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Durable Solid Lubricant Coatings for Foil Gas Bearings to 315° C

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DURABLE SOLID LUBRICANT COATINGS FOR FOIL GAS BEARINGS TO 315° C

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Abstract

The durability and friction characteristics of bonded solid lubricant films on compliant gas bearings were measured. Coating compositions, which were judged to be suitable for use to at least 315° C, were selected for this study. Most the data were obtained with polyimide-bonded graphite fluoride coatings and with silicate-bonded graphite coatings. These coatings were applied to the bore of Inconel 750 foil bearings. The journals were A286 stainless steel, with a rms surface finish of 0.2 μm. The foils were subjected to repeated start/stop cycles under a 14 kPa (2 psi) bearing unit load. Sliding contact occurred during lift-off and coast down at surface velocities less than 6 m/s (3000 rpm). Testing continued until 9000 cycles were accumulated or until a rise in starting torque indicated that the coating had failed. The coatings were evaluated in the temperature range from 25° to 315° C. Comparisons in coating performance as well as discussions of their properties and methods of application are given.

INTRODUCTION

The compliant foil gas bearing is an ideal mechanism for supporting high-speed, high-performance, turbine driven rotors. The main advantages of this type of bearing over conventional rolling element bearings are the longer bearing fatigue life and the potential for elimination of liquid lubrication systems. Therefore, problems with lubricant vaporization, coking, and the complexity of external lubricating equipment are minimized. This bearing type also offers reduced power losses due to the low frictional drag of a gas film at high speeds.

The current state of the art for the lubrication of foil bearings has the temperature capability of about 260° C using bonded PTFE coatings. Work has been done to develop coatings with capabilities to 650° C (e.g. 1,2). The coatings for 650° C applications are plasma sprayed, sputtered, or ion-plated materials. While such coatings can give acceptable performance at high temperatures, they are not usually as effective from room temperature to 315° C as the layer lattice class of solid lubricants. Therefore, this paper will concentrate on coatings capable of achieving effective lubrication to 315° C for intermediate temperature applications; specifically, turbomachinery driven by compressor bleed air from turbojet engines.

Polyimide-bonded graphite fluoride (PBGF) was selected as the primary coating material for evaluation in this study. PBGF has been shown to achieve long wear life and low friction coefficients in pin on disk experiments in the temperature range of interest, (e.g., 3,4).

Silicate-bonded graphite/cadmium oxide (SBGC) has been used to lubricate foil bearings at temperatures to 420° C (5). Therefore this composition was selected as a primary baseline material for judging the comparative effectiveness of PBGF as an intermediate temperature foil bearing lubricant.

The scope of this study therefore was to determine the frictional characteristics and the durability of polyimide-bonded graphite fluoride and of silicate-bonded graphite/cadmium oxide coatings on Inconel 750 foil bearings from 25° to 315° C. In addition, some preliminary experiments with MoS_2 and other graphite coatings were performed.

EXPERIMENTAL MATERIALS

Polyimide-Bonded Graphite Fluoride Coatings

Characteristics. - The polyimide used in these coatings has good tribological properties in its own right. In previous studies, using a pin on disk apparatus it was shown that polyimide coatings alone have low wear rates and friction coefficients of 0.2 or less at temperatures above about 100° C. At lower temperatures wear and friction increase markedly. This transition in properties has been correlated with second order relaxations in the molecular bonds of the polymer between 25° and 100° C (6). The exact transition temperature varies depending upon the specific polyimide under study. The addition of graphite fluoride $(CF_{1.1})_n$ to the polyimide coating composition counteracts the tribological deficiences of polyimide below the transition temperature. In effect, the undesirable friction transition below 100° C is totally masked by the solid lubricant addition.

Preparation and application. - A thick precursor solution of pyralin polyimide (PI-4701) is formed into a sprayable mixture by adding a thinner consisting of N-methylpyrolidone and xylene. Graphite fluoride, with a fluorine-to-carbon ratio of 1.1, is mixed in equal parts by weight of polyimide solids. The precursor solution contains 43 percent weight solids. The coating is applied to the Inconel 750 foil by means of an artist's airbrush. Only one thin layer at a time is applied to prevent "running." Each layer is then cured by heating at 100° C for 1 hr then 300° C for 2 hr. Three or four separately cured layers were required to achieve the desired 10 μm coating thickness. The above coating formulation and procedures were developed by R. L. Fusaro (4) who also applied the PBGF coatings evaluated in this program.

Silicate-Bonded Graphite/Cadmium Oxide (SBGC)

Characteristics. - It has long been known that graphite is not an intrinsic lubricant, but requires the absorption of vapors such as water or hydrocarbons to provide a low friction coefficient (7). Above approximately 100° C, desorption occurs and high friction is again observed. However certain solid additives such as cadmium oxide (CdO) and other oxides and salts have been shown to stabilize the lubricating effectiveness of graphite over a broad temperature range (8). A dry film lubricant consisting of sodium silicate-bonded graphite and CdO has shown promise for the lubrication of foil bearings (5). This composition was chosen for further study in this program. The following coating procedure was performed according to the practice described by B. Bhushan in Ref. 9.

Preparation and application. - The mixture consists of 3 parts graphite to 1 part CdO with sodium silicate as a binder and wetting agents for dispersion of the solution. The graphite is 99 percent pure electric-furnace synthetic graphite. Synthetic graphite is used rather than natural graphite because it exhibits a higher temperature tolerance. A very fine powder with 95 percent of the particle sizes finer than 325 mesh is used.

