N84-30072

NASA Technical Memorandum 83727

# Effects of Water-Vapor on Friction and Deformation of Polymeric Magnetic Media in Contact With a Ceramic Oxide

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Prepared for the
Joint Lubrication Conference
cosponsored by the American Society of Mechanical Engineers
and the American Society of Lubrication Engineers
San Diego, California, October 22-24, 1984

E-1986

# EFFECTS OF WATER-VAPOR ON FRICTION AND DEFORMATION OF POLYMERIC MAGNETIC MEDIA IN CONTACT WITH A CERAMIC OXIDE

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## ABSTRACT

The effects of humidity (water-vapor) in nitrogen on the friction and deformation behavior of magnetic tape in contact with a Ni-Zn ferrite spherical pin were studied. The results indicate that the coefficient of friction is markedly dependent on the ambient relative humidity. In elastic contacts the coefficient of friction increased linearly with increasing humidity; it decreased linearly when humidity was lowered. This effect is the result of changes in the chemistry and interaction of tape materials such as degradation of the lubricant. In plastic contacts there was no effect of humidity on friction below 40-percent relative humidity. There is no effect on friction associated with the breakthrough of the adsorbed water-vapor film at the interface of the tape and Ni-Zn ferrite. The coefficient of friction, however, increased rapidly with increasing relative humidity above 40 percent in plastic contacts. The change in friction is reversible on humidifying and dehumidifying. This effect is due to softening of the tape surface and changes in the chemistry and interaction of the tape. With a mechanical activity that takes place during sliding, water vapor adsorbed on the tape surface tends to promote chemical degradation of the tape long before the surface may otherwise deteriorate.

## INTRODUCTION

Magnetic recording has been developed to a highly refined state. The term can be applied to any recording technique in which some phase of magnetics is intimately associated with either the recording or playback process. In most magnetic recording and playback devices, recording is conducted with a magnetic head (slider) in sliding or intermittent contact with a magnetic media, such as a magnetic tape or disk. A small amount of wear and high friction of magnetic head and medium may render the recording process unreliable. The magnetic head and medium are therefore required to have good wear resistance and low friction. The gradual change in the characteristics of the head and medium accompanying the wear process has also been the concern of manufacturers of media, heads, and recording devices.

This investigation examines the effects of humidity (water vapor) in moist nitrogen on the friction and deformation behavior of magnetic tapes in contact with a Ni-Zn ferrite hemispherical pin. Experiments were conducted with loads to 1.0 N at a sliding velocity to 6 mm/min in single-pass and multipass sliding at 23° C. Multipass sliding experiments were conducted in reciprocating motion.

## BACKGROUND

Much of the research conducted with media and heads in the magnetic recording industry was and is empirical [1-17]. Investigators have concerned themselves with such factors as contact pressures, relative sliding velocity, temperature, hardness, and humidity, and they have used onsite testing or other shortcut methods. For example, Carroll and Gotham state that the friction of magnetic tapes rises with increasing humidity [1]. The tribological properties and surface characteristics, however, of magnetic tapes are not clearly understood. We really need to know the fundamental mechanisms involved with such tribological characteristics as friction and wear of the medium and head and thus what is necessary to achieve low friction and high wear resistance.

Miyoshi and Buckley conducted fundamental studies on the friction and wear behavior of ceramic oxides such as Mn-Zn and Ni-Zn ferrites to gain an understanding of the tribological properties of ferrites [8-12]. Ni-Zn and Mn-Zn mixed ferrites are ceramic semiconductors and are important as magnetic materials for use in highly developed magnetic recording devices. Ni-Zn ferrite has been used for computer memory systems, such as magnetic recording disk files, while Mn-Zn ferrites have been used for video- and audio-tape recorders to enhance certain desirable properties and suppress undesirable ones in certain applications.

The results indicated that the coefficients of friction for ferrites in contact with various metals are related to the relative chemical activity of the metals. The more active the metal, the higher the coefficient of friction [9,10]. They also correlated the coefficient of friction with the free energy of formation of the lowest metal oxide.

The interfacial bond can be regarded as a chemical bond between the metal atoms and oxygen anions in the ferrite surface. Mating the highest atomic density directions and planes of ferrite surfaces resulted in the lowest friction. This result suggests that crystallographic orientation is important in the friction behavior of ferrite [11].

Fracture wear of ferrites as a result of sliding was determined to be due to the primary cleavage of the (110) planes [11]. The study herein extends this investigation to tribological properties of magnetic media in contact with a ceramic oxide.

Polymeric magnetic tape consists of a layer structure as shown in Fig. 1. Primary components of the magnetic layer are the magnetic oxide particle, the binder, the lubricant, the dispersant, and other minor additives. The magnetic tapes used in this investigation contained powders coated on a polyester film backing (film thickness, 23 μm; film width, 12.7 mm). The tapes designated 1 and 2 used in this investigation were made with polyester-polyurethane binders, which are the most widely used binders for magnetic tape applications. The magnetic layers contain magnetic oxide particles in excess of 70 percent of the layer by weight and as much as 60 percent by volume.

## APPARATUS

The apparatus used in this investigation is shown schematically in Fig. 2. It was basically a pin (rider) on a flat. The magnetic tapes (12.7 mm wide, 30 mm long) were mounted on hardened steel flats and retained in a vice mounted on a screw-driven platform. The platform was driven through the screw by an electric motor with a gear box that allowed for changing the sliding velocity. Motion was reciprocal. The pin was made to travel 10 mm on the tape surface. A switch then reversed the direction of motion so that the pin retraced the original track from the opposite direction. This process was repeated continuously.

The ferrite hemispherical pin specimen was loaded against the magnetic tape with deadweights. The arm retaining the pin contained strain gages to measure the tangential and normal forces. The arm containing the pin could be moved normal to the direction of the wear tracks and thus multiple tracks could be generated on a single surface. The entire apparatus was housed in a plastic box.

When the friction and deformation of the tape were examined, the entire plastic box was controlled with air at a relative humidity of 40 percent and at room temperature (23° C). When the effects of water vapor on friction and deformation were examined, the nitrogen atmosphere in the box was controlled in two ways. In the first, the entire plastic box was filled with dry or humid nitrogen, as indicated in Fig. 3(a). In the second, dry or humid nitrogen was admitted locally through a nozzle onto the tape surfaces, in contact with the pin specimens, as shown in Fig. 3(b).

# EXPERIMENTAL PROCEDURE

The Ni-Zn ferrite hemispherical pin specimen was polished with a diamond powder (particle diameter, 3 μm) and an aluminum oxide ($Al_2O_3$) powder (1 μm). The pin radius was 2 mm. The pin surface was rinsed with 200-proof ethyl alcohol. After the system shown in Fig. 3(a) was conditioned to the desired environment and humidity, a polished Ni-Zn ferrite pin and a new as-received tape were placed in the experimental apparatus.

## Friction and Deformation

A tape and pin were preconditioned in air in the plastic box and maintained at that condition for 15 to 20 minutes. The specimen surfaces were then brought into contact and loaded.

To obtain consistent experimental conditions, contact was maintained for 30 seconds before sliding. The friction experiment was then begun at a load to 1.0 N. Both the load and the friction force were continuously monitored during a friction experiment. Sliding velocity was 1.5 mm/min over a total sliding distance of 10 mm.

