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Evaluation of Temperature and Material Combinations on Several Lubricants for Use in the Geostationary Operational Environmental Satellite (GOES) Mission Filter Wheel Bearings

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ABSTRACT

A bearing test apparatus was used to investigate lubricant degradation rates and elastohydrodynamic transition temperatures for several perfluoropolyether (Krytox) formulations, a pentasilahydrocarbon, and a synthetic hydrocarbon (Pennzane 2001A) in a MPB 1219 bearing, which is used in the geostationary operational environmental satellite (GOES) mission filter wheel assembly. Test conditions were the following: 1000-hour duration, 75°C, 20 lb. axial load, vacuum level $<1x10^{-6}$ Torr, and a 600-RPM rotational speed. Baseline tests were performed using unformulated Krytox 143AB, the heritage lubricant. Krytox additive formulations showed small reductions in degradation rate. Krytox GPL-105, a higher viscosity version, yielded the least amount of degradation products. Both the silahydrocarbon and Pennzane 2001A showed no signs of lubricant degradation and had ample amounts of free oil at test conclusion.

INTRODUCTION

The Geostationary Operational Environmental Satellite (GOES) program is the key element in providing the United States with continuous and reliable weather data. The satellite operates in geosynchronous orbit and monitors the United States, Atlantic, Pacific, and Central and South America. The main instruments on the satellite are the Imager and the Sounder. The Imager provides data on radiant energy and reflected solar energy. The Sounder is used to measure vertical atmospheric temperature and moisture profiles, surface and cloud top temperature, and ozone distribution [1].

Space mechanisms use a variety of components that incorporate angular contact bearings, including the filter wheel assembly in the Sounder unit on the GOES spacecraft. Often, the only source of lubricant for the bearings comes from an impregnated cage and a few milligram charge loaded upon buildup [2].

The Sounder in the GOES satellite uses a filter wheel assembly to perform spectral analysis of light. The assembly consists of 18 filter windows arranged in three concentric rings on a 28.2 cm (11.1 in.) diameter disk. The wheel is rotated at a constant speed of 600 RPM. To ensure proper operation of the filter wheel assembly, wobble and jitter of the aluminum disk must be minimized and temperature maintained. The filter wheel has heaters and precision temperature control circuits that maintain the housing to within 1°C of the set temperature [1].

The wheel incorporates a duplex pair of angular contact bearings. The bearings are manufactured by Timken Aerospace Bearings (MPB) and are designated 1219. The bearings have an O.D. of 30.16 mm (1.1875 in.), a bore of 19.05 mm (0.75 in.), eighteen 3.175 mm (0.125 in.) TiC coated 440C balls, and a preload of 89 N (20 lb). The raceways are diamond polished and acid-passivated. The bearing uses a porous polyimide cage that is impregnated with approximately 130-mg of Krytox 143AB. An additional 20-mg charge of free oil is added at buildup. The design operating temperature was 8°C to 38°C. Under these conditions, the bearings will operate in the elastohydrodynamic lubrication (EHL) regime. The design life of the bearing pair is 7 years with an operational life of 5 years.

In past GOES missions, higher filter wheel temperatures have been observed. In GOES 8, the motor housing reached temperatures of 53°C every day and had reached a high of 59°C. This raised concerns about the possibility of a transition from EHL to boundary lubrication and also reduced filter wheel life due to lubricant evaporation.

A life test of filter wheel bearings was performed at ITT concurrently with the build up of the flight system. During these tests, the temperature was cycled between 18°C and 44°C and no significant problems or torque anomalies occurred. However, it should be noted that the temperature cycles were lower than seen in orbit. Efforts were made to induce torque anomalies, but were not successful. At the conclusion of the test, the bearings were disassembled and appeared in good condition with ample free oil.

Analysis of the test bearings was performed at Aerospace Corp [3]. The Aerospace results provided some evidence for evaporative loss of oil in the test bearings. This heightens concerns in flight bearings, because of the higher temperatures experienced in orbit.

