HELICAL PACK TAPE RECORDER TRANSPORT

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ABSTRACT

This report describes the work accomplished on Contract No. 961348, Helical Pack Magnetic Tape Recorder Transport. This contract and its companion design specification #GMY-50340-DSN call for the design of an endless loop transport capable of handling 2000 feet of 1/2 inch magnetic tape. The design requirements are unique in calling for a helical tape format.

Although the contract goals were not wholly achieved, some worthwhile progress was made considering the advanced nature of the requirements. Important areas of progress were the development of a technology for forming helical tape from standard tape, the analysis of the various possible transport configurations, and finally, the problem definition phase of the Model Study work.

Many problems arose during the performance of this contract. A number of these problems had to remain unsolved or with only projected solutions due to reaching the limit of the funds allocated in the contract. At no time, however, did a problem arise which appeared to be insurmountable, thereby rendering the helical tape concept unfeasible. Rather, the opposite was true. With an increasing familiarity with the helical tape format, there came a greater awareness of its advantages in a number of tape transport applications.

In summary, the report initially discusses these advantages and then relates them to the JPL specification requirements. Next, the tape forming problem is analyzed with the details of the forming machine design concept and mechanization following. There were some problems which arose regarding the quality of the formed tape where only projected solutions were generated. The details of these projected solutions are documented.

The analysis of the possible transport configurations follows and the advantages of a twin reel design are enumerated. Due to the extremely experimental nature of the transport design a Model Study was undertaken prior to constructing an operational transport. The details of the Model construction and the problems encountered in its fabrication are discussed.

During the limited amount of testing which was carried out on the Model some significant problems arose. Even with a Model it was found to be very difficult to incorporate the requisite design changes and the program ground to a halt due to lack of funds. Before this occurred some worthwhile ideas were generated which were not translated into hardware. For the record, these ideas are documented here in as much detail as possible.

Although all the program objectives were not met, in retrospect it is seen that some unforeseen problems caused the overall program to be under-budgeted. Other factors contributed to this. For example, in the duration of the program the Kinelogic burden rate rose from 62 to 93%. This, combined with a small increase in the G & A expense, caused a reduction in the amount of manhours available for the project. The actual hours available amounted to 82% of the amount incorporated in the original proposal. None of the problems encountered appears to be insurmountable. When an application demanding the demonstrable advantages of the helical format appears, a continuation of this program is technically feasible. Initially the program goals should be set on a slightly less advanced concept than that detailed in JPL design specification #GMY-50340-DSN. Enough has been learned of the problem areas to permit plotting a course which avoids a head-on confrontation with the major problem areas while still realizing significant advantages from the helical format.

INTRODUCTION

To properly introduce the reader to the Helical Pack Magnetic Tape Recorder Transport Program some of the history of its inception is required as a background. Typically, tape recorders for use in interplanetary spacecraft applications are required to exhibit small size, low weight, low power consumption and high reliability. These parameters as measured against data storage capacity give an index of efficiency for such a device.

One of the operational characteristics which was shown to materially enhance the overall reliability of a spacecraft recorder was the embodied in an endless loop configuration. Such a device eliminated a number of functions normally associated with a reel-to-reel configuration - most notably the requirement to reverse. With the ability to reverse, the maximum access time could be cut in half.

To capitalize on these advantages a number of endless loop tape recorders had been designed and built using conventional straight tape. These units had demonstrated their operational stability and met the functional requirements with a few exceptions. These few exceptions were important, however, in the extremely rigorous spacecraft recorder application. Where large storage capacity was required the tape was normally wound on a reel with the off-feed coming from the center and the on-feed at the outer circumference. This achieves stable and consistent operation at the expense of reversability and incurs another penalty from the reliability standpoint due to the layer-to-layer sliding which this geometry entails. In addition, there is a definite limit to the amount of tape which can be handled successfully.

In this particular context, the helical tape format shows to the best advantage. It can provide endless loop operation with no layer-to-layer sliding. With a suitable symmetrical configuration it promises to be fully reversible. The storage capacity varies with the length of the cylindrical pack and a good form factor permitting a high storage density is readily obtainable. There is, of course, no dead space required as compared with a reel-to-reel tape recorder. The helical tape pack on its reel is inherently resistant to the effects of shock and vibration. Torsional vibration effects can be effectively minimized as the constant diameter reel of tape has a constant inertia.

On a closer acquaintance, the helical tape format shows other important advantages. The preceding were the main ones used as the basis for initiating the Helical Pack Magnetic Tape Recorder Transport program. The discussion that follows gives the details of the work performed, the problems encountered and their solutions or projected solutions. For convenience, the discussion is grouped under four major headings as follows:

(1) Review of JPL Specification Requirements
(2) Tape Forming Problems
(3) Tape Transport Problem
(4) Work planned for future (Project incomplete due to lack of funding)

1. DISCUSSION, JPL Specification Requirements (Summary).

A brief review of the JPL Design Specification GMY-50340-DSN is in order at this point. This specification covers the design requirements for a Helical Pack Magnetic Tape Recorder Transport to be used for interplanetary spacecraft applications. As such, it refers to the Mariner C Environmental Specification No. 30250B. In deference to the experimental nature of the Helical Tape Transport Program, however, full compliance is not required. The environmental specification reads as follows: "The transport design shall contain no inherent design features that would prevent its future capability of operating within the electrical design requirements of this specification during and/or following the environmental tests listed in JPL Specification 30250B." Even in this form, the environmental considerations had an important bearing on the subsequent design decisions.

The main areas of progress during the program were in the mechanical aspects of the transport. The specifications called for a 2000 ft tape length with a mean diameter of 4.0 inches giving approximately 1 foot per turn. With a mean thickness of 1.8 mils per turn the resulting tape pack length is 3.6 inches. Half inch wide tape was to be used and the two ends of the helix were to be joined to form an endless loop. Tape moving and guidance means were to be provided to give bi-directional tape movement over the heads with nominal tape speeds of 0.15 inches per second and 15 inches per second. The transport mechanism was required to operate on 10 watts of power, weigh less than 10 pounds with a package volume not to exceed 300 cubic inches.

