INTRODUCTION

The trend toward increased speed and greater capabilities in computers has created the need for tape drives with increased data rate and decreased access time. The IBM Hypertape Drive (Fig. 1) was developed to meet these demands with the added objectives of increased reliability and automatic tape handling.

The Hypertape Drives, controlled by the IBM 7640 Hypertape Control Unit, can presently be used with the IBM 7074, 7080, 7090, and 7094 systems. The tape used is 0.1 mil oxide on a 1 mil Mylar* base; it is one-inch wide with 1800 feet on a reel. Ten tracks are written across the tape—eight for information purposes and two for error detection and correction. In alphanumeric mode, six of the information tracks are utilized per character. In packed numeric code, two 4-bit characters are written side by side across the tape (Fig. 2). The character density is 1511 per inch; tape speed is

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Figure 1. IBM 7340 Hypertape Drive with Automatic Cartridge Loader.

Figure 2. Hypertape Character Formats.
112.5 inches/sec. This results in an alphanumeric data rate of 170,000 characters/sec, or a packed numeric data rate of 340,000 characters per second with an average access time of 4.2 milliseconds and an average inter-record gap of 0.45 inch.

The drive utilizes a single fluid-coupled capstan to control the tape motion. The use of such a capstan greatly simplifies the tape path and makes possible the use of simple channel guides to give proper tape tracking and to minimize tape skew.

The tape tension supplied by the vacuum in the columns holds the tape tight around the capstan. Moving (or stopping) the tape is accomplished by moving both the tape and the capstan. The read-write head is the only component in the tape path that is mounted on the recording side. This head is hydrodynamically air lubricated; thus, the moving tape is separated from the head by a thin layer of air.

Transport Design and Cartridge

To achieve high reliability and automatic handling of tape, the tape is packaged in a cartridge; the height of the drive is kept low to facilitate the manual loading and unloading of the cartridge in the drive. Limiting the height of the drive posed restrictions on the length of the tape buffers and the tape reel control system.

The use of a cartridge satisfied the following objectives:
1. Minimization of tape load and unload time.
2. Unload without rewind.
3. Protection of the tape from damage caused by operating personnel or contamination by foreign particles.

The cartridge as shown in Fig. 3A houses the "supply reel", the magnetic tape, and a "take-up" reel in a dust-resistant environment. It is constructed such that the sides, back, and top (including handle) are assembled into one unit. The front cover of the cartridge is removable to permit reel replacement. This cover (Fig. 3B) pivots at the front top and is secured by two latches. The latches also furnish the cover closing pressure. A flat tension spring holds each reel against a rubber ring that serves as a dust seal and brake. The back of the reel hub contains teeth; the tension spring serves to keep them engaged to the machine teeth when the cartridge is transport oriented.

The tape transport accepts this cartridge (Fig. 4A), automatically opens the cartridge cover, engages the tape reels (Fig. 4B), and causes the tape to thread into operating position. Packaging both supply and take-up reels in the cartridge increases the capabilities of the drive by eliminating the need for rewind before unload. The tape can be unloaded at any position in the reel; then loaded at a later time to approximately the same location to continue processing or, if desired, it could be rewound on an off-line drive.
The basic dimensions of the cartridge, including the carrying handle, are:

- 17” long
- 10.2” high
- 2.2” wide

The cartridge is equipped with a file protect device (Fig. 5) that, by command, either manual or computer programmed, prevents writing on the tape. The setting of file protect by the computer causes a solenoid to depress a plunger, and the indicator will reveal the letters FP. The status of the device is readily apparent to the operator when looking at the rear of the cartridge. Once a cartridge has been file protected, it can only be removed from the file protect status manually under operator control with the cartridge removed from the transport.

**TAPE MARKS**

Processing of tape in a cartridge necessitates the presence of safeguards against completely unreeling tape off the reels. Therefore, tape prepared for usage on Hypertape drives has three tape marks which, besides defining the usable limits of tape, guard against tape reel run-off.