These results also showed some lubricant degradation, but not an unusually high amount. Furthermore, concerns were raised about reactions of the lubricant with the TiC coated balls. Other observations showed extensive oil degradation when the TiC coated balls had become pitted and this was observed in the life test bearings. The final recommendations from Aerospace were to consider other, lower vapor pressure lubricants and a more benign surface chemistry [3].

In 1994, tests to study the effect of bearing temperature on film forming capabilities of Krytox 143AB were performed at NASA Glenn Research Center [4]. The facility used for these experiments is the same as described later in this paper. During these preliminary tests, the bearing was both hard and soft loaded and then heated to 85°C. These tests indicated a transition from the EHL regime to mixed lubrication began around 54°C, but the main transition occurred at about 70°C.

These short-term tests showed no signs of oil degradation, although much of the free oil was gone when the bearing was disassembled. The retainer had only lost about 1 mg of oil [4].

The purpose of the study reported here was to continue to examine the effects of temperature and materials on the degradation rate and EHL properties of Krytox 143AB, some additive formulations of Krytox 143AB, Krytox GPL-105 – a higher viscosity than 143AB, Pennzane 2001A, and a trisilahydrocarbon in MPB 1219 test bearings.

EXPERIMENTAL

MATERIALS

For this study, polyimide cages were used except for one baseline test, where a phenolic cage was employed. Polyimide was chosen because of its use in current space mechanisms. The raceways were 440C, and in one test the raceways were coated with a thin lead film. The balls were all 440C, with some tests using TiC coated 440C. Five lubricant/additive combinations were tested, Krytox 143AB, Krytox 143AB with a phosphine additive (MLO 89-184), Krytox TFL-9078 (143 AB with 2% of an anticorrosion additive), Krytox GPL-105 (a higher viscosity than Krytox 143AB), a pentasilahydrocarbon, and Pennzane 2001A (a multiply alkylated cyclopentane). Lubricant viscosities are listed in Table 1.

TABLE 1 – Viscosity properties of test lubricants

Lubricant	Viscosity at 40°C	Viscosity at 100°C
Krytox 143AB	85	10.3
Krytox GPL-105	160	18.0
Pentasilahydrocarbon	131	20.8
Pennzane 2001A	108	14.6

The lead coatings were used to try to provide a less reactive surface for the Krytox. Lead coatings may also provide the added benefit of lower friction through shear within the lead itself [5] in the event that the bearing enters the mixed or boundary lubrication regime. Lead coating may also offer the advantage of a smoother surface and therefore a lower composite surface roughness, yielding lower transition speeds to elastohydrodynamic film formation.

For all the tests either 440C or TiC coated 440C balls were used. The TiC coated balls provide the bearing with similar benefits as the lead coated raceways. The TiC provides a less reactive and smoother surface. The effects on life enhancement in boundary lubrication using TiC coated balls versus uncoated 440C balls with Krytox 143AC and Pennzane 2001A was examined by Jones et al. [6,7]. Depending on stress level, an enhancement in lifetime between two and four times was observed with Krytox 143AC, but no life enhancement was seen when using Pennzane 2001A.

APPARATUS

The apparatus used for these experiments was first introduced by Jones et al. [4] and is shown in Figure 1. The system is designed to operate at $<5x10^{-6}$ Torr and between temperatures of 20° to 100°C. The device has a computer data acquisition (DAQ) and control system based upon LabVIEW™. The DAQ monitors bearing temperature, torque, load, cross-bearing electrical resistance, and rotational speed. Motion is provided by a computer controlled stepper motor and ferrofluidic feedthrough. The system allows either a constant rotational speed between 0 and 1000 RPM or a precise dither at a desired angle. The rig uses a soft, dead weight loading system. A heating unit can maintain the bearing at a constant temperature between ambient and 100°C or impose a temperature ramp.

Cross-bearing electrical resistance is monitored throughout the test. The inner race is electrically isolated from the rest of the rig. The outer race is grounded. A 1.5-volt supply is provided at the inner race though a 1.5 KΩ resistor. The voltage at the inner race is measured to obtain the voltage drop across the bearing and the cross-bearing resistance can be calculated. Resistance data can be calculated from the voltage drop. From the resistance data, the lubrication regime can be determined. A low contact resistance indicates operation in the boundary or mixed regime. A high or infinite resistance indicates either operation in the EHL regime or the build up of an electrically insulating friction polymer [8].