Cadmium oxide is 99.9 percent pure (commercially pure). It has particle sizes of which 95 percent are finer than 200 mesh. Sodium silicate is 99 percent pure having a composition of 8.9 percent Na_2O, 28.7 percent SiO_2, and the balance water. Excluding the water, 30 weight percent sodium silicate is used to give adequate bonding. Higher contents become too abrasive. A wetting agent with a cloud point of 65° C is used. The mixture of graphite and CdO is dissolved in distilled water and ball milled for 4 hours. Sodium silicate and one drop of the wetting agent are added and the solution is stirred vigorously. The solution is heated to 65° C (150° F) just before application to the foil. It is sprayed by an airbrush about 25 μm (1 mil) thick and left at room temperature for 30 minutes. The coating is baked in an oven at 65° C (150° F) for 2 hours then baked at 150° C (300° F) for 8 hours. After curing the coating thickness is 12 to 18 μm, and is subsequently burnished to a thickness of 10 μm.

APPARATUS AND TEST PROCEDURE

Start/Stop Bearing Test Appartus

The bearing test machine is shown in Fig. 1. A machine of the same general design is fully-described in Ref. 5; a summary of the important features are given below.

The apparatus is designed to run unattended. Timer switches operate each start stop cycle at 20 second intervals. Program time switches control the amount of time that the test is run by shutting down the heaters and electric drive motor at the end of the test sequence. A temperature control unit is used to maintain the bearing temperature at the desired level. Heating is provided by eight 500-watt quartz lamps.

The test spindle is driven by a 1 HP induction motor running at 3450 rpm. A pulley ratio of 4:1 is used to provide a 13,800 rpm (28 m/s) spindle speed. The spindle is turned on for 13 seconds and off for 7 seconds (total cycle time 20 s). This time allows the bearing to fully lift off during the start cycle and the spindle to completely stop during the stop cycle. A fiber optics impulse counter is used to count each cycle.

The bearing is mounted in a floating housing which is restrained from rotation by a torque arm that bears against a calibrated flexure plate. Deflection of this plate is a function of bearing torque and is sensed by a capacitance probe. Journal velocity and bearing torque are plotted simultaneously by a recording oscillograph. Typical velocity and torque profiles for one twenty second start/stop cycle are given in Fig. 2.

Test Bearing and Test Journal

A schematic drawing of the test bearing is given in Fig. 3. It is a partial arc 38.1 mm (1.5 in.) diameter journal bearing. The bearing is of the same design as that previously reported in Ref. 10. The bearing consists of a bump foil and a smooth top foil.

The smooth foil receives the coating to be evaluated. The material of construction is Inconel 750. The two foils are attached to a key by spot welding. The key is fitted into a keyway in the floating bearing housing and secured in place by tapered pins. The test bearing has one bump more than one-half the total number of bumps in a complete circular bearing, which results in a 186° pad arc. Rotation of the journal is into the free end of the foil. This partial arc bearing was designed specifically for coating evaluation experiments. It is capable of lift-off at about 3000 rpm (6 m/s) at a radial unit load of 14 kPa (2 psi). However it is not intended to be used as a functional journal bearing. A functional bearing would be a full circular single or multi-segment bearing with a larger length over diameter ratio, typically 1.0.

Test Procedure

All tests were run at a maximum surface velocity of 28 m/s at 13 800 rpm and at a 14 kPa (2 psi) unit load. This is reportedly a typical radial load at start-up for foil bearings in turbomachinery (ref. 9). The tests were terminated either when solid lubricant failure was indicated by a sharp rise in bearing starting torque or 9000 start/stop cycles were successfully completed. The choice of 9000 start/stop cycles as a satisfactory coating life was partly arbitrary. However it is approximately the number of start/stops that would be experienced by a bearing in a machine that is started on the average of five times per day over a five year period. In practice, some starts can be expected to be cold, others at intermediate bearing temperatures, and others at the maximum bearing temperature depending upon the length of time the machine is shutdown before restart. Therefore a test procedure was employed in which start/stop cycles were perfomed at ambient, two intermediate temperatures, and at a maximum temperature of 315° C. The procedure was conducted in the following sequence:

I. 500 start/stop cycles at ambient
II(a). 250 start/stop cycles at 120° C
II(b). 250 start/stop cycles at 230° C
III. 500 start/stop cycles at 315° C

The above sequence was repeated a maximum of six times for a total of 9000 start/stop cycles.

RESULTS AND DISCUSSION

Bearing Torque

Relatively short duration experiments were performed early in the program to generate baseline data with: (1) commercially-available, dry film lubricants; (2) silicate-bonded graphite/cadmium oxide (SBGC), and (3) polyimide-bonded graphite fluoride (PBGF). These experiments were conducted to obtain quantitive torque profiles and apparent friction coefficients.

Friction coefficients for these coatings at various temperatures are summarized in Table I. These coefficients were calculated directly from bearing torque measurements. The starting friction coefficients (μ_1) tabulated here will be termed "apparent" because they are higher than the generally accepted values of coulomb friction for the coatings being evaluated. There may be some factors contributing to the starting torque in addition to sliding friction. These factors may include dynamic elastic deformation forces acting on the highly-conformable foils. Lift off occurred at about 3000 rpm. Therefore, (assuming proper bearing clearance) during normal "airborne" operation at 13,800 rpm, the computed friction coefficient (μ_2) was due to viscous shear of the gas film.

