INTRODUCTION

The development of the electronic data processor has far outstripped similar developments in peripheral devices that feed, store, and receive data from the central processor. This imbalance has resulted in overall systems whose capability, performance, and size is primarily limited by the peripheral or ancillary devices. While a factor in commercial applications, these shortcomings are particularly serious for equipment that must operate in military environments, under the control of military personnel. The Army and Navy, and their suppliers, have learned through experience that commercial or semi-militarized equipment will not operate reliably, nor can it be readily maintained under these conditions. These problems, when coupled with the severe size and weight limitations placed on transportable equipment, provided the impetus for this development program.

Since 1956, the Navy has been developing large-scale data processing systems for command and control applications. During this time the Navy has played an important role in advancing the state-of-the-art in this field, particularly in the area of militarized equipment.

This period of time has seen the shrinking of the central processor from a room-sized, vacuum tube machine to a table-top size, microelectronic unit. It has seen the reliability improve from a 30-hour mean time between failure (MTBF) to the 1500-hour MTBF currently being achieved in the CP-642A shipboard computer. It has not, however, seen comparable improvements in size and reliability of computer peripheral equipment.

Since the Navy is dependent on tape transports in most of its computer installations, it has been acutely aware of the need for highly reliable tape transport. The Navy has utilized automatic tape testing, ultrasonic tape cleaning, and special test equipment to improve the system “down-time” caused primarily by tape transport failures.
The U. S. Army has also been a large-scale user of data processing equipment. The variety of uses to which the computer systems have been placed such as stock control, intelligence evaluation, fire control, personnel management, etc., dictated the necessity for developing equipment capable of operating over a wide range of environmental conditions. The mobility and flexibility of the Atomic Age Army require lightweight, small, and easily maintainable equipment packages. The Army's experience in interim use of commercial or semimilitarized data processing equipment has served to pinpoint the need for using fully militarized equipment whenever there is a requirement for mobility or even a slight deviation from a commercial environment.

The Army began its militarized computer system development in 1958 with the Fielddata family of computers (MOBIDIC, BASICPAC, etc.). The peripheral equipment development commenced at the same time and has been directed towards a group of peripheral devices that are completely interchangeable within the family. The early portion of this program was fraught with many problems. Nevertheless, this experience formed the basis for the writing of a detailed description of Army requirements in a militarized tape transport.

As a result of this experience, in 1962 both the Army and Navy embarked on individual programs to improve the performance and ruggedness of tape transports.

Stimulated by the needs of the services for militarized peripheral equipment, demonstrated by their own experience as prime contractor for the Army's Mobile Digital Computer (MOBIDIC), Sylvania in 1960 undertook a company-sponsored research and development program to identify the peripheral equipment problem areas and to initiate programs to solve these problems. The initial study clearly indicated that the magnetic tape transport systems should be the initial point of attack. A program to establish the particular specifications and requirements, and to carry out research and development in significant technical areas was established. Among the major areas of initial study and development were the following:

a. Tape drive methods to meet military computer requirements.
b. Tape loop buffering and tape supply and take-up control.
c. Recording and playback techniques, systems, and circuits.
d. Data reliability and error detection and correction methods.
e. Capstan speed control and synchronizing methods.
f. Operational features of human and machine handling of the tape medium.
g. Mechanical and electronic packaging methods for size and weight reduction.

In mid 1962, as a result of this development program and in response to requirements defined by the Army and the Navy, Sylvania was awarded contracts to deliver service test models to the two services.

GENERAL DESIGN OBJECTIVES

The general objectives defined by the Army and Navy specifications were quite similar except where each service had operating requirements peculiar to its own mission.

The major common design objectives were the following:

Improve Reliability and Performance by:

a. Elimination of human handling of the recording medium.
b. More positive machine control of the recording medium.
c. Major reduction in tape loading time (cartridge and automatic loading).
d. Major reduction of critical machine parts by simpler design.
e. Increase in effective data handling rates (less tape skew).