## Effects of Water Vapor

After admitting dry nitrogen gas into the system shown in Fig. 3(a), a polished Ni-Zn ferrite pin and a new as-received tape were placed in the experimental apparatus and maintained at that condition for 15 to 20 minutes. The specimen surfaces were then brought into contact and loaded. Single-pass sliding friction experiments were conducted with the same magnetic tape, but on different tracks, at loads of 0.25 and 0.5 N in a dry nitrogen atmosphere. The atmosphere was then humidified to the desired humidity of 78 percent by admitting humid nitrogen into the system.

After the experiments in nitrogen at relative humidities to 78 percent, the system was gradually dehumidified to a dry nitrogen atmosphere. Single-pass sliding experiments were conducted with the same tape, but on different tracks, in the desired atmosphere during the dehumidifying process. In each experiment a new repolished ferrite pin was always used and it was held at that condition for 15 to 20 minutes. Each value for the coefficient of friction is the average of measurements obtained from three to five single-pass sliding experiments.

Multipass sliding friction experiments were also conducted with the magnetic tape in contact with Ni-Zn ferrite pins in dry nitrogen and in humid nitrogen at a relative humidity of 78 percent. In each experiment, the new ferrite pin traveled and retraced the original tracks on the tape.

To examine friction response to humidity changes, three sets of environmental conditions and experiments were conducted. In the first set, a tape was preconditioned in dry nitrogen in the plastic box shown in Fig. 3(b) and maintained at that condition during the entire sliding friction experiment. After sliding for about 40 seconds in dry nitrogen, the area where the tape contacts the ferrite pin was flooded with humid nitrogen having a relative humidity of 61 percent; but, a dry nitrogen atmosphere was maintained in the plastic box. The area flooded with humid nitrogen included less than 100 $mm^2$ of tape. Multipass sliding friction experiments were also conducted in the same manner as those in the single-pass sliding.

In the second set, a tape was preconditioned with 63-percent relative humidity in the plastic box shown in Fig. 3(b) and maintained at that condition during the entire sliding friction experiment. The vicinity surrounding the tape-ferrite contact was flooded with dry nitrogen after sliding for 40 seconds in the humid nitrogen atmosphere. Multipass sliding friction experiments were also conducted in the same manner as those in the single-pass sliding experiments. In the third set, a tape was placed in air at a relative humidity of 41 to 43 percent. The vicinity surrounding the tape in contact with the pin had been flooded with dry nitrogen (Fig. 3(b)). At a sliding time of approximately 30 seconds, the supply of dry nitrogen was stopped and humid nitrogen, with a relative humidity of 61 percent, was admitted to the contact area for about 30 seconds. After admitting humid nitrogen for 30 seconds, the supply of humid nitrogen was stopped and dry nitrogen was again allowed to flow into the contact area.

The dry and humid nitrogen gases were admitted through an inlet valve at relative pressures to $3\times10^3$ Pa. To obtain consistent experimental conditions, contact was maintained for 5 minutes before sliding. The friction experiment was then begun. The load and friction force were monitored continuously during the friction experiment. Sliding velocity was 0.1 mm/sec over a total sliding distance of 10 mm.

## RESULTS AND DISCUSSION

### Friction and Deformation

Single-pass and multipass sliding friction experiments were conducted with a magnetic tape (tape 1) in contact with a polycrystalline Ni-Zn ferrite pin in laboratory air. Traces of friction as a function of sliding time were relatively smooth, with no evidence of stick-slip.

The coefficients of friction measured at various loads on the tape are presented in Fig. 4(a). The coefficient of friction was not constant but decreased as the load increased at loads to 0.25 N. Above 0.25 N, however, the coefficient of friction increased as the load increased. Figure 4(b) presents data for the coefficients of friction as a function of the number of passes. When repeated passes were made, the coefficient of friction for the tape exhibited generally small changes with the number of passes at any load up to

1.0 N. The data of Fig. 4 raise the question of how the interface deforms with sliding action.

The tracks on the tape, which the ferrite pin was made to traverse, at loads to 1.0 N were different when examined by optical and scanning electron microscopy. Essentially no detectable wear track existed on the surface of the tape at a load of 0.1 N. The surface of the track was very similar to that shown in Fig. 5(a), which presents an example of the surface of the as-received magnetic tape (tape 1). At 0.25 N and above, the sliding action produced a visible wear track on the magnetic tape, as shown in Fig. 5(b). The scanning electron micrograph clearly reveals a degree of plastic deformation at the tips of the asperities on the magnetic tape. Thus, although the sliding occurred at the interface, elastic deformation resulted in both the tape and the Ni-Zn ferrite pin at loads to 0.25 N. At 0.25 N and above, plastic deformation occurred in the tape, but the Ni-Zn ferrite primarily deformed elastically. Figure 5(b) shows the blunt appearance of the asperities on the wear track after five sliding passes. This bluntness resulted primarily from the plastic deformation of asperities on the tape.

From the nature of deformation at the interface between the hemispherical pin and the flat, friction behavior can generally be divided into two categories - that is, elastic and plastic contact. In the elastic contact region the friction decreased as the load increased. The relation between coefficient of friction $\mu$ and load $W$ is given by an expression of the form $\mu = KW^{-1/3}$ where $K$ is constant [13,14]. The exponent can be interpreted simply as arising from an adhesion mechanism, with the area of contact being determined by elastic deformation.

For example, the coefficient of friction measured for the polyester backing in contact with the Ni-Zn ferrite pins at various loads indicated that the coefficient of friction decreased as the load increased. With sliding, elastic deformation occurs in the surfaces of both the polyester backing and the Ni-Zn ferrite pin [15]. By contrast, when deformation was plastic, the coefficient of friction for a hard, spherical solid pin in contact with a soft, solid tape increased as the load increased. A typical example of this is presented in Fig. 4(a) at loads of 0.25 N and above [15].

## Effects of Water Vapor on Friction and Deformation

Plastic deformation. - The coefficient of friction measured for tape 2 was 0.14 in dry nitrogen at a load of 0.5 N (shown in Fig. 6(a)) with open symbols). The atmosphere was then humidified to the desired humidity (up to 78 percent) by admitting humid nitrogen into the system.

On humidifying, the coefficient of friction remained low below 40-percent relative humidity. It increased rapidly with increasing relative humidity above 40 percent, as indicated by the open symbols in Fig. 6(a). On dehumidifying, the coefficient of friction decreased rapidly between 78- and 40-percent relative humidities. It remained low below 40-percent relative humidity. The friction behavior of the tape as a function of relative humidity on dehumidifying is very similar to that on humidifying.

At the load of 0.25 N the results are consistent with those at the load of 0.5 N, as indicated in Fig. 6(b). At 0.25 and 0.5 N, the sliding action produced a visible wear track on the magnetic tape. The question is how the interface deforms in both high humidity and dry nitrogen with sliding action - that is, whether the tape can deform readily in a moist atmosphere. To examine the deformation behavior of the tape surface, multipass sliding friction experiments were conducted with magnetic tape in contact with polycrystalline Ni-Zn ferrite pins in both dry and humid nitrogen at a 78-percent relative humidity.