There was not much variation in the room temperature starting torque among the various coatings. Computed values of μ_1 from starting torques were about 0.3 for MoS_2 and graphite coatings. The friction coefficient μ_1 with as-sprayed PBGF was higher, about 0.4. This was reduced to 0.3 by applying a burnished (rubbed-on) overlay of graphite fluoride to the surface of the PBGF coatings. Significant differences in starting torque did however occur at elevated temperatures.

While the graphite coatings maintained a steady value for μ_1 of about 0.3 from 25° C to 315° C, μ_1 for PBGF coatings decreased from 0.4 at 25° C to 0.2 at 315° C for the as-sprayed coatings and from 0.3 at 25° C to 0.1 at 315° C for the burnished coatings.

Friction coefficients while airborne (μ_2) were uniformly low (less than 0.1) in all of the tests. They tended to be lower with the thinner coatings, indicating that the increase in clearance provided by thin, smooth coatings was beneficial in achieving a satisfactory gas film thickness at the relatively low speed (for gas bearings) of 13 800 rpm (28 m/s surface velocity).

Figs. 4 and 5 give representative steady-state friction coefficients as a function of bearing temperature for SBGC and PBGF coatings respectively. The friction coefficients plotted are apparent starting friction (μ_1), friction while airborne (μ_2), and maximum apparent friction during coast down (μ_3). Friction coefficients during coast down (μ_3) were generally higher than μ_1 but followed the same trends with time and temperature. No explanation for higher torque during coast down than during start up has been found.

Running-in effect. - Considerably higher values of μ_1 than the steady state values so far given were usually observed early in the endurance tests, and may be attributed to a "running-in" mechanism at the coating/journal contact. This is illustrated on Fig. 6 which gives starting friction coefficients for a PBGF coating as a function of test duration for the first two programmed temperatures sequences (3000 start/stop cycles). Friction decreased steadily from 0.53 to 0.40 during the first 500 start/stop cycles at room temperature, demonstrated erratic behavior during the next 500 cycles at intermediate temperatures, then became steady at 0.25 during 315° C operation. Steady state behavior prevailed during the next programmed 1500 start/stops with μ_1 of about 0.3 at room temperature, 0.25 at intermediate temperature, and 0.23 at 315° C.

There are several factors that contribute to the reduction in bearing starting torque as the number of start/stop cycles accumulate: (1) the well-known preferred orientation of solid lubricant crystallites occurs, aligning low shear strength crystal planes parallel to the sliding direction; (2) as-sprayed surfaces are relatively rough and sliding generates a smooth surface which is more favorable to efficient gas bearing operation; (3) this smoothing action also increases the effective radial clearance of the bearing, a factor which can be conducive to lower bearing torque.

Coating Endurance

Coating endurance is here defined as the number of start/stop cycles accumulated by a test bearing before the coating wears through to the foil metal substrate. Failure was determined by a substantial increase in starting torque and verified by visual inspection of the foil and journal surfaces. Results of the endurance tests are summarized in Table II.

The heat-cured, bonded MoS_2 coatings survived 175 to 400 start/stop cycles at room temperature before failure. Heat-cured proprietary graphite coatings survived approximately 1000 start/stops (500 at room temperature and 500 at 230° C). The relatively short lives of these proprietary coatings was probably due to the fact that the Inconel 750 foils were not pretreated to enhance coating adherance except by lightly sanding the surface with 200 grit sandpaper. (Roughening the surfaces by sandblasting severely distorted the thin foils.) However, even with this very mild pretreatment silicate-bonded graphite/cadmium oxide and polyimide-bonded graphite fluoride were very durable and adherent. Their performance in long duration start/stop endurance tests is described below:

Polyimide-bonded graphite fluoride (PBGF). - Endurance tests of four PBGF-coated bearings were conducted at temperatures from room ambient to 315° C. All four coatings survived 9000 start/stop cycles of the standardized endurance test procedure. In fact, one PBGF coated bearing was subjected to an extended period of start/stop cycles. After 32,000 start/stops at ambient conditions, the bearing coating was still performing with acceptable friction characteristics. This durability was achieved in spite of the fact that the smooth foils were not pretreated (other than a light sanding) prior to applying the coatings. Sliding contact during starts and stops polished the coatings to a reflective finish, and a very thin transfer film of coating material was deposited on the journal. The coatings were especially glossy in the areas of highest pressure contact, that is over the bumps of the supporting bottom foil and at the edges of the foil which are the areas of minimum film thickness. Photomicrographs and surface profiles of the foil bearing and journal after 9000 start/stop cycles are shown in Figs. 7(a) to (b).

In one endurance test, it was noted that extraordinarily high torque was present at the beginning of the experiment. The bearing fit was suspected to be tight and total liftoff never occurred. The coating was given a light sanding to reduce its thickness, thus increasing the radial clearance between the bearing and journal. A thin film of $CF_{1.1}$ was burnished over the finished surface. This procedure resulted in normal torque characteristics.

Silicate-bonded graphite/cadmium oxide. - These coatings also demonstrated good durability, but they did not survive the programmed 9000 start/stop cycles. The two coatings tested survived 7500 and 4500 start/stop cycles. Failure was indicated for both bearings by excessive bearing torque, by coating wear to the substrate foil material, and by scuffing of the A286 steel journal.