Improve Operational Simplicity and Program Flexibility by:

a. Designing foolproof tape loading and unloading procedure.
b. Increase flexibility through duplexed or time-shared elements.
c. Elimination of programming restrictions reflected by low dynamic machine response.

More Effective Design Utilization of Space by:

a. Reducing system inertia loads (storage reels and prime movers).
b. Reducing power and air-cooling requirements.
c. Increasing packaging density of electronic and mechanical components.

There were two major Navy design requirements not shared by the Army. First, the individual transport must be small enough to fit through a standard shipboard hatch. Second, the machine had to withstand, while in operation, the shipboard shock and vibration caused by high-energy underwater explosions close to the hull of the ship. Such a "near miss" explosion causes severe shock peaks and causes the ship structure to go into vibrational modes. The Navy requires that the equipment while operating, be tested on test equipment designed to simulate these conditions.

The Army specification has one requirement that is unique among requirements for digital tape transports. It has been determined that a data link channel is necessary for communications between computers. In a field situation, it is probable that this data link will have a bandwidth similar to a normal voice communications channel. To transmit over this narrow bandwidth channel the data rate must be reduced from its normal 45,000 characters per second to 300 characters per second. The magnetic tape transport was selected to provide this facility. The buffering equipment between the tape transport and the transmitting device has a 30-character memory. Thus, as a safety factor, transmission into and out of the buffer must be synchronous, within \( \pm 12 \) characters per block of data. Data must be recorded at 30.0 characters per second and be readable at the higher rate and vice-versa; conversion of a transport to or from low-speed mode must take less than one hour.

**Army and Navy Technical Requirements**

Although procured under separate R & D contracts, the Army and Navy Tape Transports are similar in their operating characteristics. Table I summarizes these characteristics and shows both Army and Navy specifications.

**OVERALL SYSTEM DESCRIPTION**

The basic tape transport module without the cartridge dust and RFI cover is shown in Figure 1. The Army and Navy models are physically similar but have a number of operational differences. As illustrated, the tape is contained in a pre-loaded cartridge. The operator simply plugs the cartridge into the opening in the front panel and presses the tape load control. The balance of the loading and threading cycle is completely automatic under machine control including locating the tape at the beginning-of-tape marker. Total loading and threading time will not exceed 10 seconds. The cartridge can be unloaded and removed at any time in the computation cycle without rewinding the tape. Rewinding under controlled tension is provided by an off-line rewind device.

The physical characteristics of the basic tape transport module are:

a. Height: 21\( \frac{1}{4} \) inches
b. Width: 17\( \frac{1}{4} \) inches
c. Depth (overall): 22\( \frac{27}{2} \) inches
d. Weight: 340 pounds

The Tape cartridge physical characteristics are:

a. Height: 16\( \frac{3}{8} \) inches
b. Width: 1.660 inches
c. Depth: 8 inches
d. Weight (with tape): 6.6 pounds

When withdrawn on its slides, access to the major electronics elements is provided by the openings on the right side of the electronics package mounting door as indicated in Figure 1. Access to the other electronic packages, in-
terconnection wiring, and mechanical and electromechanical elements is provided by swinging the electronic package mounting door out of normal position as illustrated in Figure 2. The tape metering drive elements and maintenance control panels are accessible from the opposite side of the main deck.

Tape drive and rapid start-stop is achieved by the use of a pressure clamp air blanket coupling the tape to the counter-rotating capstan on command. Excess loop tape buffering is controlled by a 13-inch vacuum well with continuous photo-cell tape position sensing.

All mechanical motions associated with the automatic threading and loading are performed by pneumatic actuators under control of the rotary central control pneumatic valve. By performing the high-speed tape drive functions and all mechanical motions with air pressure, only a single air source is required rather than both vacuum and pressure sources as would be required with a vacuum capstan machine.