The system uses a single MPB 1219 angular contact bearing. It is mounted within a fixture, also shown in Figure 1, that holds the inner race fixed and rotates the outer race. A thermocouple is mounted touching the inner race and measures bearing temperature. Heat is provided by a band heater that encompasses the housing. Torque is monitored using an in-line torque meter.

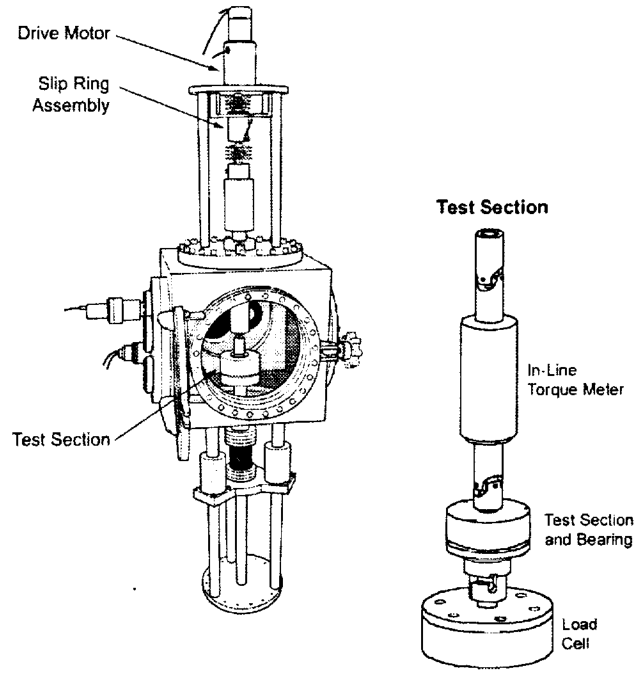

Figure 1 – Vacuum bearing rig facility and bearing fixture

TEST PROCEDURE

Before each test, a new bearing was prepared. The bearing was received unlubricated. First, it was separated and the cage was cleaned for five days in hexane using a soxhlet extractor. It was then dried in a vacuum oven at 100°C for 1 day. Then, the cage was allowed to cool under vacuum, removed, weighed, and immediately placed in the desired lubricant. In vacuum, the cage was soaked in lubricant for three days at 100°C, removed, excess oil wiped off, and reweighed. The difference in the weights was recorded as the retainer weight uptake.

The balls and raceways were cleaned using a solvent/ UV ozone process. The parts were first ultrasonically rinsed for ten minutes in the following solvents respectively: hexane, methanol, and distilled water. They were removed, rinsed with methanol, and dried with nitrogen. Then, they were placed in an UV ozone box for a total of fifteen minutes. The parts were rotated every five minutes to ensure that all surfaces were treated.

The bearing was reassembled and weighed. A syringe was used to inject several small drops of lubricant into the bearing. The bearing was rotated and reweighed. The weight change is termed the lubricant uptake. The target lubricant uptake was 20 mg.

Once the bearing was assembled, it was mounted into the system and an 89 N load was applied. This load corresponds to an approximate maximum Hertzian stress of 1.0 GPa at the ball/race contact. The chamber was evacuated. When the pressure dropped below $5x10^{-6}$ Torr, the test started. The bearing was spun at 600 RPM.

The bearing was run for twenty-four hours to achieve steady state operating conditions. The heater was then turned on and the bearing temperature raised to 75°C. During this time, the resistance was monitored to study the transition temperature between EHL and boundary/mixed lubrication. The bearing was run at these conditions for 1,000 hours and then the heater turned off. The bearing was allowed to reach steady state conditions and then the test was terminated.