This brief summary shows that a fairly sophisticated mechanism was required. When it is considered that the bit storage capacity was 1.5×10^8 tracks with a limit on tape jitter of $\pm$ 5 percent and on skew $\pm$ 150 microinches across the 1/2 inch tape width, the program is seen to be an ambitious one indeed.

2. Tape Forming Problem

2.1 Preliminary Analysis. With a view to establishing the design requirements for a machine to form a helical tape pack, the preliminary analysis concentrated on the properties of the Mylar-base material used in tape manufacture. As a result of this analysis, it was decided to attempt to form the tape at room temperature. While a dramatic reduction in Young's Modulus and yield point occurs as the Mylar temperature is increased, there is a corresponding drawback in the variable memory exhibited by the material during subsequent cooling.

To achieve a true helical form, it was determined that a bending operation was required rather than a stretching operation. This eliminated any thoughts of using helical rollers or similar stretching device as originally proposed. Furthermore, satisfactory bending could only occur if the whole cross-section of the tape was stressed past the yield point. In other words, the neutral axis of bending had to be off to one side of the tape. The only way to do this was to have the tape as part of a composite beam structure during the bending process.

This type of analysis reduced the forming problem to its essentials and the problem became one of mechanizing these basic operations into a continuous process. Once the tape was formed in a helix, the problem arose of stabilizing it to withstand the ambient temperature range specified for the spacecraft environment. The tape formed at room temperature would have locked-in stresses which would relax at higher temperatures causing uncontrolled distortions from the required helical format. It was decided to try to normalize the Mylar by winding the formed tape on a mandrel of the required final diameter and with the tape pack firmly clamped between moveable end flanges subjecting the whole assembly to a controlled temperature cycle. This cycle was proposed to be of sufficient duration and at a high enough temperature to normalize the forming strains and eliminate any further distortion under actual service conditions.

2.2 Forming Machine Design Concept and Mechanization. The forming machine design concept as noted above was based on the idea of bending the tape rather than stretching it. The basic idea was quite new and

and unique in our experience. A schematic diagram illustrating its operation is shown in Figure 1. To obtain the necessary continuous operation it was proposed to utilize two flexible and resilient belts to support the tape during the bending process.

The belts were stretched between two pulleys. On one pulley the belts were deliberately spaced apart to permit the entry of the tape from the supply reel. On entry to the forming belts the tape was prestressed to a point just below yield. Clamping pressure was then applied to grip the tape firmly between the two belts as the resulting sandwich bent around the drive pulley.

The mechanization of this concept was a working model to verify the validity of the original idea. As initially constructed, the unit did form tape into a helical form; however, some development was required before satisfactory continuous operation could be achieved. The first tests samples were wrinkled radially due to the clamping pressure being maintained after the belts started to straighten again. The amount of pretension and the point of entry into the clamping roller both reacted on the tape diameter and closer controls had to be maintained.

On resolving these problems, a suitable electric drive mechanism was added to permit manufacturing the helical tape in quantity. With this addition, tape was produced in sufficient quantity to permit experimenting with the normalizing process.

2.3 Tape Quality Problems and Proposed Solutions. Apart from the radial wrinkling of the tape and the failure to obtain the planned tape diameter due to springback, there were other problems affecting tape quality which proved to be more subtle and difficult to solve. A close examination of the early samples of formed tape disclosed microscopic cracks in the oxide layer. In addition, at the outer edge where the greatest stretching took place, small pieces of oxide flaked or spalled of the Mylar substrate.

On attempting to beat-treat or normalize the formed tape, the oxide layer blocked to the Mylar backing. The temperature and clamping pressure used in normalizing the tape was varied in an attempt to avoid the blocking but with no immediate success.

Investigating these problems meant acquiring a knowledge of the binder systems and their constituents. Unfortunately this information was regarded as company confidential by the recording tape manufacturers. It was found, however, that binders are basically compounded from mixtures of plastics. Depending on the proportions of the mix, the resulting binder will be predominantly thermoplastic or thermosetting. A thermoplastic binder will deform with the Mylar under the forming conditions imposed in our machine with no signs of cracking or spalling. It will have a low blocking temperature however. The thermosetting binders will check and spall under the forming strains. At first, it was thought that a tape could be found which would meet both these conflicting requirements. Other problems arose which caused the normalizing pressure and temperature requirements to be completely incompatible with the conventional oxide coatings.

These problems were associated with other tape imperfections which could only be removed by using temperatures of 220-250°F and clamping pressures of 200 to 500 psi. The major imperfection of this nature was a radial curvature of the formed tape. Reversing the tape in the machine caused the direction of curvature to reverse also. The concave side stayed on the Mylar side of the tape. Also, a run with plain Mylar showed no curvature. Strangely enough the curve remained when the oxide was washed off the tape with solvent prior to forming. This indicated the curvature was due to the surface finish or pretreatment of the Mylar prior to coating.

The success with plain uncoated Mylar stock prompted us to proceed to obtain a full pack of uncoated tape for use in the transport design and testing. A 2000' helical pack was quickly obtained and successfully normalized. It immediately suggested the possibility of post-forming coating or plating. Preliminary inquiries in this direction disclosed no technical obstacles but rather a problem in materials handling to accommodate the helical format. Two other possibilities which time did not permit to be evaluated were the use of double sided tape to eliminate the radial curving and the use of mold release or similar coatings to inhibit the blocking under temperature and pressure.

Another factor affecting tape quality was the progressive deterioration of the forming machine belts due to wear. The belts were fabricated from a neofrane sheet stock and under the high friction loading, shreds of this material pulled out of the belt surface and adhered to the tape. Also the forces on the belts are such that a flat thin belt deformed excessively. This was thought to contribute to the radial curvature noted earlier. To counteract these effects a mold was fabricated and two belts were molded out of an unfilled natural rubber. These belts had a square cross section and preliminary tests indicated a substantial reduction in the radial bowing. Trouble was experienced in making the belts track properly in order to have room for the formed tape to exit from the machine. This resulted in the tape tending to be pulled straight again with resulting wrinkling and damage. Time did not permit a satisfactory solution to this problem but there is no reason to believe it to be insurmountable.

