MECHANICAL DESIGN OF THE CARTRIDGE AND TRANSPORT FOR THE IBM 3480 TAPE DRIVE

Daniel J. Winarski
William W. Chow
Joseph G. Bullock
Fred B. Froehlich
Thomas G. Osterday

IBM General Products Division, Tucson, Arizona 85744

ABSTRACT

The IBM 3480 Tape Drive has achieved significant improvements over its predecessor, the 3420, in speed, recording density, and floor-space requirements. The 3-megabytes-per-second data rate of the 3480, which is 2.4 times that of the 3420, was accomplished through the use of chromium dioxide tape stored in a compact, high-density, single-reel cartridge threaded to a take-up reel. A sixfold increase in recording density over the 3420 allowed reduction of the size of the 3480 cartridge, which was essential for rapid acceleration of the tape in the 3480's reel-to-reel transport. This eliminated the need for vacuum columns, thereby greatly reducing ambient noise and power requirements. However, the increased data density demanded substantial improvements in tape guiding and tape-motion control. This paper describes how mechanical analysis and design contributed to the achievement of these advances and aided in overcoming the ensuing problems.

electrical-power requirements. Thus, a smaller tape reel meant faster accelerations and better performance for the reel-to-reel drive. However, the smaller the reel, the higher the data density needed to achieve the same data capacity as the standard 3420 reel. As the data density increased, greater demands were placed on tape guiding and tape motion. A compromise between reel size and tape guiding and tape motion was reached with a 100-mm-diameter reel and a signal density of 972 flux changes per millimeter. The tape that is used consists of a chromium dioxide coating on a polyethylene terephthalate substrate, with a nominal thickness of 31 µm.

After the reel geometry was sized, the design of the cartridge became the important issue. The concept of a two-reel cassette was eliminated in favor of a single-reel cartridge. Thus, high-volume cartridge cost was traded off against the addition of a tape threader in the drive. When the cartridge design and threading requirement had been established, tape guiding and tape tension control were analyzed. Thus, the core design of the tape drive evolved.

Figure 1 shows an internal view of the tape drive. Threading is accomplished by a pantocam threader that guides the leader block of the cartridge, to which the tape is attached, around the tape path. The leader block is inserted into the take-up reel, and the tape is brought to the correct tension to complete the threading operation. Guiding of the tape over the magnetic head is accomplished by compliant guides seating the tape against reference flanges.

The remainder of this paper describes the mechanical components mentioned above and the reasons for their design.

CARTRIDGE

The 3480 single-reel tape cartridge [2] is both an advance in the state of the art and a major departure from the traditional large-system tape reels. The half-inch chromium dioxide tape, 18-track format, and 38000 byte/inch density give 200 megabytes of capacity at a 24K-byte block size. This makes the 4 x

- A threader pin (Fig. 3(a)) is used to thread the tape path. As the cartridge is being loaded into the 3480 drive, this pin pin engages the leader block (Fig. 3(b)). The threader pin then pulls the leader block and attached tape through the tape path to thread the drive. This threading operation is completed when the leader block is automatically inserted into a slot in the drive take-up reel (Fig. 4(a)).

- When the leader block is threaded into the take-up reel, its outer surface becomes a portion of the hub of the take-up reel (Fig. 4(a)). The leader block has designed-in compressibility [2] to help reduce tape deformation at the take-up reel hub and leader-block interface (Fig. 4(b)). Undesirable tape deformation must be avoided because it would result in a loss of signal caused by tenting of the tape over the magnetic head (Fig. 4(c)).

Because the cartridge leader block was designed to facilitate automatic threading of the tape drive and to be an integral part of the take-up reel, it was carefully designed to meet cartridge, threading, and take-up reel constraints. This made the leader block the most multifunctional component in the 3480 transport.

File-Protect Switch

The file-protect mechanism on the tape cartridge is a thumbwheel selector on the edge of the cartridge (Fig. 2) and can be set to either of two positions. When the selector is in the file-protected position, a white dot on the flat part of the selector shows. This symbol means that the cartridge is file-protected and can be used only for reading data. When the selector is in the unprotected position, the round part of the selector is visible and no symbol shows. This means that the cartridge is unprotected and can be used for both reading and writing. Human factors heavily influenced the design of the switch. Because it is manually rotatable and is not removable from the cartridge, no special tools are required and there are no loose parts to be

[7]. Furthermore, an interlayer slip could cause permanent damage to the tape, and creases, commonly called z-folds, might form as a result [8,9]. These creases would tent over the magnetic head, as illustrated in Fig. 4(c), causing a loss of magnetic signal.

