SURFACE LUBRICATION OF MAGNETIC TAPE

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Summary. IIT Research Institute has developed a technique that greatly increases the operating life of the magnetic tape media as well as that of the head. This is accomplished by the application of a very thin coating of an inert lubricant to the surface of the media. Tests have been performed with a variety of commercially available tapes and various head materials. Greater than 5 million passes of 3M 900 on a loop tester were achieved with no apparent effect on the tape. Without lubrication, the same tests achieved only 30,000 passes. Head wear was decreased by as much as a factor of ten where lubricated tape was used. This paper describes the technique and gives typical test results obtained by IITRI and others.

Introduction. The minimization of friction between the magnetic media (i.e., tape, cards, drums, etc.) and the magnetic transducer (heads, etc.) is an important requirement in recording systems. Frictional forces and associated thermal effects may lead to the rapid deterioration of the tape, deposition of debris on the record and reproduce heads, excessive head wear or loss of signal, resulting in the functional failure of the system. Accordingly, some form of lubrication is used in magnetic tapes in order to reduce the coefficient of friction between the tape and the head. Manufacturers of quality magnetic media products incorporate lubricating compounds as additives in the tape coatings. The coating formulation into which lubricating compounds are introduced consists essentially of a dispersion of magnetic oxide particles (e.g., Gamma Ferric Oxide, Chromium Dioxide, Nickel-Cobalt doped Fe_20_3, etc.), in an organic resin that comprises the binding matrix for the magnetic material. This binder system is applied to the tape substrate, such as polyethelyne terupthylate or aluminum, by coating processes common to the trade. The lubricating agents used in magnetic coatings include natural, petroleum-based products[1,2], synthetic liquids such as esters of dicarboxylic acids and branched chain alcohols, e.g., (2-ethylhexyl sebacatate), polysiloxane fluids (silicone fluids) as well as solid lubricants, such as talcum[3], molybdenum sulfide[4] and fluorinated polymers[5].

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The main function of these lubricants is to reduce the amount of close contact between the solid surface (metal, ferrite, plastic, etc.) of record and reproduce heads and the surface of the magnetic media by interposing an easily shearable or interaction lessening layer of lubricating agent at the interfacial boundary of those elements that remain in sliding contact when the media is in use. Incorporation of lubricating compounds within the bulk of the magnetic coating has an advantage in that it affords a means of replenishing the friction-reducing agent at the tape surface, exposing new layers of lubricant as the coating wears. A major disadvantage is that internal lubricants, having a chemical incompatibility with most binders, have undesirable effects on the structural integrity of the magnetic pigment/binder system since they impair interfacial bond conditions and interfere with the proper polymerization of the resin.

The incorporation of lubricants has been identified as a major limit of tape life in extensive studies[6]. Layer concentrations, while reducing the dynamic coefficient of friction, actually reduce tape life. It is postulated that since the lubricants migrate to the surface of the tape, they also migrate to the substrate, inhibiting proper binding of the oxide to the substrate. Consequently, only small quantities of lubricants can be added before severe degradation is noticed and when the quantities of lubricants added are small, the effects on lubricity or coefficient of friction are similarly reduced.

The addition of a separate lubricant layer, in an attempt to eliminate the problems discussed, has been postulated previously. This work relates to the addition of finite sized solid lubricant particles to the surface of the magnetic media, polytetra fluoroethylene having a size of..05 to 0.5 microns[7], DuPont vydax with an initial size of around 5 microns but subsequent reduction to from 1/2 to 1 micron[8], or molybdenum bisulfide and graphite particles of colloidal size (between 10^{-4} and 10^{-6} centimeters)[9].

The incorporation of finite sized solid lubricant particles also causes separation of the magnetic media from the magnetic transducer by at least a distance equal to the size of the particles. This causes a loss in recorded signal on the tape and subsequent reproduce losses as defined by the functio[10]

$$e^{-2\pi \frac{S}{\lambda}}$$

where λ is the recorded wavelength and S is the distance from the surface of the magnetic oxide to the gap of the reproduce transducer. Thus, at extremely short wavelengths (< .05 mil) frequently encountered in demanding instrumentation applications, it is obvious that reproduce signal output will be severely reduced by incorporating surface coated finite sized solid lubricant particles. No successful method which incorporates these principles is being marketed today, despite the previous disclosures.

