KRYTOX LUBRICATION TAPE STUDY

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SUMMARY

The investigation into the use of Krytox, a fluorinated oil, as a tape surface lubricant did not result in its incorporation in the Landsat C wideband video tape recorder. Unfortunately, the tape used in this evaluation was found to be excessively abrasive to the magnetic heads. In spite of the 5 to 1 head wear reduction credited to the surface lubricant, the resultant head life fell short of the 1500 hour goal. Time limitations did not allow a second trial with another tape.

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1. Introduction

1.1 Performance History of the Landsat (ERTS) Wideband Video Tape Recorder (WBVTR)

A WBVTR in Landsat A, launched in July 1972, operated for approximately 1000 hours before complete tape breakdown rendered it useless. This orbit history substantiated the many tape life test results obtained during the development stage of the Landsat recorder. Life test data ranged from 1000 hours to as high as 2000 hours and indicated that tape breakdown could be anticipated after the 1000 hour point. Short of random electrical or mechanical component failure, the WBVTR was considered capable of achieving operational life of 1000 hours or 2000 tape passes. Since this was a program design goal, it was considered adequate for Landsat A and B*.

1.2 Life Improvement

Landsat C, the next in this series of Earth Observatory Programs, provided for a general upgrading of the spacecraft for extension of life. A tape life goal of 1500 hours or 3000 passes was established for the WBVTR and to achieve the additional life, RCA considered two areas:

1. Headwheel Panel Modification

   The present Landsat headwheel panel had evolved from an initial design where 250 hours of tape life was acceptable. The increase in tape life to the present apparent 1000 hours was in a large

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* At the time of this writing, a WBVTR in Landsat B launched January 1975 has passed 1000 hours of operation accumulated over a three year period and is still operating with no degradation.

part due to a redesign of the headwheel panel. With more recent knowledge gained over the years about the tape breakdown mechanism, additional headwheel panel changes were suggested to increase the life of the tape.

2. Surface Lubrication of Tape

A process developed and patented by the Illinois Institute of Technology Research Institute (IITRI) for the use and application of Krytox, a fluorinated oil, to magnetic tape to act as a surface lubricant. This process has been found to increase both head and tape life in other recorder applications.

After some review, it was jointly decided to concentrate solely on the surface lubrication techniques for tape life improvement. The vigors of changing a high precision component as the headwheel panel and the possible impact on the layout of the tape deck was considered too great for the theoretical improvement. However an encouraging attempt to consider a Krytox surface lubricant was made at RCA during the Landsat B period, 1973-1974. Using an RCA TR-70 broadcast video tape recorder and a Krytox treated 3M500 tape, 10,000 passes were achieved with no signal degradation on a short test sample as compared to an untreated sample that survived only 3000 passes. In the subsequent attempt to treat the Landsat tape, (3M-MTA20237 75669) an excessive amount of lubricant was used or left on the tape surface which led to a severe case of stiction and prevented further testing. This was believed to be in part due to the rougher surface of the MTA 20237 tape, as compared to the 3M500, trapping more lubricant and in part due to the manual application of lubricant techniques then used. The Krytox consideration was then dropped because schedule commitments did not allow further work. Since then, IITRI has developed a coating machine which promised to eliminate the variables of manual application.

2. Tape Improvement Program

RCA in conjunction with IITRI was to develop the tape surface lubrication parameters with the objective of achieving 1500 hours of operation reliably. The program developed two major tasks.

2.1 Tape Selection

The 3M formulation MTA 20237, used in the Landsat recorders, is a version of a tape developed during the mid '60's. Its main attribute is a "hard" oxide binder system designed to withstand high temperature operation, however, it sacrifices signal to noise and surface smoothness. With the proliferation of transverse scan video recorders and all the tape development it engendered, in all liklihood a modern commercially available tape would be more suitable for improved Landsat performance. Commercially available tapes would be reviewed and the most promising would be evaluated along with the MTA 20237.

All the flight recorders up to this point used tape of the type MTA 20237 from one batch or lot designated 75669. Toward the end of the Landsat B Program, a new lot of MTA 20237 designated 87784 was ordered as a backup to the dwindling supply. This new lot was to be considered as potential tape stock for Landsat C. It is a program requirement that every separate tape lot be qualified before it is acceptable for WBVTR use. The Tape Qualification Test is comprised of two parts:

1. High Temperature Test

   A short section of tape, 3 to 5 minutes long is subjected to two cycles of 50°C operation in the WBVTR. The headwheel is checked for gunking, glazing and cleanliness of operation. This test serves to evaluate the durability of the oxide binder system.

2. Life Testing

The WBVTR with a full tape load, 30 minutes minimum, is cycle tested until failure to develop head wear data and life properties of the tape. For this program, all candidate tapes were required to pass the High Temperature Test before further consideration as a surface lubricated prospect.

2.2 Surface Lubrication

The selected tape was then to be treated with a range of lubricant levels and evaluated to determine the optimum. Lubricant thickness determination would be based on the life extension testing on the TR22 at IITRI and compatibility testing at RCA on the WBVTR. Only the final selected tape and lubricant thickness would undergo the Tape Qualification Test.

3. Roles of Participants

3.1 IITRI's Function

3.1.1 Characterization Tests

A set of tests measuring physical, chemical and electrical parameters of tape. IITRI in its tape studies for NASA had developed guideline requirements for each of the parameters listed that are conducive to long life in untended sattelite recorders. IITRI would perform these lists on all candidate tapes.

1. Oxide Resistivity
2. Chlorine Content
3. Flexibility
4. Thermal Stability
5. Lubricant Content
6. Abrasion Wear
7. Loop Life

8. Oxide Thickness

9. Substrate Thickness

10. Back Coating Thickness

11. Back Coating Resistivity

12. Cupping

13. Static Coefficient of Friction

14. Dynamic Coefficient of Friction

3.1.2 Preliminary Tape & Coating Thickness Evaluation

IITRI, using an RCA supplied TR22, a commercial video recorder, modified for short cycle operation and to measure tape dropouts would run comparison tests of the candidate tapes and different coating thickness. A test sample would be 45 seconds of tape with dropout activity measured over a fixed 33 second section. The extra length allowed for initial servo lockup and an overrun margin at the end. A cycle or pass could then be accomplished in under 60 seconds. A recorded signal of approximately 200 u in. wavelength was amplitude detected for dropout performance. The threshold detector was set at 40% of peak amplitude and could detect a dropout as small as 140 nanoseconds. The duration of the dropout was also monitored by gating a 10 MHz source to a counter with the dropout pulse.

It is accepted that the TR22 results are not directly applicable to the performance of the WBVTR, but it would provide a separate basis for quickly comparing the relative performance of different tapes and lubricant coating thicknesses.

3.1.3 Surface Lubrication

IITRI is to coat sample levels for RCA's testing in parallel and the final selected thickness would be applied to 10 rolls for life testing and flight use. The final 10 rolls to be verified for coating uniformity.

3.2 RCA's Function

3.2.1 Tape Supply

RCA is to provide for suitable quantities of candidate tapes for testing and to classify and select tapes for potential flight use.

3.2.2 Compatibility Tests

The WBVTR is a reel to reel transverse scan recorder with a capacity of 2000 feet of 2 inch tape or 30 minutes of recording time (Fig. 1). Flangeless reels used to store the tape are differentially coupled to a negator spring system to maintain tape tension. It has two modes of commandable operation, Analog with 3.5 MHz BW or 15 Mb/s Digital data. With an operating temperature range from 0^{o} to $45^{o}C$, the performance of the WBVTR is critically dependent on many properties of the tape. The use of a surface lubricant should not materially change any of the critical tape parameters. RCA will test effects of the surface lubricant on:

1. Mechanical Handling
    a. Capstan slippage due to transfer of the lubricant would increase tracking error.
    b. Coefficients of friction. A significant increase, real or apparent, or the development of stiction could overload the tape drive system. A significant decrease could increase the tape coasting time and make the stopping point unpredictable. Tape handling and guiding characteristics should not be altered by the presence of the lubricant.
    c. Tape pack integrity on the flangeless reels is dependent on the tape layer to layer friction to withstand vibration and temperature changes. A shift of the tape pack could result in severe mistracking and possible damage to the tape.