The approach to the interlayer-slip phenomenon involved both passive and active means of control. Passive means of control encompassed the selection of the hub material with the least stochastic potential for interlayer slip. Hundreds of reels with hubs of various materials were tested over a three-year period. The result of this experimentation was the selection of a composite, glass-filled polycarbonate, which gave the smallest probability of interlayer slip in the operating environment of the 3480 [10]. Thus, the hub material is a commercially available polymer which best matches the thermal and hygroscopic behavior of the tape over the range of environments to which it is exposed.

The next step was to check actively for interlayer slip each time a cartridge was loaded in the drive to detect which cartridges were exposed to severe environmental stress. Immediately upon loading and threading, the drive winds five wraps of tape onto the take-up reel and then executes five special start-stop-backhitch operations [11]. Each start is an acceleration stress test. If an interlayer slip occurs during this high-acceleration test, it is detected by the pulses from the drive motor's fine-line tachometer. A flag is set to indicate whether or not the reel has slipped. If the tape shows interlayer slip, a Locate EOT (end of tape) command is executed, followed by a high-speed rewind to subject the tape to appropriate tension before use [9].

CLEANING CARTRIDGE

The cartridge for the 3480 substantially reduces the time required to clean the drive and minimizes operator involvement. Drive cleaning is enhanced through the use of a "dry" cartridge that contains a half-inch-wide fabric. The fabric is encased in a modified tape cartridge.

is attached, around the tape path and inserts the leader block into the take-up reel. The take-up reel is aligned for the leader block insertion by a light-emitting diode-phototransistor (LED-PTX) pair. This alignment is important to prevent the leader block from crashing into the hub of the take-up reel. After the tape is threaded, the threading pin remains engaged with the leader block, resting in the axis of rotation of the take-up reel. Thus, in the unloading operation, the pantocam linkage does not need to locate the leader block again.

Unloading of the tape consists of repositioning the take-up reel to the alignment dictated by the LED-PTX pair, retracing the leader block through the tape path, and reinserting the leader block in the cartridge. During this operation, the supply-reel motor is biased to spool in the tape as the leader block is brought around.

TAKE-UP REEL

The take-up reel accepts the leader block, the outer edge of which forms a portion of its outer hub (Fig. 4(a)). This interface is especially significant, for serious plastic deformation of the adjacent tape could result if a discontinuity were to exist between the take-up reel and the leader block.

On either the supply or the take-up reel, tape wound under tension results in each new layer imposing a radial compressive stress on previously wound layers [6]. These radial stresses, exerted on the inner layers, can be a problem whenever a discontinuity is formed in the cylindrical surface of the hub (Fig. 4(a)) or a discontinuity is formed at the point where the end of the tape is attached to the reel hub of the cartridge.

This problem results in a plastic deformation of the tape (Fig.4(b)) in the region of the discontinuity, which can cause the tape to tent (Fig.4(c)) over the magnetic head, resulting in a loss of magnetic signal. The degree of tenting and the seriousness of the plastic deformation are directly related to where the suction force on the tape jumps between two distinct levels. If the tape enters the vacuum pocket deeper than the triangular hole, a large amount of venting causes the suction force to drop to a minimum to reduce this overpenetration.

HEAD-GUIDE MOUNT

A tape drive must be provide with guides, one on each side of the magnetic head, to move the magnetic tape repeatedly across the read and write elements of the head. The tape-guiding mechanism that is used is illustrated in Fig. 8.

The tape guides consist of a compliant guide (leaf spring) that exerts a distributed load on one edge of the tape. This causes seating of the opposite edge of the magnetic-recording tape against a reference lower flange. The tape is also wrapped around a cylindrical guide surface, or D-bearing, to increase its buckling strength (resisting the compressive load of the leaf spring). A hydrostatic air-bearing causes the tape to float on a thin film of air to minimize friction [15].

Compliant Guides

Each compliant guide consists of a leaf spring which has been photoetched from thin, nonmagnetic, stainless steel. The elasticity of the leaf spring is controlled by the number, thickness, and length of the radial fingers.

The compliant guide seats the tape against the reference lower flange by exerting a distributed load on the edge of the tape. This load, q, opposes the vertical motion of the tape, Z, proportional to the spring rate, K, of the compliant guide along the angle of wrap of the D-bearing, θ, and is given by

$$q(\phi) = - KZ(\phi) \qquad 0<\phi<\theta. \tag{1}$$

$$q(\phi) = A^{*}\exp(\ Ra\phi)^{*}\cos(Ra\phi) + B^{*}\exp(\ Ra\phi)^{*}\sin(Ra\phi) + C^{*}\exp(-Ra\phi)^{*}\cos(Ra\phi) + D^{*}\exp(-Ra\phi)^{*}\sin(Ra\phi) \quad (4)$$

where $a = \sqrt[4]{K/4EI}$, $0<\phi<\theta$.