The foil and journal surfaces were periodically inspected, and were in very good condition at all times prior to actual coating failure. For example, after 500 start/stops at room temperature, the foil bearing was in very good condition with polished areas over the bumps and at the foil edges. A light transfer film of coating material was apparent on the journal. After one complete heating sequence from room temperatures to 315° C, and an accumulated 1500 start/stops, the journal surface was oxidized and also coated with a transfer film. The foil was highly polished except for a few areas between the bumps.

Inspection of the surfaces after coating failure revealed severe coating wear to the substrate metal over much of the foil surface.

The oxide film on the journal was worn away, the steel surface was circumferentially scored, and a great deal of coating transferred to its surface. Figures 8(a) and (b) are photomicrographs and surface profiles of the journal and foil bearing surfaces.

Discussion of Comparative Endurance

These results demonstrated that both polyimide-bonded graphite fluoride (PBGF) coatings and silicate-bonded graphite/cadmium oxide (SBGC) coatings are effective solid lubricants for foil bearings to at least 315° C. The PBGF coatings had superior durability; none of them failed in the endurance tests of 9000 start/stop cycles. The SBGC coatings were less durable but nevertheless had very respectable endurance lives; they survived thousands of start/stops before failure.

Bearings coated with the graphite coatings had a more constant and consistent torque than those coated with PBGF. An apparent starting friction coefficient of 0.30±0.03 was characteristic of graphite lubricated bearings at all test temperatures while the apparent starting friction coefficients of bearings coated with PBGF ranged from 0.4 at room temperature to 0.2 at 315° C for a well run-in coating. Room temperature friction coefficients as high as 0.5 were observed during run-in at room temperature. Friction was appreciably reduced by burnishing $CF_{(1.1)}$ onto the bearing and journal prior to the bearing tests. The effect of these burnished films persisted over thousands of start/stop cycles.

CONCLUSIONS

Polyimide bonded graphite fluoride (PBGF) coatings were evaluated to determine their suitability as dry film lubricants for foil gas bearings at temperatures from 25° to 315° C. A silicate-bonded graphite/cadmium oxide (SBFC) coating, which is a known foil bearing lubricant, was evaluated as a baseline for comparison. The experimental program led to the following conclusions:

(1) Both coatings were effective foil bearing lubricants from 25° to 315° C. At room temperature, bearing torques during start-up (prior to lift-off) were about the same for both coatings. However, while starting torque remained relatively constant for SBGC at all temperatures, it decreased with increasing temperature for PBGF.

(2) Both coatings are durable; they are capable of surviving thousands of starts and stops over a 25° to 315° C operating temperature range. All PBGF coatings tested survived 9000 start/stop cycles over the indicated temperature range. SBGC coatings survived 4500 to 7500 start/stop cycles before they failed. Failure occurred when the coatings wore-out in the minimum gas film thickness areas at the sides of the foils and over the bumps on the support foil.

(3) Friction coefficients computed from bearing torque at low sliding velocities (before lift-off) are higher than the values usually observed for the dry film lubricants employed. Other factors such as foil elastic deformations may be adding to the coulomb friction of the sliding surfaces.

(4) Starting torque tended to decrease with accumulated start/stop cycles and then leveled out at a steady state value. This can be expected of normal "run-in", but in a gas bearing the smoothing of the coating surface, and an increase in effective radial clearance also contributes to this behavior.

REFERENCES

1. Suriano, F. J., Dayton, R. D., and Woessner, F. G., "Test Experience with Turbine-End Foil Bearing Equipped Gas Turbine Engines," ASME Paper 83-GT-73 (1983).
2. Bhushan, B., "Development of R. F. Sputtered Chromium Oxide Coating for Wear Application," Thin Solid Films, 64, pp 231-241 (1979).
3. Fusaro, R. L. and Sliney, H. E., "Lubricating Characteristics of Polyimide Bonded Graphite Fluoride and Polyimide Thin Films," ASLE Trans., 16, 3, pp 189-196 (1973).
4. Fusaro, R. L., "Effect of Load, Area of Contact and Contact Stress on the Wear Mechanisms of a Bonded Solid Lubricant Film," WEAR, 75, 2, pp. 403-422 (1982).
5. Bhushan, B., and Gray, S., "Development of Surface Coatings for Air-Lubricated, Compliant Journal Bearings to 650°C," ASLE Trans., 23, 2, pp 185-196 (1980).
6. Fusaro, R. L., "Molecular Relaxations, Molecular Orientation, and the Friction Characteristics of Polyimide Films," ASLE Trans., 20, 1, pp 1-14 (1977).
7. Savage, R. H., "Graphite Lubrication," J. Appl. Phys., 19, 1, pp 1-10 (1948).
8. Peterson, M. B. and Johnson, R. L., "Friction Studies of Graphite and Mixtures of Graphite with Several Metallic Oxides and Salts at Temperatures to 1000° F," NACA TN-3657 (1956).
9. Bhushan, B., Ruscitto, D., and Gray, S., "Hydrodynamic Air Lubricated Compliant Surface Bearing for an Automotive Gas Turbine Engine: II - Materials and Coatings," CONS/9427-2, NASA CR-135402 (1978).
10. Ruscitto, D., McCormick, J., and Gray, S., "Hydrodynamic Air Lubricated Compliant Surface Bearing for an Automotive Gas Turbine Engine: I - Journal Bearing Performance," CONS/9427-1, NASA CR-135368 (1978).

