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Engineering Organization of Input and Output for the IBM *701* Electronic Data-Processing Machine

LOUIS D. STEVENS

THE International Business machines Corporation (IBM) type-*701* electronic data-processing machine is to be a general-purpose high-speed electronic calculator utilizing the Williams type of electrostatic storage. The binary system of notation is used internally with a word size of either 36 bits (a full word) or 18 bits (a half word): transmission is parallel throughout the machine except to and from magnetic tape. Instructions are of the single-address type with 32 possible operations, and a maximum address capacity of 4,096 half words; each instruction occupies one half word of storage capacity.

In addition to the high-speed electrostatic storage with a maximum capacity of 2,048 full words, the machine is provided with a slower access time magnetic drum storage of 8,192 full words, and a completely integrated and flexible input and output system consisting of one card reader, one card recorder, one alphabetic printer, two twin magnetic tape reader-recorders, and manual input and output by means of the operator's control panel.

A more detailed description of the general characteristics and of the organization of the machine has been presented previously.[1,2]

Input-Output System

The input-output system of type *701* is so designed that the use of an input or an output device by the calculator is accompanied by the performance of five distinct functions:

1. Selecting. An input-output unit to execute either a reading, a writing, or an auxiliary operation such as rewinding a tape.
2. Interlocking the operation of the selected input-output unit with the execution of the calculator program.
3. Copying data to and from the electrostatic memory and the input-output units.
4. Synchronizing the signals between the input-output unit and the calculator.
5. Disconnecting the input-output unit from the control of the calculator after the operation for which the unit was selected (and connected) has been completed.

These five functions are performed in such a manner that the inactive waiting periods normally associated with the use of an input-output unit may be utilized for useful operations by the calculator. This is accomplished by allowing the calculator to continue with the execution of its program during these otherwise inactive periods, and to converse with the input-output equipment only at those times when these devices may be in a position to transmit or receive data in full-word increments to or from the electrostatic memory. The following general description of the use of an input-output unit by the calculator will make the operation clear.

An input-output operation is initiated by the execution of a Select instruction (read or write) which places the desired unit under calculator control and sets the unit into motion to perform the function required. After the execution of select instruction the calculator may continue with its program, until the selected input-output unit has reached a position where it requires a word to write or a place to store a word which has been read. Just previous to this point, the calculator must have executed an instruction which is known as copy and skip or simply as copy. This instruction provides an address in electrostatic memory at which a word to be written may be located or at which a word that has been read may be stored.

Upon reaching a copy instruction in its program, the calculator will delay the execution of further instructions until the selected input-output unit has reached a position that will allow the memory address associated with the copy instruction to be utilized. Since most transfers of data between the storage and input-output units consist of more than a single word, successive copy instructions are required, one for each word to be transferred. These successive copy instructions only need be available just previous to the time an input-output unit may utilize the storage address, thus making the time between successive copy instructions available for useful operations.

From the foregoing it can be seen that the copy instruction not only supplies the necessary storage address for data transfers between the storage and input-output but also provides a synchronizing and interlocking function between the slow-access input and output devices and the faster access electrostatic storage. The skip function of the copy instruction will be described later as part of the discussion of the card reader and magnetic tape reader and recorder.

Since the calculator may continue with its program after an input-output device has been selected for reading or writing, it is necessary to provide an interlock, which will remember that a unit has been selected, and should the program arrive at another select instruction, its execution will be delayed until the previously selected unit has completed its operation. This interlock is known as the input-output interlock. It is turned on simultaneously with the selection of an input-output unit and will remain on as long as the selected unit is in operation. It will remember the unit selected and the function (reading or writing) for which it was selected. The need for this is due to the manner in which information is transferred to and from the electrostatic storage and the input-output devices. The storage address is supplied by a copy instruction, and the direction of information flow is determined by the setting of the input-output interlock.

Information transfer between the electrostatic storage and the input-output equipment is always routed through the multiplier-quotient register (M/Q). These transfers of information take place in single full-word increments and one copy instruction is required for each full-word transferred. Figure 1 shows, in block diagram form, the interconnection of the various units with the M/Q register of the calculator.

Each time a selected input-output unit is in a position to transfer information, the program must have arrived at a copy instruction just previously, to supply the required storage address. Should no copy instruction be available when required, a disconnect signal will be generated which will turn off the input-output

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This paper is a report of the efforts of many people in the IBM Engineering Laboratory. While it is impossible to name all of them at this time, I wish to recognize, and add my words of appreciation for, the fine contributions they made.

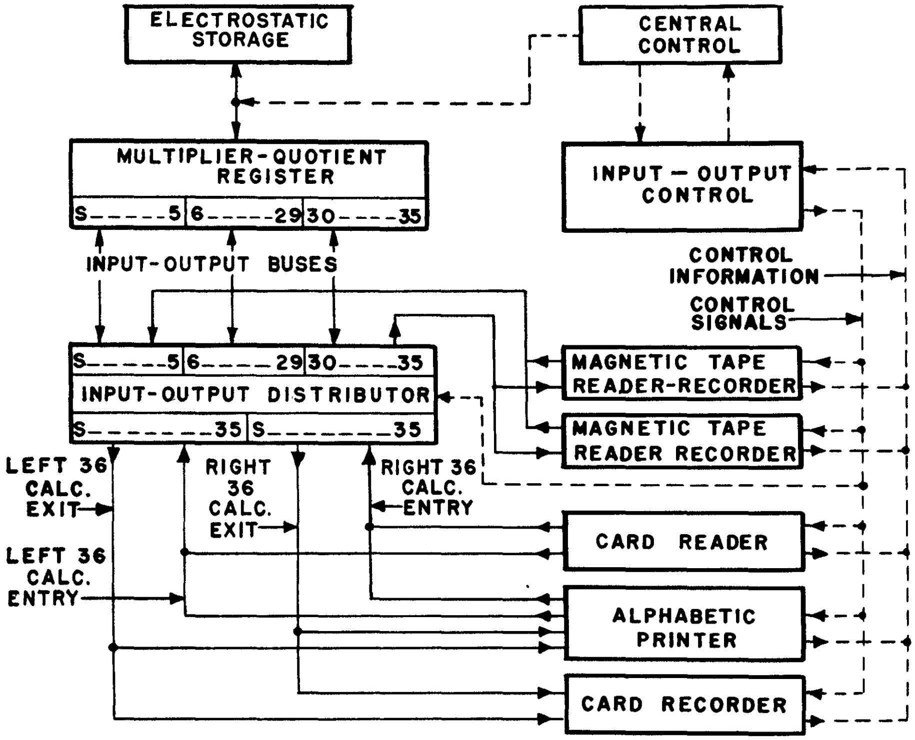


Figure 1. Input-output system information and control signal paths

interlock and prevent any further information transfer. In this manner an input-output unit will be disconnected from the system automatically, simply by not supplying it with information to write or not taking the information which it might read. Should an attempt be made to transfer information by giving a copy instruction with none of the input-output units connected, the machine will recognize this as a mistake and light a copy check lamp on the operator's control panel.