Tape transport modules can be arranged in different combinations to fit particular applications and data processing system requirements. Figure 3 and 4 illustrate two particular system arrangements being provided. Figure 3 represents a four-module Navy system with integral compressed air source, cooling air distribution system, power control panel, and logical tape transport selection and decoding matrix. The system is designed to operate during shipboard
shock and vibration. The cabinet can be disassembled for loading through shipboard hatchways.

Figure 4 shows a two-module Army system with an integral air source. A structural rack adapter is provided to permit the system to be mounted in a 56½ inch vertical opening in a standard 19-inch panel mounting configuration. Cooling air pressure and volume is provided externally. This permits either mounting the tape system and adapter to standard 19-inch rack structures, built as integral with a shelter structure, or into a cabinet as shown in the illustration.

General Approaches to Meeting Specification Requirements

1. Error rate not to exceed one character error in $10^7$ characters read-in Army system. This is achieved by the pneumatic handling of the tape, built-in single bit error correction and specialized read-write circuit and magnetic head design.

2. Data rate capability for the Army system of 45,000 and 300 character per second. At the 300 characters per second read mode, the number of characters read out cannot deviate from the number of cycles of the 300 cycle external synchronizing frequency during the same period by greater than $\pm 12$ characters in any one block (maximum block length to be 35,810 characters). This is accomplished by providing a 150/1 difference in tape drive speed with high speed (45,000 char/sec) at 100 inches per second, 450 bits inch and low speed (300 char/sec) at $\frac{3}{4}$ inches per second, 450 bits per inch. At low speed read, the capstan drive speed is continuously controlled by a comparison of the data read from the tape and the synchronizing signal, increasing or decreasing the tape speed to stay within the $\pm 12$ characters tolerance. Special read head and circuit techniques are utilized to maintain proper signal-to-noise ratios at the low speed.

3. Capability for 45,000 or 90,000 characters per second operation or dual 45 KC redundant required by the Navy system. This is accomplished by providing a 16-channel system at 450 bits per inch, 100 inches per second. The redundant 45 KC recording can be utilized in an automatic error correcting system which is provided in the external Tape Control System.

4. Normal operation during shock and vibration. This is accomplished by the structural rigidity of the basic machine and cabinet, the non-critical adjustment design approach and low dynamic sensitivity of the drive system and the use of a tailored shock isolation system to reduce shock levels transmitted to the tape transports.

5. Operational simplicity. This is provided by the cartridge loading and automatic threading where the operator does not handle the tape and performs no intricate threading operations.

6. Reduced size. High density electronic and mechanical packaging are used to reduce volume. The vacuum well is reduced to about $\frac{3}{4}$ of conventional length by reel-servo control techniques.

7. Reduced tape wear. The only contact between the tape oxide surface and any fixed or moving surface is at the magnetic head. In addition, the stresses on the tape introduced by high tensile and compressive forces associated with normal pinch roller drives are eliminated by the pressure clamp approach.

8. Improved maintainability. By the use of modular design, all electronic sub-units are readily replaceable. Test points and an internal maintenance control panel are provided. All mechanical sub-assemblies are readily accessible and minimum adjustments are required.

SIGNIFICANT TECHNICAL DEVELOPMENTS

A brief technical discussion of four of the more unusual technical developments associated with the tape transport is provided below.

Pneumatic Pressure Clamp Tape Drive Method

Tape is normally imparted its high-speed acceleration, deceleration, and running forces by the use of dual counter-rotating capstans.
The tape is maintained out of contact or in light contact with the capstans during non-drive. One of the following methods is normally utilized to marry the tape to the capstan causing rapid acceleration of the tape to the capstan surface speed.

a. Electromagnetically actuated pinch rollers.

b. Vacuum introduced into the capstan to draw the tape to the capstan.

Or a single capstan in constant contact with the tape may be utilized.