Upon conclusion of the test, the bearing was reweighed. It was then disassembled and the retainer was also

TABLE 2 – Tested bearing materials and lubricant charges

#	Lubricant	Ball Material	Race Material	Cage Material	Retainer Lube Uptake (mg)	Bearing Lube Free Oil (mg)
1	Krytox 143AB	440C	440C	Phenolic	49	25.4
2	Krytox 143AB	TiC Coated 440C	440C	Polyimide	151	21.1
3	Krytox 143AB	TiC Coated 440C	Lead Coated 440C	Polyimide	114	18.3
4	Krytox 143AB + MLO89184	440C	440C	Polyimide	189	1.9
5	Krytox GPL-105	440C	440C	Polyimide	177	17.6
6	Krytox formulation TFL-9078	440C	440C	Polyimide	168	18.8
7	Pentasilahydrocarbon	440C	440C	Polyimide	81	18.6
8	Pennzane 2001A	440C	440C	Polyimide	70	8.3

reweighed. The bearing was then photographed and IR spectra taken to document the amount of degradation products present on the retainer, raceways, and balls.

A variety of material and lubricant combinations were tested and are listed in Table 2. After the test, the bearing was re-weighed, disassembled, and the retainer re-weighed. The total weight loss, retainer weight loss, and difference between them are listed in Table 3.

TABLE 3 – Lubricant weight loss

#	Total Loss (mg)	Retainer Loss (mg)	Difference (mg)
1	41.7	20.0	21.7
2	N/A	49.5	N/A
3	43.6	22.1	21.5
4	70.7	67.4	3.23
5	18.6	9.34	9.22
6	80.9	65.6	15.3
7	9.2	N/A	N/A
8	66.1	N/A	N/A

RESULTS

All of the bearings lubricated with Krytox had a black residue on at least some their components. The retainers also appeared to be dry and no free oil could be seen in the bearing or on the balls.

Bearing 1 (440C balls/phenolic cage) showed moderate amounts of degradation products on all of the components. The insides of the retainer pockets showed the heaviest buildup of residue. The balls had a dull finish and black residue is evenly spread across the surface. In the groves of the raceways, a similar appearance was observed. All of the parts looked dry.

Bearing 2 (TiC coated balls/polyimide cage) had a similar appearance to bearing 1, except the balls were shiny with very little black residue on them. The retainer also had a greater buildup of residue outside of the ball pockets than the bearing 1 retainer. Again, all of the parts looked dry.

Bearing 3 (TiC coated balls/Pb coated raceways) had approximately half the amount of residue on all of the parts except the balls. The amount of residue on the balls was not even, ranging from being completely covered in residue to barely a trace. No free oil was observed in the bearing and the retainer also appears dry.

Bearing 4 (Krytox 143AB + a phosphine additive) had little residue on the raceways. All of the balls were dull and covered with the residue. The retainer had a moderate amount of buildup inside the ball pockets and a fair amount of residue around the outside. The bearing was dry.

Bearing 5 (higher viscosity Krytox fluid) was the most pristine of the bearings that used Krytox based lubrication. The only sign of residue was a slight band on the groove of the inner race. All of the other parts looked as they had upon buildup. However, no free oil was in the bearing and the retainer looked dry upon conclusion of the test.

Bearing 6 (Krytox 143AB + 2% anticorrosion additive) showed residue on the insides of all of the ball pockets. The balls themselves were blackened, having more residue on them than any other part from any other bearing in this test. The raceways were free of residue and looked pristine. No free oil was observed in the bearing.

Upon teardown, bearing 7 (Pentasilahydrocarbon) looked as it had upon buildup. No signs of degradation products were observed and there was ample free oil in the bearing and on the balls. The retainer still had a 'wet' appearance, and even had a pool of oil near the ball pockets.

Bearing 8 (Pennzane 2001A) exhibited the same appearance and residual oil as bearing 7. The amount of degradation products on each bearing is summarized in Table 4.

TABLE 4 – Amount of degradation products found on each part of bearing

#	Outer Race	Inner Race	Retainer	Balls
1	Moderate	Moderate	Moderate	Moderate
2	Moderate	Moderate	Moderate	Light
3	Light	Light	Light	Moderate
4	Light	Light	Moderate	Moderate
5	None	Light	None	None
6	None	None	Light	Heavy
7	None	None	None	None
8	None	None	None	None

DISCUSSION

Transition from elastohydrodynamic to mixed lubrication occurred at approximately 70°C with Krytox 143AB, which correlates well with previous results [4].