Two of the marks sense the (BOT) beginning of tape and (EOT) end of tape. They are located 15 feet from the physical ends with 1800 feet of tape between them. The third mark, which is referred to as (EWM) Early Warning Mark, is located 40 feet away from the EOT in the BOT direction.

When a reel of tape is installed in a cartridge, a few layers, up to or including BOT, are wrapped around the cartridge reel. No adhesive in any form is used to anchor the tape to the hub, since the increased thickness due to the adhesive results in embossing the layers of tape above it. Embossed tape has a detrimental effect on the read-write reliability.

The EWM marker is used to signal the computer that the end of tape is approaching. By locating it 40 feet from the EOT, almost \(\frac{3}{4}\) of a million characters could be recorded before the EOT is reached.

Each of the three tape marks consist of a row of holes punched in the tape as shown in Figure 6. BOT and EOT marks are made of 12 holes, 0.093 inches in diameter; no usable information can be stored on that section of tape. The EWM, on the other hand, is made of 23 holes, 0.040 inches in diameter, and is located between track 1 and the edge of tape. Thus it does not interfere with the recorded data.

Sensing of tape marks is done optically by the use of a lamp and photocells in each of three positions. The sensing station is located just below the data head. The lamps are fixed in the tape path, while the photocells assembly is moved to position with the head. The drive...
interlocks, in case of sense-unit malfunction, to guard against tape reel run-off.

**AUTOMATIC TAPE LOADING AND UNLOADING**

Factors that affect the ease of loading and unloading tape were carefully studied and were reflected in the design of the tape path shown in Fig. 7. Note the absence of rollers or bearings on the recording surface of the tape, and how the data head is the only surface touching the recording surface. During loading and unloading this head is retracted into the drive, away from the tape.

Automatic tape loading and unloading have simplified the operation of the Hypertape drive and drastically reduced the time needed to complete a load or unload cycle. The computer can start processing tape ten seconds after the operator inserts a cartridge in the drive.

The Automatic Cartridge Loader (ACL) feature further increased the capabilities of the drive and made it possible to load and unload cartridges into the drive automatically under the control of the computer.

A brief description of the load-unload cycles and the automatic cartridge loader follows:

**LOAD CYCLE**

To process a reel of tape, the operator places a cartridge in the drive and closes the pressurized housing door. This starts the automatic cycle by retracting the cartridge, meshing the reel hubs to the reel shafts, and opening the cartridge cover (Figure 4). The steps followed during the rest of the loading cycle are summarized with reference to Figure 8.

1. The right reel is braked while left reel lowers the tape into the left column (steps 0-3).
2. When tape reaches the tape-in-column switch, the left reel is braked and the right reel lowers tape into the right column (steps 4-6).
3. When tape in right column reaches the tape-in-column switch (step 7) two functions take place simultaneously:
   a) The auxiliary vacuum applied to the tape in the left column at point (A) is turned off. (This vacuum was applied at the beginning of the load cycle to guard against tape bottoming).

![Figure 7. Tape Path of Hypertape Drive.](image)

![Figure 8. Method of Tape Loading.](image)
b) Reel motion is under control of the reel servo system and tape in both columns is lowered to the center (step 8).

4. The data head is brought into the read-write position with the tape.

5. Tape is moved toward BOT for approximately one second, or until BOT is sensed, to guarantee having the EOT mark to the left of the mark sensor. After the tape load cycle is complete, the drive is ready to process tape under computer control.

UNLOAD CYCLE

The unload cycle is started by a computer command or by manual control and consists of:

a) retracting the data head, and
b) removing the tape from the columns by winding it on the right reel (the left reel is braked during this operation). When the end of the tape loop approaches the cartridge, the motor torque is limited to insure a safe tape tension between the two reels in the cartridge. The cartridge is then moved to the discharge position during which the reels are unmeshed and the cover is closed.

AUTOMATIC CARTRIDGE LOADER

In the standard Hypertape drive, the cartridge is loaded and unloaded manually by the operator. The Automatic Cartridge Loader feature (ACL) makes it possible to automatically change cartridges under the control of the computer within seconds, thus eliminating computer idle time caused by unavailability of operator.