After evaluating and testing models of the various approaches to rapid acceleration-deceleration of magnetic tape and equating them against the military environments, it was concluded that pneumatic drive techniques offered the best potential for the planned militarized application. Extensive experience with pinch-roller type machines in semi-military environments indicated that the device reliability and tape stresses induced would be undesirable in the military application. Vacuum drive systems required an additional vacuum source and a precision rotary joint that would be susceptible to damage in the dust environment. The study and subsequent tests also indicated that a unique pneumatic drive utilizing pressure rather than a combination of vacuum and blow-off pressure would provide the optimum drive.

The operation of the pressure clamp drive is illustrated in Figure 5. A capstan surface was developed that provides a self-generating film of air (hydrodynamic) during periods of non-motion of the tape. The surface is also designed to permit rapid collapse of the air film under external pressure. To drive tape, air pressure is rapidly introduced through a slotted manifold surrounding an arc of the capstan, which forms a blanket over an approximate 80° arc of the capstan, collapsing the capstan-tape air film and forcing the tape into contact with the capstan. The result is a smooth, controlled start with no overshoot or excessive instantaneous accelerations, as shown in the Figure 6 upper start oscilloscope picture. The tape is not sub-

![Figure 5. Sylvania Pneumatic Tape Drive.](image)

![Figure 6. Start-Stop Characteristics.](image)
jected to excessive tensile or compressive forces. Approximately ¾ millisecond is re-
quired for the valve actuation and air propaga-
tion and 1½ milliseconds is required for the
tape to come from the stopped position to full
operating speed. The total start time is, there-
fore, approximately 2¾ milliseconds. The
mechanism for accomplishing the tape start is
amazingly simple with the only moving part
being the high-speed magnetic valve disk. The
high-speed pneumatic valve, which was a major
development under this program, has been re-
duced from the original 2½ inch diameter by
5-inches long valve to the “mini-valve” shown
in the lower right of Figure 7 which is approxi-
mately ¾-inch diameter by ½-inch long, while
increasing speed and life. The moving element
is a simple magnetic iron disk ½-inch by ¼-
inch thick. Driving is accomplished by apply-
ing a shaped current pulse which first applies
a short duration high current peak for fast
action followed by a low current steady hold-
ing level to the magnetic coil terminals. The
magnetic disk is drawn about 0.014-inch to the
coil against the air pressure, opening the output
air path and releasing compressed air from an
accumulator at approximately 35 psi into the
manifold and through its distribution system
to the tape surface. There is no adjustment
required and valves have been operated more
than 100 million cycles without failure. To stop
the tape drive, the power is simply removed
from the valve. The air pressure forces the disk
back onto the seat, cutting off the drive air. The
built-in tape path system friction plus a con-
trolled vacuum tape drag, adjacent to the head,
brings the tape to a rapid, controlled stop with-
out the need of additional braking. The stop
characteristic is shown in the lower view of
Figure 6. This also provides a fail-safe ar-
rangement in that unplanned loss of power
causes both valves to be forced into the stop
condition by the residual air pressure prevent-
ing simultaneous drive in two directions.

The complete valve, manifold, and capstan
assembly is illustrated in Figure 7. The valve
coil is in the lower right with the valve body
above showing the air inlet hole. The air con-
trol disk is in place in the valve against its
O-ring seat. Above the body can be seen the
manifold with a radius matching the capstan
radius. The air distribution slots are directly
below the opening for the valve. A relationship
of approximately 0.003 inch is maintained be-
tween the manifold and the capstan. A major
requirement of the capstan surface is its ability
to quickly regenerate an air film between itself
and the tape mylar surface when drive pres-
sure is removed and, conversely, allow rapid
collapse of the air film when drive pressure is
applied. Following a theoretical aerodynamic
analysis of the relationships between the valve,
manifold, tape and capstans, a variety of sur-
faces were investigated. The surface shown
provided the proper characteristics and offered
lower production costs.

Cartridge Tape System with Automatic
Loading and Threading

A major problem in the utilization of mag-
netic tape is its handling during loading,
threading, and unloading from the tape han-
dling mechanism. Mishandling of the tape dur-
ding this operation is one of the major causes
of tape errors. The threading requires good
operator dexterity. This condition is aggra-
vated when the operation is carried out by
military personnel in a less than perfectly clean
environment. A second factor involves the loss
of machine availability during the load, thread,
unload, and rewind cycles.