Figure 7 presents the coefficients of friction as a function of number of repeated passes. When 50 repeated passes are made, the coefficient of friction in nitrogen at 78-percent relative humidity decreases slightly, but continuously, as the number of passes increases. However, the coefficient of friction measured in dry nitrogen is constant after 10 passes. It is anticipated from the results shown in Fig. 7 that the tape in contact with the Ni-Zn ferrite pin in nitrogen at 78-percent relative humidity deforms plastically more than does the tape in dry nitrogen.

In order to determine tape surface deformation with sliding action in both dry and humid nitrogen, the wear tracks on the tape, where 50 repeated passes were made, were examined by scanning electron microscopy. Figure 8 presents scanning electron micrographs of the as-received surface and wear tracks generated in dry nitrogen and in humid nitrogen at 78-percent relative humidity. The as-received surface of the tape has the coarsest structure of the surfaces shown in Figs. 8(a) to (c). The scanning electron micrographs shown in Figs. 8(b) and (c) clearly reveal a degree of plastic deformation at the tips of the asperities on the magnetic tape. Considerable plastic flow occurs in the tape, which was in sliding contact with Ni-Zn ferrite in the humid nitrogen at 78-percent relative humidity. It is obvious that the degree of plastic deformation of the tape sliding against Ni-Zn ferrite in the humid nitrogen is much higher than that in the dry nitrogen. The surface softening of the tape due to water vapor results in the humid nitrogen.

Elastic deformation. - At loads of 0.05 and 0.1 N both tape and Ni-Zn ferrite primarily deformed elastically and the sliding occurred at the interface. Figure 9 presents the coefficients of friction as a function of relative humidity. On humidifying, the coefficient of friction increased continuously with increases in relative humidity, as indicated by the open symbols in Fig. 9(a).

On dehumidifying, the coefficient of friction decreased continuously with decreases in relative humidity. The friction behavior of the tape as a function of relative humidity on dehumidifying is very similar to that on humidifying. At the load of 0.05 N the results are consistent with those at the load of 0.1 N, as indicated in Fig. 9(b).

<u>Frictional response to humidity changes</u>. - A tape was preconditioned in dry nitrogen in the plastic box and maintained at that condition during the entire sliding friction. After sliding for 40 seconds in dry nitrogen, the vicinity around the tape-ferrite pin contact (less than 100 $mm^2$) was flooded with humid nitrogen having 61-percent relative humidity.

Figure 10(a) presents the coefficient of friction as a function of the sliding time resulting from such environmental conditions. In the first pass, right after admitting humid nitrogen, the coefficient of friction increased. The coefficients of friction measured at the area flooded with humid nitrogen were 30 to 40 percent higher than those in dry nitrogen. With repeated sliding passes, the tape exhibited about 2 to 2 1/2 times higher friction than it did in dry nitrogen, when local humidity was raised.

A tape was preconditioned at 63-percent relative humidity in the plastic box and maintained at that condition during the entire sliding friction experiments. The vicinity surrounding the tape-ferrite contact was flooded with dry nitrogen after sliding for 40 seconds in the humid nitrogen atmosphere.

Figure 10(b) presents a typical coefficient of friction as a function of sliding time. Another surprising aspect of humidity dependence is clearly seen in Fig. 10(b). When the contact area was flooded with dry nitrogen, the coefficient of friction decreased dramatically. The tape, with the surface flooded with dry nitrogen, exhibited about 80 percent of the friction in the single pass of sliding and 60 percent in the multipass of sliding of that obtained in the humid nitrogen atmosphere.

Figure 11 presents a typical coefficient of friction as a function of sliding time for magnetic tape in contact with the Ni-Zn ferrite pin. The vicinity surrounding the tape contact with the pin had been flooded with dry nitrogen. At approximately 30 seconds of sliding time, the supply of dry nitrogen was stopped and then the humid nitrogen, at 61-percent relative humidity, was admitted to the contacting area for about 30 seconds. After admitting humid nitrogen, the supply of humid nitrogen was stopped and dry nitrogen was again allowed to flow into the contact area.

Figure 11 clearly indicates the marked increase in coefficient of friction as the humidity increases. Only a short transient time (around 10 sec) is needed for the friction to decrease or increase in relation to the humidity changes.

## Mechanism of Tape Friction and Humidity Effect

The previous sections have shown that sliding occurred primarily at the interface, and the coefficient of friction is greatly influenced by the interaction of tape and Ni-Zn ferrite surfaces. When tape and Ni-Zn ferrite are brought into elastic contact, interfacial adhesion can take place and shearing of adhesive bonds at the interface is responsible for friction. With respect to Fig. 9, the coefficient of friction increased linearly with increasing humidity, and it decreased when humidity was lowered. In elastic contact the changes in friction on humidifying and dehumidifying are reversible.

If a Ni-Zn ferrite pin is in sliding contact with a Ni-Zn ferrite flat, the adsorption of water on the surface does not effect the coefficient of friction, as shown in Fig. 12. There was no change in friction with relative humidity. The experiments with the ferrite-ferrite contact were identical to those with the tape-ferrite contact. Therefore, the effect of humidity on friction for tape-ferrite contact, seen in Fig. 11, is primarily due to an alteration of the tape surface. The most probable effect of humidity on friction behavior of a tape in elastic contact is the result of changes in the chemistry and interaction of tape, such as the degradation of the lubricant.

With respect to Fig. 6, when the tape is plastically deformed during sliding, the coefficient of friction remained low and constant below 40-percent relative humidity and there was no humidity effect on friction. In this region the coefficient of friction is associated with a breakthrough in the adsorbed water-vapor film by the Ni-Zn ferrite pin, because the load applied to the tape surfaces in contact is sufficiently high and plastic deformation occurs. The adhesive bonding occurring at the tape to ferrite contacts through the water-vapor film in humid nitrogen below 40-percent humidity is similar to that in dry nitrogen.

Above 40-percent relative humidity, however, the coefficient of friction increased rapidly with increasing relative humidity, as shown in Fig. 6. The effect of humidity on friction of a tape under such conditions is due to softening of the tape surface and changes in the chemistry and interaction of the tape such as the degradation of the lubricant and the binder's stability. Bradshaw, et al., found that exposure to high humidity and elevated temperatures for long periods (several weeks) can result in the hydrolytic degradation of the tape-binder system and that the primary mechanism relevant to magnetic tape involves the scission of the chainlike structure of the polymer by the action of water, which effectively breaks the polymer into small fragments having low-molecular weights [16].

The experiments reported herein were conducted at room temperature, and the exposure time of tape to humid nitrogen atmosphere was less than 1 hour.

Figs. 6 and 9 shows that there is reversibility of friction on humidifying and dehumidifying. The removal of the adsorbed water-vapor film from the surfaces of tape and Ni-Zn ferrite reverses the coefficients of friction to those before humidifying and results in low coefficients of friction. Thus, the exposure of tape to humid nitrogen for short periods at room temperature may result in a negligibly small amount of hydrolytic degradation of the tape binder. The scission of the chainlike structure of the polymer by the action of water vapor would also be negligible.

With the mechanical activity that takes place during sliding, however, water vapor adsorbed on the tape surface tends to promote chemical degradation of the tape long before the surface may otherwise be ready for such deterioration. The binder degradation can lead to deterioration of the mechanical properties.