The ACL consists of a unit which mounts on top of the drive and allows the sequencing of two cartridges automatically. The basic components of this unit are: three cartridge positions on one level, two moving arms that have the ability of advancing the cartridges from one position to the next, and an elevator that loads and unloads cartridges into the Hypertape drive.

The method of operation is seen in the sequence of sketches in Fig. 9. With cartridge A in use in the drive, cartridge B is in the ACL. When a "Change Cartridge" command is given, cartridge A is unloaded to the cartridge holder in the drive and the elevator of the ACL brings it up to its upper position. Next, both cartridges are moved forward a step. This leaves cartridge A in the discharge pocket and places cartridge B on the elevator's platform which lowers it into the cartridge holder of the drive.

Following this cartridge loading sequence, the tape drive takes over. During the processing of cartridge B, cartridge A can be removed, and another cartridge loaded in the ACL.

CAPSTAN DRIVE MECHANISM

A single clutched capstan is used to control the motion of the tape as shown in Fig. 7. Acceleration (or deceleration) of the tape is accomplished by accelerating both the tape and the capstan assembly. The tape is kept from slipping over the capstan surface by wrapping the tape 180° around the capstan, using one pound tape tension, and by covering the capstan surface with a thin layer of grooved rubber.

The mechanism that controls the motion of the tape and capstan was designed in a single subassembly, as shown in Figs. 10 and 11.
sealing of this area prevents loose wear particles from entering the tape compartment. To eliminate the problem of flexing a rigid shaft during this operation, flexible couplings are mounted on the rubber roller shafts. Flywheels are mounted on the drive roller shafts to minimize speed variation due to high start-stop ratio. A two-speed synchronous motor belt drives both the forward and reverse drive roller shafts and produces tape speed of 112.5 in/sec. for normal operation, and 225 in/sec. for high-speed rewind.

Fast starts and stops were produced by the mechanism described; however, it was necessary to minimize tape vibration and overshoot. This was accomplished by unique design of the capstan which has a layer of fluid between its tape driving surface and drive wheel shaft. The reasons for and contributions of this unique design follow.

FLUID-COUPLED CAPSTAN

In the early stages of development, when a solid (non-viscous) capstan was used, the start back end of the capstan (drive wheel) is surrounded by three rubber-covered rollers, two of which are continuously running and give forward and reverse motion; the third is stationary and is used to stop the capstan. The rollers are brought in contact with the capstan's drive wheel by the action of moving coil actuators.

To execute a start operation, the forward or reverse roller is brought in contact with the drive wheel while simultaneously retracting the stop roller. All three rubber rollers act on one common surface away from the tape; proper time to 112.5 in/sec. was less than the specified 3.0 milliseconds. However, extreme tape velocity variation occurred at the data head after the above velocity was initially reached. The damped periodic variation was as much as 30% above and below the nominal velocity. Stop times were also within specification, but periodic oscillations around zero velocity were present.

Experimental analysis of the system showed that the velocity variation was mainly due to:

a) Excitation of the natural frequency of longitudinal vibration of the tape.

b) Excitation of the natural frequency of torsional vibration of the capstan assembly acting as a free shaft with an inertia on each end.

c) Torsional vibration (overshoot) of the capstan assembly due to elastic torsional deformation of the drive-roller rubber and drive shaft during capstan acceleration.

d) Undamped vibration of the drive roller actuator arm which caused the roller to repeatedly lose contact with the drive wheel.

Due to the complexity of the vibrational system (several mass, spring and damping elements) and the discontinuous forcing functions, a largely experimental approach was taken to the analysis and reduction of the velocity variation.

The problem was divided into two parts; the first consisted of controlling the actuator arm and roller bounce away from the capstan's drive wheel without affecting the short transfer time. This was successfully accomplished by using rollers covered with \( \frac{7}{8} \) nitrile-base rubber of 85-90 Durometer hardness, and by controlling the actuator current pulse as described in the section on actuators.

The second part, which consisted basically of excitation of the natural frequency of the tape in the column, proved to be one of the major technical problems in the Hypertape drive.