Utilizing a preloaded tape cartridge with the
tape ends semi-permanently attached to the in-

Figure 7. Exploded View of Capstan, Manifold,
and Valve.
ternal reels eliminates the handling problems, significantly reduces the load and unload times, excludes the necessity to rewind the tape prior to removal and requires no operator skills. In addition, the tape in the cartridge is protected during external handling and transportation. The preloaded cartridge with 7½ inch diameter reels containing 1200 feet of 1½ mil tape or 1800 feet of 1 mil tape one inch wide is shown in Figure 8. A snap-on dust cover is provided to protect the tape during handling while it is out of the machine. The fully automatic control system for operating the cartridge operates as follows.

The compressed air source for the tape drive is also used to provide the pressures and motions required to automatically load and unload tape. The mechanical functions performed are as follows:

a. Disengage reel from cartridge and force it into driving contact with reel servo drive motor.
b. Shuttle magnetic head and manifolds out of the tape path during load and unload and back into position during normal tape operation.
c. Move head up and down to remove it from contact with the tape during shuttling and high-speed rewind.

A pre-programmed rotary pneumatic control valve was developed to carry out the above controls in minimum space, with maximum reliability and providing positive interlocking to prevent simultaneous or out-of-sequence operations. Linear, pneumatic actuating cylinders are utilized to perform the motions. A schematic diagram of the air control and motion operations is shown in Figure 9. The central control valve less its front cover, rotary stepping solenoid, and wafer controls switch is shown in Figure 10. The grooves on the spindle provide the air switching between the inlet and outlet ports on the periphery. Each operation rewinds the application of pressure to one side and exhaust to the other side of a pneumatic cylinder. Head up-down positions are controlled by the linear solenoid on the left end of the valve shifting the spindle axially. This allows head up during high-speed rewind and return to normal without changing the load-unload sequence of the valve. During operation, the pressure is maintained on the proper cylinders to hold them firmly fixed in position. The cartridge load and control functions are as follows:

a. Inserting the cartridge fully into the front panel recess causes a mechanical latch to lock it in against accidental gravity release and switches sense proper seating.
b. Operator presses front panel automatic load control and machine control takes over and performs the balance of the load functions automatically as follows:
c. Air pressure applied to reel load cylinders separates the reels from the cartridge brake and couples them positively to the servo motor.
d. The reel servo torque motors then slowly feed tape off the reels into the vacuum well until the tape loop is properly sensed by the photocells at the central position in the vacuum well.
e. Air pressure is then applied to move the head and manifold shuttle forward, positioning the head in its precise position above the tape.
f. The rotary valve spool is moved axially to locate the head down to the proper contact angle with the tape.
g. Completion of the head down position signals the machine control system to...
energize the "locate Beginning-of-Tape sequence circuit" and closes the reel servo control loop.

The locate Beginning-of-Tape sequence circuit first drives the tape forward briefly to assure that the beginning-of-tape marker is past the position sensor and then in the reverse direction until the precise beginning-of-tape mark is located. At this point, the Tape Ready front panel indicator lights and the transport control is switched to remote control (computer or tape control unit). This total operation takes approximately ten seconds, plus actual rewind time.

The unload cycle operates essentially in reverse of the load cycle and can be initiated at any point in tape use without rewinding tape.