We know that the surfaces of materials in sliding contact are highly strained by the mechanical activity that takes place. Under such conditions, on a surface and in the surficial layers of the tape with the adsorbed water-vapor film, the chemistry of the binder and the lubricant can be changed markedly by the strain. The higher the degree of strain, the lower the chemical stability of the binder system and the greater the hydrolytic degradation of the binder.

Similar phenomena have been observed with other materials. For example, on a crystalline surface of a metal the crystallinity and crystallographic orientation can be changed markedly by strain. The higher the degree of strain, the lower the temperature for recrystallization. Consequently, a highly strained crystalline surface tends to promote recrystallization of the solid surface long before the surface may otherwise be ready for such recrystallization [17-19].

Furthermore, on the amorphous surface of a metallic glass, sliding is accompanied by a high degree of strain at room temperature, even when the sliding velocity is very low. This induces crystallization of the metallic glass surface long before the surface may otherwise be ready for such crystallization [20].

## CONCLUSIONS

As a result of sliding friction experiments conducted with magnetic tapes in contact with a Ni-Zn ferrite hemispherical pin in air, dry nitrogen, and humid nitrogen, the following conclusions are drawn:

(1) The friction behavior of magnetic tapes can be divided into two categories by the nature of the deformation of the tape. In elastic contacts, the coefficient of friction decreases as the load increases. In plastic contacts, the coefficient of friction increases as the load increases.

(2) The coefficient of friction is strongly dependent on the ambient relative humidity. In elastic contacts the coefficient of friction increased linearly with increasing humidity, and it decreased linearly when decreasing humidity. In plastic contacts, although the coefficient of friction remained low below 40-percent relative humidity and there was no effect of humidity on friction, the coefficient of friction increased rapidly with increasing relative humidity above 40 percent. The change in friction is reversible on humidifying and dehumidifying both in elastic and plastic contacts.

(3) The effect of humidity on friction of a tape in elastic contacts is due to changes in the chemistry and interactions of the tape such as the degradation of the lubricant. In plastic contacts, it is due to softening of the tape surface and changes in the chemistry and interaction of the tape result when the relative humidity is above 40 percent. No effect of humidity on friction below 40-percent relative humidity is associated with the breakthrough in the adsorbed water-vapor film at the interface of tape and Ni-Zn ferrite.

(4) With the mechanical activity that takes place during sliding, water vapor adsorbed on the tape surface promotes chemical degradation of the tape long before the surface is otherwise ready for such deterioration.

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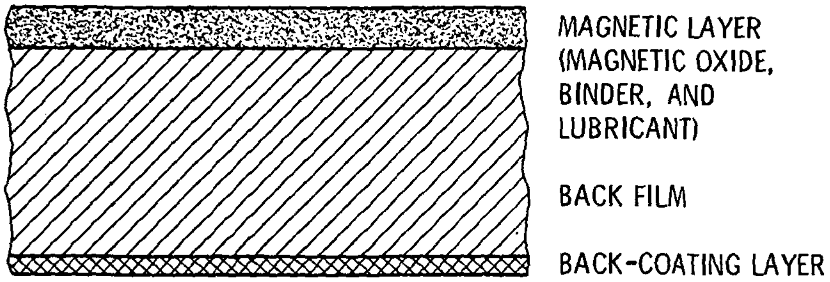


Figure 1. - Schematic of magnetic tape.

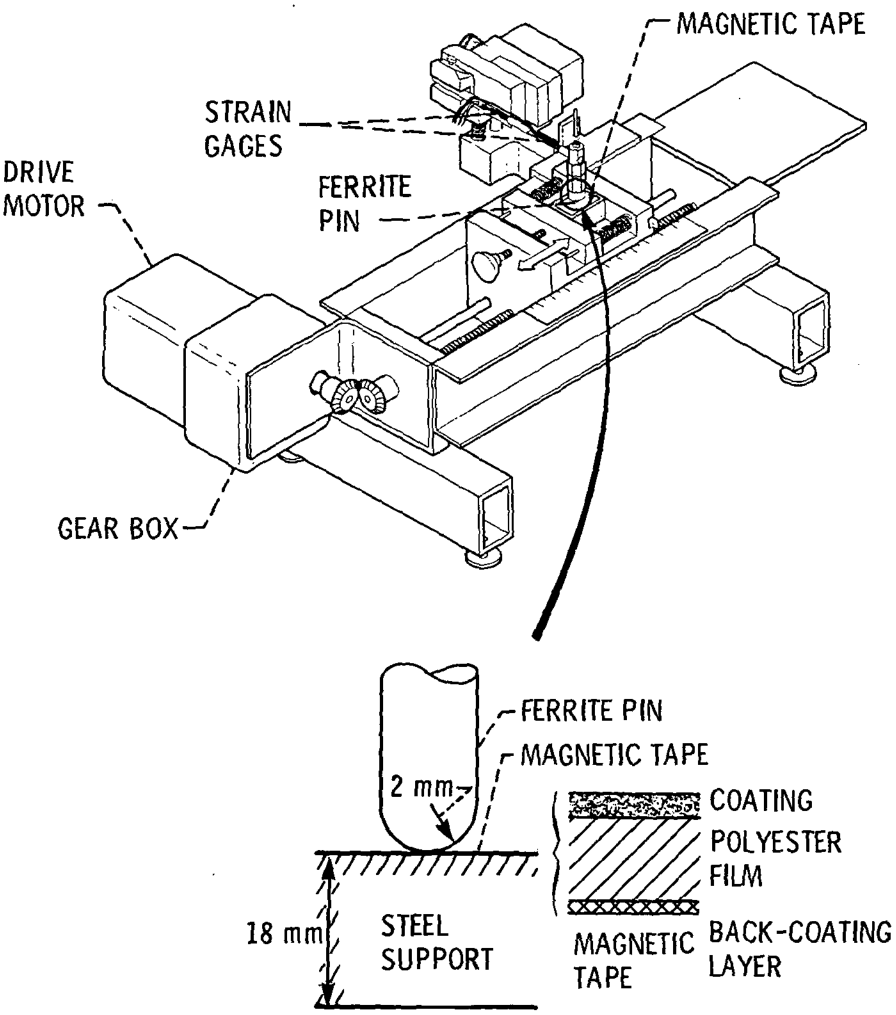
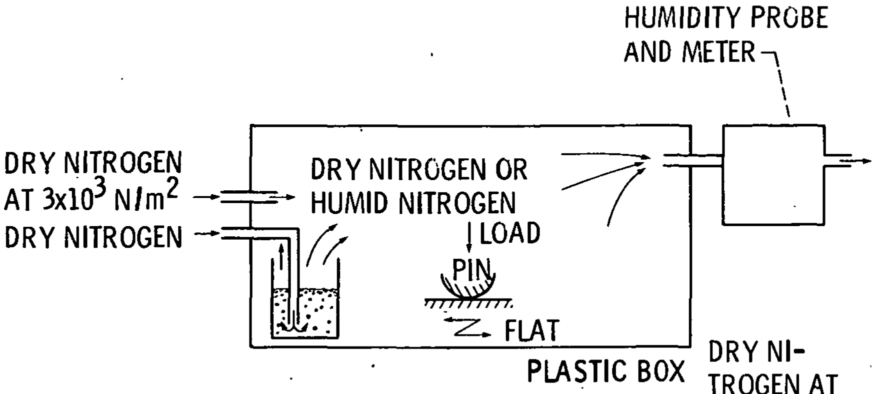
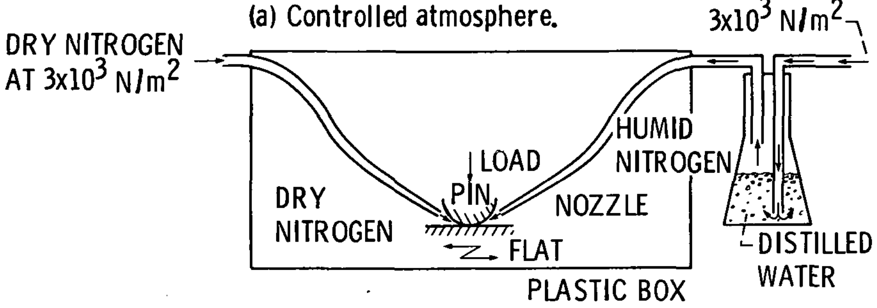