Analysis showed that the torque pulse as applied by the drive roller to the capstan dropped sharply when the roller surface and capstan speed became equal. The sharpness of this drop is above the natural frequency of the tape in the column and excited it into vibration. Theo-
Theoretically, the response of a spring-mass-damper system acted upon by a pulse-type forcing function is largely determined by the pulse's shape, amplitude and duration. Generally, the smoother and more symmetrical the pulse, the lower the amplitude of the residual vibration. Thus, modification of the torque pulse was necessary to control the vibration.

Based on the above, a successful solution was obtained by decoupling of the tape and its driving surface from the rest of the capstan by a fluid coupling. The use of such a coupling appropriately changed the shape and amplitude of the input torque pulse applied to the drive surface, and thus eliminated the velocity variation due to the longitudinal vibration of the tape and reduced the variation caused by other sources. Typical tape velocity vs. time curves before and after using the fluid coupled capstan are shown in Fig. 12.

Figure 12. Fluid-Coupled Capstan Versus Solid Capstan.

The fluid coupled capstan as shown in Fig. 13 has a thin layer of silicon fluid separating the tape driving portion of the capstan (capstan's front end) from the capstan shaft and drive wheel; thus, the capstan's front end can rotate with respect to the drive-wheel shaft. This motion is restrained only by the viscosity of the silicon oil layer and the friction in the bearings and oil seal separating the two subassemblies of the capstan.

The torque transmitted through the fluid coupling is a function of the differential velocity between the capstan's front end and the drive-wheel subassembly; therefore, an appreciable amount of slippage occurs while accelerating and decelerating the capstan. When the capstan is moving tape at constant velocity, on the other hand, a slippage of 0 to 0.2% of the nominal velocity occurs between the two surfaces, as determined by the frictional characteristics of the bearings, oil seal, and tape path.
In summary, the fluid coupled capstan has smoothed the input torque pulse as seen by the tape in comparison to the input torque pulse as supplied by the drive rollers as shown in Fig. 14. The use of this capstan made it possible to accelerate the tape to 112.5 in/sec. in an average of 2.5 milliseconds with a velocity variation less than 5%. Typical velocity vs. time curves during acceleration and deceleration are shown in Fig. 15.

**ACTUATORS**

The three rubber rollers that drive or stop the capstan are brought in contact with the capstan's drive wheel by the action of three actuators. These actuators utilize the moving-coil principle, and were chosen because of their fast response and relatively constant force with stroke. It takes less than one millisecond to transfer the roller from its retracted position to the capstan drive wheel. The constant force, on the other hand, reduces sensitivity to the roller gap.

![Figure 15. Typical Start and Stop Time Curves.](image)

**Figure 16. Actuator Arm Assembly.**

The actuator, as shown in Fig. 16, consists mainly of a permanent magnet, return path, bobbin and moving arm. The moving arm was designed to give a high output force at the rubber roller. Pivoting of the arm to the assembly is accomplished by the use of a flexure plate. The use of such a plate eliminated the problems associated with pivot points such as fretting corrosion which would cause jamming. It also made possible the preloading of the actuator arms. Forward and reverse rollers are preloaded away from the capstan drive wheel, while the stop roller is preloaded towards it. Thus, in case of power failure, the capstan is stopped and no tape damage occurs.

For the actuator to supply the force and transfer time required, the arm design and driving current were optimized as described below:

1. **Arm Design:** The actuator arm was designed to give the minimum transfer time by:
   a) Keeping the mass of the bobbin, arm and rubber roller as small as possible, and by designing a short moment arm; i.e., the roller was located as close to the pivot as possible.
   b) The transfer distance of the roller before contacting the capstan's drive wheel was made only 0.003 inches.

2. **Driving Currents:** The actuator's driving current is controlled to give the desired acceleration and damping. Two high-current pulses are used to properly control actuator motion when the roller is driven into contact. The first high-current pulse gives quick transfer time; the second pre-
vents the rubber roller from rebounding. A low holding current is applied after the transfer damping period; it provides the roller contact force necessary to maintain constant velocity and minimized coil heating. The shape and effect of the current pulses on the rubber roller motion is shown on Fig. 17.