TABLE I. - TYPICAL FRICTION COEFFICIENTS FOR FOIL BEARINGS WITH VARIOUS COATINGS

Coating	Temperature, °C	Friction coefficients	
		μ_1	μ_2
		Starting	Running at 28 M/sec (13 800 rpm)
Bonded MoS_2 (heat cured)	25	0.27	0 to 0.06
Bonded graphite (heat cured)	25	.30	0 to .08
	150	.30	0 to .08
	230	.26	0 to .08
Silicate-bonded graphite/CdO	25	.30	0 to .05
	150	.33	0 to .05
	230	.28	0 to .05
	315	.30	0 to .05
Polyimide bonded graphite fluoride			
- As-Sprayed	25	.40	0.06 to .08
	150	.26	.06 to .08
	230	.23	.06 to .08
	315	.20	.06 to .08
- Burnished $CF_{1.1}$ Overlay	25	.30	.03 to .05
	150	.25	.03 to .05
	230	.20	.03 to .05
	315	.10	.03 to .05

TABLE II. - COATING DURABILITY

Coating type	Range of bearing temperatures, °C	Endurance life number of start/stop cycles to failure	
		Minimum	Maximum
Bonded MoS_2 [a] (heat cured)	25	175	400
Bonded Graphite[a] (heat cured)	25 to 230	800	1000
Silicate-bonded graphite/CdO	25 to 315 25 to 430	4500 [b]2070	7500
Polyimide-bonded graphite fluoride	25 to 315	>9000	>9000

[a] Proprietary coatings bonding agents unknown.
[b] Only one test to 430° C.

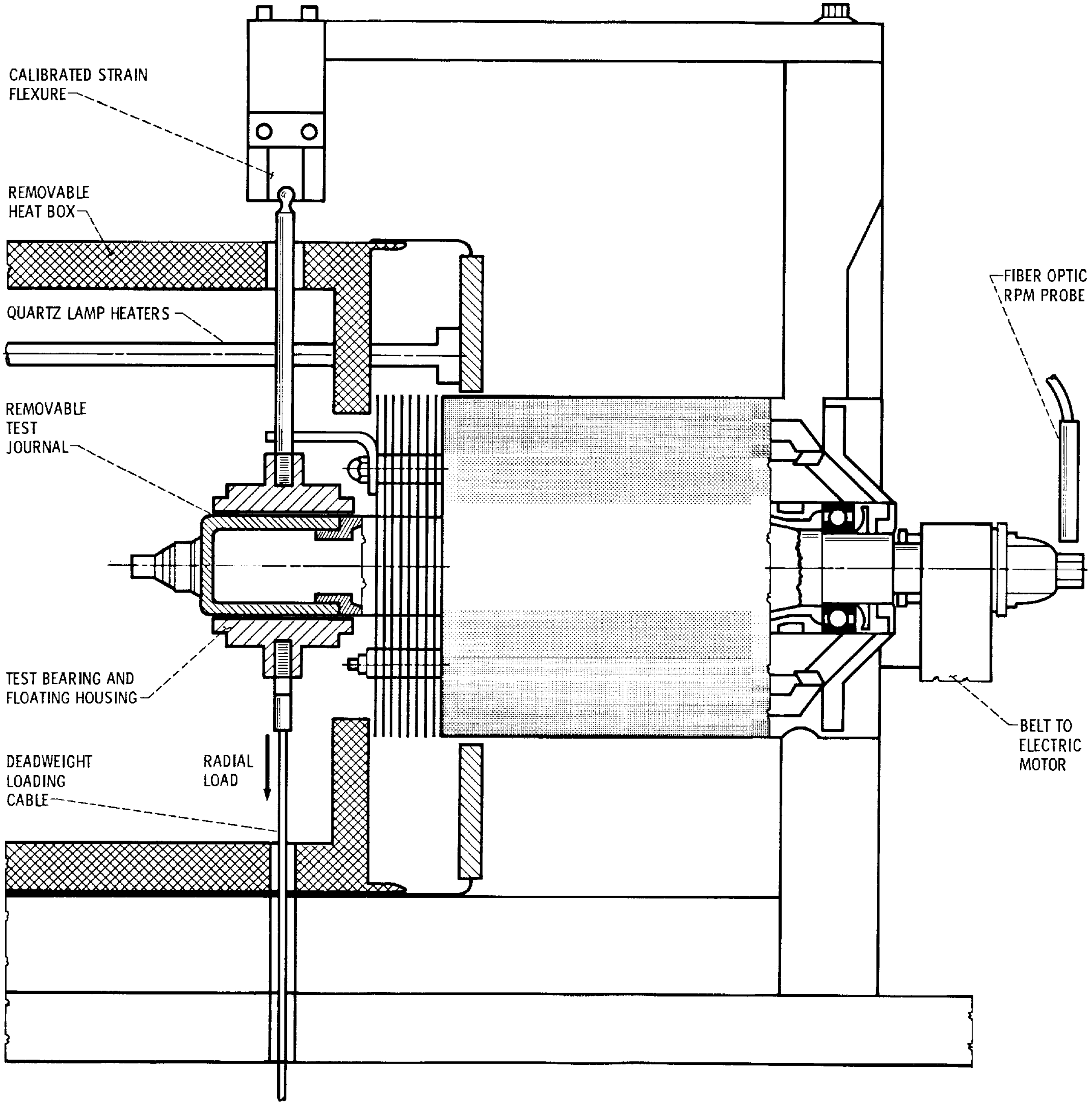


Figure 1. - Foil journal bearing materials test rig.