3. Transport Problem

3.1 Transport Configuration Analysis. In order to perform satisfactorily, a tape transport requires a tape guidance system which is inherently stable in operation. This stability is easy to achieve in a conventional recorder using crowned rollers or simple edge guidance. With the helical format there are no simple ways to achieve stable tracking. There is no equivalent to a crowned roller and edge guiding is of questionable merit. It is impossible to apply a straight tension to an unsupported piece of helical tape without distorting it.

The preliminary analysis centered on the single reel approach embodied in the original proposal. In our attempts to achieve a stable configuration two drawbacks to this approach became evident. It did not lend itself to a simple stable mechanization which would also be reversible, a firm specification requirement. The complicated geometry for even unidirectional operation was very much a function of package and would impose an unwelcome restriction on the transport versatility.

At this point, it was recognized that the helical tape format was vastly different from our previous experience with conventional recorders. This was accentuated as samples of formed tape became available from the forming machine. Where the layout of a conventional recorder is mainly a problem in two dimensions, a helical pack recorder involves three dimensions and the spatical relationships of all the various components are very critcal. Hardware design details were neither simple or obvious and the time required to fabricate any change parts for the device to handle this medium could be expected to be longer than normal.

With this greater appreciation of the problems, it became apparent that we were not in the position to launch into the design of Helical Tape Pack Magnetic Recorder Transport as called out in the JPL Specification. As an alternative, it was proposed to mechanize the most promising transport configuration into a working model. The model would be constructed as simply as possible with the sole aim of demonstrating the feasibility of the helical concept.

3.2 Twin Reel Configuration - Design Advantages. The configuration selected as the basis for the Model Study was quite different from the single reel configuration of the original proposal. By having two reels side by side, each wound in the opposite lay to one another, the tape could be transferred from one reel to the other through a simple loop.

The design of the transfer guide mechanism at each end of the twin reels would be identical and also symmetrical. Some idea of the simplicity of this approach may be gained by studying Figures 3 to 5 in the Appendix. There are a number of advantages in this configuration which are important in satellite applications. The twin counter-rotating reels have a minimum gyroscopic effect and minimum external torque effect. Although the shape factor is not so good as a single reel configuration, the dual reel unit promises to allow a greater utilization of the space inside the reels. The ability to vary the recorder tape capacity by simply changing one dimension is an important advantage. The sketch of Figure 6 shows how a flyable unit might look in practice.

3.3 Mechanization for Model Study To Construction Problems. For the Model Study an attempt was made to provide flexibility in the design for future configuration changes. For instance, molded plastic tape guides were incorporated into the design in such a way that they could be changed if necessary to effect improvements in tape management in a continuing experimental program. In addition the design of the reels and end guides was such that the lengths of the two tape packs could be varied if necessary.

From the experience gained with the forming machine it was apparent that the dynamics of the tape motion through a transport mechanism would be difficult to predict. When wound closely on the reel with even moderate tensions, it proved impossible to move the pack axially along the reel. The tape did not prove exceptionally fragile. The need for vibration to shock resistance to the inability to tension the tape indicated a need for continuous guiding of the free lengths of tape to avoid overstressing and mistracking.

To obtain a helical guide the end plates were cast from polyester resin. A special mold was used which was cored to provide bushings for the reels. A piece of Mylar 0.020 inch thick was cut from sheet stock to use as a core for the helical guide. Liberal use of parting compound permitted the Mylar pieces to be pulled out after the guide was cast.

Some problems were encountered with the casting resin due to shrinkage and overheating in the mold. Finally two matching end plates were produced. After clean up and boring out the bushings they were assembled with the reels and the pack of clear, uncoated Mylar for an initial trial.

3.4 Analysis of Model Testings. The initial tests showed the shaped guide performed as expected. They also showed the need for exact synchronizing between the two reels if the tape were not to bind on the reels and inhibit the necessary axial motion. Modifications were made to provide positive coupling from reel-to-reel. Mylar belts were also installed in the end guides to control the friction between the guides and the tape. This friction on the free lengths of tape and on the ends of the packs caused loops to accumulate at the off-going ends of the twin pack and the drive would stall.

When all of the minor modifications had been tried and stable operation was still not achieved, a major modification was planned. This was not incorporated in the Model due to a shortage. This redesign is more fully described in section 4. below.

The important point to be clasified here is the limited amount of testing which was possible in the program. Unforeseen difficulties delayed the initial assembly of the Model until the end of January. The design work for this unit was completed in November 1965. Similar delays were encountered in incorporating the subsequent modifications. The testing had to stop in the middle of April due to a shortage of funds. In retrospect it can be seen that this program was very much experimental not a straightforward design and development program. Unfortunately the time available for purely experimental work was severely limited due to the hardware availability.

4. Design Projections

4.1 Model Modification. The results from the limited amount of testing on the Model Study to date have shown the following requirements must be met if stable operation is to be achieved.

1) Enclosed cast guides for free lengths of tape.

2) Zero tape tension on reels for free axial tape motion.

3) A decoupling mechanism is required to provide tape tension across the heads.

4) Strict control of the friction forces is required to maintain zero tension.

5) The on-feed must automatically co-relate with the off-feed for stable operation.

There are a great number of ideas for mechanizing a helical pack recorder and some of these ideas promise to give stable operation, in theory at least. We know now some of the problems involved in putting these ideas into practice. The idea we are presenting here for incorporation into the Model not only gives inherent stability, but can also be readily mechanized with present technology.

Briefly then, the transport mechanism would use twin reels as before with each reel keyed to the other by means of interconnecting gearing. Each reel would be slightly longer than its share of the pack. The extra length at each end would be covered by a flexible resilient, hat-sectioned flange. The brim of the section would support the ends of the pack and the straight crown covers the end of the reel. The flange is keyed to the reel on a radius close to the central axis of the reel. This construction permits the flange to be raised over a conical guide roller to let the tape in or out while still having the reel outer diameter available as a centering guide.