Card Reader, Card Recorder, and Alphabetic Printer

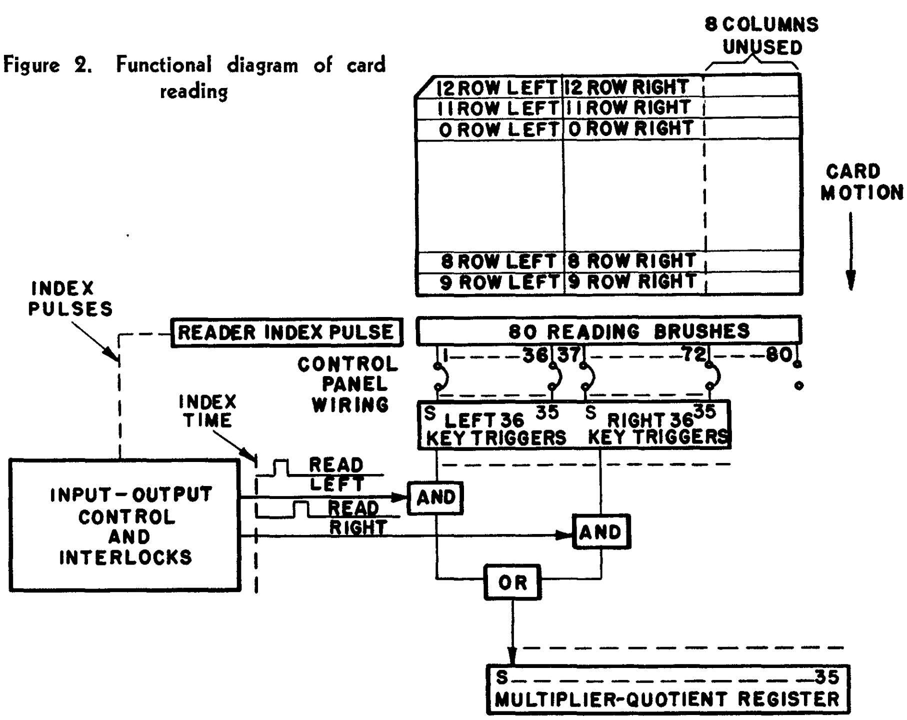
The card reader, the card recorder, and the alphabetic printer are referred to collectively as type-*701* card machines, since each of these devices is a development from a prototype punched card accounting machine. The reader was developed from a type-*402* card feed, the recorder from a type-*517* (*523*) card punch and the printer from a type-*407* accounting machine. Each of these machines retains many features of its well-known prototype but some new functions have been added to make them more suitable for use as input-output by type *701*.

The card reader and card recorder accept standard IBM cards nine's, edge-first, and are capable of feeding these cards at the maximum rate of 150 cards per minute in the case of the reader and 100 cards per minute for the recorder. The printer has no facilities for handling cards, and is supplied with information directly from electrostatic storage, by way of the M/Q register and the input-output distributor. It is capable of printing 120 characters per line at the maximum rate of 150 lines per minute. Since the printer is designed to print from a conventional card, the information which the calculator supplies it from electrostatic storage must be in the same form as that obtained from cards. Information can be stored in electrostatic storage in such a manner that it resembles information punched on cards. A group of full words required to do this is referred to as a card image. The manner in which a card image is formed and used by the card machines will become clear later.

Reading, punching, and printing proceed on a card row-by-row basis as each machine goes through its mechanical cycle. For example, when reading a card, each card row is handled by the calculator as if it were composed of two full-words of 36 binary digits each, and since there are twelve rows on a card, each complete card is considered as 24 full-words of 36 binary digits per word. If the 24 words of information from a card are considered as a card image when these words are stored in electrostatic storage, it is possible to read conventional card punching (or any other system of punching) and translate the resulting card image to binary information which is usable by the calculator. Conversely, it is possible to translate from binary to an appropriate card image in the electrostatic storage so that any desired punching or printing, either conventional or special, will result.

Since a single copy instruction can supply only one storage address, and a maximum of one full word can be located at any such address, it is necessary to supply two copy instructions for each card row of reading or punching, and for each line of printing. The time at which these copy

Figure 2. Functional diagram of card reading



instructions are required is determined by 'index pulses' from the card machine in operation. The index pulses from each machine are derived from electromechanical contacts and are used to indicate to the input-output control each time a selected card machine has arrived at a position where an information transfer to (or from) storage, and thus a copy instruction, is required.

Card Reader

Figure 2 indicates in functional form the manner in which card reading is accomplished. The card reader is set in motion by the execution of a read (card reader)-select instruction. As each row of the card comes under the reading brushes, the data punched in that row (two words) will cause appropriate ones of 72 key-trigger circuits located in the input-output distributor to be turned on. These key triggers are of a special design and are not used for the purpose of storing information but to provide reliable electronic signals from the electromechanical contacts of the reading brushes. Appropriate signals from the card reader and the calculator will cause the data to be transferred from the input-output distributor, one word at a time, by way of the M/Q register to a specified address in the electrostatic storage, in the following manner.

Shortly after the key triggers have been set by a card row coming under the reading brushes, an index pulse will be emitted by the card reader to indicate to the input-output control that two words are available for reading. The control will then send out a read-left-word pulse to sample the left 36 key triggers and place this word in the M/Q register, providing that a copy instruction had previously been executed by the calculator to make available a storage address for this word. If such is the case, then the word will be stored at the address designated by the copy instruction.

The calculator will then be allowed to continue with its program, until the control emits a read-right-word pulse at which time another copy instruction must have been executed, or else the word cannot be stored. Repetitive copy instructions and reading may continue as described for each of the 12 2-word rows punched in the card. However, should a copy instruction not have been executed previous to any read-left or read-right pulse, a disconnect will be initiated and will prevent the reading of further information from the card.

However, if 24 copy instructions are executed, thus storing the 24 words from the 12 card rows, then a 13 index pulse will be emitted by the card reader. This signal is called the end-of-record indication since it indicates that a complete unit record of information has been accepted by the calculator. The execution of a copy instruction after receipt of an end-of-record signal by the calculator will cause the next two instructions following the copy to be skipped, thus providing a simple and automatic exit from a repetitive procedure which may be supplying the successive copy instructions.

When all the cards in the hopper of the card reader have been read, the operator may either stack more cards in the hopper and continue as if the file of cards had been continuous, or he may end the file by depressing the start button on the reader with the hopper empty. When this is done, an end-of-cards interlock within the reader is set, and upon the next selection of the reader a signal will be emitted which indicates that the card reader had finished reading a file of cards. The execution of a copy instruction after an end-of-file signal from the reader will cause the next instruction in the program following the copy to be skipped. This provides a distinction between end-of-record and the end of last record (end-of-file).