The Capstan Control System

General Requirements

For normal computer data handling operation (as well as during low-speed data transmission) the synchronous capstan motor is powered by a magnetic frequency standard and a power amplifier. (Low-speed capability is achieved by replacing the capstan motor with a motor-gearhead, a minor field-change.) The capstan must move tape at 100 ips ± 1 percent, irrespective of the computer program, and therefore the capstan motor speed must be constant, well within one percent. Since load disturbances occur each time tape motion is started or stopped, electronic means were developed to anticipate and damp-out the resultant speed variation. For low-speed operation, the capstan must operate at 3/4 ips with read data synchronized to the data terminal reference signal.
Description of High-Speed Capstan Control

The synchronous capstan motor acts as a torsional spring. That is, a variation in load torque (caused by starting or stopping tape) requires a corresponding variation in torque angle (the angle between rotor magnetic field and the stator rotating magnetic field) before the motor can provide the called-for load torque. This spring action, together with the total inertia of the motor and capstan-drive system comprises a mechanical resonant circuit, essentially undamped. When the load disturbances occur, a train of oscillations results, continuing until the motor settles at the new torque angle. One technique for reducing the effect of transient loads is to use a large flywheel. It was not possible, however, to design the required inertia into a device of reasonable size. Also, a large flywheel makes it difficult to achieve rapid re-wind speeds. In the Sylvania magnetic tape transport, these oscillations are minimized by stepping the stator magnetic field to the new torque angle, and damping (electrically) any residual disturbances.

Stepping the stator magnetic field is accomplished by advancing the phase of stator excitation as load is increased, and retarding the phase when load is removed.

Damping is accomplished by an additional phase-shift, proportional to change in motor speed, sensed by a tachometer.

Phase-shifts are generated in a delay multivibrator, whose timing is controlled by an amplifier. Amplifier inputs are tachometer variations and Forward or Reverse commands.

Description of Low Speed Capstan Control

The specific requirement of the low-speed capstan servo is to match the data-rate read from the tape to the 300 pulse per second data terminal clock to within ±12 characters in a maximum block of 35,810 characters. This tolerance is dictated by the 30-character buffer in the data terminal and provides a ±3 character safety margin. The servo, then, strives to maintain a one-for-one relationship between "clock-in" and characters read by adjusting tape speed. It corrects for both short and long-term effects of tape slippage, tape-dimension changes, recording speed variations and any other errors that result in a variation in the data-storage density on the tape. The servo is designed to compensate for such variations up to a maximum of ±3 percent of nominal data rate.

A block diagram of the speed-control loop is shown in Figure 11. A small synchronous motor is used to drive the capstans through a gearhead. The speed of the motor-gearhead is closely controlled by the frequency of its drive power. The synchronous motor is of the hysteresis type. Although these motors are relatively inefficient, they are particularly useful for this application in that they supply a relatively constant torque all the way up to synchronous speed, and very good damping at synchronous speed. These characteristics make it possible to accelerate the motor by slowly changing the power frequency without loss of synchronism or introduction of phase oscillations. Should the motor lose synchronism, it

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Figure 11. Capstan Servo Block Diagram.

From the collection of the Computer History Museum (www.computerhistory.org)
will simply accelerate until synchronous speed is regained.

The rate of the data pulses from the tape reader is proportional to tape speed. Close control of the data rate could be achieved simply by keeping the frequency of the motor power constant except that data spacing on the tape does vary from normal as outlined above. These variances cause disturbances as indicated in Figure 11. The purpose of the closed-loop control is to compensate for the effect of these disturbances, since a close tolerance is required on the data rate when the recording system is transmitting its data via the data terminal.

Closed-loop control is achieved by letting the input synchronizing pulses serve as a reference for tape speed. This is done by comparing the synchronizing pulses and data pulses in an up-down counter as shown in Figure 11. The counter will store a number which increases or decreases depending on an excess of deficit, respectively, in data rate. By means of circuits, the stored number is used to increase or decrease the motor speed to achieve a data rate exactly equal to the input synchronizing rate.