Other attempts to eliminate the weakening effects of lubricants in magnetic coating systems have been made in the direct application of friction reducing treatments, such as solid fluorinated polymer films, to read-record heads of magnetic recording equipment[11]. The effectiveness of this approach is inevitably lessened by the inherently abrasive nature of conventionally lubricated magnetic tape, which taxes the film on the heads, and leads to the deposition of abraded film fragments on the tape surface or in the gaps of the heads, thereby interfering with recording or reproducing processes.

The work carried out at IIT Research Institute eliminated the previously encountered disadvantages of friction reducing treatments by a deposition of an inert liquid film on a fully manufactured (cured) magnetic media. The film contains no particles, is a compound that is characterized by good lubricating and thermal properties, is inert with respect to the normal formulation constituents, and has low surface tension and vapor pressure characteristics. The deposited film need only be molecularly thin to impart adequate lubricating properties to the tape.

Characteristics of the Surface Lubricant. A coating of an inert liquid lubricant with a low surface tension, high molecular weight, and excellent lubrication and wetting properties is either dispersed in a suitable solvent and applied to a magnetic media or is applied undiluted to the surface of the media to form a very thin layer of lubrication between the media and the transducer.

The selection of a liquid lubricant free of particles such as those described earlier is essential. A low surface tension, preferably lower than the critical surface tension of the resin binder, is desirable in as much as such a lubricant spontaneously spreads on the tape surface, wetting the microscopic asperities and depressions that are characteristics of typical tape topography. Good wettability is required to ensure lubrication of those elements of magnetic tape that are likely to come into frictional contact with the transducer surface, and to facilitate entry of the liquid lubricant into microscopic tape depressions, which then serve as miniature reservoirs from which the lubricant is transferred to the media and to transducer surfaces over extended periods of tape usage.

Since the sustained action of the friction reducing compounds depends also on its resistance to volatilization, a relatively low vapor pressure, preferably less than 1×10^{-2}, mm Hg at 25°C, is desired for the lubricating agent.

Other desired properties of the selected surface coating include the following:

a. High degree of chemical inertness so as not to react with the wide variety of binder systems presently in use in the manufacture of magnetic media.

b. High thermal and oxidative stability to permit usage in a wide variety of media applications where thermal extremes would preclude a conventional lubricant's usage.

c. Nonflammable to allow its usage in magnetic media required to be self-extinguishing when exposed to fire.

d. Inertness with metals, glasses and plastics at temperatures below 100°C to ensure that there is no damage to magnetic transducers or guides, vacuum columns, capstans, etc.

e. Wide range of viscosities as a function of temperature to facilitate application in commercial processes.

f. Non-deposit forming to prevent build-up on magnetic transducers, guides, vacuum columns, capstans, etc.

The fluorocarbon compounds and their derivatives are particularly attractive in tape lubricating applications because of their low friction, low surface tension and good thermal properties. Their chemical inertness minimizes the danger of modifying (weakening) the mechanical properties of the magnetic coating.

A preferred compound for the treatment of magnetic media which satisfies all of the aforementioned conditions is a perfluoroalkyl polyether having the general formula

$$F\text{-}\left[CF(CF_3)CF_2O\right]_n C_2F_5$$

such as the Krytox^R family of oils (Krytox^R types 143AZ, 143AA, 143AY, 143AB, 143AX, 143AC, and 143AD) manufactured by the E. I. DuPont de Nemours and Company, Inc., Petroleum Chemicals Division. These oils are characterized by a molecular weight from about 2000 to 7000,a viscosity of 18 to 495 centistokes at 100°F, a surface tension of 16 to 19 dynes/cm and a vapor pressure of less than 1 x 10^{-2} mm Hg at 25°C. The Krytox^R oils are also characterized by a high degree of chemical inertness, high thermal and oxidative stability, nonflammability, and are not deposit forming.