Figure 2. - Friction and wear apparatus.

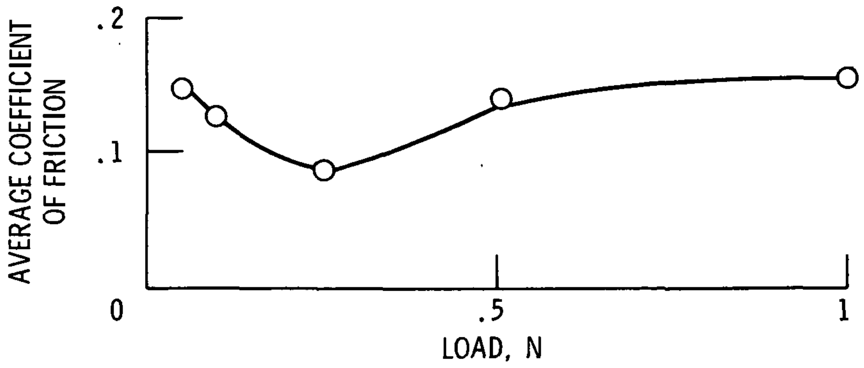


(a) Controlled atmosphere.

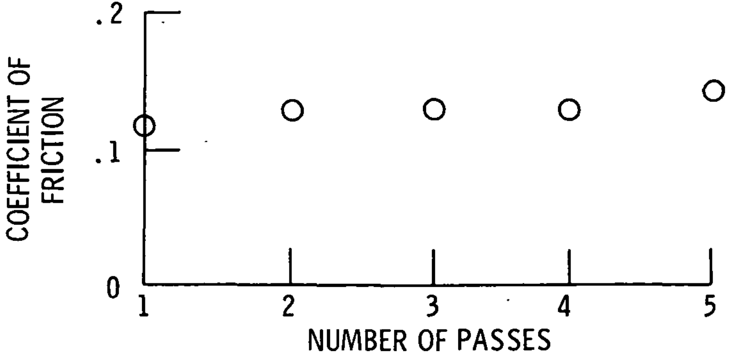


(b) Locally controlled atmosphere.

Figure 3. - Environmental modification of friction and wear apparatus.

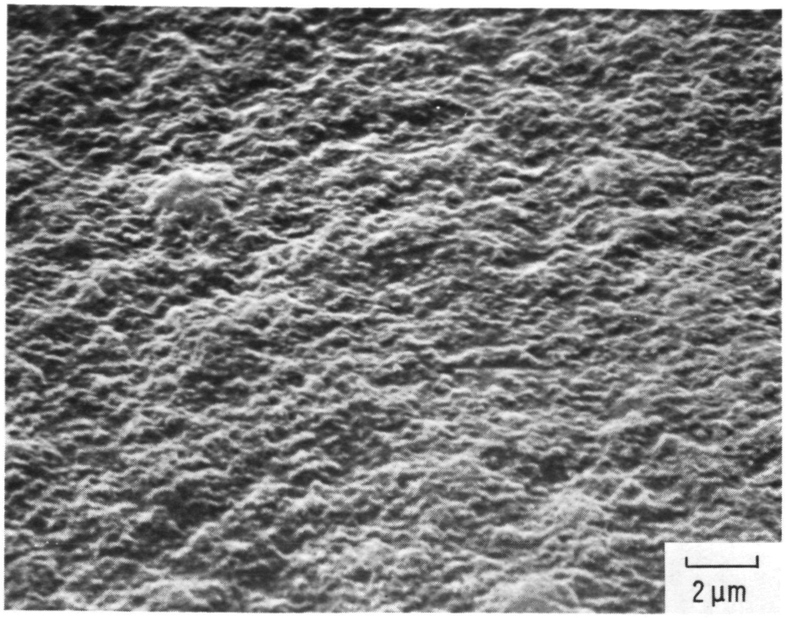


(a) Load. Single-pass sliding.

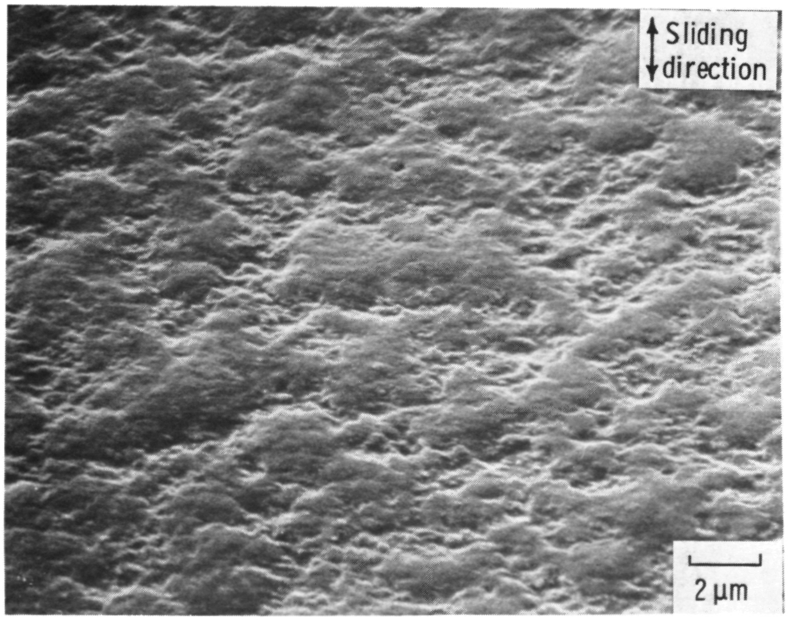


(b) Number of passes. Load, 0.5 N.

Figure 4. - Coefficient of friction for Ni-Zn ferrite sliding on magnetic tape (tape 1) in laboratory air as function of load and number of passes.