Two of the boundary conditions of the above solution relate to the moment and force exerted on the tape at a reel, say, caused by staggered wraps or motor-shaft misalignment. The last two boundary conditions imply no lateral or skew motion of the tape at the magnetic head. The solution of Eq.(4), under the above boundary conditions, enabled the spring rate of the compliant guide, K, to be tailored to the geometry of the drive and the physical characteristics of the magnetic tape.

D-Bearings

Each D-bearing is a 90° segment of a cylinder. The height of each D-bearing is slightly less than the width of the tape; therefore, an edge of the tape protrudes above the top of each. It is this protruding edge that is in contact with the compliant guide overhead. The compliant guide cannot exert too much force on this unsupported, protruding edge; otherwise, tape buckling will occur.

Wrapping the tape around a cylindrical surface strengthens the unsupported tape edge against buckling and more tape-edge load can be tolerated than if the compliant guide exerted its distributed load on a straight section of tape. However, the wrapping of the tape presents a problem. The following belt equation [17] shows that the friction drag exerted on a tape wrapped around a cylindrical surface is an exponential function of the Coulomb coefficient of friction, μ, and the wrap angle, θ:

$$\text{Frictional drag} = (e^{\mu\theta}-1) \quad (5)$$

Lateral and Skew Settings

The magnetic head must be aligned with the reference lower flanges or the tape would be wrongly steered by the same guides intended to stabilize the tape. The head is placed laterally, by a shimming process, and then penetrated into the plane of the tape to provide the correct wrap angle for hydrodynamic lubrication [18].

Because the 3480's high linear density and read track width, the skew of the head relative to the reference lower flanges is the most critical of all the alignments [19]. In the past, skew tapes were used to align the head with the drive. However, the generation of precision skew tapes required that the signal be read both from the front side and through the back side of the tape. This reading of the signal from both sides of the tape allowed the skew-tape-generation machine to check itself. The high-density signal on the chrome dioxide tape could not be read through the back side of the tape, which meant either having an uncheckable standard or abandoning the skew tape process and choosing an optical method.

The optical method consists of aligning the lower flanges of the head-guide mount parallel to one axis of a precision X-Y stage of a high-power microscope using a polar rotator. The high-power microscope is used to observe the outer write tracks in reference to the other axis of the X-Y stage. Because the X-Y stage axes are perpendicular, the write tracks of the head can be properly angled perpendicularly to the lower flanges. This small angle rotation, accomplished by a skew plate and a differential screw, was only one possible method [20] of aligning the head. A functional test tape (unverifiable skew tape) is then used as a validity check of the optical alignment.

Cleaner Blade

Before the tape reaches the head, as it comes out of the cartridge, it passes over a cleaner-blade assembly, whose function is to scrape debris from the surface of the tape and to "vacuum" it away. The assembly used is the same as

TENSION TRANSDUCER

The nominal tape tension is set open-loop by the microcode of the tape-transport electronics. Tension transients are controlled by a feedback loop. The tape tension is sensed by the tension transducer shown in Fig. 11, whose position in the tape path can be seen in Fig. 1, next to the take-up reel. Its output is fed through a filter on the power amp board, which compensates for the mechanical resonances of the system. This filtered tension signal is then applied differentially to the reel motors through the motor drivers.

The tension transducer is a hydrostatic air bearing with a radius of 15 mm. The tape has approximately 180° of wrap on the bearing. In the center of the face of the air bearing is a sense hole, which is connected to a solid-state pressure transducer. The device senses tape tension by sensing the air pressure between the moving tape and the fixed surface of the air bearing. The sense hole is kept clean of debris by an air purge, which constantly blows a small amount of air out of it. This provides a slight dc shift in the pressure levels seen by the pressure transducer, which is nulled during calibration.

The assembly requires a simple adjustment for the null, but no adjustment for the gain is necessary. This calibrated assembly also provides accurate over-and under-tension limit sensing when used with a common, bipolar, window-detection circuit. It protects the drive from excessive tape-tension conditions, which could damage the tape or the head. The vented flanges stabilize the air bearing and are used to prevent tape vibration that would degrade read/write performance. They also provide positive tape guiding between the head-guide assembly and the machine reel.

REFERENCES

1. J. Irwin, J. Cassie, and H. Oppeboen, "The IBM 3803/3420 Magnetic Tape Subsystem," IBM J. Res. Develop., September 1971, pp.291-400.

2. M. E. Richard and D. J. Winarski, "Single Reel Magnetic Tape Cartridge," U.S. Patent 4,426,047; 17 January 1984.

3. M. E. Richard, "Leader Block for Single Reel Tape Cartridge", U.S. Patent 4,452,406; 5 June 1984.

4. M. E. Richard and H. Rinkleib, "Single Reel Tape Cartridge with Leader Block Door Seal", U.S. Patent 4,383,660; 17 May 1983.