With these flanges available the end guides are simplified considerably. At each end of the machine, the guide assemblies differ only in the presence of a recording head in the one where the oxide side of the tape is on the concave side. The curved, cast guide forms as assembly with a conical roller at each end as shown in the attached sketch. This assembly is arranged to feed the tape into the takeup reel flexible flange at a slightly larger pitch diameter than required. In order to reach the required diameter that is established by the takeup reel velocity and the velocity of the tape leaving the supply reel, the tape must slip slightly with respect to the flexible flange and seek the smaller diameter required for continuous operation. Since there is an attempt to drive this section of tape faster than is required, there will be no tendency to throw a loop on the supply side and the system becomes self equalizing. Figure 7 is a simple sketch showing the basic elements described.

One of the more important details is the curvature of the flexible flange as it guides the on-feeding tape from the conical roller into the end of the pack. This would be contrived so that a side force would be generated on the tape. The accumulated side force over a length of tape would generate the tension necessary to pull the tape through the guide. As the tape passes into the pack, however, it would pull into a smaller radius until the tension was dissipated and a zero tension wind was achieved. The reverse action takes place, of course, on the off-feed side. Here the side push of the flange against the tape pushes the tape out to a larger radius and generates a tension over the conical roller.

The two conical rollers in each end guide are not externally driven. Tape speed is established and maintained by driving the two reels in unison. The goal of zero tension in the packs will be reached by experimentally adjusting the central guiding through with its conical rollers into the proper position after which it will remain fixed. While some experimentation will be required to establish the correct geometry for this proposed modification, there is nothing in the way of new technology required. The loading of the transport should be greatly simplified as the guide can now be open along one edge. Since the flanges are keyed to the reels and then clamped to the packs, our goal of no layer to layer sliding will be achieved. In the transition from pack to guide and back again, the flange will act as a conical roller. Because of its flexibility and resilience, however, it can be likened to a conical roller of constantly changing angle.

4.2 Future Development of a Helical Tape Recorder. This development program is largely an investigation into the feasibility of using a helical tape pack in tape recording applications. Some general comments can now be made on its feasibility and its advantages for other applications can be projected.

There are no insurmountable problems in preparing a helical tape pack. Certainly our attempts to produce a satisfactory pack have been quite successful and the problem areas have been mapped out for later solution.

If a larger pack diameter relative to the tape width was used, a number of simplifications would occur. The cracking and spalling could be eliminated by selecting a thermoplastic binder. The radial curvature could be minimized or even eliminated by using double sided tape. Heat treat could be done, not in a pack, but by passing the tape over a suitable guide and using induction heating and air blast quenching. This would eliminate the blocking problem.

Some important advantages of the helical pack are not utilized in the transport under design. For very high speed recording or playback, a helical pack recorder could have a very simple speed control. The tape could be permanently mounted on a reel with the head interposed between adjacent turns. The accelerations on the tape would be minimized since pulleys and guides could be eliminated. Another significant application is, of course, in a random access recorder since each part of the tape is accessible from outside the pack. A simple mechanism would permit opening the pack and radially inserting a recording head at the required point on the tape. It must be concluded that the helical format is feasible and has significant advantages for some tape recording applications.

CONCLUSIONS

If the evaluation of the work performed on the Helical Tape Transport Program is based on the requirements of JPL Design Specification GMY-50340-DSN, it is evident that we fell short of this goal. If the program is judged on the progress made with a new and potentially very useful concept, however, it is equally evident that significant progress has been made. The goal set by the Design Specification was dictated by existing requirements at JPL at the time of the programs' inception. In retrospect, it is evident that a more general specification, allowing some leeway for design compromises, would have been better suited to the experimental nature of the program. An endless loop, reversible tape recorder with 1.5×10^8 bit storage capacity suitable for use in space environments would have been an adequate description of the basic program goal.

The forming problem was very much affected by the specification requirements. The 4-1/2" outside diameter required a differential strain of 28% on the 1/2" tape width. Since the inside diameter has to be strained above the yield point of 5% for successful forming, the outside diameter has to have a 33% strain minimum. These values are much in excess of practical levels with commonly available tapes. On the positive side it did prove possible to form helical tape. The concept for the forming machine was successfully mechanised and a tape pack of 5-1/2" outside diameter was produced. A number of factors adversely affected tape quality. Acceptable quality could have been achieved, however, by the simple expedient of increasing the tape diameter. While a 10" diameter pack would have posed space and weight problems, it might have enabled us to successfully produce a large capacity endless loop recorder. The design specification did not permit this possibility to be explored.

In designing the transport one of the first problems encountered concerned the ratio of the pack diameter to length. To fit 2000 feet of tape into a 4-1/2" diameter helix resulted in a pack length of 3.8 inches. This proved too large to permit a simple mechanisation to pass the tape from one end of the reel to the other. This was a major factor in the decision to use the dual reel configuration. With a 10" pack diameter the corresponding pack length would be 1.7 inches, a much more manageable combination.

As it was, the twin reel configuration had several unique advantages to offer in simplifying the tape path design. It also promises to meet the space limitations. Although satisfactory stable operation had not been achieved when the program ended, there was no indication that this was impossible. There proved to be insufficient time available to perform the development testing that the experimental nature of the program warranted. At the conclusion of testing, a number of promising ideas for design improvements remained untested. As a result no conclusion can be made as to the ultimate feasibility of the Helical Pack Format.