A reduction in the amount of degradation products was evident in the bearing with the lead-coated raceways when compared to the uncoated raceways. The reduction is attributed to the lower surface roughness, allowing for easier EHD film formation, and reduced reactivity between the Krytox and lead.

Also, using the increased viscosity Krytox GPL-105 reduced the amount of degradation products formed compared with the Krytox 143AB and is most likely due to the increased EHD film thickness. For these tests, uncoated 440C balls and races were used with the GPL-105, but it is expected that the same benefits that were observed using coated balls and raceways with the 143AB would be observed with the GPL-105.

Both additive formulations of Krytox exhibited a reduced amount of degradation products on the raceways, but a much greater amount on the balls themselves.

The bearings lubricated with the pentasilahydrocarbon and Pennzane 2001A fared the best. Neither showed any indication of lubricant degradation and had visible amounts of free oil remaining after the test. These tests were also conducted using non-coated parts. Replacing the balls with TiC-coated 440C balls and/or coating the raceways would lower the composite surface roughness and allow for even better EHD operation at lower speeds and higher temperatures. Lead coated raceways also provide a protective layer in case of asperity contact through the EHD film.

CONCLUSIONS

The silahydrocarbon and Pennzane 2001A exhibited the best behavior during these short-term, high temperature tests and should be considered for longer-term tests. Also, a higher viscosity Krytox fluid exhibited a clear improvement over the currently used Krytox and should be considered as an alternative to the current system. TiC coated balls and lead coated raceways also resulted in improved bearing appearance using Krytox based lubricants through reduced composite surface roughness and reduced chemical reactivity between the surface and the lubricant. The lead coating also provides lubrication during asperity contacts.

REFERENCES

1. "GOES I-M DataBook," Loral Space Systems, Ref #S–415–19, August 1996.
2. Jones, W.R., Jr., Jansen, M.J., "Space Tribology," Chpt 31 from Modern Tribology Handbook, pp. 1159–1181, CRC Press, New York, 2001.
3. Didziulis, S.V., Carré, D.J., Radhakrishnan, G., "Analyses of Lubricant and Ball Bearing Samples from the NASA/GOES Filter Wheel Life Test," Aerospace Report ATR–99(2160)–4, Sept. 30, 1999.
4. Jansen, M.J., Jones, W.R., Jr., Pepper, S.V., Predmore, R.E., Shogrin, B.A., "EHL Transition Temperature Measurements on a Geostationary Operational Environmental Satellite (GOES) Filter Wheel Bearing," NASA/TM—2001-210670, January 2001.
5. Conley, P. Space Vehicle Mechanisms, John Wiley & Sons, Inc., 1998.
6. Jones, W.R., Pepper, S.V., Jansen, M.J., Nguyen, Q.N., Wheeler, D.R., Schröer, "The Effect of Stress and TiC Coated Balls on Lifetime of a Perfluoropolyalkylether Using A Vacuum Rolling Contact Tribometer," NASA/TM—2000-209925, March 2000.
7. Jansen, M.J., Jones, W.R., Jr., Pepper, S.V., Wheeler, D.R., Flühmann, F., Schröer, A., Loewenthal, S.H., Shogrin, B.A., "The Effect of TiC Coated Balls and Stress on the Lubricated Lifetime of a Synthetic Hydrocarbon (Pennzane 2001A) Using a Vacuum Spiral Orbit Tribometer," NASA/TM—2000-210525, October 2000.
8. Konchits, V.V., Myshkin, N.K., "Evaluation of the Interface at Boundary Lubrication Using the Measurement of Electric Conductivity," *Wear*, 172, 29–40, 1994.
9. Jones, W.R., Jr., Pepper, S.V., Herrera-Fierro, P., Feuchter, D., Toddy, T.J., Jayne, D.T., Wheeler, D.R., Able, P.B., Kingsbury, E., Morales, W., Jansen, R.H., Ebihara, B., Helmick, L.S., Masuko, M., "The Preliminary Evaluation of Liquid Lubricants for Space Applications by Vacuum Tribometry," Proc. from the 28th Aerospace Mech. Symp., Cleveland, Ohio, May 19–20, 1994.

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