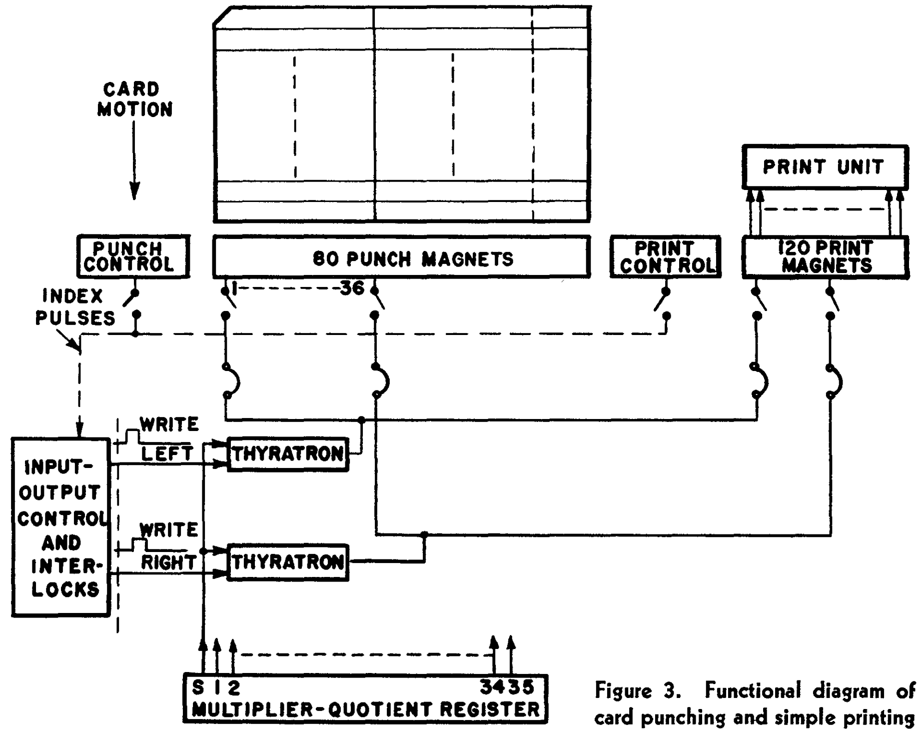


Figure 3. Functional diagram of card punching and simple printing

Card Recorder

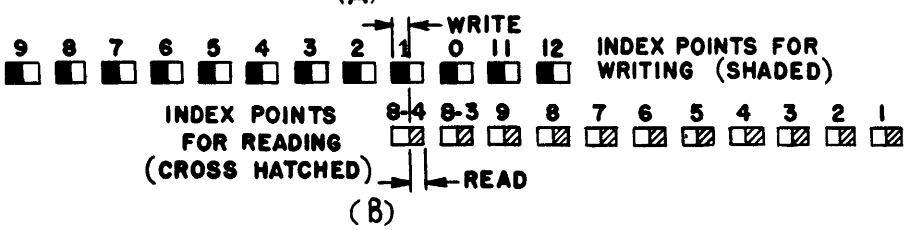
The card recorder operates in a manner similar to the card reader in that at each index pulse (each card row) two copy instructions are required. These copy instructions are used to obtain the information which is to be punched from the card image in electrostatic storage. Figure 3 indicates in a functional manner the method used in punching cards. The card recorder is selected by the execution of a write (card recorder) instruction and as each card row comes under the punching station an index pulse to the input-output control will cause a write-left and then a write-right pulse to be generated. If the M/Q has been filled with a word by a copy instruction previous to each sample pulse, any of the left and then the right 36 output thyratrons will be fired when a binary one is in the corresponding M/Q register column. Should the M/Q not have received a word as a result of a copy instruction at either write-left or write-right time, a disconnect will be initiated and further punching in that card will be impossible. Similar action occurs at each of the 12 card rows, and thus it is possible to punch a card in any desired system by merely assembling the appropriate card image in electrostatic storage before punching is initiated.

Alphabetic Printer

The 48 different characters which may be printed in any of the 120 print positions of the alphabetic printer are shown in Figure 4 (A) along with the corresponding card image code required to select each character. The printer is selected to write by the execution of a write (printer) instruction, in which case the func-

DIGIT ↓ / ZONE →	NO ZONE	12(R) ZONE	11(X) ZONE	ZERO ZONE
BLANK	*	+(ξ)	—	0
1	1	A	J	/
2	2	B	K	S
3	3	C	L	T
4	4	D	M	U
5	5	E	N	V
6	6	F	O	W
7	7	G	P	X
8	8	H	Q	Y
9	9	I	R	Z
8-3	+(#)	.	$	,
8-4	—(@)	⌑	*	%

(A)



(B)

Figure 4. (a) Printer symbols and code for card image used in printing

(b) Printer index points showing overlap of writing and reading when checking printing with echo impulses

tional operation of the system is similar to card recording, and will not be described again. When a type wheel on the printer has been selected for printing a certain character, a timed echo impulse representing the digit portion of the selected character will be available for reading later in the print cycle as indicated in Figure 4 (B). Provision has been made to take advantage of these echo pulses to check the accuracy of printing. For writing with checking, the printer is selected by the execution of read (printer) instruction (the write instruction provides for writing only). The echo impulses are read into electrostatic storage in much the same manner as a card is read on the card reader. However, the situation is complicated by the fact that four of the echo impulses overlap with the last four index times during which printing is still being set up. This situation is shown in Figure 4(B), and during these overlap index times it is necessary for the input-output control to interpret the four required copy instructions per index pulse so that two of these instructions are used to write and the next two used to store the returning echo impulses.

In addition to the checking facilities, the printer is supplied with an automatic tape-controlled carriage similar to that on type *407*. However, by use of special outputs from the calculator and a special input to the calculator, the tape control of the carriage may be combined with automatic control from the calculator program.

Magnetic Tape Reader and Recorder

In addition to the card reader, card recorder, and alphabetic printer, type *701* is provided with four magnetic tape readers and recorders. A view of one of the tape units is shown in Figure 5. Notice that each unit is composed of two tape drive mechanisms. Each of these mechanisms is an independent tape unit as far as its functional use with type *701* is concerned, and they are combined in one cabinet for compactness and economy of construction.

The tape unit has many unique mechanical and magnetic features which are described in other papers in this volume and the comments here will be restricted to the functional connection of the tape unit to the *701* system.

Long-term high-volume storage with a reasonably short access time to the next unit record is provided by the magnetic tape unit. The access time to the next unit record on tape from the stopped position is set at 10 milliseconds, and the reading and writing rate of unit records is 1,250 words per second. The information density on the tape of 200 words per foot corresponds to a bit density of 100 bits per inch in each of seven parallel tracks. The tape is plastic back with red oxide coating. Six of the seven tracks contain six bits of one 36-bit word, the seventh track contains a check bit which is used to check the correctness of reading and writing in the other six tracks. Since a full word is 36 bits, six groups of six bits each are required for a full word on tape. Transmission of information to and from the tape is done in a partially serial fashion, each group of six bits with its check bit being transmitted in parallel and the six groups of a word occurring in serial sequence. The M/Q register is used as a buffer between the serial-parallel tape and the parallel calculator in both reading and writing operations. The information paths from the M/Q register to the tape are indicated in Figure 6.