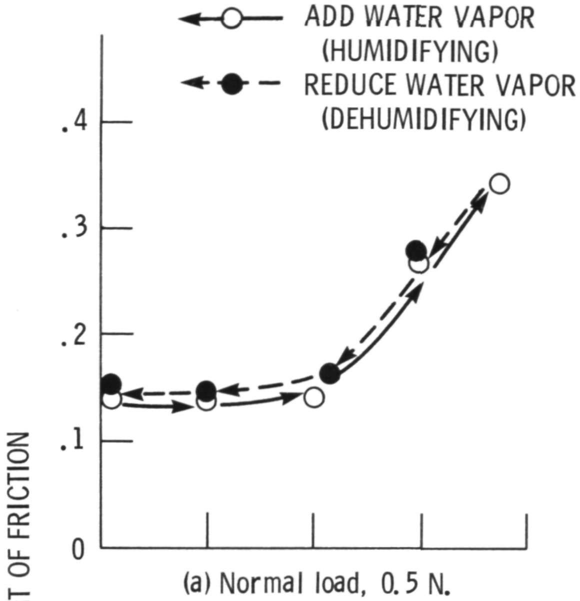


(a) As-received surface.

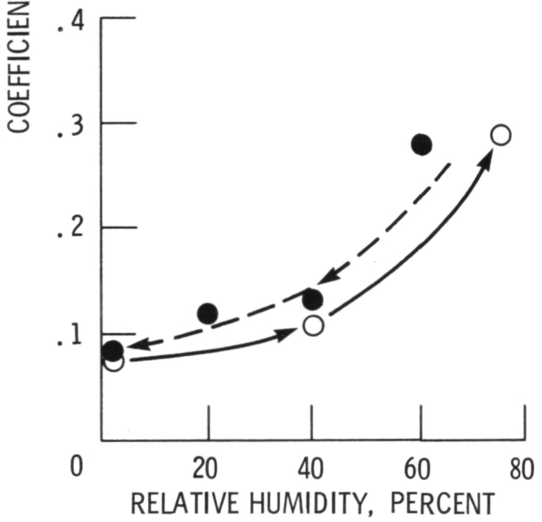


(b) Wear track after 5 sliding passes.

Figure 5. - Scanning electron micrographs of as-received surface and wear track on magnetic tape (tape 1) after 5 passes in sliding contact with Ni-Zn ferrite pin. Normal load, 1.0 N; sliding velocity, 1.5 mm/min; relative humidity, 40 percent; temperature, 23° C; laboratory air.



(a) Normal load, 0.5 N.



(b) Normal load, 0.25 N.

Figure 6. - Effect of humidifying and dehumidifying on friction of magnetic tape (tape 2) in contact with Ni-Zn ferrite pin. Sliding velocity, 0.1 mm/sec; temperature, 23$^{0}$ C; environment, nitrogen.

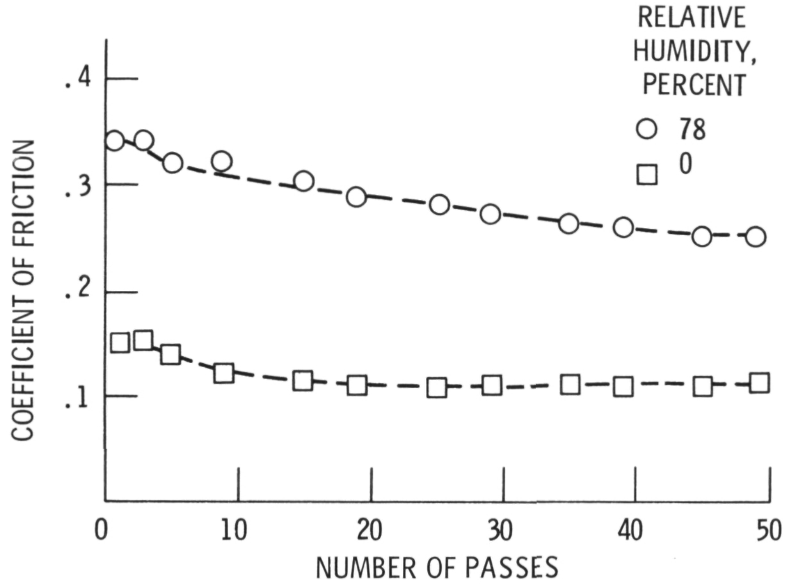
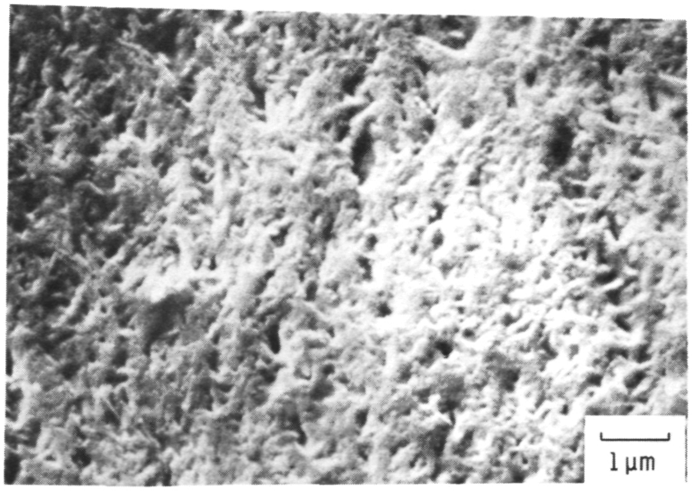
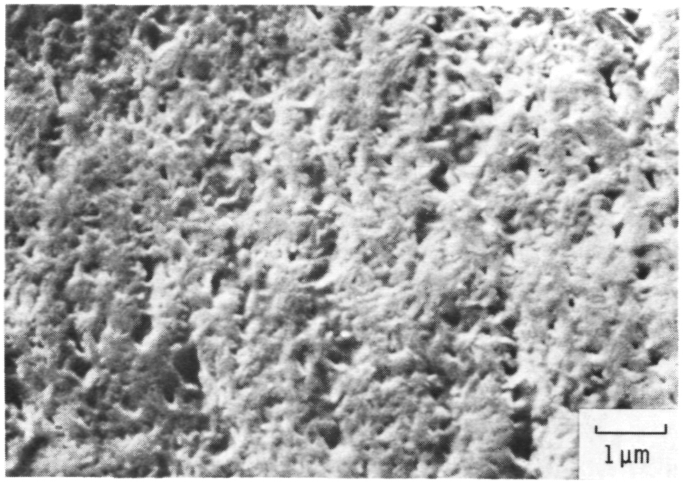


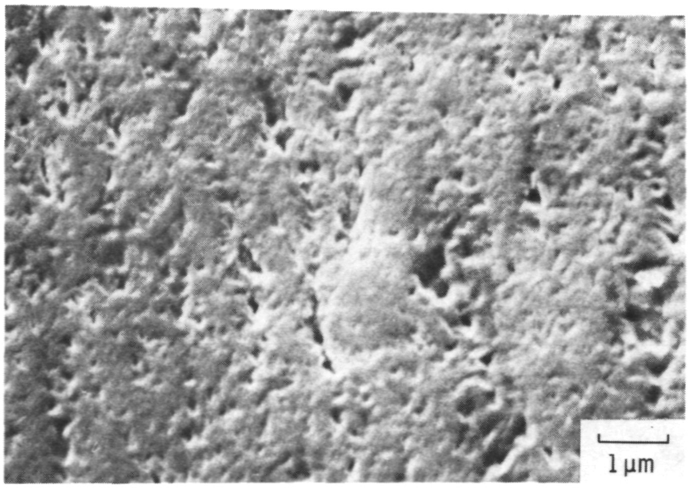
Figure 7. - Coefficient of friction as function of number of repeated passes for magnetic tape (tape 2) sliding against Ni-Zn ferrite pin. Normal load, 0.5 N; sliding velocity, 0.1 mm/sec; temperature, 23° C; environment, dry and humid nitrogen.