Life testing of these actuators has shown exceptionally good results. So far, over three billion cycles have been successfully accrued on several actuators.

BRAKE-INDEXER

To stop the tape and capstan, a stationary rubber roller is brought in contact with the capstan's drive wheel. The rubber-roller shaft is connected through a flexible coupling to a hydraulic brake-indexer, as shown in Fig. 11. The purpose of this device is to insure stopping of the capstan in approximately 2.5 milliseconds while allowing slight rotation of the rubber roller during every stop operation.

The brake-indexer was designed so that its mass moment of inertia is much greater than that of the capstan. When the stationary stop roller is brought in contact with the rotating capstan drive wheel, part of the kinetic energy of the capstan is converted into heat due to slippage. At the same time, the roller is accelerated so that the remainder of the energy is dissipated as heat in the indexer itself.

The internal construction of the brake-indexer consists of a finned rotary hub which works in shear against a stationary finned housing. The viscous media in this unit is a high-viscosity silicon fluid. To obtain indexing of approximately 0.010 inches, oil viscosity of 40,000 centistrokes was used.

Indexing the stop roller has given especially good results by distributing the wear and heating caused by successive stops over the circumference of the roller. The use of a hydraulic device with no mechanical contacts, on the other hand, has given consistent stop times and accurate indexing. It also eliminated the problems associated with dimensional changes and frictional wear associated with mechanical indexers.

REEL-DRIVE SYSTEM

The establishment of tape cartridge loading height in the Hypertape drive posed restrictions on the vacuum columns and type of reel-drive system that could be considered. This led to the use of continuous control and a non-center seeking system. The non-center seeking system would make available maximum tape buffer length for tape reversal; with tape stopped, the system would be center seeking to allow for tape movement in either direction from static. With tape moving in the forward direction, the loop position is high in the left column and low in the right so that full advantage of the tape buffer can be realized during a dynamic reversal; the opposite applies when the tape is moving in the reverse direction.

The continuous control, on the other hand, with its ability to apply the correct amount of power when needed and for as long as needed, made it possible to operate within a 10-inch effective vacuum column length. The reel motor is controlled by the motion of the loop in the column. The design of a capacitive sensing device (described later) as a tape-loop sensor gave the desired result. Through this unit both the loop position in the column (X), and the rate of change or velocity of the tape in the column (Ẋ) were obtained.

The magnetic tape reels are controlled by two identical isolated reel control systems. The right reel control system, as shown in Fig. 18, consists of a standard d-c motor which is connected to the reel hub through a 4:1 pulley ratio.
ratio, thus making it possible to use a relatively small motor with only \( \frac{1}{4} \) the torque required to control the tape. To control the power to the motor, the output of the loop position sensor is detected, amplified and added to a reference signal \( V_r \), then differentiated by the use of a lead network. The output of the lead network is a function of the position \( X \) and velocity \( \dot{X} \) of the loop in the column. The net signal is then amplified and used to control the current to the motor's armature by the use of magnetic amplifiers and silicon controlled rectifiers.

The loop position signal \( X \) controls the power to the motor when the loop is stationary; i.e., when the velocity of the tape leaving or entering the column equals that of the tape over the capstan. When a dynamic reversal takes place, an appreciable signal \( \dot{X} \) develops due to the loop's velocity. This signal results in an increase of the power to the motor.

The motion of the motors is also controlled during the tape load and unload cycle. During these operations the torque applied is controlled by the various column and catenary sensing stations.

**CAPACITIVE LOOP-POSITION SENSOR**

Sensing the location of the loop in the column is accomplished by the use of the following capacitive method. This method was chosen because of its high reliability coupled with simplicity of construction and linearity of output.

A capacitance value that is a function of the loop's position in the column is obtained by utilizing the pressure differential in the vacuum columns to activate a moving diaphragm between two metal plates, as shown in Fig. 19. The diaphragm consists of a metal layer with Mylar on both sides.