A word to be written on the tape is placed in the M/Q register by the execution of a copy instruction in much the same way as in writing on cards or printing. Exit from the M/Q register to the tape is by way of the right six (30-35) places of the M/Q. The word to be written on tape is shifted in total to the left, serially, around the ring shift path, until the first six bits of the word (*S*-5) have been displaced and arrive at the location (30-35) of the M/Q register. The six bits of the word, now located at (30-35) are transferred in parallel to the tape together with the check bit. The check bit to accompany the six information bits is determined by counting the binary ones in the 6-bit group to be written and making the check bit either a one or a zero so the total of binary ones in the 7-bit group is an odd number. In this manner, for each copy instruction supplied by the program a complete full-word is written on the tape as six groups of six bits each (with a check bit for each group). The tape will continue to run as long as copy instructions are available to supply new words. Thus a unit record on tape is not limited to any specific number of words

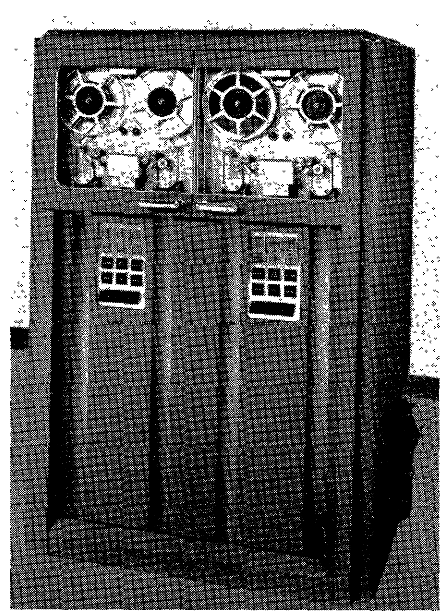


Figure 5. Tape unit

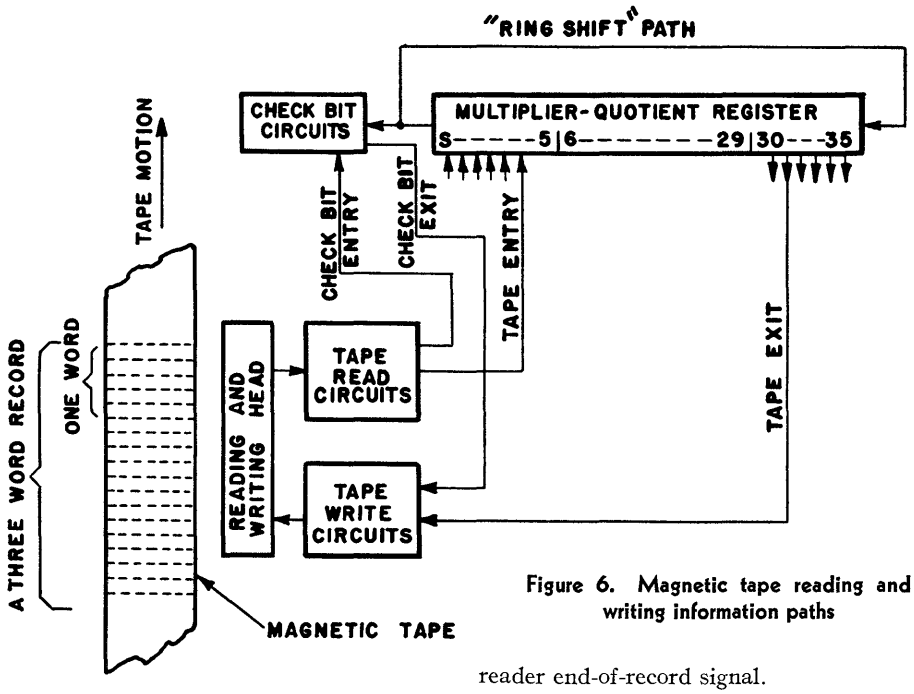


Figure 6. Magnetic tape reading and writing information paths

and may be any length from one word to the limit of the available space in the electrostatic storage.

The M/Q register is used in a similar manner when reading from the tape, except that the register is used to arrange the six separate groups into a complete full-word before the information is stored by a copy instruction. Each group of six bits is entered into the M/Q columns *S*-5 as shown in Figure 6, and then ring-shifted left in steps of six places. During the shifting operation, the group and its check bit are inspected to determine if the check bit corresponds to the correct one. If this check fails, a tape check light is turned on. After six groups have been entered into the M/Q register from the tape, the complete word is stored by execution of a copy instruction.

When reading, the tape unit will run the tape through a complete unit record, once it has been selected by a read instruction, and it is not necessary to store any of the information from the record unless desired. Thus it is possible to step the tape along in search of a particular unit record merely by supplying read instructions. The end of a record on the tape is identified by the tape unit by the large gap in the information. This gap is caused by the clean tape which is used in accelerating and decelerating the tape at the start and at the end of writing a unit record on tape. The sensing of this gap in information is used not only to stop the tape from feeding but to supply a signal to the input-output control to cause an end-of-record skip of two instructions following the next copy, in much the same manner as the functioning of the card reader end-of-record signal.

In addition to the end-of-record signal, the tape unit will also emit an end-of-file signal when it has read the last record on a reel of tape. This signal is generated when the tape unit is selected to read another unit record and, after a specified length of time finds no information available. In addition to stopping, the tape will set up an end-of-file skip in the program much the same as a card reader end-of-file. The extra long gap at the end of a file of information on tape is obtained by the execution of write-end-of-file instruction that cleans tape for a specified length past the last record.

In addition to the functions described in the foregoing the tape unit is capable of reading tape while the tape is moving in the backward direction, as well as being capable of completely rewinding a reel under program control.

Manual Input and Output

One function of the operator's control panel is to provide a means of manual input and output. This input-output function is provided as a part of the over-all function of manual machine control which will not be discussed here. Manual input is provided to the left 18 bits of the M/Q register from keys on the operator's panel. Appropriate instructions may be executed manually to store the contents of the M/Q register. The contents of any storage location may be inspected by means of neon lamps on the operator's control panel. These neons are connected to all major registers within the machine. It is necessary first to execute manually an appropriate instruction, which will place the contents of the desired storage location into an appropriate major register.

In addition to the manual information input facilities, manual control inputs have been provided. These control inputs consist of six switches located on the operator's control panel. Each of the switches has an address which may be used with a sense instruction. When a sense instruction with the appropriate address is executed, the position of one of the switches is sampled. If the sampled switch is off, the program continues in normal sequence, but if the switch is on the instruction immediately following the sense instruction will be skipped. The sense switches thus provide manual control over the course of a program, a function which has been found very useful.

In addition to the six sense switch inputs, four sense outputs have been provided. These outputs consist of neon lamps connected to trigger circuits which may be turned on by the execution of a sense instruction with the appropriate address. The sense outputs have been utilized for all types of indications, but their widest application has been in indicating the cause of error stops in programmed checks of machine operation.

Conclusions

The input and output system for the IBM type-*701* electronic data processing machine has been described along with the functional operation of the system. It is believed that this input-output system will represent something new in the field of high-speed electronic data-processing equipment. Previous machines of this type have been seriously hampered by the lack of adequate input and output facilities of one type or another. The *701* system is composed of the most suitable of the input-output devices of each type which are available today, and these devices have been arranged into an integrated system. When the *701* is released it may well be one of the first machines to exemplify a new era of data-processing machine development, in which much of the effort previously concentrated on the development of storage and control systems will be devoted to the development of more suitable input and output equipment and techniques.