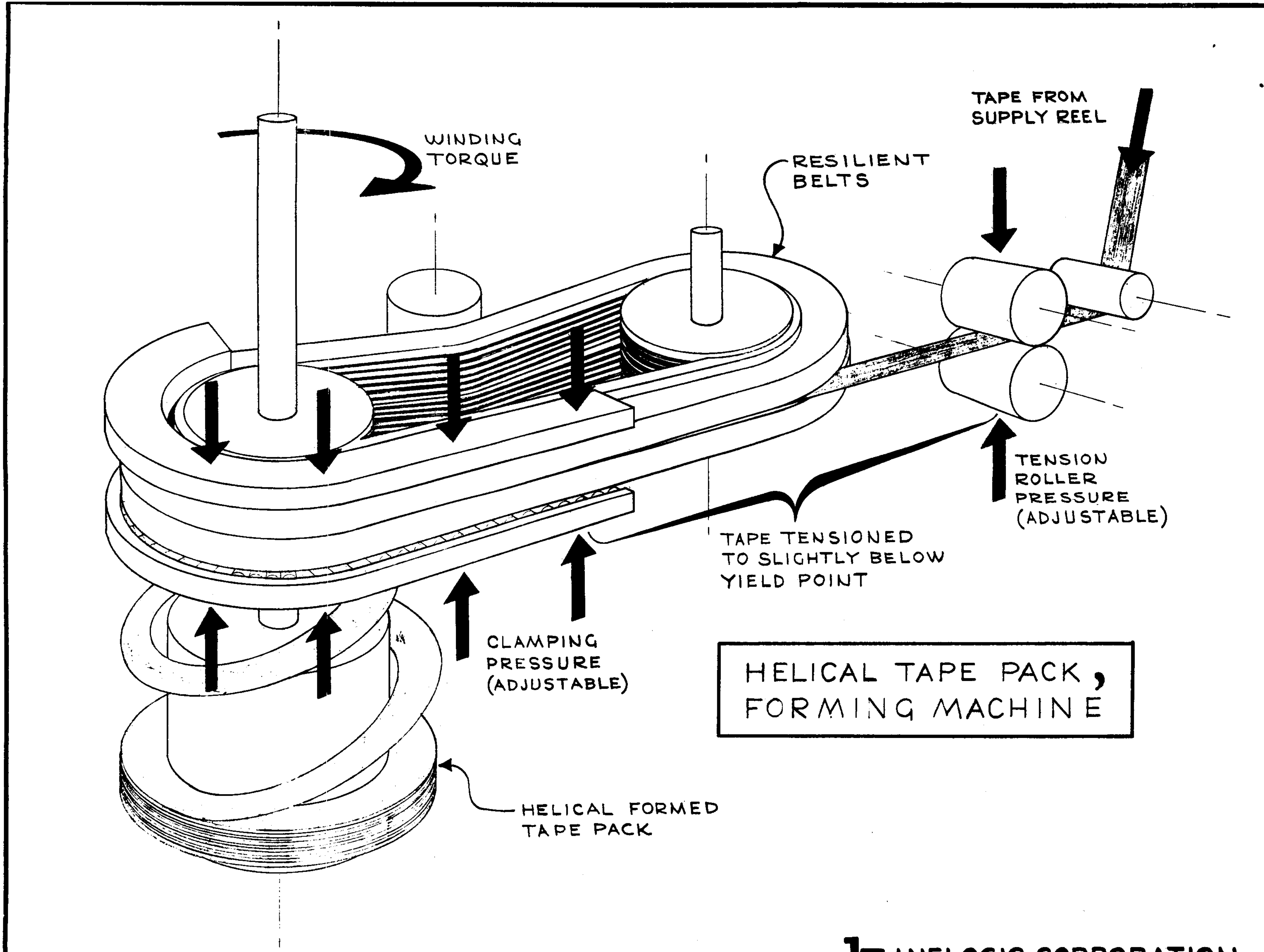

WINDING TORQUE
RESILIENT BELTS
TAPE FROM SUPPLY REEL
TENSION ROLLER PRESSURE (ADJUSTABLE)
TAPE TENSIONED TO SLIGHTLY BELOW YIELD POINT
CLAMPING PRESSURE (ADJUSTABLE)
HELICAL FORMED TAPE PACK
HELICAL TAPE PACK, FORMING MACHINE
KINELOGIC CORPORATION

FIGURE 1.