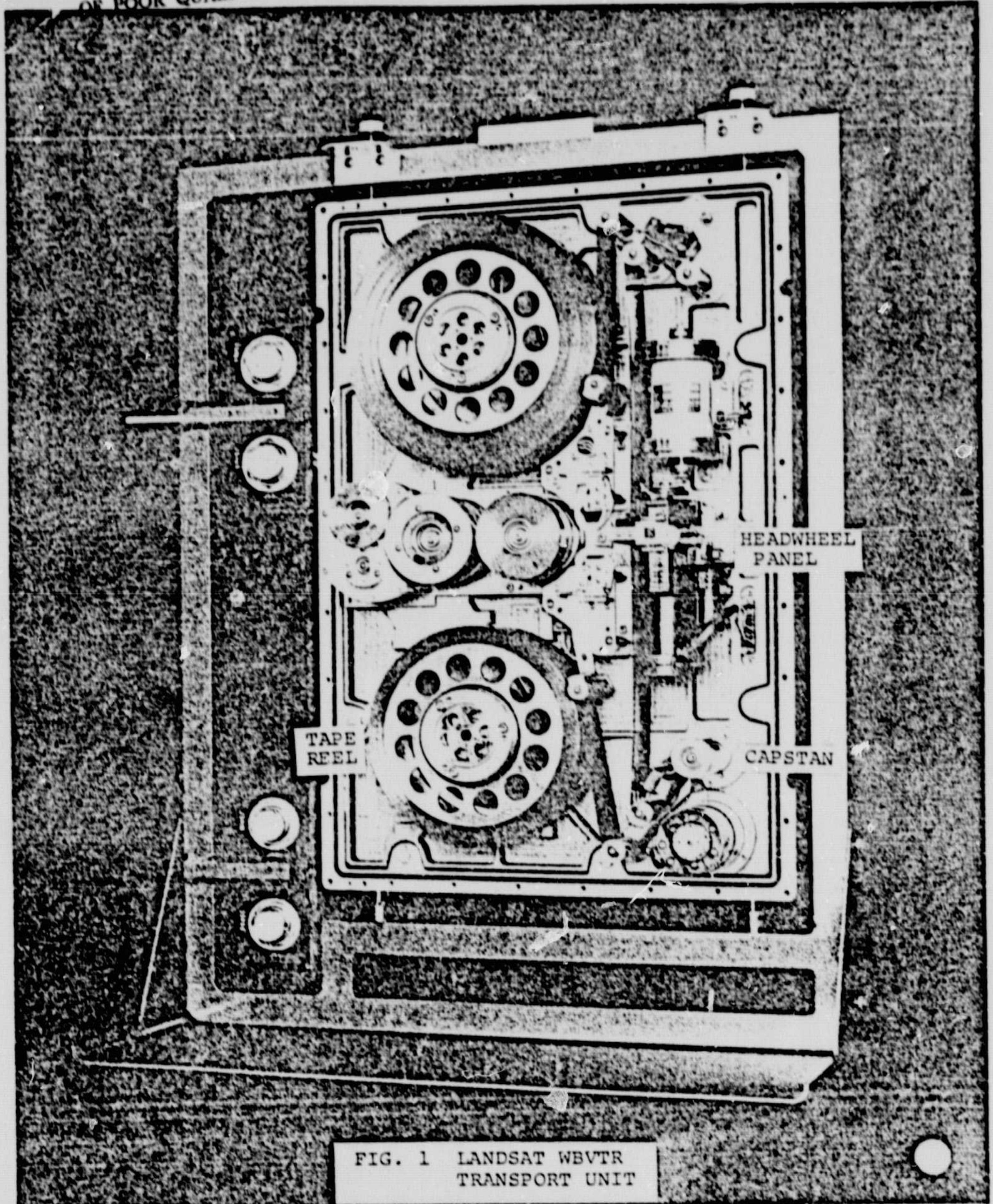


FIG. 1 LANDSAT WBVTR
TRANSPORT UNIT

d. Temperature stability. The operating temperature range of the WBVTR is not expected to tax the properties of the very stable oil, but its presence on the tape surface must not materially alter the nature of the wear products such that the rate of generation or accumulation on the headwheel is increased at the temperature extremes.

e. Transverse loading. The rotating headwheel motor should encounter a minimum increase in torque loading especially at the lower temperatures.

2. Signal Response

The purported thickness of coating is predicted not to cause any significant separation losses. Both longitudinal and transverse tracks are to be checked for magnetic transparency. Head buildup of lubricant or wear products will be closely watched.

RCA is to perform the High Temperature Test on all tape candidates as an initial qualifier. Compatibility tests will be run on the same tapes and coating thicknesses as those being considered by IITRI.

3.2.3 Tape Qualification Test

RCA will perform the full qualification test on the final selection of tape and coating thickness.

4. TEST RESULTS

4.1 Tape Selection

Initially, the commercial tapes to be considered along with the 3M MTA 20237 87784 were:

1. 3M-400 Quad Video
2. 3M-500 Instrumentation
3. AMPEX 178 Quad

These commercial tapes have a standard oxide coating thickness of 0.4 mil compared to 0.2 mil for Landsat tapes. The thicker tape would decrease the total recording time which is determined by a maximum tape pack diameter by 15%. Their use would also require a modification of the headwheel panel tape shoe guides to prevent tape pinching. The manufacturers were requested to produce 0.2 mil coating thickness versions for Landsat. Only AMPEX could comply within the time frame of the schedule requirements. Another tape, a 3M-361, made for helical scan recorders was available in the proper thickness. It also came with impressive credentials, smooth finish and good signal to noise with a durability that can withstand still scan operation. In addition, another recorder program had successfully used this tape under severe temperature extremes. The candidates tapes then to be considered for the Landsat Program are identified as:

1. 3M-MTA 20237 87784 - A reorder of the previous Landsat tape.
2. AMPEX 775-98511-07 - A thin coating version of their type 178.
3. 3M-MTA 86150 16863 - A transverse oriented version of their type 361.

As expected, IITRI found up to a 6 dB signal level improvement at 7 MHz (200u in wave length) and a much smoother surface finish from the AMPEX 775 and 3M-MTA 86150 as compared to the 3M-MTA 20237. This was in part confirmed by RCA in testing the AMPEX 775.

In the WBVTR, signal improvement was 1.5 dB at 14 MHz (150u in wave length). The WBVTR is a faster scanning machine than the TR22. The AMPEX 775, with very few nodules, was very smooth except for an occasional pin hole. Pin holes are believed to be caused by pockets of volatile binder components coming to the surface during the curing process. In spite of this, the 775 had 4-5 times lower BER (bit error rate) than the MTA 20237 87784.

A comparison of the two MTA 20237's, the new 87784 against the old 75669, revealed the 87784 was "rougher" and would exhibit a 2-3 times higher initial BER. This, however, was not substantiated by later surface profilometer tests. The 75669 measured 8.5u in peak to peak surface finish while the 87784 measured only 3u in. By the time that the new MTA 20237 and AMPEX 775 were being subjected to the High Temperature Test at RCA, IITRI reported their findings of severe stiction on both the AMPEX 775 and 3M-MTA 86150 after only 300-600 passes. The failure was the same in both cases. After some period of cycling on the TR22, the tape would adhere to the stationary elements of the transport and could not be moved. Another roll of AMPEX 775 was tested at IITRI and the problem was confirmed. The WBVTR seemed to be resistant to the stiction problem and a deliberate attempt to cause stiction in the WBVTR was conducted. After operation at 50^{o}C, a 775 tape was allowed to cool down to room temperature without any tape motion. No evidence of the problem was discerned.

Another sample of 775 tape cycled to 600 passes on the TR22 was installed on the WBVTR. Again no problem was noticed. The use of roller guides, lower tape tension and the lack of reel braking probably makes the WBVTR less prone to develop stiction than the TR22. The problem was attributed to the ultra smoothness of the new tapes which was further accentuated by the burnishing action of several hundred passes. The phenomena then pass related could be expected to occur in the WBVTR at a later stage. A microscopic examination of 775 tape that had seen 600 passes showed that surface damage is occuring before stiction is noticed. A trial surface lubricant was tried on one of these tapes and tended to enhance the problem rather than reduce it. Both the AMPEX 775 and 3M-MTA 86150 were dropped from any further consideration and no further testing was performed on these tapes. Effort then concentrated on evaluating lubricant thickness levels on the 3M-MTA 20237.