(a) New tape (as-received surface).

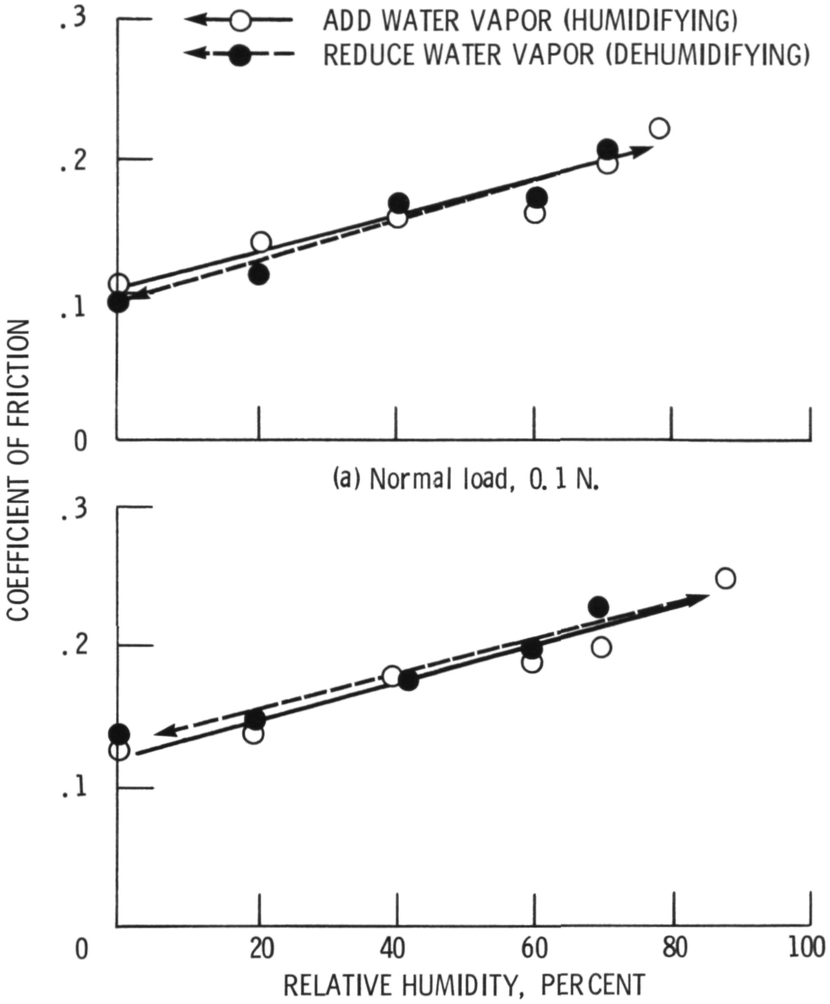


(b) Wear track obtained in dry nitrogen.



(c) Wear track obtained in humid nitrogen. Relative humidity, 78 percent.

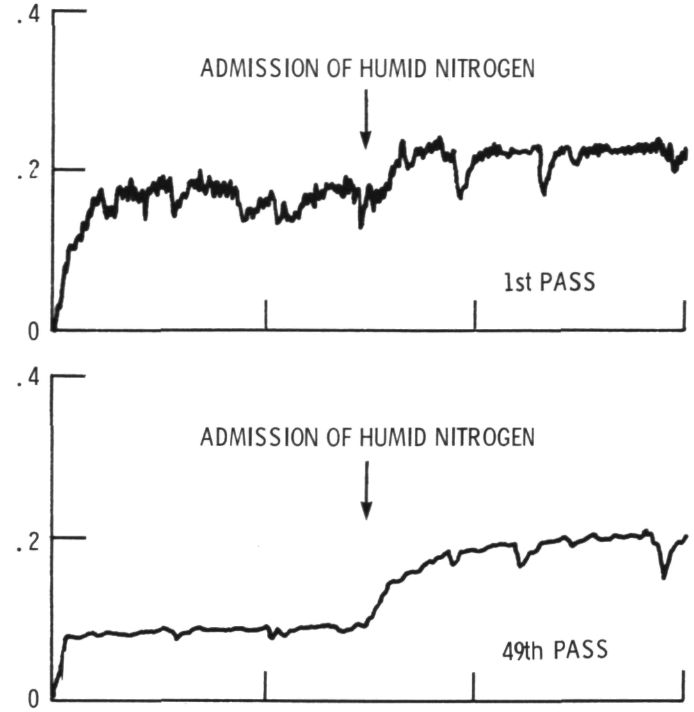
Figure 8. - Scanning electron micrographs of as-received surface and wear tracks on magnetic tape (tape 2) after 50 passes sliding against Ni-Zn ferrite pin. Normal load, 0.5 N; sliding velocity, 0.1 mm/sec; temperature, 23° C; environment, dry and humid nitrogen.



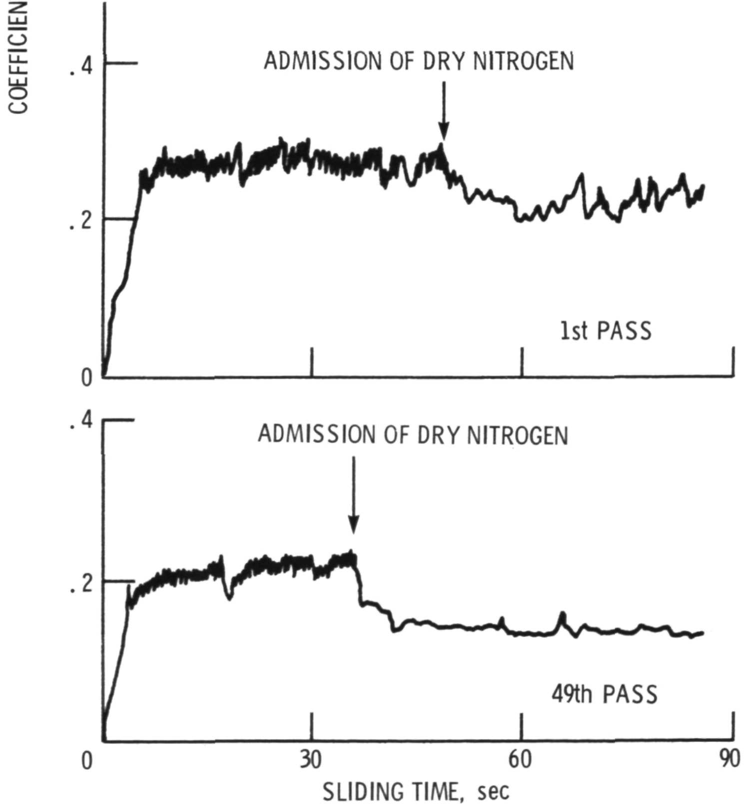
(a) Normal load, 0.1 N.

(b) Normal load, 0.05 N.