The advantages derived from the use of perfluorinated alkylpolyether treatments for magnetic tape in regard to reduced head/tape friction and corresponding increased head wear and tape life have their basis in the low surface energy and high lubricity that characterizes perfluorinated compounds. This low surface energy, which is associated with the close packing of fluoro-substituted CF_3 groups along the carbon-carbon backbone, reduces the interaction between two surfaces that are brought into mutual contact when a thin coating of perfluorinated compound is deposited on one of these surfaces. The low surface energy condition of solids treated with such a compound is reflected in the large contact angles that these surfaces exhibit in comparison with uncoated tapes.

Method of Application. The surface lubricant may be used without dilution or dispersed in a suitable solvent such as trichlorotrifluoroethane (Freon TF). The application of this and other liquid lubricants may be accomplished by conventional methods of knife, spray roller coating, or by deposition. It is extremly critical, however, that the amount applied be carefully controlled to insure that as near to a molecularly thin layer as possible be applied.

A typical application method consists of transporting the media either as a web or as a ribbon over the top roll of a reverse roll coater to achieve contact over approximately 30 degrees. The lubricant is picked out of a fountain located at the base of the lower roller by the driven lower roller. The lubricant may be heated or cooled to a desired temperature to achieve the desired viscosity necessary for proper application by cooling or heating coils mounted within the base of the fountain. The surface finish of the lower roller may be very smooth or treated by sandblasting or chemical etching to achieve the desired quantity of lubricant to be removed from the fountain. An instrumented variable loading doctor blade may be lowered to the surface of the lower roll to remove excess lubricant picked up by the lower roller from the fountain.

The lubricant is then passed by the lower roller to the upper roller at a line contact between the lower roller and the upper roller. The line contact loading may be adjusted by two variable loading helix springs. The upper roller is heated to a temperature of 125° to 150°F to modify the viscosity of the selected lubricant. The upper roller surface should have an extremely smooth surface finish to ensure thin layer transfer to the tape.

Tape from a supply reel may be guided to the top surface of the reverse roll and wrapped between 30 and 90 degrees over the top roller. Precision supply and take-up tension servo systems are used to tension the web correctly as it passes over the top roller. The preferred direction of the top roller is in the direction opposite to the tape motion. However, either direction may be utilized depending on tape absorption. The speed of the tape passing over the top roller may be from several inches per second to hundreds of feet per minute.

Following the application of the surface lubricant, the surface is buffed using industrial clean grade natural filament buffing material. This buffing treatment promotes dispersion of the applied lubricant to cover the surface asperities frequently found in magnetic media. The direction of rotation of the buffers is preferably in the direction opposite to the web motion. The speed and quantity of the surface stations is a function of the surface conditions of the buffing media. It has been found that this is not a necessary process, in some instances, for those media having an extremely smooth surface prior to the application of lubricants.

Surface Coated Magnetic Media Test Results. Various forms of magnetic media were prepared using the lubricating techniques developed by IITRI. The test results have indicated a significant improvement in tape life (as measured by dropout activity, oxide shed, etc.), head wear (measured using both “soft” and “hard” heads), static and dynamic coefficients of friction, together with negligible effects on other media characteristics.

Test Series 1--Tape Life and Dropout Activity. A section of 3M (Minnesota Mining and Manufacturing Company) Type 500, two-inch wide vide tape was surface lubricated with the preferred lubricant. The tape was recorded before lubrication using an RCA Type TR 70 video machine. The dropout counts over each segment were logged. Following the surface coating procedure, the dropout counts were again logged and found to be identical. There was found to be no reduction in the video signal output when played back on the TR 70. The coated section of the tape was then subjected to repeated reproduce passes over the TR 70. An identical piece of 3M Type 500, not treated with the surface lubricant, was subjected to the same procedure. Dropouts for the untreated tape became significant after about 3000 passes. The treated tape was run for 10,000 passes without significant increase in dropouts.

Test Series 2--Wavelength Response and Digital Response. A length of 3M Type 900 tape, one-half inch wide, was prepared with surface lubrication. A typical wavelength response test was then performed on both uncoated and coated samples using an Ampex FR 1600 recorder. For wavelengths between 0.03 mil and 10 mil, no difference in response between the coated and uncoated samples was seen.