4.2 Lubricant Thickness Evaluation

4.2.1 Sample Level Testing At RCA

A tape from the Landsat B stock, an MTA 20237 75669, was trial coated to the proposed four levels of lubricant thickness to check the coating machine setup. This tape was evaluated at RCA as a preview of events. Level 1 (thinnest), Level 2 and Level 4 (thickest), each three minutes long, were cycle tested for over 150 passes. It was encouraging to find that no signal loss or tape handling deficiencies existed in any of the samples. Level 3 was omitted because progressive differences between level samples could not be detected.

The formal test was run with a tape from the MTA 20237 87784 stock which was coated to the same four levels. Two separate samples were produced to permit parallel evaluation by IITRI and RCA. WBVTR testing of Levels 1 and 4 started with three minute test sections which were cycled to 420 and 600 passes respectively. Again no tape performance deficiencies were noticed in either sample. Differences between the two levels were not distinguishable by either appearance or performance.

The test cycle was shortened to one minute and the Level 1 and 4 samples were tested for an additional 3000 plus passes each. The results were the same, no distinguishable differences were seen between the two levels. An untreated sample was then installed and cycled tested to 3000 passes. The only difference now seen between the treated and untreated tape was the appearance of the oxide accumulation on the rim of the headwheel. With the treated tape these oxide deposits tended to have a wet look or a smeary appearance. The amount of deposits were small in all cases and never developed to a destructive point. This was substantiated by the low BER's at the end of testing, from all of the samples, which indicated that no tape deterioration was taking place.

The WBVTR testing philosophy for sample evaluation was strictly a negative one. The samples of various coating levels were scrutinized carefully for compatibility of operation in the WBVTR. Performance differences in signal levels, frequency response, tape guiding, servo tracking jitter, headwheel jitter and debris accumulation were reviewed. Life improvement of the tape was to be evaluated with the TR22 and the final life test.

4.2.2 Sample Testing At IITRI

IITRI tested untreated and Levels 3 and 4 coated samples of the MTA 20237 on the TR22. The testing was begun on the untreated tape. The tape was run for 1500 passes with dropout measurements conducted at various intervals during the test. The total number of dropouts and their average duration were recorded (Figures 2 and 3). The data was averaged over 10 runs for an interval measurement. After 1500