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IBM Magnetic Tape Reader and Recorder

W. S. BUSLIK

THE purpose of the magnetic tape reader and recorder, as the name implies, is to record digital information onto magnetic oxide tape and to read it. Re-use of the tape also requires erasing before recording. The erasing, recording, and reading occur at the magnetic head which is described elsewhere with its associated circuitry. This paper will be confined to a description of the methods employed in handling this tape for most efficient use.

Most efficient use of the tape means conformance with the following requirements. Tape is to run at 75 inches per second in both directions. Rapid starting and stopping of the tape are to consume not more than 5 milliseconds from the time the start or stop signal is given. Uniform speed is to be reached in that interval of time. The tape should be capable of reversal in 10 milliseconds. These requirements apply to the piece of tape in the immediate vicinity of the recording station. The bulk of the tape can be handled much more leisurely. Reels are 8 inches in diameter and carry a maximum of 1,400 feet of tape.

Control of the tape functions is either from the calculator or from a control panel at the tape reader. In addition to these specific requirements, some less well defined points have to be considered. Speed should be as uniform as possible. Tape wear should be reduced wherever possible. Because the seven bits of information across the tape form a group, it is essential that the reading of these seven bits be completed before any of the seven bits belonging to the next group come into the reading position. This then requires that the tape be held as close to the same position as possible, from machine to machine as well as from forward to backward speed.

Machine Layout

With these points in mind, the machine layout in Figure 1 was conceived. This shows the record-erase head in a shield in a central location, easily accessible, approximately 4 feet off the floor. To either side of it is a series of pulleys and capstans, constituting the drive mechanism for the portion of the tape near the head. The tape passes through this section essentially horizontally. It then makes a 90-degree turn, entering the two vertical vacuum columns. These serve as buffer storage between the drive mechanism and the relatively sluggish reels which are located above the rest of the mechanism at a convenient height off the floor. The reels are easily detachable from their shafts, which are each driven by a set of three magnetic powder-type clutches.

Reel Clutches

These clutches are shown in more detail in Figure 2. One of the three clutches (the one in front) is stationary and serves as a brake. The other two are driven in opposite directions and, when energized, rotate the reel so as to supply tape to the vacuum column or remove tape from the vacuum column. All three are mounted on a common shaft with three rotors keyed to the shaft. When a clutch is energized, a rigid connection is established between its rotor and housing. A single clutch unit is shown in Figure 3. The innermost part is the bell-shaped rotor whose hub is keyed to the shaft. Its rim is surrounded by a mixture of magnetic iron powder and graphite. As long as no magnetic field exists, the rotor rim can move freely in this iron-graphite mixture, or the clutch housing can rotate freely around the rotor on the two ball bearings that locate it on the shaft. The clutch housing carries a coil which can establish a magnetic flux in the iron surrounding it. This flux, passing through the rim of the clutch rotor and the magnetic iron powder mixture, will solidify the latter, forming a torque-transmitting medium between the clutch housing and its rotor and shaft. Due to the inductance of the coil, current in it builds up gradually and, since torque transmitted is proportional to current (and flux), a rather smooth acceleration is produced. This is essential because shock in the reel will cause slippage of the tape on the reel and eventual breakage. The magnetic powder clutch was selected here for its ability to produce rather smooth accelerations and large torques with relatively small control currents. Its wear characteristics are very favorable because there are no linings or friction materials to be replaced. The iron-graphite mixture will not wear the clutch parts, only tending to polish them. To contain the iron-graphite mixture in the vicinity of the flux gap, a series of labyrinth-type ridges was designed into the clutch parts. These utilize centrifugal forces to return the powder back to the magnetic gap.

The entire clutch assembly as shown in Figure 2 can be removed from the machine after loosening four screws in front and disconnecting it by pulling a 15-position plug. Individual clutches are then easily replaced.

The clutches, and thereby the reels, are controlled from the tape in buffer storage. Each set of three clutches and associated reel and vacuum column represents an on-off servo system, which is completely independent of the motion of the tape in the vicinity of the head.

Vacuum Column Storage

The vacuum columns are vertical columns of rectangular cross section, just wide enough to accommodate the 1/2-inch tape. The front face of the vacuum column is transparent so that tape can be observed at all times. The top of the vacuum column is open; the lower end is connected to a manifold and thence to a vacuum pump which maintains a vacuum of about 10 inches of water. The tape is inserted so as to follow the sides of the column, forming a semicircular loop at the bottom. Vacuum is thus maintained below the loop and atmospheric pressure above it. This pressure difference is used to control the reels. Two holes in the back of the column are drilled at about one-third of the length from either end and are connected to pressure (or vacuum) switches, which effectively sense whether the loop of tape is above the holes or below them. Thus, the length of column is divided into three regions and the vacuum switches can sense in which of these the loop of tape is located at any time. Now, if the loop is in the region between the two switches, the brake clutch is energized and the reel stands still. If the loop is below the lower vacuum switch, the take-up clutch will be energized, turning the reel in the direction in which it will pull tape out of the vacuum column until the loop reaches the center again. If the loop is in the top third of the column, the reel is rotated to supply tape into

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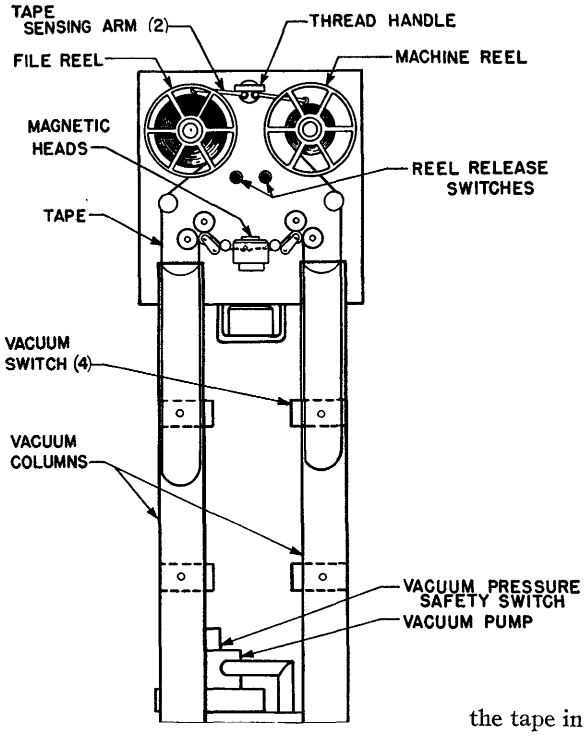


Figure 1 (left). Machine layout

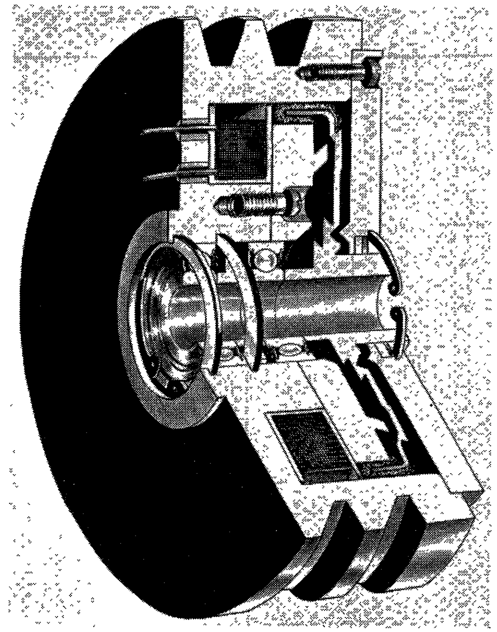


Figure 3 (right). Magnetic clutch

the column until the loop is lowered into the center region again. By the proper arrangement of the switch contacts no relays or tubes are required in the control circuit.