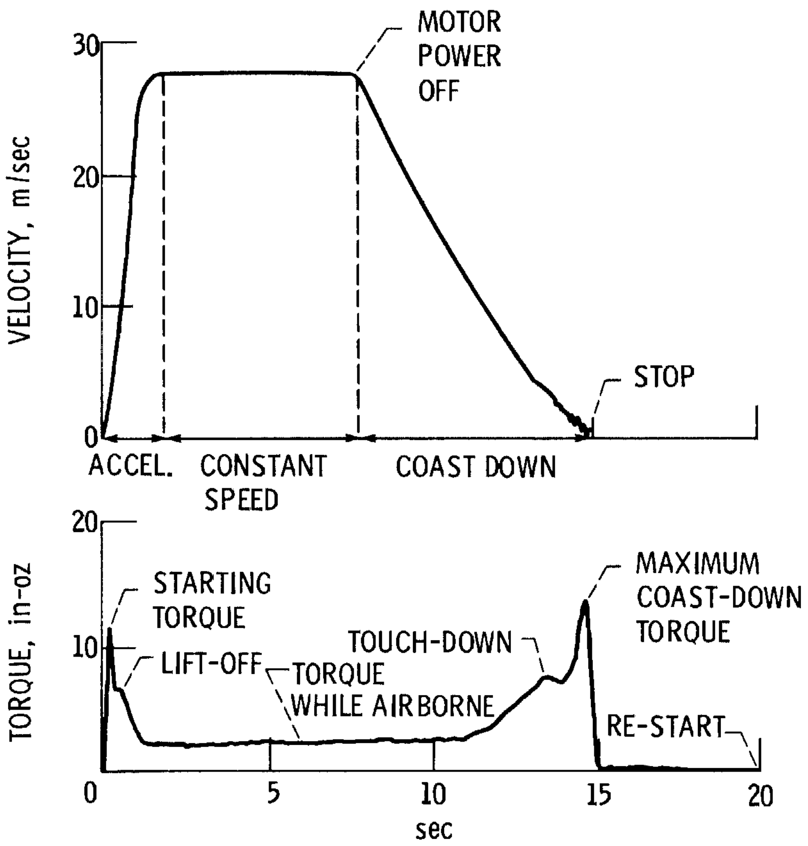


Figure 2. - Typical torque profile of a foil bearing during a single start/stop cycle.

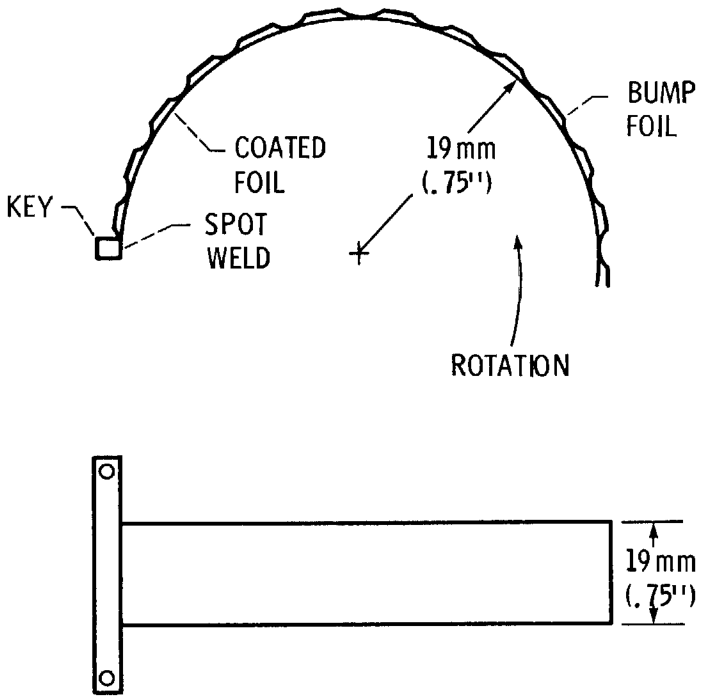


Figure 3. - Compliant foil gas test bearing for coating evaluations.