The electronics include a digital-to-analog (D/A) converter which converts the count into a d-c voltage. This voltage is added to a reference voltage in a d-c amplifier which is used as a buffer to provide the necessary impedance level and stability to control the frequency of a voltage-to-frequency (V/F) converter. This converter is an electromagnetic device with an extremely linear V/F transfer characteristic. The output of the V/F converter is raised in a power amplifier to a sufficient level to drive the synchronous motor. Linearity and drift in the electronics is kept within a close tolerance to minimize these additional disturbances. Any small drift in the V/F converter frequency will be quickly compensated for by the integrating action of the up-down counter. The asynchronous-to-synchronous converter in front of the counter is used to synchronize the asynchronous tape and reference signals. This prevents race conditions in the counter.

**Reel Servo System Requirements**

a. To follow any sequence of commands supplied to the tape without exceeding the limits of the vacuum well. (Approximately 10 inches working length.)

b. To operate without excessively accelerating or decelerating tape on the reels to the point where tape damage could result. A maximum acceleration or deceleration of 3000 in./sec/sec was established.

c. To operate with motors of minimum size and power requirements.

d. To be capable of very slow open loop operation for load and unload.

e. To be capable of double speed operation for rapid rewind.

**General Description**

The reel servomechanism is a Type 1 control system. That is, a constant rate-of-change of tape position (at the reel) requires a constant tape-loop error-position in the buffer well. This type of control, utilizing tachometer feedback (characterized according to diameter of tape on the reel so that feedback is tape speed rather than motor speed), was chosen to allow the tape-loop excursion (during a capstan reversal) to encompass the whole buffer well rather than half the buffer well as would occur with a position servo. This choice results in halving the required torque, so that the reel servo motor (torquer) is little more than half the size of that for a comparable position servo. It uses half the power and subjects the tape to smaller acceleration, thereby preventing tape damage.

The choice of a Type 1 servo, in combination with controlling the motor through a bilateral-switching power amplifier, results in the optimum servo; one that performs the control function in a minimum buffer well using minimum power. A block diagram of the reel servo is shown in Figure 12.

**Error Sensing**

a. Position Error. The amount of tape reserved in the vacuum buffer well is sensed by an array of photoconductors, equally spaced along the length of the buffer well, connected in a bridge circuit (see Figure 13), and illuminated by lamps similarly spaced on the opposite side of the well. Since the magnetic tape is opaque to visible light, the number of photoconductors illuminated is determined by the position...
of the tape-loop in the buffer well, fixing the amount of current flow into a summing resistor. The voltage drop across the summing resistor, then, is proportional to the tape-loop position, and is called the position-error signal.

b. Rate Error. Tape speed at the reel is not easily sensed, and therefore, is computed from the product of reel shaft speed and the radius of tape on the reel.

Reel shaft speed is sensed by a DC tachometer mounted integrally with the reel torquer, whose output is a DC potential directly proportional to shaft speed.

Radius of the tape on the reel is sensed by an array of photoconductor illuminated via fiber optics (see Figure 14) whose input faces are located between the reel and the buffer well. The fiber optic faces are sequentially masked from their source of illumination as the tape content of the reel increases. Masking of the illumination causes individual photoconductors to act as an open circuit, sequentially disconnecting characterized resistors from the tachometer circuit, so as to multiply the tachometer signal by the tape radius. This product is called the Rate Error Signal.

The error amplifier is a direct-coupled amplifier that uses internal series voltage feedback to stabilize gain. Inputs to its first stage, a differential amplifier, are position-error signal, rate error signal, and zero-level correction.

A magnetic amplifier, controlled by the error amplifier is used as a pulse-width modulator to control the power stage. The latter consists of
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Pairs of cascaded switching transistors which connect either +30 or -30 volts to a smoothing filter at a switching rate of 4KC. The pulse-width modulation causes the output of the filter to vary in amplitude and phase as required to control the direction of rotation and the torque of the reel motors. The reel motors are DC torquers, with permanent-magnetic excitation rated for peak speeds of 1300 rpm and peak torques of 567 inch-ounces.

A current-limiting loop limits the maximum motor torque so that tape cannot be damaged by excessive accelerations.

Servo Operation

Utilization of the reel servo motors at low speed during the automatic loading, threading, and unloading has been described earlier. The following describes the operation of the reel servo for normal tape running.