The vacuum switch used is shown in cross section in Figure 4. The heart of this switch is the diaphragm which compresses a return spring when vacuum is applied and thereby transfers an electrical contact. For reliability's sake, two sets of contacts in parallel are used, and after a year of operation no failures have been reported.

The vacuum in the column does not serve the clutch control alone, but also provides sufficient tension to wind a tight reel. Besides, it maintains tension on the tape in the drive mechanism, preventing the formation of loops when starting abruptly.

Start-Stop Mechanism

Fast starting and stopping is accomplished by the mechanism shown in Figure 5. This figure shows the main plate of the machine transparent, and the items behind it are shown somewhat lighter than the parts in front of it. The magnetic head is omitted here. The drive is symmetrical except for the reverse magnet (1) which is off to the left of the center line. There are two constantly rotating drive capstans (2) and two fixed stop capstans (3). All four are rubber-covered and ground concentric. A light nylon idler (4) mounted in fork (5) moves between the stop and start capstans and may be pressed against either one by the linkages behind the main plate. The tape runs oxide-side down under idlers (6) over nylon idlers (4) and vertically down into the vacuum column. The right drive capstan turns counterclockwise and the left one clockwise. Therefore, the tape can be moved forward (left to right) by bringing the right nylon idler (4) to bear against the right drive capstan (2); and right to left by squeezing it between the left nylon idler (4) and the left drive capstan. As indicated, the tape is always pulled away from the head when starting. Similarly, when stopping, the tape is stopped after going from left to right by being squeezed between the left nylon idler and the left stop capstan, and conversely. The linkages in back of the main plates do not permit both nylon idlers to make contact with a capstan simultaneously, thereby tape breakage is prevented. These linkages are actuated by the moving coil (8) which through rod (9) provides vertical motion of link (10) and by the reverse magnets (1) which impart a horizontal displacement to link (10). Thus, the reverse magnet biases the mechanism into forward or reverse status and the moving coil puts it into start or stop condition. The moving coil suspended in the magnetic field of a permanent magnet (11) makes it possible to obtain very short start and stop times. Actual transfer time of the mechanism from start to stop, or from stop to start, is 2 milliseconds, which includes current rise time in the moving coil. This coil is connected in a bridge circuit with four (*5687*) tubes making reversal of coil current possible in a fraction of a millisecond.

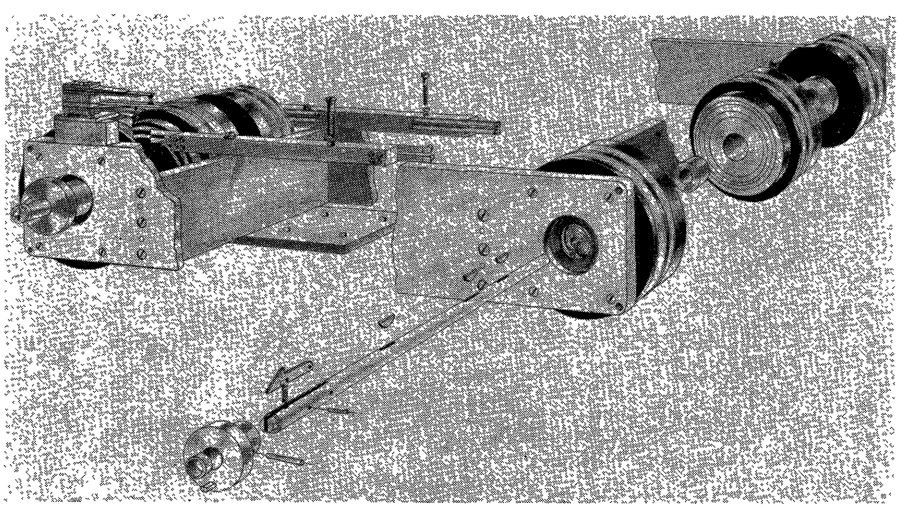


Figure 2. Reel clutches

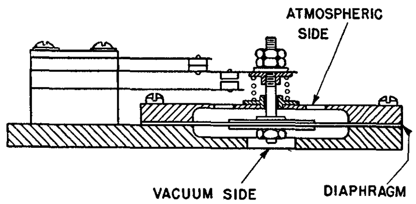


Figure 4. Vacuum switch

Forces required for rapid acceleration of the tape are rather large. Approximately 10 pounds pressure is required between the nylon idler and the capstan. This in turn calls for about 5 pounds at the moving coil. To obtain this force about 200 milliamperes have to flow through the 800 turns of number 40 wire on the moving coil. This large current can be maintained only for a short period of time (about 12 milliseconds) at starting and stopping. During steady running or stopped condition only a small current (60 milliamperes) flows, because only a small force is required to keep the tape moving, once it has been brought up to speed.

To achieve these rapid starts and stops, all displacements in the start-stop mechanism have been kept small. The nylon idler, for instance, moves not more than 0.004 inch when transferring from stop to start condition. This leaves just enough air gap between the rollers for the tape and a splice to run through freely, even if splices should occur on both sides simultaneously. Adjustment of this mechanism is therefore fairly important. Adjustments are made at the reverse magnet and the stop capstans, which are eccentric and may be rotated to open or close the gaps between rollers. They can be locked in place by means of a screw (7).

Tape Alignment

To maintain proper alignment of the tape, the split idlers (6) are used. These have to hold the tape parallel to the main plate and also keep the tape a fixed distance from it, both regardless of variation of width of the tape. To avoid too complicated an alignment system, it was preferred to maintain the alignment of one edge of the tape only and let the other move freely. Figure 6 shows how this is done by the split idler. The left edge of the tape is held a fixed distance from the plate which is set by grinding a little spacer to the proper thickness. The right-hand half of the idler is pushed to the left by a spring and at all times assures contact between the rim of the left half-idler and the left edge of the tape. When the tape expands in width, it spreads the split idler. The track farthest away from the guided edge of the tape is therefore most subject to misalignment when the tape expands or contracts laterally between the time of recording and the time of reading. If the distances of two split idlers from the main plate are the same, a minimum of skew can be expected. Measurements have shown that split idlers can be very effective in reducing skew to a minimum; also, that alignment between machines can be very closely controlled. In addition to the split idlers, guides are provided directly at the head to keep the tape in line laterally. These

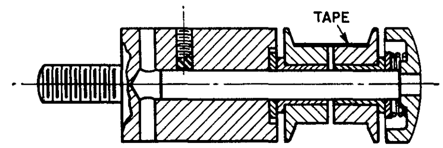


Figure 6. Split-idler pulley

guides are fixed and are an integral part of the head assembly.