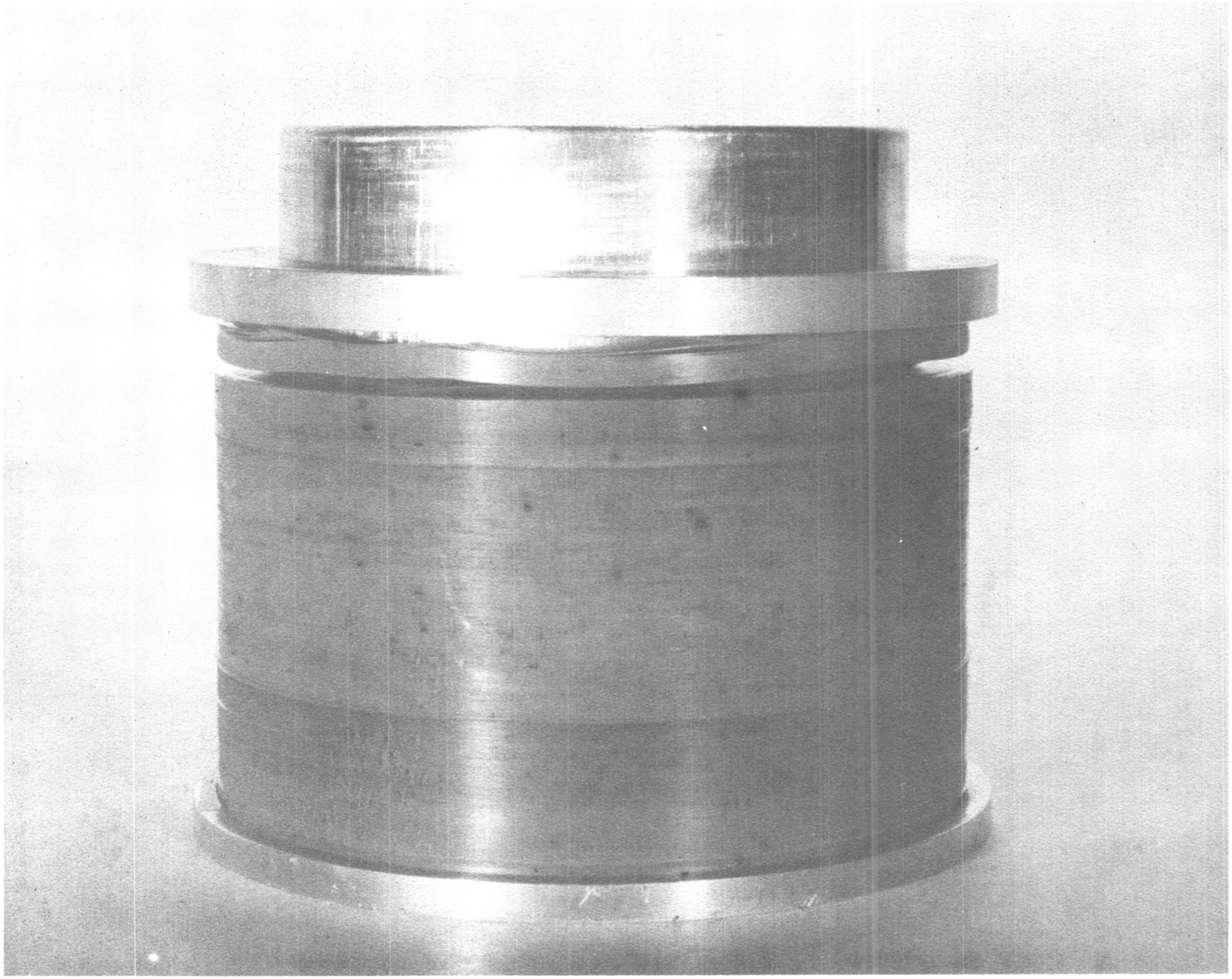


FIGURE 2. FORMED TAPE PACK

FIGURE 3.

Model of Helical Tape Transport, Dual Reel Configuration

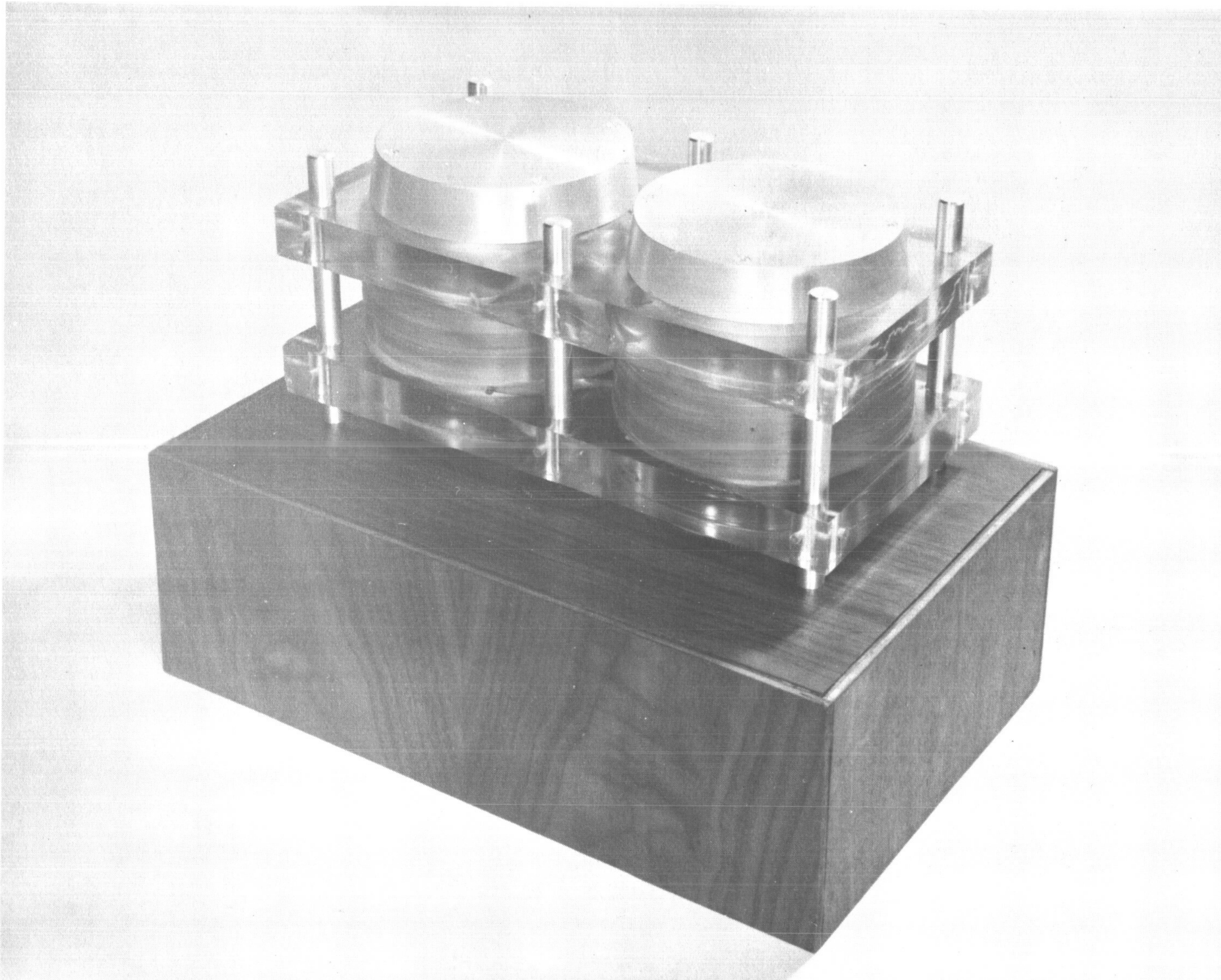


FIGURE 4.