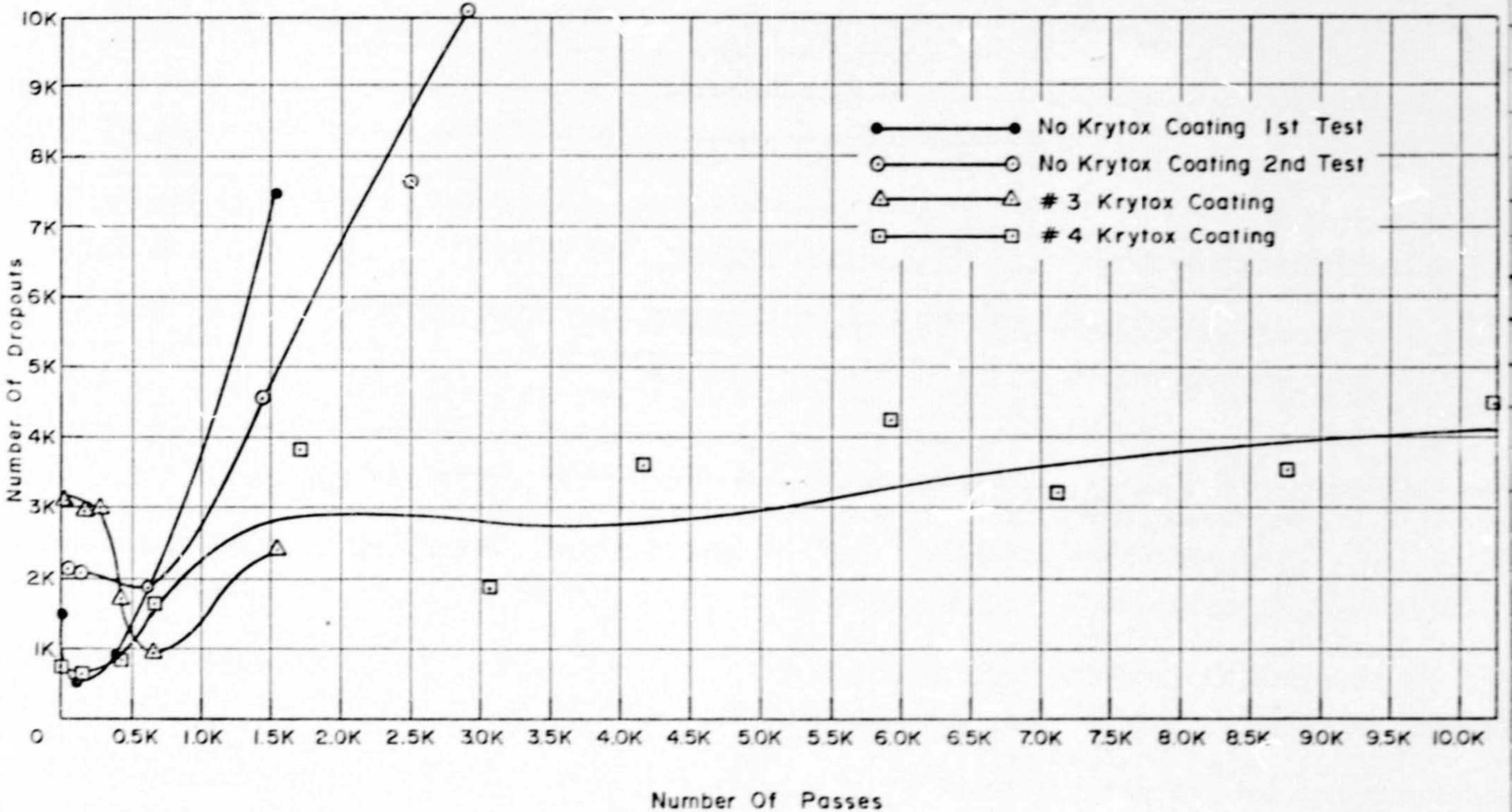


FIGURE 2 NUMBER OF DROPOUTS VS. NUMBER OF PASSES
TAPE TYPE MTA - 20237

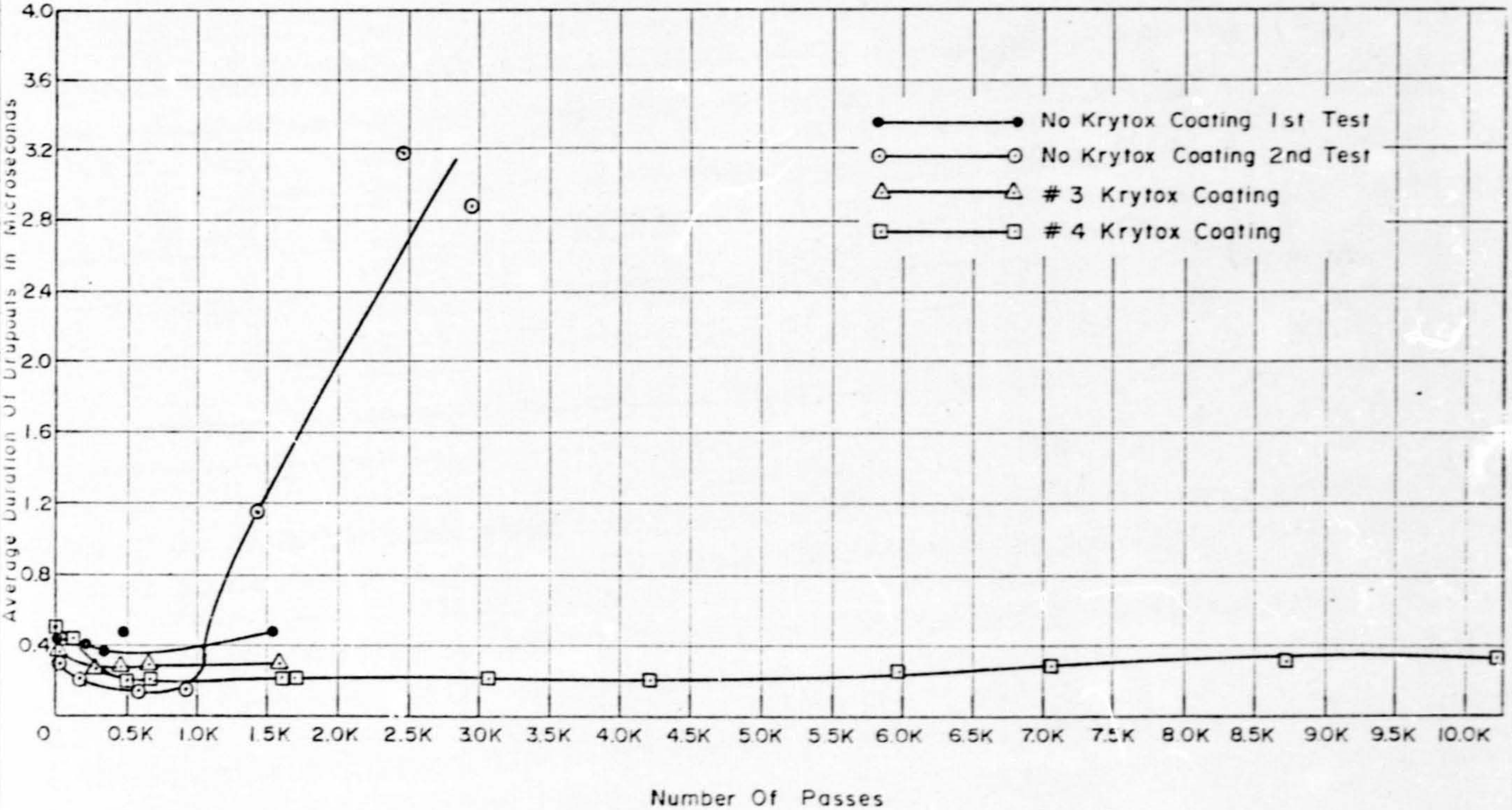


FIGURE 3 AVERAGE DURATION OF DROPOUTS VS. NUMBER OF PASSES
TAPE TYPE MTA - 20237

passes, the dropout count increased to 15 times the minimum. The next sample tested was coated to Level 3. After 1500 passes the dropout count had only increased 2.5 times. The tests were repeated with a new headwheel panel because of problems of scability with the old headwheel panel. This time it was decided to extend the testing beyond 1500 passes and increase the lubricant coating to Level 4. For the second run, the untreated tape had a 5.5 time dropout growth after approximately 3000 passes. The Level 4 sample showed a somewhat flat dropout growth even out to 10,000 passes. With a 5000 count taken as an indication of end of life, the treated tape showed at least a six times improvement in life.

Based on this performance, the surface lubricant thickness of Level 4 was selected for final testing.

4.2.3 High Temperature Test, Level 4

The Level 4 coating of the MTA 20237 tape was given a final confirmation with the High Temperature Test in the WBVTR. The remaining sample, just three minutes long, was subjected to 2 cycles of room ambient to 50°C temperature change. Testing was extended for a longer than normal period and 850 passes were accumulated. Examination of the headwheel showed increased amounts of oxide debris had collected on the headwheel rim at the end of the cycling. This is somewhat to be expected considering the prolonged time of operation at 50°C.

4.3 Characterization Tests

It was decided not to perform the characterization tests on the two commercial tapes that developed adhesion problems. Instead, the tests would be performed on the MTA 20237 tape before and after treatment with the surface lubricant. These results are shown in Table 1.

4.3.1 Oxide Resistivity

The specification for oxide resistivity states that the resistivity shall be between 5 and 500 Megohms per square. The test result of untreated and treated 3M MTA 20237 tape indicates an average of 0.234 and 0.212 megohms per square respectively. The low range had originally been established for iron oxide formulations in which excessive carbon was found to severely weaken the binder. In these cases, the carbon was observed as one of the constituents of debris which accumulated. 3M MTA 20237 tape exhibited resistivity significantly lower than the minimum specified. The MTA 20237 samples thus failed the oxide resistivity test.

4.3.2 Chlorine Content

Tape types exhibiting a chlorine content show increased adhesive interaction with various head materials. In addition, its presence or the possible formation of decomposition products could accelerate degradation of either the head surface or the binder polymer itself. The test result of 3M MTA 20237 tape indicates no chlorine content.

4.3.3 Flexibility

The stiffness of magnetic tape is a factor in predicting the tendency to produce oxide binder debris. It has been determined that the more flexible tapes were less likely to generate debris. The existing specification for half inch tapes with nominal base thickness 1.0 mil should not be less than 30 degrees deflection. The test result of 3M MTA 20237 tape indicated a 60.75° deflection (based on ½" width). The MTA 20237 passed this test.

4.3.4 Thermal Stability

The upper operating temperature limit was found to be one of the most critical factors encountered in both the frictional and debris performance of the heads and tape. Several failure mechanisms, including binder softening and deposition of melted or plasticized debris on the head, were observed during the high temperature test performed at 175°C. A loss of surface shine and base shrinkage was observed, but no adhesion was noted.

4.3.5 Lubricant Content

Lubricant content should be between 1.0% and 2.0% of the total weight of the binder system, including oxide. The test result of 3M MTA 20237 tape lubricant content is 1.29% which falls within specified limitations. The lower limit of percent lubricant content is necessary to obtain the desired reduction in coefficient of friction, while excessive quantities are believed to be a factor in weakening the integrity of the binder polymer system.

4.3.6 Abrasive Wear

The test is designed to obtain information about the susceptibility of magnetic tapes to surface damage, independent of tests performed on loop and reel-to-reel transports. The number of passes required to remove the oxide will provide a measure of the tape's susceptibility to abrasive wear. The test result of untreated 3M MTA 20237 tape indicated an average of 1477 and 8433 passes respectively. The factor of six increase in abrasive wear between coated and uncoated samples is a relative indication of the increased durability when tapes are surface lubricated.

4.3.7 Loop Life

The test is designed to test rapidly, under controlled conditions, the durability of sample tapes as well as the headwear caused by the tape on a known head. Both treated and untreated tapes, 54 inches in length, were tested. Chrome heads were used. Tests were run at a tape tension of 8 oz., with a tape speed of 30 ips and a wrap angle of 15^{o}. At the end of 330,000 passes with the untreated tape, the oxide particles started loosening and production of wear products was pronounced. The head was profiled and it had an average of 15u inch headwear. The treated tape tested under the same condition showed no observed particle loosening and no measureable headwear.

4.3.8 Static and Dynamic Coefficient of Friction

The values of static and dynamic coefficient of friction are used to calculate the critical stick slip speed of the various types of tapes. In addition, these values are utilized to calculate the head pressure. The storage and retrieval of information retrieval of information requires intimate contact between the tape and head. The head pressure is a function of tape tension, wrap angle, head radius and coefficient of friction. The existing specification for static and dynamic coefficient of friction between the media and head surface is 0.40 $\pm$ 10% respectively. The treated 3M MTA 20237 tape has static and dynamic coefficients of friction 0.397 and 0.375 respectively which is within the specified range.

4.3.9 Cupping

Cupping is defined as the transverse curvature of a strip of tape viewed "end on". It is found to be due to a differential absorption of moisture by base film and coating. Cupping affects the winding properties of the tape width. More importantly, it is not possible to ensure the essential intimate contact between tape and head across the tape when pronounced cupping is present without subjecting the tape to undesirable tension during use. The specification for differential cupping shall not exceed 1^{o}. The result indicates a differential cupping 0.15^{o} which is within accepted levels.

4.3.10 Tape Parameters

Additional testing was performed on the MTA 20237 to define the standard tape parameters.

Oxide surface finish	5u inch
Saturation Induction, Bm	957.7
Residual Induction, Br	729
Coercivity, Hc	262
Squareness Ratio, Br/Bm	0.76

Magnetic properties measured in the direction of orientation using a field strength of 1000 oe.