5. S. M. Graham, "Magnetic Tape Reel Clamp with Extended Center Pole Piece," U.S. Patent 4,343,441; 10 August 1982.

6. D. Connolly and D. J. Winarski, "Stress Analysis of Wound Magnetic Tape," American Society of Lubrication Engineers, Vol.SP-16, October 1984, pp.172-182.

7. J. Eige, A. Patel, S. D. Roberts, and D. Stedman. "Tape Motion Control for Reel-to-Reel Drive", U.S. Patent 4,125,881; 14 November 1978.

8. Ford Kalil, Magnetic Recording Tape for the Eighties, NASA Reference Publication 1075, Superintendent of Documents, Washington, DC, April 1982, p.49.

9. Charles A. Milligan and Daniel J. Winarski, "Tape Media Interlayer Check," U.S. Patent 4,389,600; 21 June 1983.

10. S. M. Graham, M. E. Richard, and D. J. Winarski, "Tape Reel Hub," IBM Technical Disclosure Bulletin, Vol.24, No.5, October 1981, p.2417.

21. F. B. Froehlich and P. Y. Hu, "Stationary Magnetic Head with a Fluid Operated Tape Lifter," U.S. Patent 4,479,158; 23 October 1984.

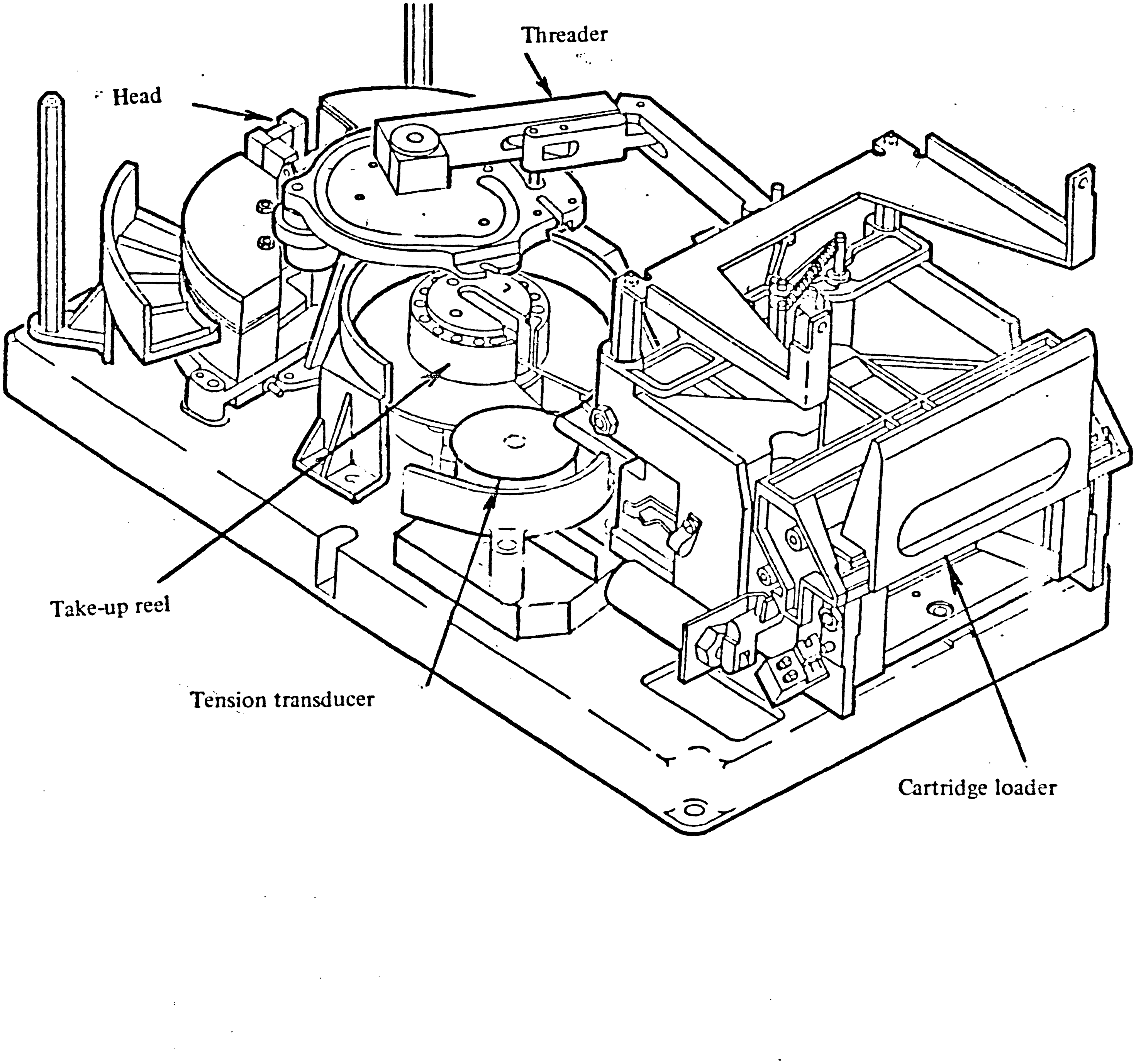
Threader
Head
Take-up reel
Tension transducer
Cartridge loader