![Capacitive Loop Position Sensor](image19)

An insulating plate connects the diaphragm area to the back surface of the vacuum column through \( \frac{1}{4} \)-inch holes spaced \( \frac{1}{4} \) inch apart. The perforated metal plate on the back side of the unit is connected to a common chamber which has a vacuum level equal to half that of the column vacuum. The half vacuum is obtained from the main column vacuum source, and therefore any change in the column...
vacuum is reflected in the half vacuum, thereby maintaining a constant ratio.

To obtain a large capacity ratio, the entire rear of each column was utilized for this unit, giving an approximate capacitor range 0.002 to 0.020 \( \mu \text{f} \).

The method of operation of this sensor is seen by referring to Fig. 19 which shows a loop of tape in the column. The section of the diaphragm above the loop is pulled against the back perforated plate due to the differential of pressure which is atmospheric in front and half vacuum in the back. The section of the diaphragm below the loop, on the other hand, is pulled against the front perforated plate, since the front is at full vacuum versus half vacuum for the back.

READ-WRITE SYSTEM

The Hypertape system uses phase encoding type of recording. There is a signal for both ones and zeros, as shown in Fig. 20. Hence, when the tape is read, the sensing and decoding of a bit depends on the phase of the recorded signal rather than its magnetic strength.\(^2\)

The data head (Fig. 21) is a two-gap write-read head with a .5 inch radius around each gap to hydrodynamically air lubricate it when the tape is in motion.\(^3\) The distance between the write-read gaps is 0.150 inches. The width of the tracks is 0.060 inches for write and 0.050 for read. An erase head (Fig. 21) is located 0.125 inches from the write head and is positioned such that erasure through the base material takes place while maintaining a slight clearance between the erase head and the back of the tape. The erase head is active any time the transport is in write status.

Sensing the amplitude of the recorded signal during writing plays an important part in controlling errors. Should the signal fall below 25\% of the nominal level, the record (under program control) is erased and rewritten on a new section of tape.

Error detection and correction while reading are dependent on the redundancy check provided by the two check bits written on tape and the amplitude of the read signal.\(^4\) The two check bits \( C_o \) and \( C_1 \) (Fig. 2) are generated during the write operation according to the two equations:

\[
\begin{align*}
C_o &= I_o \oplus I_6 \oplus I_5 \oplus I_4 \oplus I_3 \oplus I_2 \oplus I_1 = 1 \\
C_1 &= I_o \oplus I_6 \oplus I_5 \oplus I_4 \oplus I_3 \oplus I_2 \oplus I_1 = 1
\end{align*}
\]

Where \( \oplus \) means exclusive OR

The bits are divided into three zones from the two check bit equations:

- **Zone 1** Contains only the bits that appear in equation \( C_o \) and not in equation \( C_1 \)
- **Zone 2** Contains only the bits that appear in equation \( C_1 \) and not in equation \( C_o \)
- **Zone 3** Contains only the bits common to equations \( C_o \) and \( C_1 \)

Hence,

- **Zone 1** Contains \( C_o, I_1, I_6, I_7 \)
Zone 2 Contains C₁, I₂, I₅
Zone 3 Contains I₆, I₇, I₈

During the read operation, the ten bits of each tape character are checked for parity against equations C₀ and C₁. A single incorrect bit within a tape character will be detected by one or both of the check bit equations.

The check-bit equations determine if a particular character contains an error, and the envelope detector monitors the amplitude of the signal. If the signal drops below a certain level in one track, the track is “dead tracked”. This essentially resets that track for the rest of the record. Thus, if a parity error is found to occur in the zone containing the “dead track”, the bit in the error correction register is inverted; a zero is made a one, or vice versa.

If two or more tracks in the same zone are dead tracked an uncorrectable error results. However, equations C₀ and C₁ were written so that no adjacent tracks would be in the same zone. Hence, all adjacent double errors are correctable along with some non-adjacent double errors. If a double error does occur, it is more probable it will be an adjacent double error.

There are 45 possible combinations of double errors. Of these 33 are correctable. All corrections are performed on the fly without program interruption or loss of processing time.

REFERENCES