TABLE 1

TAPE EVALUATION RESULTS (3M MTA 20237)

Criteria	Untreated	Treated
Oxide Resistivity (M /sq)	0.234*	0.212*
Chlorine Content	None	
Flexibility (degrees)	60.75	
Thermal Stability	Passed	
Lubricant Content (%)	1.29	
Abrasive Wear (No. of Passes)	1477	9433
Head Wear (u in) (330K Passes)	15	0
Oxide Thickness (u in)	190	
Substrate Thickness (u in)	930	
Backcoating Thickness (u in)	9.23	
Backcoating Resistivity (K /sq)	0.15	
Cupping (degrees)	0.15	
Static Coefficient in Friction	0.46*	0.397
Dynamic Coefficient of Friction	0.44	0.375

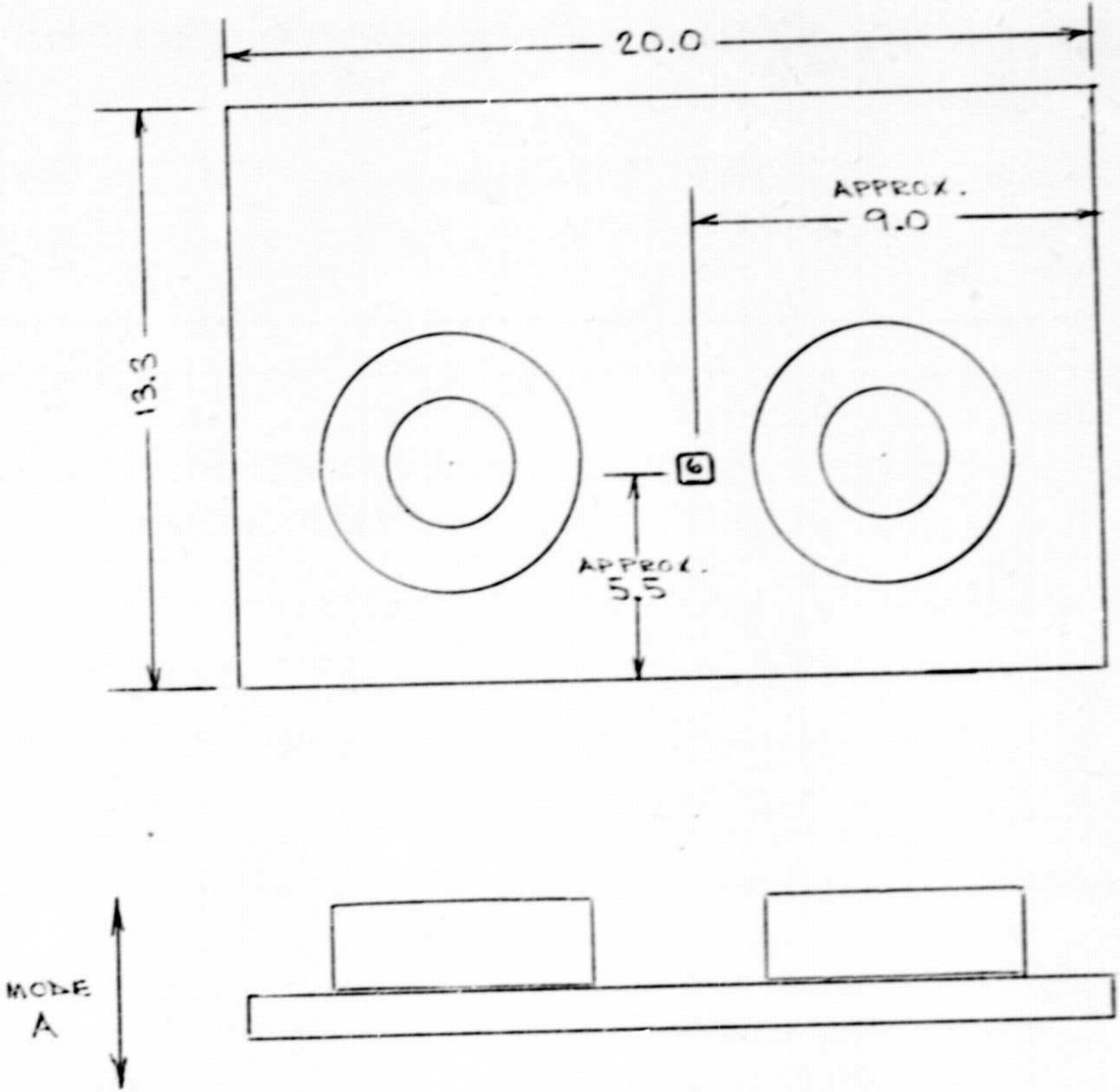
*Failed Guideline Criteria

4.4 Final Qualification Testing

4.4.1 Tape Pack Vibration

The WBVTR uses flangeless reels for the storage of tape and is dependent upon the layer to layer friction to maintain the integrity of the tape pack. To minimize the forces of launch vibration on the tape packs, WBVTR operating procedure calls for a Launch Mode configuration that requires a reel through to eliminate tension transients due to starts and stops and a final positioning at middle of tape to equalize the amount stored on both reels.

A separate test was conducted to assess the effect of the surface lubricant on the tape pack stability. Another MTA 20237 87784 tape was coated to the same #4 level as the final qualification test tape. When received, the tape was allowed a 24 hour period to adjust to the temperature and humidity conditions of the laboratory. The tape was then wound through twice on a tape winder before being loaded onto the WBVTR. Three reel throughs were then performed to develop the proper tension pattern and then the tape packs were equalized. The tape was cut and the ends secured to the tape packs. The two rolls of tape with their respective reel hubs were transferred to a vibration fixture (Fig. 4) and subjected to a 2-axes sine and random vibration of Qualification level. Since the fixture has a transmissibility of one, the output frequency/G levels were adjusted to reflect the transmissibility of the actual Landsat tape deck (Fig. 5, 6, 7, 8). The "A" mode of vibration was parallel to the reel axes and is the worse case for tape shift.



6 ACCELEROMETER LOCATION

FIGURE 4

ERTS VIBRATION TEST
ACCELEROMETER LOCATION

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PROJECT WBVTR-KRYTOX RUN NO. 1400
TEST ITEM ______ TAPE NO. ______
DATE OF TEST 7-12-76 TRACK ______
TEST SINE VIBRATION PLANE MODE A TRANSDUCER CONTROL