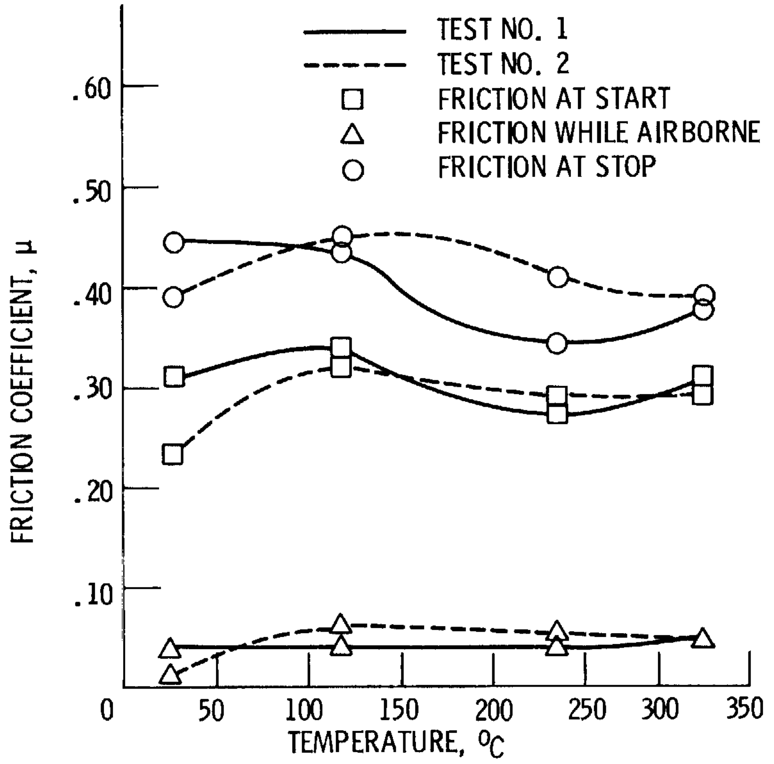


Figure 4. - Friction coefficient vs operating temperature for silicate bonded graphite/CdO coated foil bearing and A286 journal.

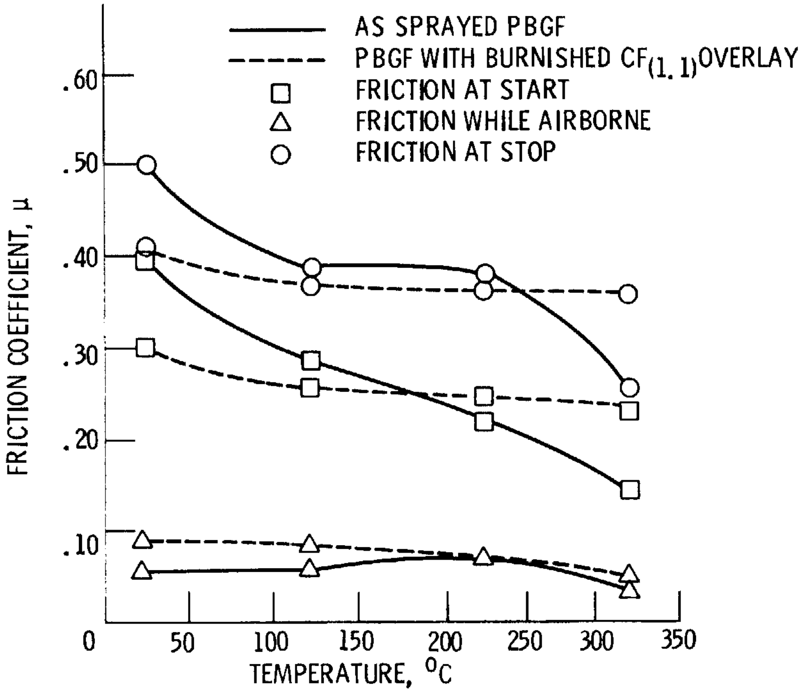


Figure 5. - Friction coefficient vs operating temperature for polyimide graphite fluoride coated foil bearing and A286 journal.

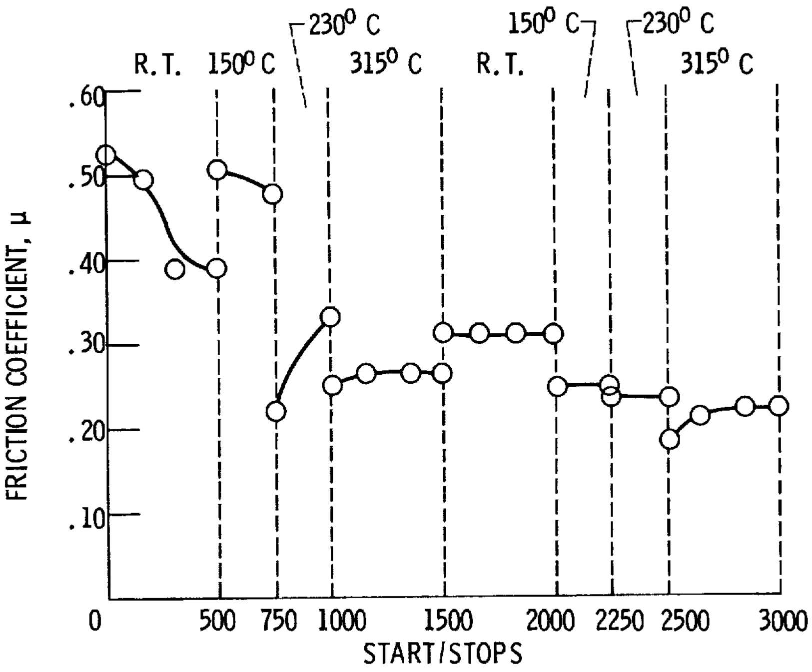
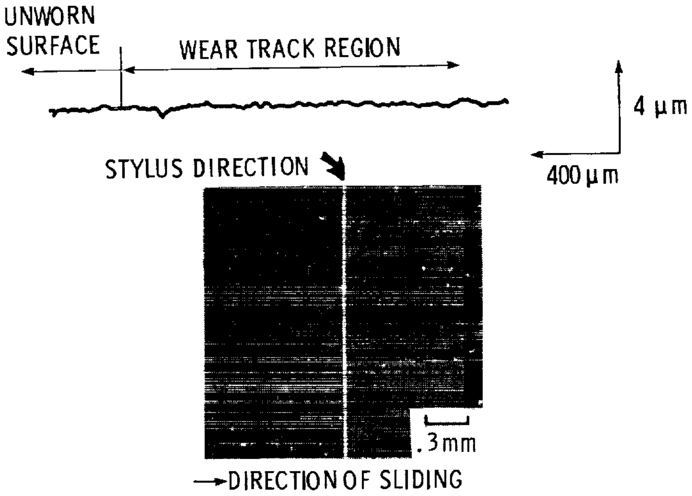
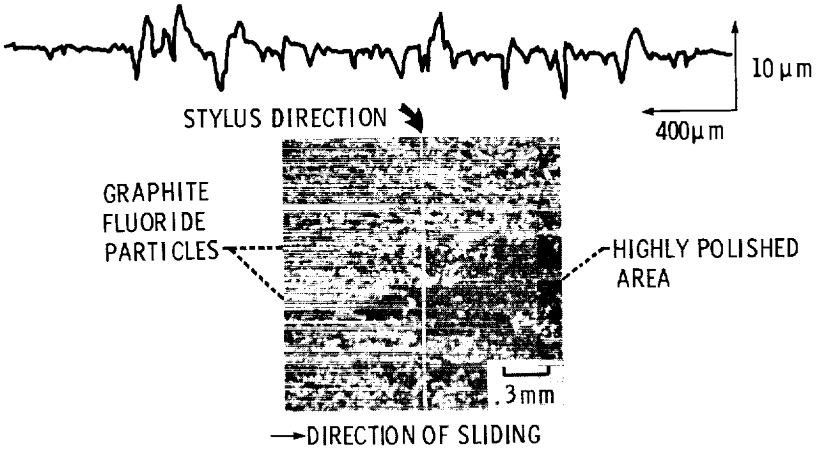