Figure 1

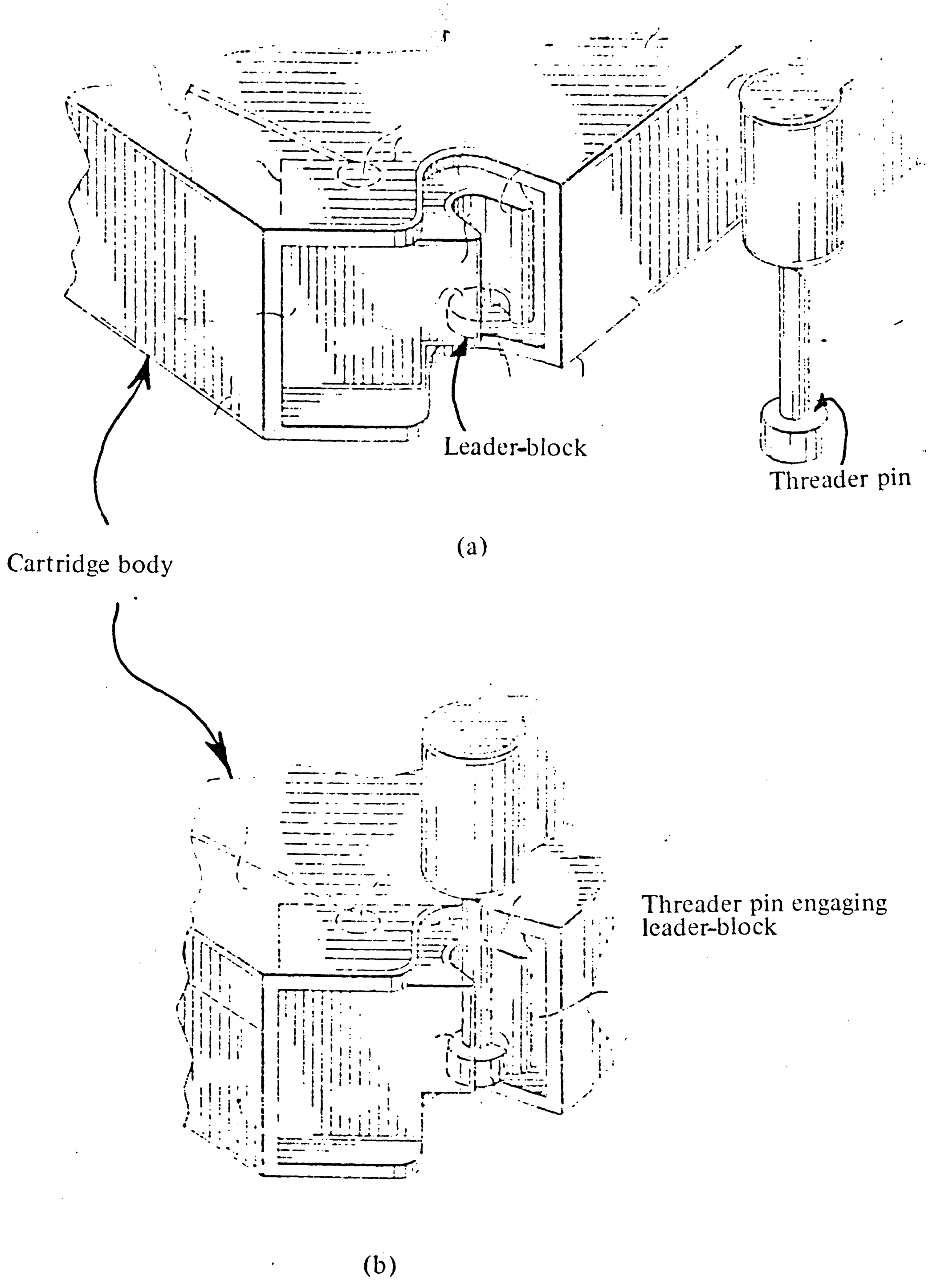
Leader-block
Threader pin
(a)
Cartridge body
Threader pin engaging leader-block
(b)