Three-quarter view of Helical Tape Transport Model

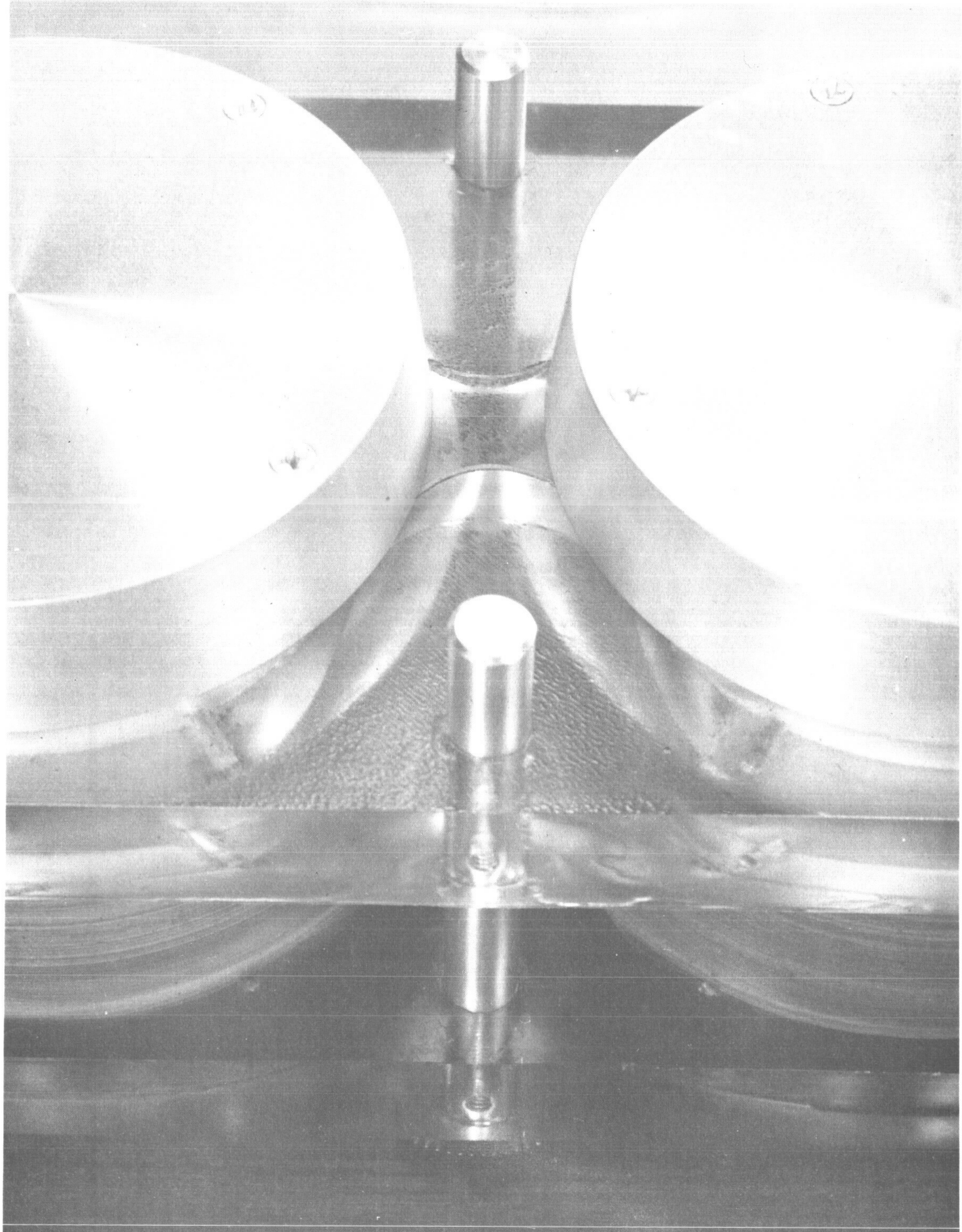
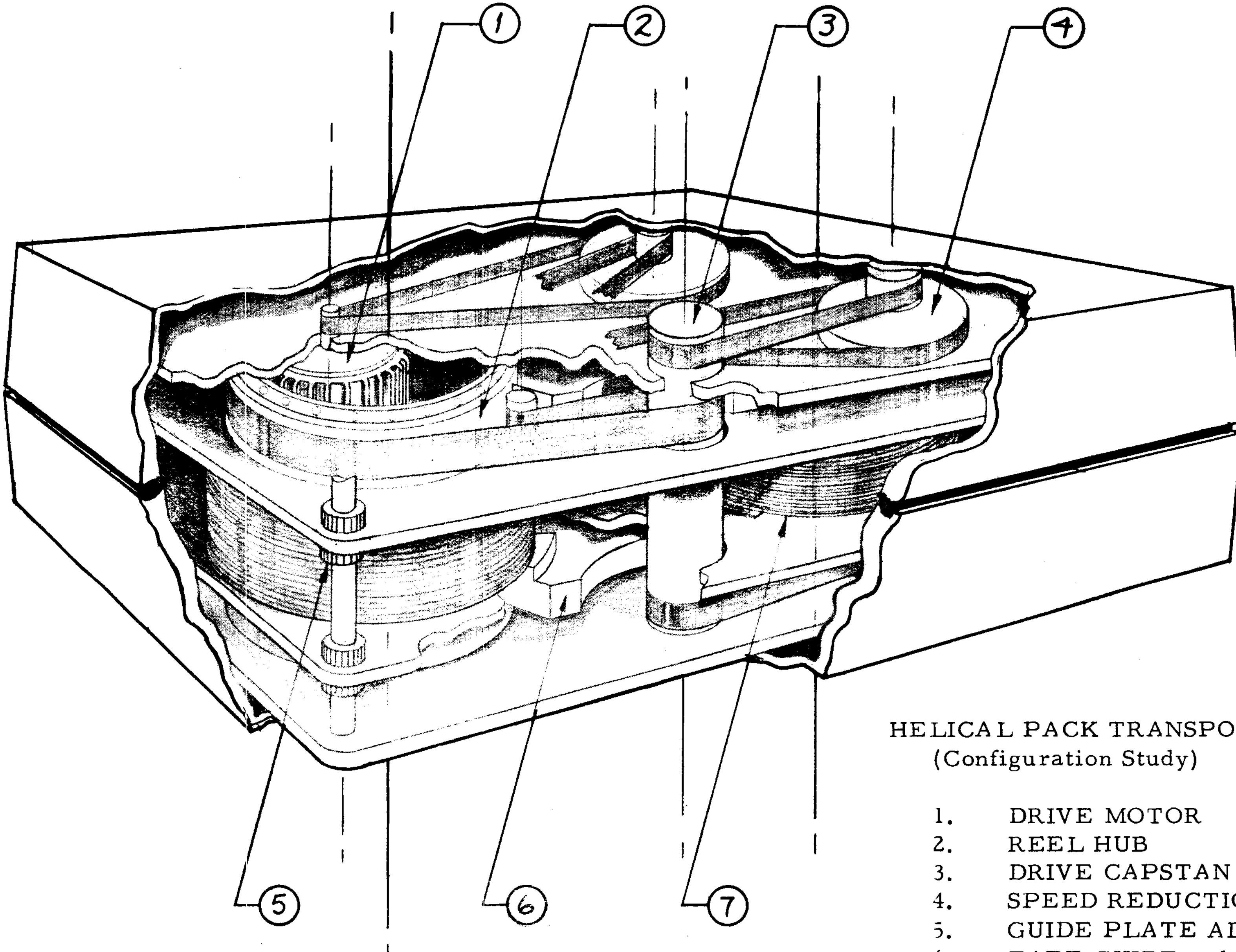