When the Start button is pushed, the reel motors operate in open loop in a sequence that threads the tape into the transport. Subsequent operation is under the command of the computer. The reel speed is slaved to the capstan tape feed. The only error sensing in the system is the position loop, which gets its signal from 26 photocells spaced along each buffer well. After the tape is prepositioned in the well according to direction, any change in tape position creates an error signal which appears at summing point A. (Refer to Figure 12.)

Because the tape speed is constant and the reel diameters vary as tape is paid off and taken up, it is necessary to apply correction to the reel tachometers. This is done by the fiber optics above the wells which sense the tape radius. The signal they generate modifies the tachometer output. The resultant is then fed back to summing point B. A computer command to stop or reverse will create a large error signal which in turn would cause excessive acceleration leading to tape damage. A non-linear feedback loop senses excess current and applies a signal at summing point C, opposing those from the position and rate loops to limit acceleration.

The dynamic braking capabilities of d-c motors are utilized to effect quick reversal. At the command for reversal, the motors act as if they are connected in series, dynamically braking each other; the current is limited to prevent excessive deceleration. When the motors come to rest, reverse polarity voltage is applied to accelerate. This method significantly reduces the power consumed during reversal, a reduction from 500 to 100 watts in this case.

CONCLUSION

In this paper, it has only been possible to present a broad picture of the technical developments of the magnetic tape system, and to describe, briefly, four of the significant technical areas. Future papers and articles will describe the details of such functions as read-write, error correction and detection, and machine control electronic and mechanical advances.

All major operating sections of the tape transport were built and tested during the development program. Two complete feasibility models of the electromechanical system were assembled and performance tested. The tests, which demonstrated that the design and reliability objectives were met included the following.

Data Reliability

In order to establish preliminary error rates, a tape transport, representative of the final tape handling and read-record head-tape relationship, was used to read and write complex blocks of data. Test data was provided and monitored by a complete computer simulator and error detection and recording system. Runs of 50 and 100 million error-free characters were achieved without the use of error correcting schemes. These results exceeded the design objectives by a factor of approximately two orders of magnitude.

Tape Wear

A tape life test was also run on the same tape transport. One block of data, containing the maximum number of Fielddata words and six different random characters, was written and then read during half a million passes over that block. At this point, the test was discontinued. The tape showed no signs of failure and the signal was down only about 10 per cent, a figure it reached early in the test run. In
addition, the error rate did not increase at any time during the test, nor did the head show any discernable wear.

**Low Speed Capstan Servo Speed Correction**

Integration tests on the low speed capstan servo were conducted to test its ability to correct for data timing errors. Errors in data positioning on the tape were recorded in varying amounts up to four percent. (The design specification was three percent maximum.) These errors were recorded under open loop with the tape at slow speed. When replayed under servo control, the accumulated error in bit deviation over the maximum block length was below the $\pm 12$ characters allowed.

**High Speed Capstan Speed Control**

To insure that the high speed capstan maintained tape speed of 100 inches per second, $\pm 1$ percent, tests were conducted taking advantage of the accurately known read-to-write head spacing. The write repetition rate was adjusted so that its period equalled the time it took for a recorded pulse to travel between the write and read head. Tape speed was then directly calculated from the spacing and the time, and under extensive testing, found to meet the specification.

**Reel Servomechanism and Tape Position Sensing System**

Utilizing the computer simulator and covering a range of worst case programming conditions, the reel servo system controlled the tape loop, keeping it within the confines of the vacuum well.

**Read-Write and Control Electronics**

All electronics were designed for worst case conditions, and operationally tested in preliminary form. These tests included high and low temperature operating extremes and high and low power supply voltage extremes.

**Equipment Status**

As of July 1963, fourteen tape transport modules, representing a variety of Army and Navy types had been fabricated, assembled, and were in the final test cycle. Twelve of these will be delivered to the services for operational tests and two will be retained by Sylvania for extensive reliability and performance tests.

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