Figure 3

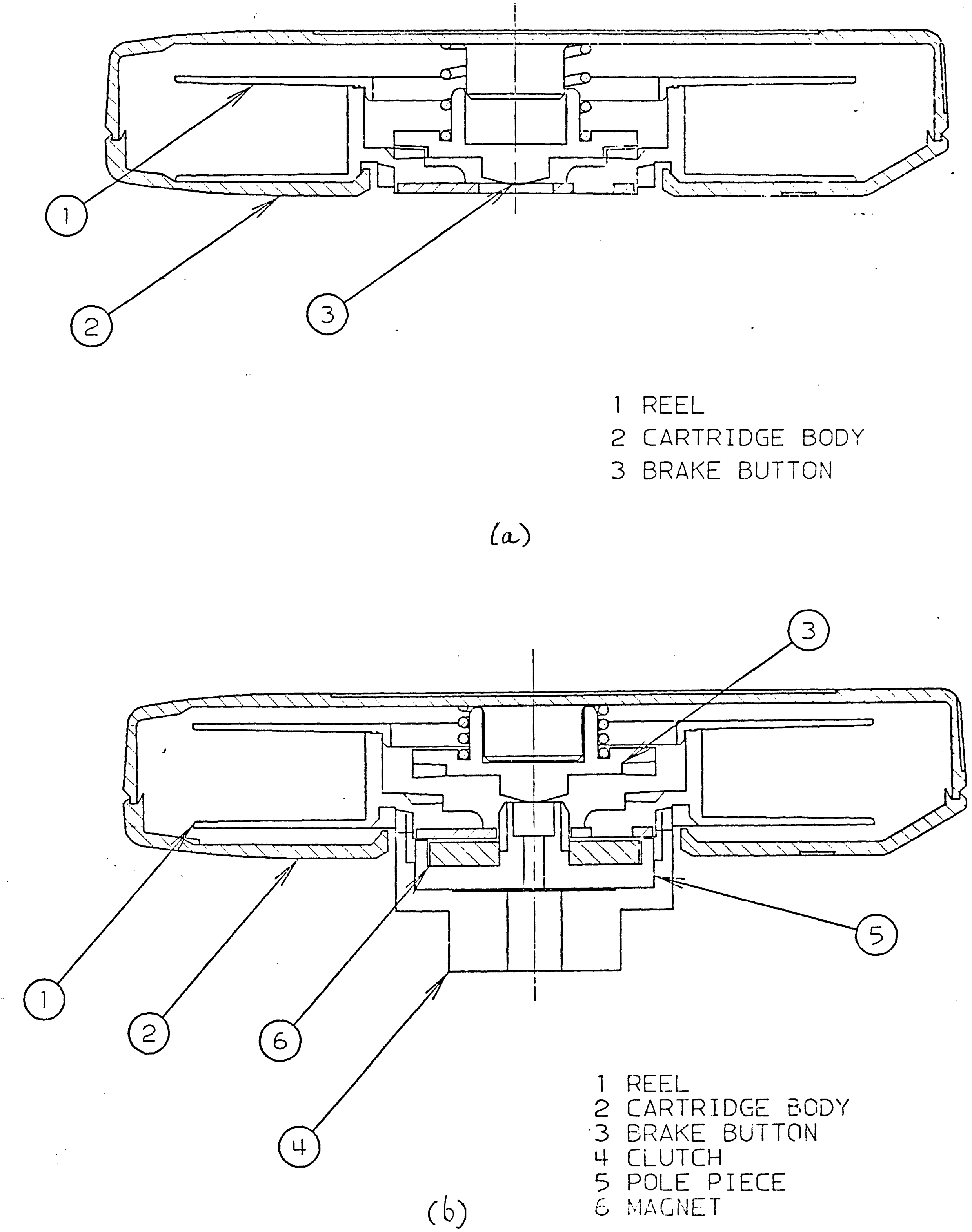
1
2
3
1 REEL
2 CARTRIDGE BODY
3 BRAKE BUTTON
(a)
3
5
1
2
6
4
1 REEL
2 CARTRIDGE BODY
3 BRAKE BUTTON
4 CLUTCH
5 POLE PIECE
6 MAGNET
(b)