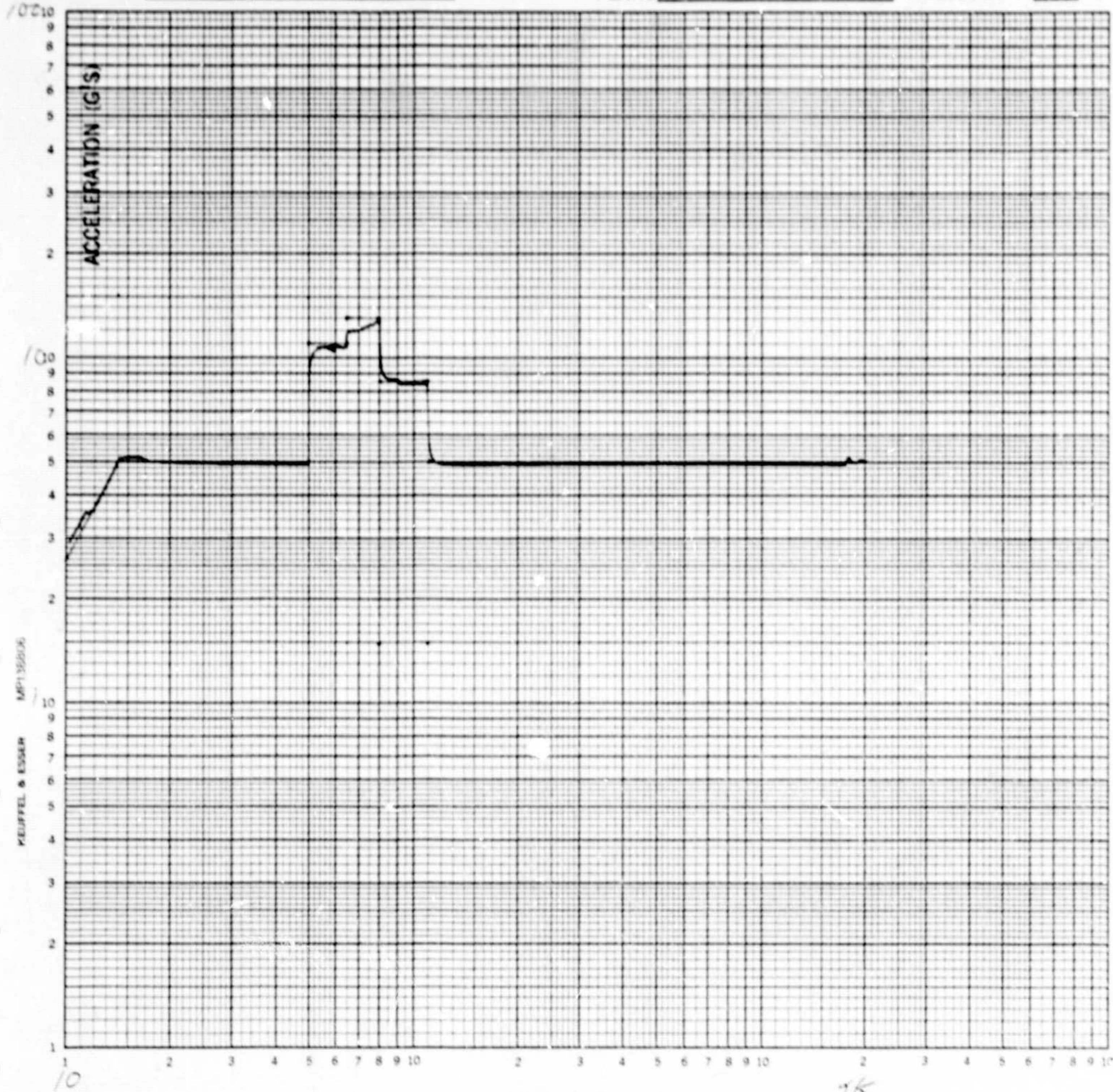

FIGURE 5

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ENVIRONMENTAL LABORATORY
CAMDEN, N. J.

PROJECT WBVTR-KR... RUN NO. 1420

TEST ITEM ______ TAPE NO. ______

DATE OF TEST 7-12-76 TRACK ______

TEST RANDOM VIBRATION PLANE MODE A TRANSDUCER CONTROL

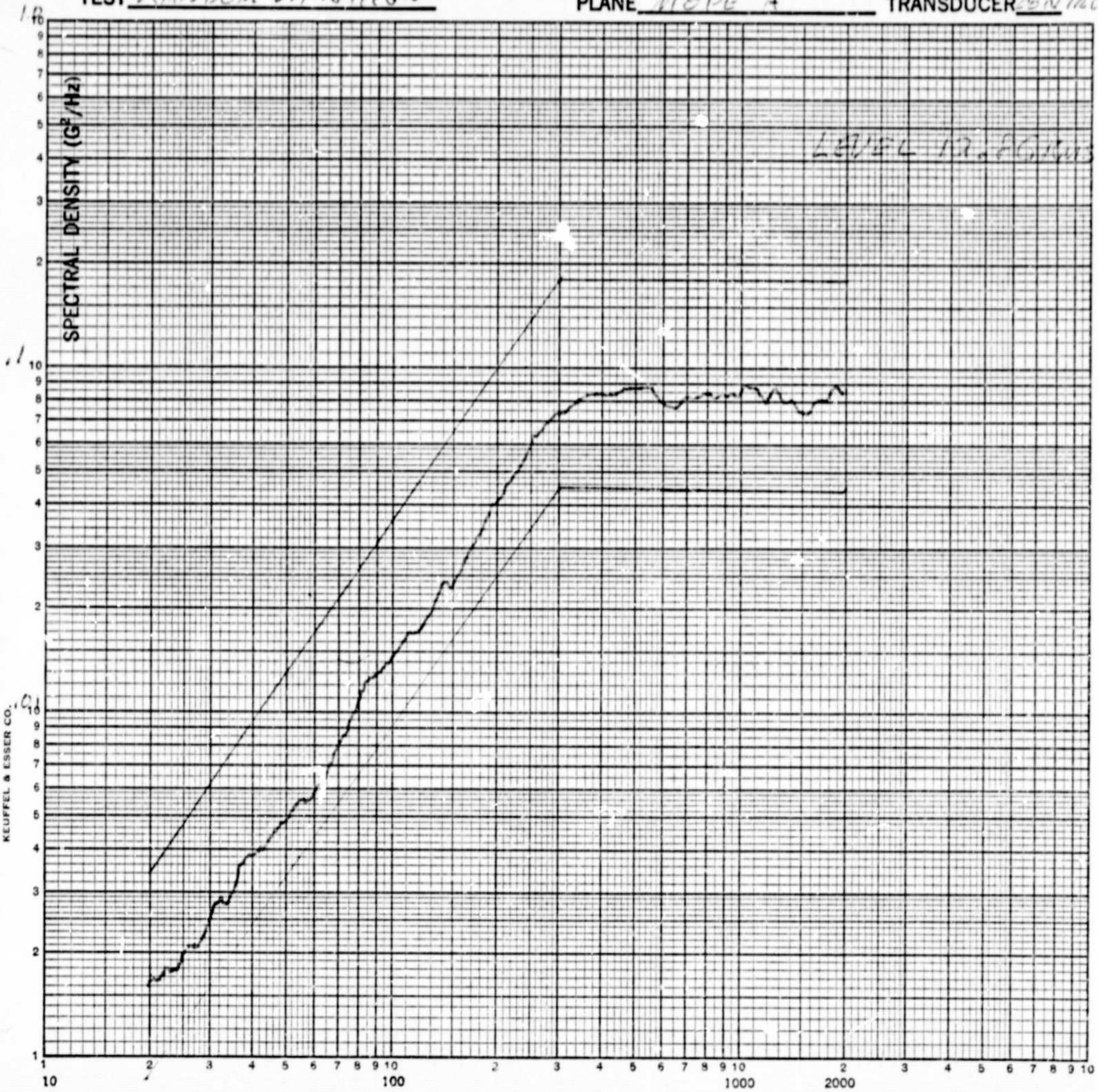

FIGURE 6

RCA
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CAMDEN, N. J.

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PROJECT WBVTR-Krytox RUN NO. 1575
TEST ITEM ______ TAPE NO. ______
DATE OF TEST 7-12-76 TRACK ______
TEST SINE VIB
PLANE MODE B TRANSDUCER CONTROL

