kinks at the loops which will cause the tape to jump away from the recording head at the light pressure that is preferable. If the pressure pad is tightened to eliminate this trouble, it causes increased wear on the tapes and heads. A fair compromise may be made by using only about 600 ft of tape in a tank. If a base material of improved resilience is developed, an increase in storage volume will be facilitated. The simplification derived from avoiding the reel inertia problem is paid for by inconvenience in changing tape. This is quite tolerable when the device is used only as an auxiliary memory.

A completely different type of tape drive is the multichannel Raytheon unit. The mechanism used with SEAC is very nearly a stock model made by the Raytheon Manufacturing Company. It has six heads across 1/2-in.-wide tape and moves the tape at 45.5 in./sec. The mechanism employs a high-speed electromagnetic friction disk brake system applied through a differential to give high-speed performance to the capstan. The tape is stored on servo-controlled reels. A low-inertia moving frame carries several idlers that store a loop of tape, and the position of this frame provides the reel servo input.

As used with SEAC, one of the channels is a synchronizing or marker channel. It contains a digit for every place in the information channels where a digit may be recorded. Synchronizing digits are placed on the tape once and not changed thereafter. At the present time we use about 80 digits per inch.

The other five channels are used as information channels. Information is printed on or read from only one channel at a time inasmuch as SEAC is not wired to receive more than one channel. Since the position of information digits is determined by the position of the synchronizing pulses, information digits are always at specific places on the information channels. This makes erasing unnecessary as new information may be superimposed on the old. Recording is always to saturation, so that writing a digit of the same polarity as the one last recorded at this spot has no effect, but writing one of opposite polarity will change the magnetic ondition of the tape at this point to saturation in the other direction.

Another advantage of having the synchronizing digits permanently recorded is that flaws on the tape can be avoided. If synchronizing digits are placed only where there are good recording spots on all channels, then only these good parts of the tape will be used. One of the ways this may be accomplished is as follows: The channel which is selected for synchronizing is printed with pulses at the packing rate to be used in the final condition. Next, the second channel is printed by reading from the synchronizing channel to actuate the print circuits. The reading amplifier gain is reduced so that no marginal pulses are accepted and only fully normal pulses will cause printing. Thus, the second channel will contain pulses only when there are good recording spots in the synchronizing channel. The process is repeated, with the third channel being printed from the second, and so on until all channels have been recorded. Now the last channel contains pulses only where there are good recording spots in all other channels. The synchronizing channel is erased and reprinted from the last channel so that it now contains pulses only where there are flawless recording spots in all channels.

A unique system is used to connect the magnetic recording head. The head is not switched but remains connected to both the reading and recording circuits at all times, as shown in figure 6.7. The nonlinearity of the diodes and the great difference in signal level between that developed across the secondary of the print transformer during printing and that developed across and head during reading are the basis of this circuit. At the low level of signals developed across the head during reading, the diodes present a high impedance to either polarity. The series diodes therefore prevent the transformer secondary from shunting the head with a low impedance. The resistance R1 must be small compared to the low-level resistance of the diodes in the grid circuit, so that a large part of the voltage developed across the head will appear at the grid of the amplifier.

During printing the diodes present a low resistance to signals of the greater amplitude. As their resistance is low compared with the impedance of the head, the series diodes do not appreciably attenuate the signal to the head. It is desirable to have the resistance R1 high compared with the grid-circuit diode resistance at the print signal level so that only a small part of the print

signal will appear at the read amplifier. It is also desirable for the resistance to be large as it will limit the amount of current that flows in the grid circuit.

Another application of the nonlinearity characteristic of diodes is in the synchronizing channel amplifier. This channel must be read while printing is carried on in other channels. The signal pickup from printing in an adjacent channel is about 50 times that of the actual snychronizing signal. Diodes are put in the grid return circuits of some stages of the amplifier where this lower impedance for the larger signals will cause the amplifier to have less gain for the unwanted pickup.

Two of the channels have been connected so that the forward direction for them is reverse for the other channels. In effect, this gives an endless loop of any length up to four tape lengths. Time for reversing is saved on problems where the same information must be read several times. At the time of writing, this unit has been in operation with SEAC for about 6 months and has proved quite satisfactory.

At present the input-output and auxiliary equipments give more maintenance trouble than those parts of the computer which use electronic components. This is partly because of the tendency to operate the mechanical devices near their top speed in an attempt to more nearly match the requirements of the computer. The volume of data handled by computer equipment suggests that more development of mechanical accessories is necessary in order to achieve long life as well as high speed and reliability.