Figure 5

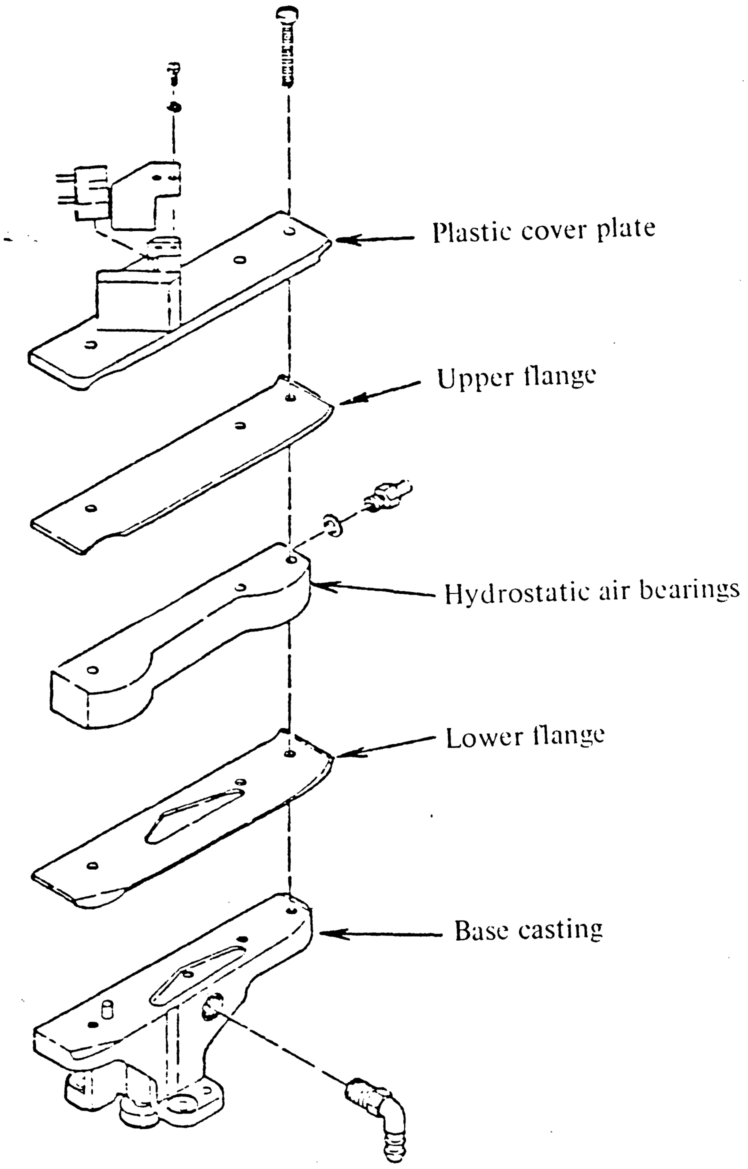
Plastic cover plate
Upper flange
Hydrostatic air bearings
Lower flange
Base casting

Figure 7

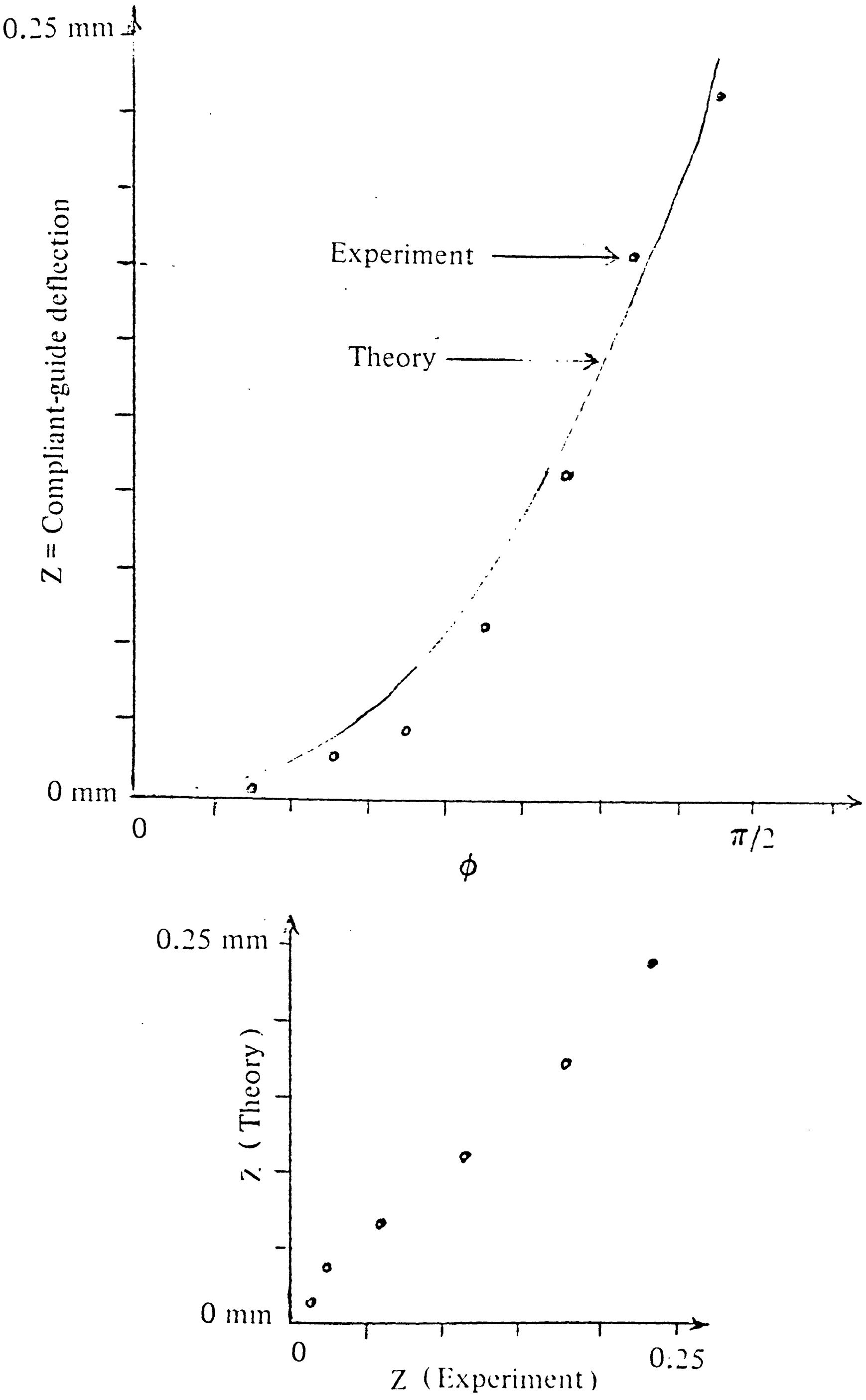
0.25 mm
Z = Compliant-guide deflection
Experiment
Theory
0 mm
0
ϕ
$\pi/2$
0.25 mm
Z (Theory)
0 mm
0
0.25
Z (Experiment)