The same tapes were then subjected to an output test at 800 and 3200 FRPI using a KYBE CS-1300 tape certifier. No difference was seen in the output of the coated and uncoated samples.

Test Series 3--Tape Life Degradation. A length of 3M Type 900 tape of a one-half inch width, was surface lubricated. A life test was then performed to determine operational integrity. The test was performed using an IITRI loop tester with a tape length of 54 in., 8 oz. tape tension, a wrap angle of 15° and an aluminum head coated with 5 mils of chrome. A tape speed of 32 ips was used. The untreated 900 showed substantial oxide removal and accumulated head debris after 30,000 passes. The tape had no useful life remaining. The treated 900, on the other hand, accumulated greater than 5,000,000 passes with no head debris or visible oxide removal. The tape appeared to be in essentially a new condition.

Test Series 4--Head Wear. A group of one-half inch wide tapes, 3M Type 900, an IITRI epoxy binder formulation, an IITRI polyamide binder formulation, an IITRI low temperature polyimide formulation, and an IITRI high temperature polyimide formulation (coated on Kapton[R]) were surface lubricated. A series of tests were performed to determine head wear caused by treated tapes in relation to untreated tapes as a function of tape footage passed over the heads. In all cases, total tape passed over the heads was one million feet. Tape tension in all cases was 8 oz. and head wrap in all cases was 15° in, 15° out, for a total head wrap of 30°. The heads were chrome-plated aluminum. The head wear as measured on a "Proficorder", Model 2, Micrometrical Mfg. Co., is shown in Table 1.

Table 1 Head-Wear for Treated and Untreated Tapes

	Headwear/million ft. (μ in.)	
Tape Type	Treated	Untreated
3M 900	0	15
Epoxy	0	5
Polyamide	0	5
Low Temperature Polyamide	0	5
High Temperature Polyamide	0	5

Note: The resolution of the measurement was between one and two microinches.

A sample of treated 3M 900 tape was passed over different head materials with an accumulated tape footage of 14.5 million feet. The wear rates as expressed per million feet of tape passes are as follows:

Mu Metal--6.5 microinches/million feet
Brass--5.5 microinches/million feet
Aluminum--17.0 microinches/million feet

The wear rates for an untreated (as received from the manufacturer) type 3M 900 was 180 microinches/million feet on an aluminum head.

Test Series 5--Tape Dropout Activity as a Function of Tape Life. A length ot 3M Type 900 tape, one-halt inch wide, was surface lubricated. Prior to the surface lubrication process, the tape contained six dropouts (amplitude decrease of 50% as measured by the KYBE Model CS-1300 at 3200 FRPI). After lubrication, the count remained at six. The prepared sample was then loaded onto a Video Research Corporation tape shuttle machine with the following settings:

a. Total Tape Wrap--30°
b. Tape Tension--8 oz.
c. Tape Speed--90 ips

The tape was shuttled for a total of 50,000 passes. It was removed after each 5000 passes to retest for dropout activity. A similar section of untreated 3M 900 one-half inch tape was subjected to the same test conditions. Dropout count for the coated tape remained constant throughout the test. An increase in dropout count was seen at each 5000 pass interval for the uncoated tape. At the end of 50,000 passes, 250 times as many dropouts occurred on the uncoated tape as compared to the count at the beginning of the test.

Test Series 6--Video Still Frame Dropout Activity. A length ot Ampex type 161 video tape, one-halt inch wide, was surface lubricated. The tape was placed on a Sony CV-1200 one-half inch EIAJ type video recorder. After recording, a frame of the tape was played repeatedly (still framed) using machine developed tensions and normal heads. After 18 hours of still frame, the video data was fully usable with no perceptible dropouts. A subsequent test using an untreated pieced of Ampex type 161, under identical test conditions, failed[**] prior to four hours of still framing.

Test Series 7--Static and Dynamic Coefficient of Friction. General Procedure. A VRC reel-to-reel tape transport capable of forward, stop, and reverse modes was used in conjunction with a head mounting system suitably instrumented to measure the drag force of the tape against the head. Three different heads were used in this test; chrome, aluminum, and brass. The wrap angles for each set of heads were as follows: Brass head=20°; Aluminum head=30°; Chrome head=30°.