Figure 6. - Effect of run-in on starting friction for PBGF coated foil bearing.

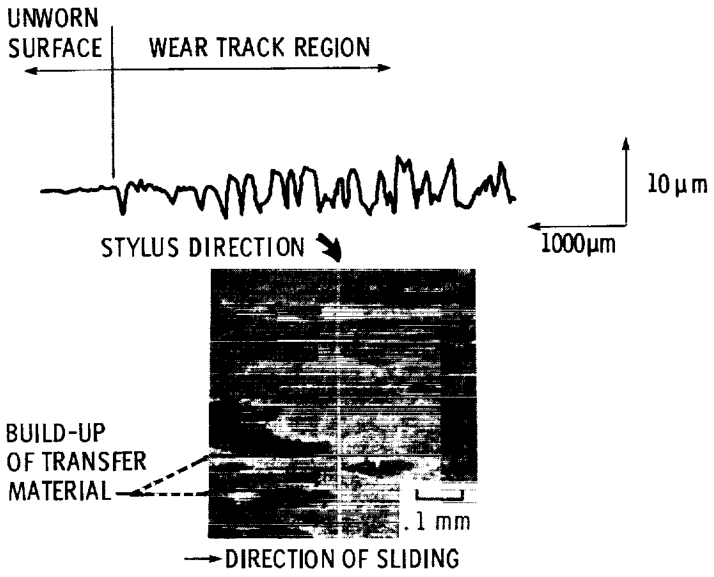


(a) Journal.

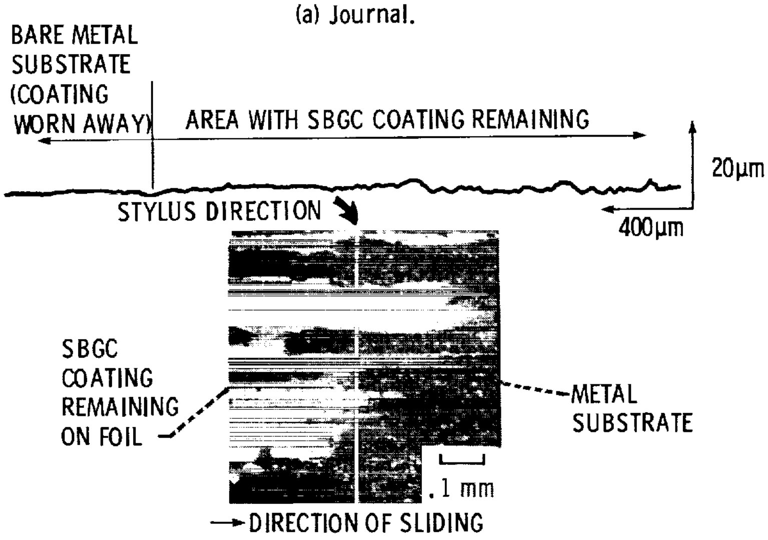


(b) Foil Bearing.

Figure 7. - Photomicrographs and surface profiles of specimens coated with polyimide bonded graphite fluoride after 9000 start/stop cycles. (Surface profiles are 90° to sliding direction.)



(a) Journal.



(b) Foil Bearing.

Figure 8. - Photomicrographs and surface profiles of specimens coated with silicate bonded graphite/cadmium oxide after 7500 start/stop cycles. (Surface profiles are 90^0 to sliding direction.)

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16. Abstract

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