Figure 9. - Effect of humidifying and dehumidifying on friction of magnetic tape (tape 2) in contact with Ni-Zn ferrite pin. Sliding velocity, 0.1 mm/sec; temperature, 23° C; environment, nitrogen.



(a) Admission of humid nitrogen. Relative humidity, 61-percent.



(b) Admission of dry nitrogen.

Figure 10. - Effects of humidity change on coefficient of friction for magnetic tape (tape 2) sliding against Ni-Zn ferrite pin. Normal load, 0.5 N; sliding velocity, 0.1 mm/sec; temperature, 23° C; environment, nitrogen.

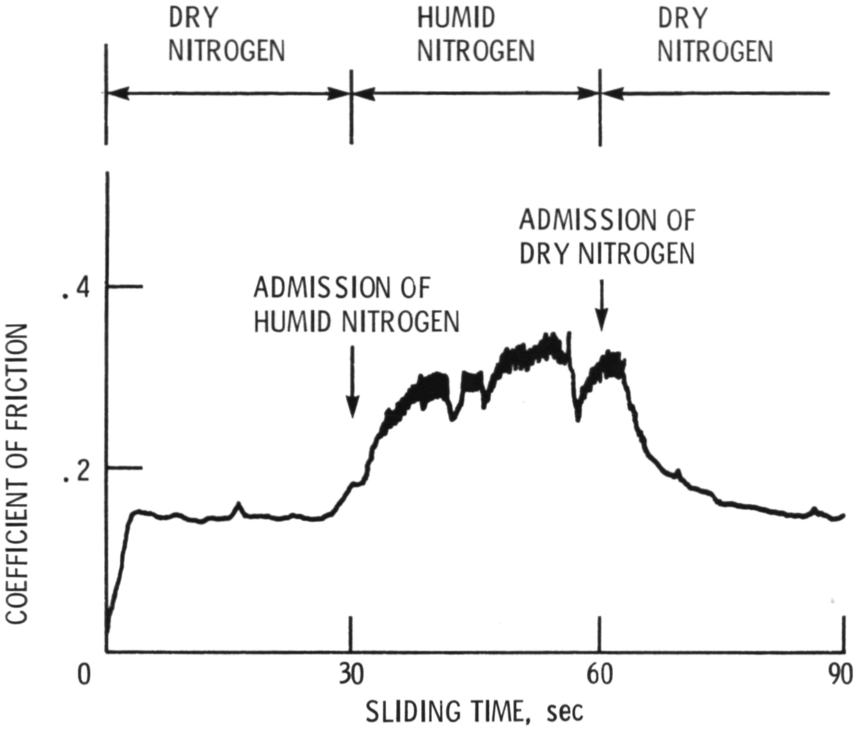


Figure 11. - Coefficient of friction as function of sliding time for magnetic tape (tape 2) sliding against Ni-Zn ferrite pin. Effect of humidity changes due to admission of humid or dry nitrogen. Normal load, 0.5 N; sliding velocity, 0.1 mm/sec; temperature, 23° C; environment, nitrogen; third pass.

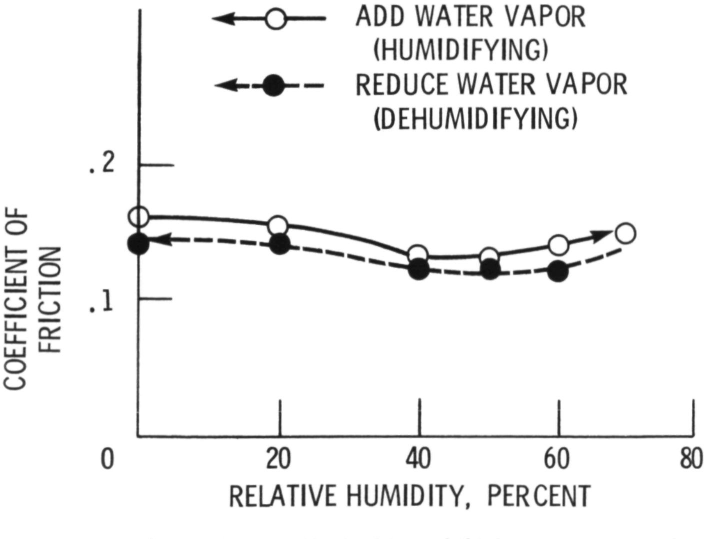


Figure 12. - Effect of humidifying and dehumidifying on friction of Ni-Zn ferrite pin in contact with Ni-Zn ferrite flat. Sliding velocity, 0.1 mm/sec; load, normal 0.5 N; temperature, 23° C; environment, nitrogen.

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|---|---|---|
| 1. Report No.<br>NASA TM-83727 | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle<br>Effects of Water-Vapor on Friction and Deformation of Polymeric Magnetic Media in Contact With A Ceramic Oxide | | 5. Report Date |
| | | 6. Performing Organization Code<br>506-53-1B |
| 7. Author(s)<br>Kazuhisa Miyoshi and Donald H. Buckley | | 8. Performing Organization Report No.<br>E-1986 |
| | | 10. Work Unit No. |
| 9. Performing Organization Name and Address<br>National Aeronautics and Space Administration<br>Lewis Research Center<br>Cleveland, Ohio 44135 | | 11. Contract or Grant No. |
| | | 13. Type of Report and Period Covered<br>Technical Memorandum |
| 12. Sponsoring Agency Name and Address<br>National Aeronautics and Space Administration<br>Washington, D.C. 20546 | | 14. Sponsoring Agency Code |

15. Supplementary Notes

Prepared for the Joint Lubrication Conference cosponsored by the American Society of Mechanical Engineers and the American Society of Lubrication Engineers, San Diego, California, October 22-24, 1984.

16. Abstract

The effects of humidity (water-vapor) in nitrogen on the friction and deformation behavior of magnetic tape in contact with a Ni-Zn ferrite spherical pin were studied. The results indicate that the coefficient of friction is markedly dependent on the ambient relative humidity. In elastic contacts the coefficient of friction increased linearly with increasing humidity; it decreased linearly when humidity was lowered. This effect is the result of changes in the chemistry and interaction of tape materials such as degradation of the lubricant. In plastic contacts there was no effect of humidity on friction below 40-percent relative humidity. There is no effect on friction associated with the breakthrough of the adsorbed water-vapor film at the interface of the tape and Ni-Zn ferrite. The coefficient of friction, however, increased rapidly with increasing relative humidity above 40 percent in plastic contacts. The change in friction is reversible on humidifying and dehumidifying. This effect is due to softening of the tape surface and changes in the chemistry and interaction of the tape. With a mechanical activity that takes place during sliding, water vapor adsorbed on the tape surface tends to promote chemical degradation of the tape long before the surface may otherwise deteriorate.

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| 17. Key Words (Suggested by Author(s))<br>Magnetic tape<br>Ferrite<br>Friction | | 18. Distribution Statement<br>Unclassified - unlimited<br>STAR Category 27 | |
| 19. Security Classif. (of this report)<br>Unclassified | 20. Security Classif. (of this page)<br>Unclassified | 21. No. of pages | 22. Price* |

*For sale by the National Technical Information Service, Springfield, Virginia 22161

National Aeronautics and
Space Administration

Washington, D.C.
20546