Magnetic Head

The head itself is mounted inside a shield, which can be opened manually for inspection of the gap and threading of the tape. A push button located just above the head releases the head shield cover and lets it open upward. Figure 7 shows the magnetic head assembly approximately as the operator would see it. The shield consists of three layers of mumetal, copper, and mumetal, to provide both electrical and magnetic shielding. The erase head is visible to the left of the record-and-read head. This implies that tape moves from left to right when recording. The surface of the record-and-read head shows longitudinal slots which run almost the full length of the head, but are filled in the center portion by intertrack mumetal shields. These slots are no longer cut the full length, as shown, and thereby some dust and oxide accumulation is avoided.

The head cover is constructed on the 3-layer principle again and shows the pressure pad at the cantilever end of a leaf spring. Pressure is adjusted to

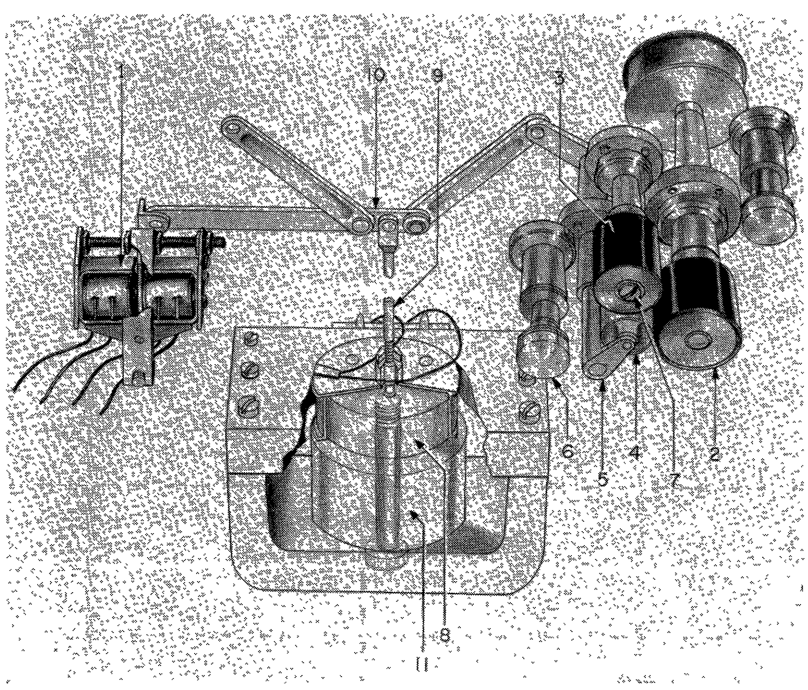
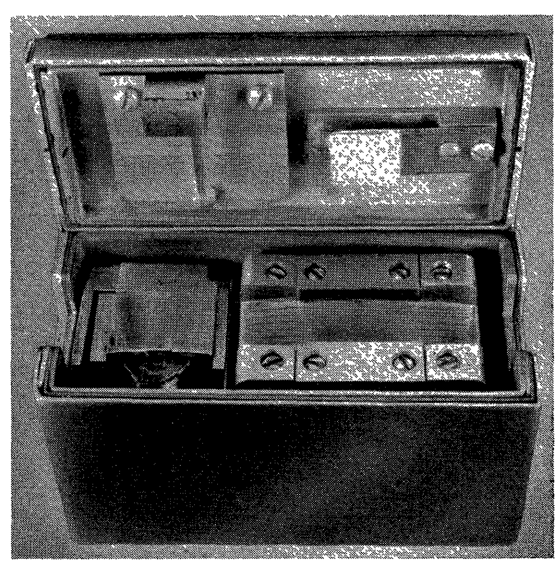


Figure 5 (left). Start-stop mechanism

Figure 7 (below). Magnetic head assembly



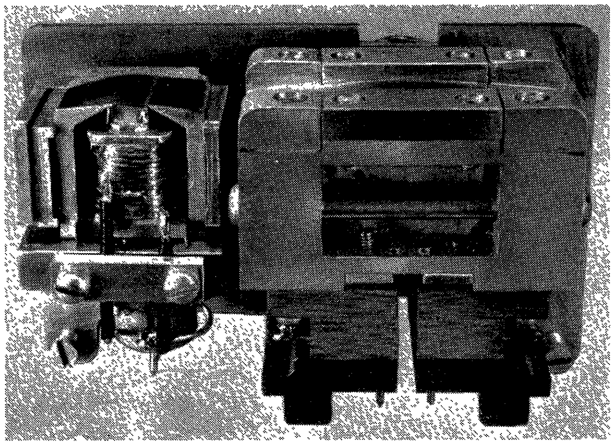
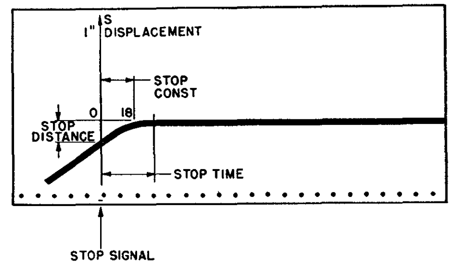


Figure 8 (left). Head assembly (shield removed)

Figure 10 (right). Typical stop picture



about 6 ounces by carefully bending or shimming the leaf spring. Since the top surfaces of the head form a 12-degree angle at the gap, which is rounded off to a radius of 1/16 inch or less, the pressure pad exerts maximum pressure at the gap. The pressure pad is displaced slightly to the left of center to give more pressure to the tape as it approaches the gap than when it leaves it. To the left of the pressure pad is the depressor rod. This is made of glass to withstand wear and cause a minimum of drag. It is located between the erase and the record-and-read head, and drops down below the head surfaces when the head cover is closed. Thus, it insures proper contact of the tape all along the head surface. Figure 8 shows the shield removed from the head assembly. The two heads are mounted to a common plate. This plate may be rotated about a vertical pin for alignment purposes. The hole that receives this pin is clearly visible behind the gap of the read-record head and in line with it. Alignment rotation is controlled by two screws at the bottom right and left corners of the mounting plate. As one screw is loosened, the other is tightened up, thus giving a positive lock. Adjustment is made while reading a master tape on which information has been recorded in the two outside tracks on a line perpendicular to the edge of the tape within 0.0002 inch. In this picture, some construction details are apparent. The head is essentially made of two symmetrical halves which are held together by horizontal studs in front and back. The two halves are held in alignment by dowels. The only parts not halved are the inter-track shields and the tape guides. Even the male plug at the underside of the head is made in two pieces. Therefore all electrical connections can be made before the two halves are joined.

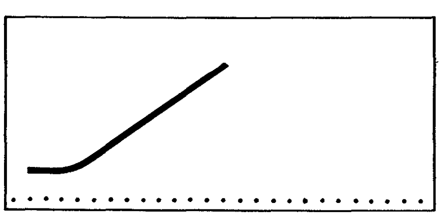


Figure 9. Typical start picture

The d-c erase head is of much simpler construction but it is also laminated. The small and large gaps of this head as shown in Figure 8 are the effective erase elements. The small gap saturates the tape in one direction and the leakage flux from the large gap is just large enough to return the oxide to zero magnetization. A small connector is mounted to the underside of this head.