FIGURE 5.

Close-up showing tape guide cast in Polyester end-plate



HELICAL PACK TRANSPORT
(Configuration Study)

1. DRIVE MOTOR
2. REEL HUB
3. DRIVE CAPSTAN
4. SPEED REDUCTION
5. GUIDE PLATE ADJ.
6. TAPE GUIDE and HEAD MTG.
7. HELICAL TAPE PACKS

FIGURE 6.

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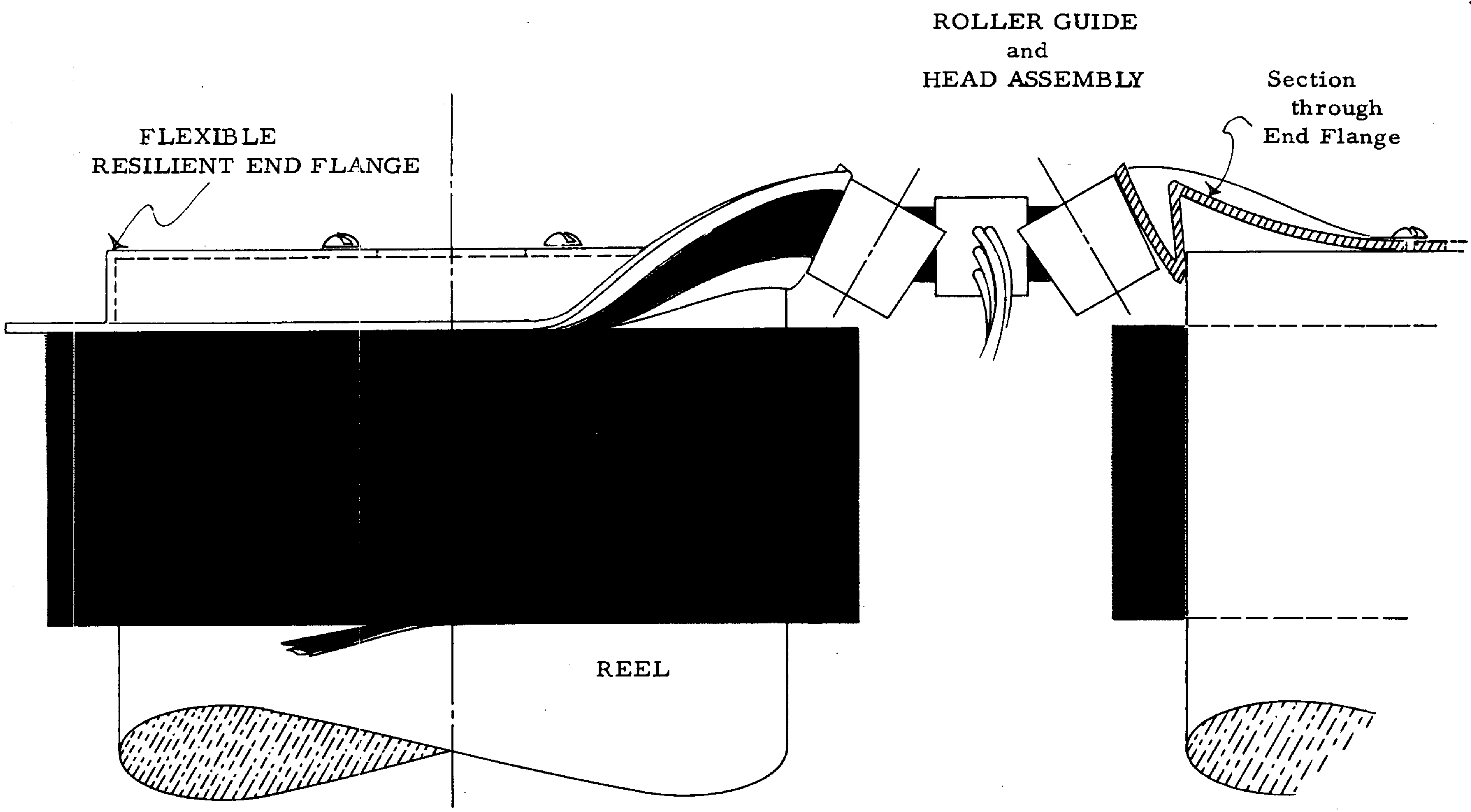

FIGURE 7 PROPOSED MODIFICATION, DUAL PACK MODEL