Figure 9

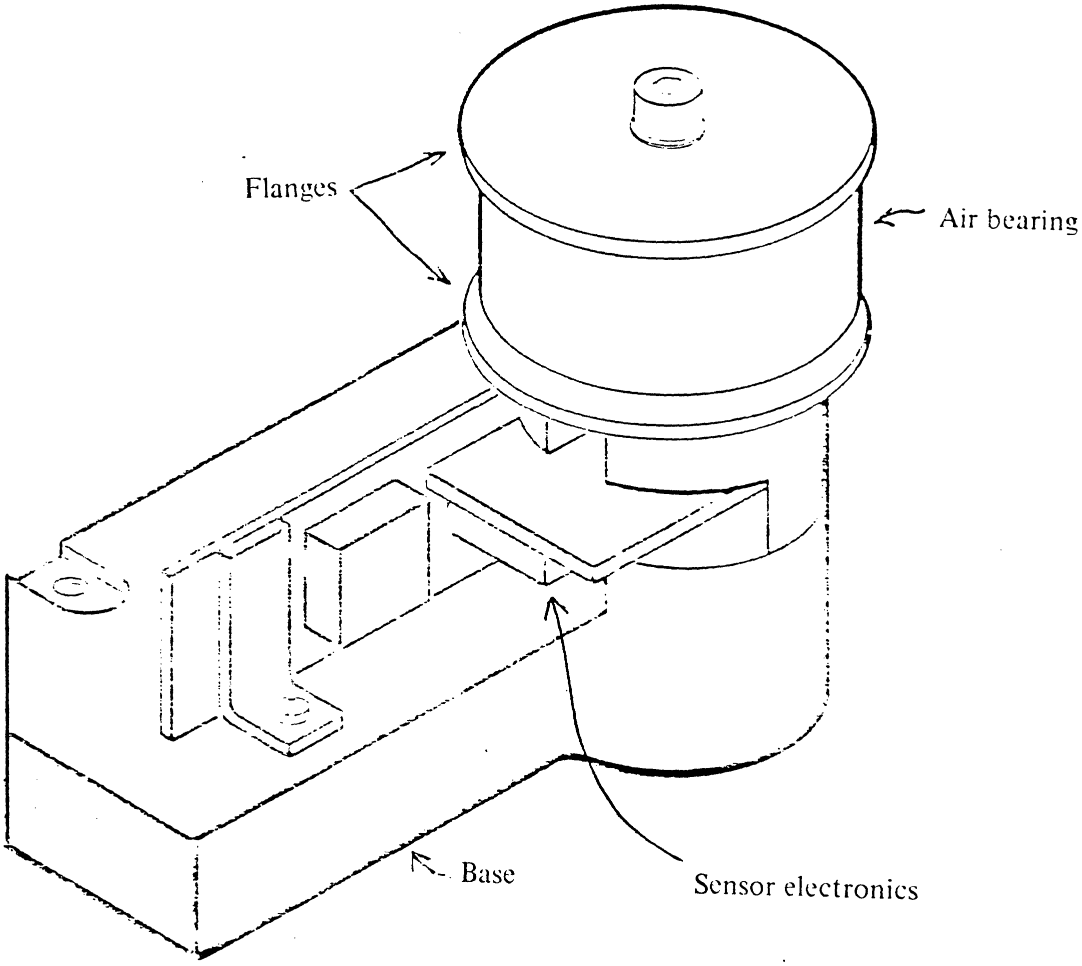

Figure 11