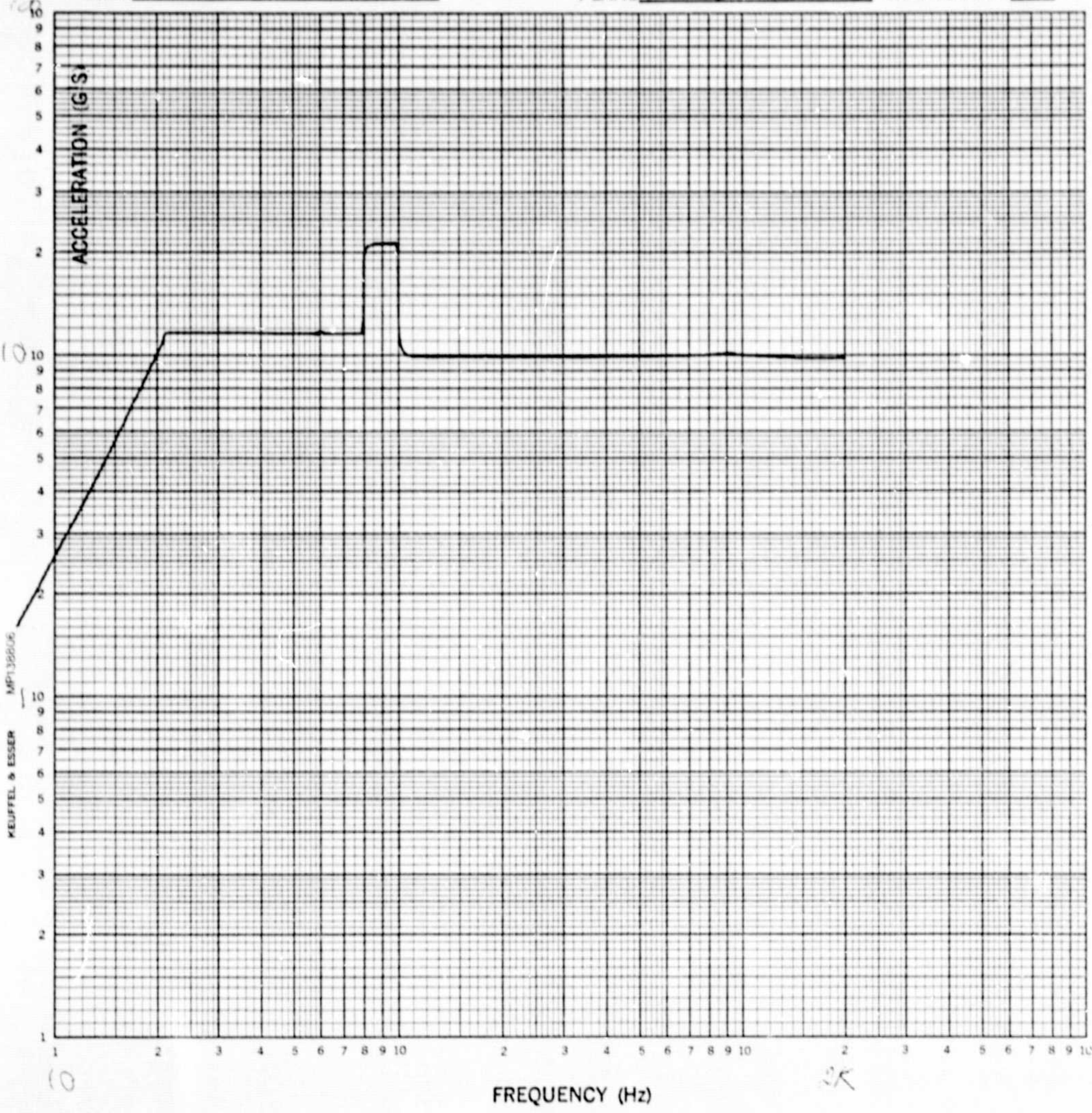

FIGURE 7

RCA
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CAMDEN, N. J.

PROJECT WBVTR-Krytox RUN NO. 1500

TEST ITEM ______ TAPE NO. ______

DATE OF TEST 7-12-76 TRACK ______

TEST RANDOM VIB

PLANE MODE B TRANSDUCER CONTROL

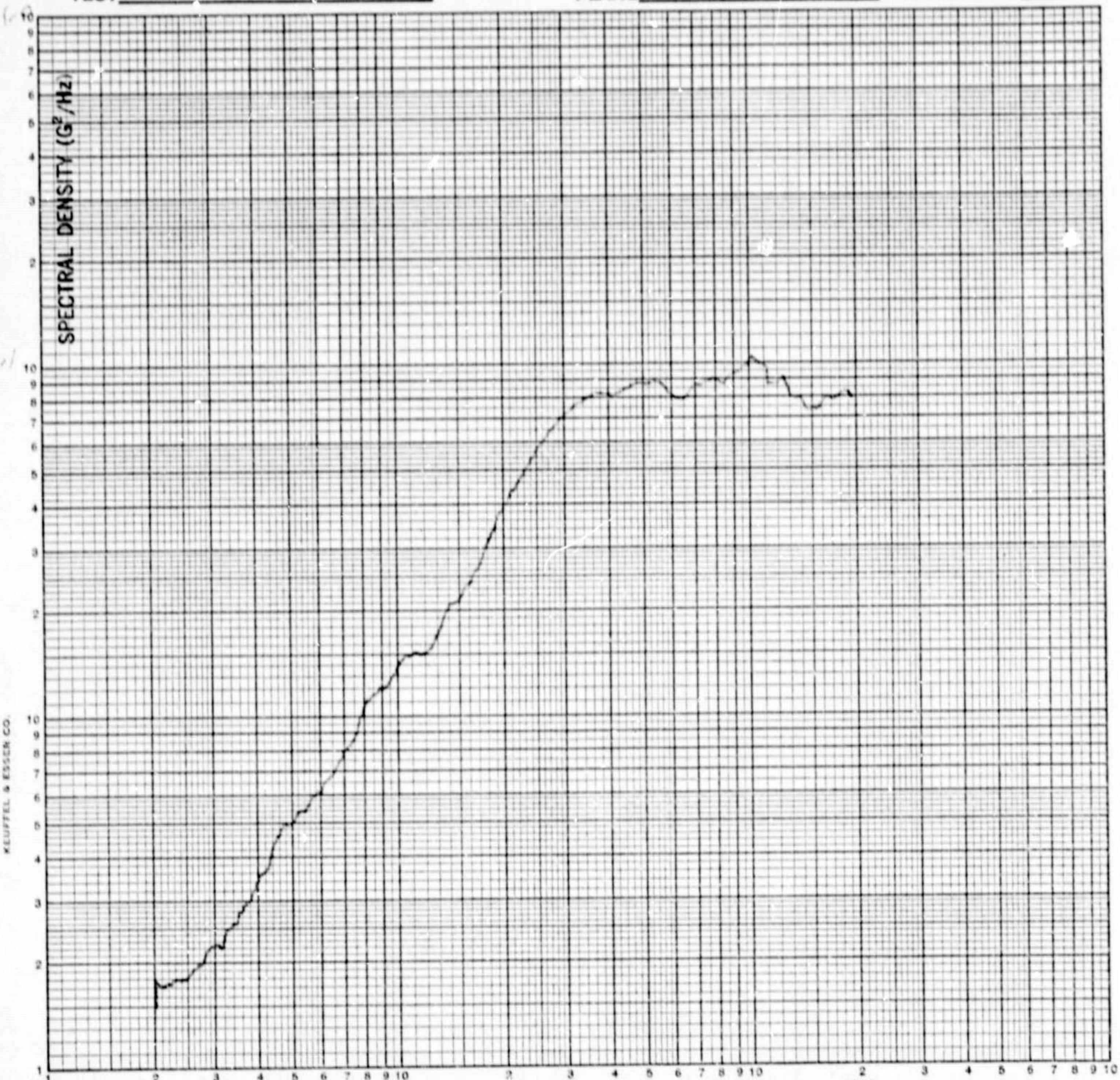

FIGURE 8

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The "B" mode is perpendicular to the reel axes and represents the thrust direction of the spacecraft during launch. The results were encouraging as no tape drop or shift was experienced.

4.4.2 Lubricant Thickness Measurement

It was obvious that a separate means distinct from the coating machine parameters be available to measure or determine the actual thickness of the surface lubricant. Since the applicator machine is only capable of coating one tape at a time and the proposed commitment of tapes to be coated for later flight use could span a wide time period, verification of coating thickness was essential. A measurement technique was developed using an Ion Probe/Mass Spectrometer.

Theory of Operation - The test specimen is bombarded by oxygen ions and the surface is removed by sputtering. The secondary ion emission is collected and monitored with a mass spectrometer. The area scanned is 150 x 200 microns using an ion spot size of approximately 10 microns. Five measurements are made in a given area and averaged for the final reading. For Krytox, the mass spectrometer is tuned for the element fluorine. The calibration reference for sputtering efficiency or rate of removal was performed on a solid block of Teflon. This reference method puts the absolute accuracy in question but does not detract from the measurement technique as a basis for comparing relative thickness of coatings.

The tape designated for the tape Qualification Testing (MTA 20237 87784 02 000K) was coated to the #4 level. Samples were removed from either end of tape for coating measurements. The results are shown for reference.

LUBRICANT THICKNESS MEASUREMENT	
Start End	35Å (0.14u in)
Finished End	75Å (0.30 u in)

Final value is the average of five separate measurements.

4.4.3 Temperature Testing

The full roll of Krytox Level 4 treated tape, MTA 20237 87784 02 000K, was installed on the WBVTR. A new headwheel panel, S/N 555 with an initial pole tip protrusion of 2.08 mils was used to duplicate actual start conditions. Baseline tests were run for reference measurements. A temperature test was run initially to expose the tape to 45°C and to confirm prior results. Low temperature testing was done at 0°C to evaluate possible increased loading from the lubricant and general operation. The WBVTR was operated for four hours at each temperature. Results were considered typical for the WBVTR at these temperatures.