The tape tension was set at 8 oz. The transport was alternately operated in a forward and reverse mode at a speed of 30 ips while monitoring the output of the calibrated head drag transducers. Two values of drag were extracted from the measured data, namely; peak-to-peak drag at the turn around point, from which the static coefficient of friction is calculated, and peak-to-peak drag while running, from which the dynamic coefficient of friction is calculated. The results were as follows:

a. The initial static and dynamic coefficient of friction for this tape against all three head materials was decreased an average of 25% when surface coated.

[**]"Failed" is defined as unable to synchronize the video picture horizontally using a typical unmodified monitor-picture is unreproducible.

b. After 30,600 passes, the coated tapes exhibited a coefficient of friction that averaged about half that of uncoated tapes.

c. The dynamic and static coefficients of friction of the coated tapes remain essentially constant between 5000 and 30,600 passes.

In addition to the tests carried out at IITRI, tests were carried out by various tape manufacturers and users. Sample quantities of tape were coated by IITRI for test purposes. The following describes results obtained by others.

3M Company. The 3M Company ran an evaluation of head wear durability, coefficient of friction, and output on two tape types, 400 and 900. For each tape type, comparative tests were run with uncoated tape from the same roll. The results were as follows:

	Uncoated	Coated
Head Wear (µin./hr)		
Quadruplex	8.4	2.3
Helical	3.2	Negligible
Durability	Identical Head Pass Marks	
Coefficient of Friction (Dynamic)		
150 gm. Load	0.08-.13	0.08-.13
150 gm. Load	0.07-.12	0.09-.11
Normalized Output (dB)	0	+1.6 (heads re-adjusted between tests)

Sony Corporation. The Sony Corporation ran tests on U-Matic and AL tapes. Included were tests of video output in which the rf signal output, signal-to-noise ratio, and chrominance output were measured. Coated and uncoated tapes gave results which were identical within at least 0.8 dB. The static coefficient of friction was about the same for both the coated and uncoated tapes, while the coated tape was more stable than the uncoated in their kinetic tests.

U.S. Government. Head wear was measured on similar Ampex 787 samples. Three samples (200 feet each) were run from the same reel. The first was untreated, while the other two were cleaned on a KYBE either before or after lubrication. The results were as follows:

	Untreated	Cleaned Before Lubrication	Cleaned After Lubrication
Head Wear (μ grams/pass)	0.43	0.13	0.18

BASF. Floppy discs were treated. Each disc was run for five million passes. No head wear was evident. In addition no track marks could be seen on the disc.

Conclusion. The test results cited in this paper demonstrate the benefits to be derived from the technique for surface lubrication of magnetic media developed by IITRI. The significant decreases in head wear and extensions in tape life can be beneficial in several ways. Increased head life means lower-replacement costs and maintenance expense. Increased tape life can also significantly reduce costs by decreasing the quantities of tape required. The higher reliability of the recording system also gives a higher probability of a successful experiment. We recommend that further study be carried out to demonstrate the benefits for specific applications.

References

1. Bishops, J.H., et al, Belg. Patent No. 703,148, Feb. 28, 1968.
2. Sony Corporation, Fr. Patent No. 1,462,080, Dec. 30, 1964.
3. Agfa-Geraert A-G., Fr. Patent No. 1,475,294, March 31, 1967.
4. Bouzek, J., Czech. Patent No. 121,360, Dec. 15, 1966.
5. Wolff, N.E., U.S. Patent No. 3,490,946, Dec. 29, 1966.
6. IIT Research Institute, Final Report, Magnetic Head/Tape Interface Study for Satellite Tape Recorders, Contract No. NAS5-11622, February 1971.
7. IBM, Technical Disclosure Bulletin, Vol. 9, No. 7, Dec. 1966, p. 779.
8. Nierotti, et al, Reeves Industries, Inc., U.S. Patent No. 3,398,011, Sept. 10, 1964.
9. Carroll, J.F., Eastman Kodak Company, U.S. Patent No. 3,476,596, Dec. 28, 1966.
10. Wallace, R.L., “Reproduction of Magnetically Recorded Signals”, Bell System Technical Journal, Oct. 1951, pp. 1145-1173.