Operation

Just above the head and close to each reel, two push buttons release the reel shafts so they can be rotated manually when loading a fresh reel of tape. Normally, the left or file reel would be replaced, whereas the right or machine reel would remain on the machine. To sense end-of-reel, a steel leader dimensionally similar to the tape is used at the bottom of each reel. This steel leader is grounded through the reel and the reel shaft. As the tape comes off each reel, it runs over an insulated aluminum roller and as the steel leader reaches it, a signal is transmitted to the machine. A typical operation when changing file reels (left reels) would be as follows. Tape is rewound from right to left. When the steel leader at the bottom of the right reel comes off and touches the right aluminum roller, the machine stops. After the head shield has been opened manually, the steel leader may be run beyond this position clear past the head by pushing a button, and it will come to rest again as it reaches the left aluminum roller. There, the tape is disconnected from the steel leader and the file reel removed. When a new reel is connected to the steel leader and a load button pushed, the tape is pulled by the steel leader through the mechanism up to the right aluminum roller, where it will stop. The head cover may then be closed and recording of information will start a safe distance from this point.

Performance

Performance of the production prototype has been very satisfactory. Since the unit has been operating largely in an air-conditioned room, problems arising from dimensional changes of the tape have been minimized. Precautions, as described in the foregoing, have been taken to allow for lateral expansion of the tape.

Stretching of the tape under tension is another potential source of trouble. This occurs most noticeably when accelerating the tape. At that time about 2 pounds of pull is exerted on the tape at the capstan. Consequently, the piece of tape between the capstan and the read station is stretched. When the tape has reached its nominal speed, the tension in the tape has become reduced and the stretched piece of tape may assume its original dimension. This contraction gives rise to a nonuniformity of speed at the read station. By keeping the capstan close to the read station, this effect can be minimized. Plastic tape shows this to a much larger extent than the stiffer paper tape.

In conclusion, some performance data should be presented. A nominal start time of 5 milliseconds has been attained. Start time is defined as the time from receiving a start signal to the time when the tape has reached its nominal speed of 75 inches per second without further speed variations larger than those normally encountered during steady running. Measurements of start time were made with a single dimension camera. This camera takes pictures of a point on the tape through a slit parallel to the motion of the tape, on film wound on a rotating drum whose axis is also parallel to the motion of the tape. In this way, a time-versus-displacement diagram is obtained on the film. A crystal-controlled timer provides a dot on the edge of the film every millisecond, and also a mark is made on the edge of the film when the start pulse is given. Figure 9 shows a typical start picture taken at a higher tape speed, 130 inches per second at the head. This higher speed accentuates the previously mentioned tape stretch. It indicates that the tape begins to move after 2 milliseconds, reaches full speed after about 3 milliseconds but, due to contraction of the tape at that time for a millisecond or so, it exceeds the speed at the capstan. The starting time for this picture according to our definition would be about 6 milliseconds. A corresponding stop picture is shown in Figure 10, also at a higher tape speed. Tape stretch will appear as a slight overshoot here but this is hardly noticeable. Stop time is 4 milliseconds. To get a more accurate picture of tape stretch during a start, dynamic tension measurements were made which confirmed the speed overshoot seen here.

Magnetic Tape Recording Techniques and Performance

H. WILLIAM NORDYKE, JR.

THE MAIN purpose of this paper is to present technical characteristics and performance data on the recording methods and equipment used in the production prototype-*701* Electronic Data-Processing Machine magnetic tape units.

Recording Techniques

The recording head longitudinally magnetizes the red oxide, plastic-backed magnetic tape in either of two saturated magnetic states. A binary information bit therefore changes the polarity of tape magnetization either from a positive saturation condition to a negative saturated state, or conversely. Figure 1 shows the relationship just described, where the y axis is the recording head magnetizing flux, and the x axis is time. This method of non-return-to-zero recording permits a greater output and a greater number of bits per inch on the tape than in systems using a return-to-zero method of recording.

Figure 2 shows how the computer information pulses are converted to changes of flux reversals in the recording head. Successive pulses flip the binary-connected trigger and alternately raise and lower the potential of point A. This change in voltage is sufficient to allow the switch tubes to be either on or off. If switch tube 1 is conducting, flux exists in a direction in the magnetic head as indicated. The core will continue to have this direction of magnetization until the next pulse is applied to the input of the binary-connected trigger. At this instant, the trigger flips, switch 1 is cut off, switch 2 conducts, and the direction of magnetization in the head core is reversed. Switch 3, which is a set of relay points in type *701*, is for the purpose of switching both tubes 1 and 2 off. Under the off condition, switches 1 and 2 act as open circuits, except for tube capacitances, thereby permitting the same coil windings to be used for reading. The time required for switching tube 1 off and 2 on is of the order of 2 microseconds. The fringing of the head gap is such that $d\phi/dx$ is relatively independent of tape speed. Here

x = distance along tape
ϕ = remanent fringing tape flux

Each switch tube, when conducting, permits approximately 10 milliamperes of current to flow through the head windings. This results in a magnetizing force of 4.3 ampere-turns. This magnetomotive force is sufficient to saturate the tape even though it is separated from the recording head gap by as much as 1 mil. The inductance of the head is 20 millihenrys per coil at 1,000 cycles per second.

Figure 3 illustrates the block diagram of the read amplifier together with clipping and shaping circuits. The same coil windings are used in reading as in writing, and points C and D are the same points as shown in Figure 2. At the standard tape speed of 75 inches per second, this head develops an output voltage of 75 millivolts peak-to-peak across two coils in series, each having 430 turns of number 42 wire. This gives an output of 87 microvolts per turn for the standard 32-mil track width. For lower tape speeds a transformer is used to couple the head to the amplifier input and thereby keep the voltage to the amplifier input relatively constant.

The input pulses at points C and D have a pulse width of approximately 20 microseconds if measured at the standard tape speed of 75 inches per second. This corresponds to a distance along the tape of 1.5 mils if measured at a pulse amplitude equal to 20 per cent of the maximum amplitude. If measured at the 10 per cent point, the pulse width becomes about 35 microseconds or 2.5 mils along the tape length. If reduced amplitude writing currents are used, considerably narrower pulses may be obtained. However, in view of present operating condi-

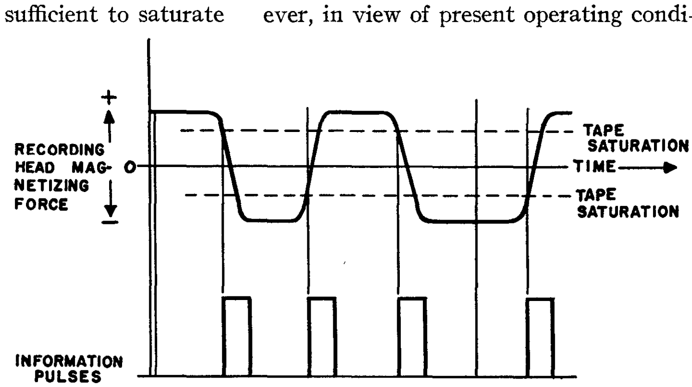


Figure 1. Non-return-to-zero reading

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