4.4.4 Life Test Cycling

An initial 10 minute cycle was selected to allow pass accumulation to occur at a faster rate than cycling the full 30 minutes. The remaining 20 minutes would be cycled tested in a second phase of the life test. BER runs and visual observations of the headwheel were periodically performed to monitor the progress of the life test. The BER runs were reduced to average values for the full 10 minute run and the results are shown in Figure 9. After 2500 passes, the headwheel panel was removed to make a scheduled head

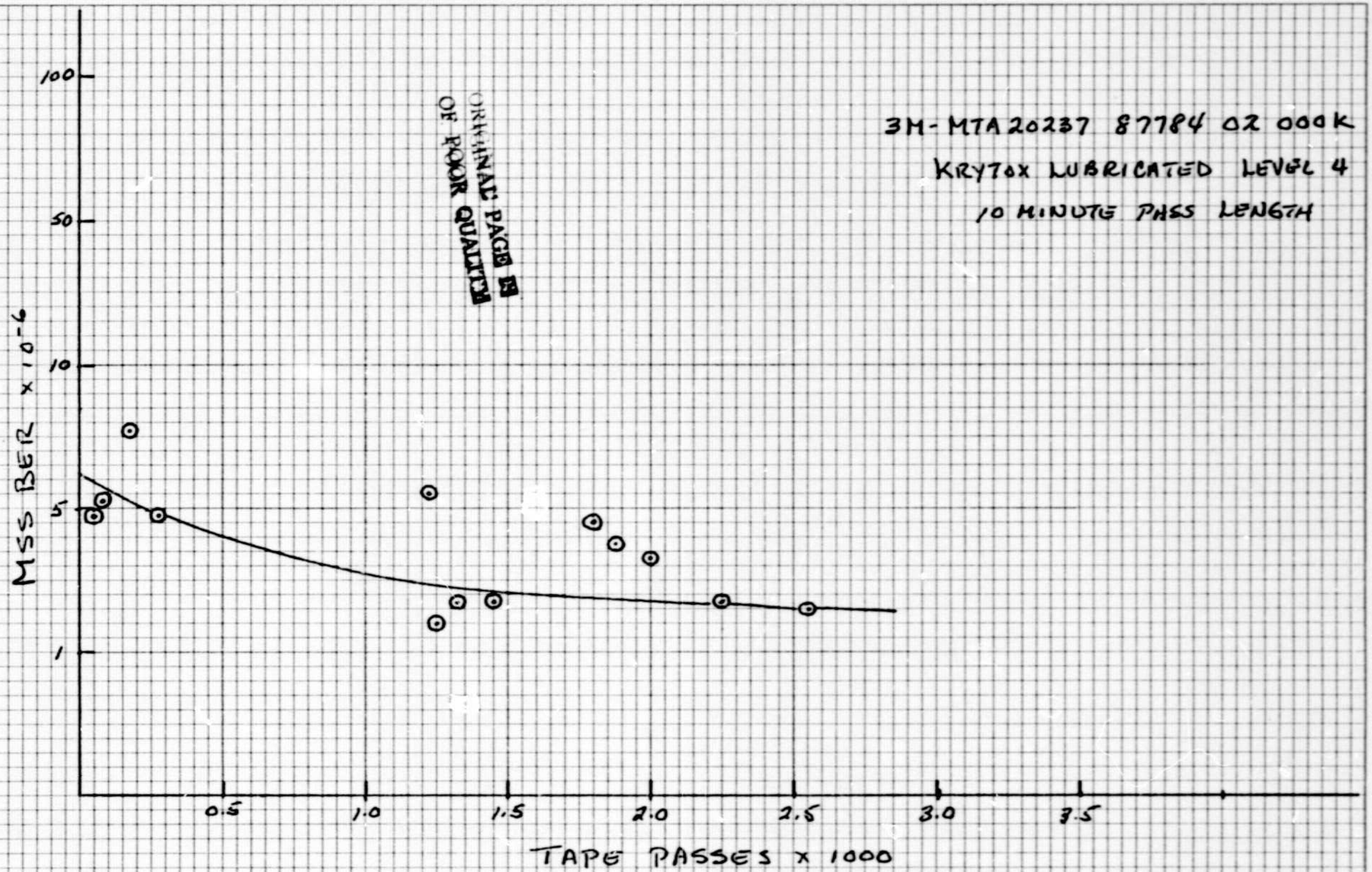

Figure 9 BER PERFORMANCE, LIFETEST

protrusion measurement for wear rate determination. The pole tip protrusion was found to be 1.48 mils, representing a loss of 0.60 mils since the start of the test. Since 428 hours had elapsed for the 2500 passes, this equaled to a wear rate of 140u in/100 hr. This wear rate projected meant the heads would barely last 1000 hours. Qualifying tape tests for Landsat A & B had indicated long term wear rates on the order of 30u in/100 hrs. The high wear explains why a record current adjustment was needed after 1200 passes to optimize BER performance.

5. Comparative Wear Testing

Additional cycle testing was performed to pinpoint the source of high wear.

5.1 Untreated Tape

An untreated MTA 20237 87784 02 000J, selected because of its adjacency in the web to 02 000K, was cycle tested over a 10 minute section to determine the innate wear properties of the 87784 tape lot. During the test, record current adjustment was required three times. At the end of only 540 passes or 90 hours, the signal performance had degraded significantly. Measurements showed that the pole tip protrusion was only 0.66 mils. For the short time of this test, the wear rate was a phenomenal 770u in/100 hr. The conclusion was that the 87784 tape lot was quite different in head wear properties than the earlier 75669 even though they shared the same MTA 20237 formulation and manufacturing processes. The resultant head wear rate was extraordinarily higher, on the order of 20-25 times the earlier tape lot. The effect of the Krytox surface lubricant was to reduce the wear rate to less than 20% of the untreated tape. Unfortunately, the resultant wear rate was still almost 5 times higher than that experienced with the old 75669 tape lot.

5.2 Reference Tape

A MTA 20237 75669 02 010C tape, from the Landsat B Program, was installed to duplicate the earlier life test data which yielded such low head wear rates. Confirmation would eliminate recorder and headwheel panel factors as contributors to the present high wear rates. A 10 minute section was cycled in the same manner as the life tests just performed. Interim wear measurements as well as the final were taken and the results are shown below. The wear rates shown are calculated as if wear rate was a constant.

HEAD WEAR RATES - MTA 20237 75669

PASSES	HOURS	WEAR RATE u in/100 Hr.
642	107	93
1086	181	77
1470	245	57

The final reading of 57 u in/100 hr. proved that the 75669 was a low abrasivity tape and that the 87784 was not.

6. Conclusions

Th three tapes considered as candidates for the Landsat Program all proved to be unsatisfactory. The two commercial type tapes, the AMPEX 775 and the 3M MTA 86150 possessed superior signal to noise qualities, but uniformly developed adhesion problems after 300-600 passes. Although the tendency to adhere to stationary transport elements was not detected in the WBVTR, the potential danger eliminated these two tapes. The 87784 lot of tape had abrasive properties that were not typical of the 3M MTA 20237 formulation. The abrasiveness of this tape went undetected in the preliminary testing because of the nature of those initial tests. Tape tests that use short sections to accumulate a high number of passes in a short period of time do not tend to yield good head wear data. An illustration of this is the test where 10,000 passes performed on a treated tape in the TR22 required only 125 hours of head tape time. The presence of the Krytox surface lubricant also tended to conceal the high head wear condition. The head life extension potential of the surface lubricant was established with a 5 to 1 lower head wear rate of the treated tape as compared with the untreated tape. The Krytox surface lubricant gave positive results in all the areas investigated. Deleterious effects on tape guiding and handling under temperature and vibration were undetectable and the loss of signal response was minimal. The tape life extension properties of the surface lubricant were never developed in the WBVTR testing. The projected results, even with the lowered head wear rate fell short of the 1500 hour goal and forced a cessation of the life test. If the decreased head wear is attributed to the lowering of the work function at the head tape interface, then a significant tape life increase can be expected. Therefore, the Krytox tape surface lubrication process still remains a promising tool for extending the head-tape life of a known recorder system.