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Analysis of a Spacecraft Instrument Ball Bearing Assembly Lubricated by a Perfluoroalkylether

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ANALYSIS OF A SPACECRAFT INSTRUMENT BALL BEARING ASSEMBLY LUBRICATED BY A PERFLUOROALKYLETHER

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SUMMARY

An analysis of a spacecraft instrument ball bearing assembly, subjected to a scanning life test, was performed to determine the possible cause of rotational problems involving these units aboard several satellites. The analysis indicated an ineffective transfer of a fluorinated liquid lubricant from a phenolic retainer to the bearing balls. Part of the analysis led to a novel HPLC separation method employing a fluorinated mobile phase in conjunction with silica based size exclusion columns.

INTRODUCTION

Perfluoroalkylethers are a relatively new generation of fluids which possess special properties that make them a promising class of liquid lubricants for use in advanced aircraft and spacecraft. Advanced aircraft will require lubricants and hydraulic fluids with high thermal and oxidative stability, and maximum fluid temperature in excess of 316 °C have been estimated for future applications (refs. 1 to 4). Spacecraft will require lubricants with very low vapor pressure to minimize evaporation and prevent system contamination.

One particular perfluoroalkylether fluid, Flombin Z25, exhibits the following properties (see table 1): excellent thermal stability, a very low pour point and low volatility, good boundary lubricating ability, chemical inertness, nonflammability properties, and high radiation resistance.

Because of its extremely low vapor pressure (6×10^{-13} torr at 20 °C) this fluid was selected to lubricate some scanning instrument ball bearing assemblies aboard several satellites. These instruments, mounted on a ball bearing assembly, are rotated by a motor such that the instruments slowly scan back and forth.

However, problems involving these ball bearing assemblies have recently surfaced. After several months in orbit, a motor torque increase was detected on several of the units, suggesting an impediment to the free rotation of the instruments. On one occasion the rotation of an instrument stopped completely. A scanning life ground test was conducted on a similar ball bearing assembly to determine the probable cause of the motor torque increase.

A two part analysis was performed; compound identification of the material on the phenolic retainer and the balls, and a surface elemental analysis of the outer race.

APPARATUS

Compound identification was performed using an HPLC apparatus combined with an ultraviolet (UV) absorbance detector and a differential refractive index (RI) detector. The UV detector monitors the absorbance at a wavelength of 254 nm at sensitivities ranging from 0.005 to 2.000 absorbance units full scale (AUFS). The refractometer is sensitive to all compounds that differ in refractive index from the mobile phase. It will detect changes in the RI as small as 10^{-7} units throughout the RI range of 1.00 to 1.75. Two silica based size exclusion columns, connected in series, were used with this apparatus. Analysis of the outer race surface was performed using a scanning electron microscope equipped with an energy dispersive x-ray attachment (EDX).

DEVELOPMENT OF AN HPLC SEPARATION TECHNIQUE

The ball bearing assembly used aboard the satellites and in the life test consisted of an inner and outer race, and 34 balls made from 440C stainless steel. A porous phenolic retainer, situated between the races and accommodating the ball bearings was saturated with the perfluoroalkylether liquid lubricant. The phenolic retainer was the only source of liquid lubricant for the bearings. Both the races and the balls were passivated (by Federal Specification QQ-P-35B) and chemically treated with tricresylphosphate (TCP).

The life test was conducted at room temperature under a vacuum of 10^{-3} torr. The ball bearing unit had an axial preload of 89N (20 lb) and rotated at 1 revolution per second. Duration of the test was 8.5 million cycles. At the conclusion of the life test, the ball bearing unit was disassembled for analysis.

Part of the analysis consisted of detection of the perfluoroalkylether in the phenolic retainer and on the balls by HPLC. This analysis was to have been performed by extracting the perfluoroalkylether from the phenolic retainer and the balls with chloroform, and analyzing the resulting solution using HPLC in the size exclusion mode utilizing Styragel based columns. Earlier work revealed that chloroform dissolves a variety fluorinated substances including the lower molecular weight Krytox 143 fluorinated oils, and partially dissolving the higher molecular weight Krytox 143 fluorinated oils. However, solubility testing revealed that the perfluoroalkylether fluid was completely insoluble not only in chloroform but in all the other common HPLC solvents (tetrahydrofuran, methylene chloride and acetonitrile). It was learned that the only solvent capable of dissolving this fluid and suitable for use as a HPLC mobile phase, was 1,1,2-trichlorotrifluoroethane, henceforth referred to as the fluorinated solvent.

Another problem arose when experimentation revealed that the fluorinated solvent swelled the size exclusion column Styragel packing, rendering the column useless. Other modes of separation, using different columns were tried, and all were found to yield an unsatisfactory separation of the perfluoroalkylether from other fluorocarbons. At this point, a silica based size exclusion column (originally developed for the separation of aqueous polymers) was tried and resulted in separation of a variety of fluorocarbons including the perfluoroalkylether.

Figure 1 is a chromatogram of the size exclusion separation of a solution, consisting of several fluorinated substances dissolved in the fluorinated solvent, illustrating the successful application of this HPLC method. As is typical of size exclusion separations, the higher molecular weight substances elute first followed by the lower molecular weight materials; for this separation the perfluoroalkylether, having an average molecular weight of 9,500, eluted first with a retention time of 9.40 minutes. Fluorobenzene (molecular weight of 96) eluted last with a retention time of 16.80 minutes

Figure 2 relates the molecular weight of a substance to its retention time. This chart was constructed by measuring the retention times of a series of fluorocarbons having widely different molecular weights and plotting the log of the molecular weights as a function of the corresponding retention times. A linear least squares regression program was used to fit the data with a straight line. A correlation coefficient of 0.9877 was calculated.

EXPERIMENTAL PROCEDURE

The phenolic retainer was soaked, for 15 min, in 4 ml of the fluorinated solvent, and then 30 μl of the solution was analyzed by HPLC. The same procedure was repeated for the ball bearings. The HPLC mobile phase flow rate was 0.4 ml/min.

The outer race of the disassembled ball bearing unit had small amounts of a deposit which were located in one area of the race. An EDX analysis was performed on an area of the outer race devoid of the deposit, and on the deposit itself.

RESULTS AND DISCUSSION

HPLC Analysis

Figure 3 is the size exclusion chromatogram of the perfluoroalkylether liquid lubricant used aboard several satellites. Its retention time is 9.40 min. Figure 4 is the chromatogram of the phenolic retainer solution which shows a peak at 9.40 min. Thus, the fluorinated solvent was able to extract the perfluoroalkylether from the retainer. The chromatogram of the ball bearing solution, figure 5, showed no peak detection.

EDX Analysis

The EDX analysis of the outer race (devoid of deposit) figure 6, revealed nothing unusual - chromium, a small amount of carbon and a balance of iron. The EDX analysis of the deposit, figure 7, however, revealed amounts of carbon and oxygen, but no fluorine.

The evaluation indicates ineffective transfer of the lubricant from the phenolic retainer to the ball bearings. Initial lubrication between the ball bearings and the races would probably be due to the TCP treatment. Under the high vacuum conditions of outer space, once the metal oxide or phosphate film wear away there is no oxygen or water vapor to react with the nascent metal surfaces to reform a protective film.

This analysis was complicated by the low vacuum (10^{-3} torr) which was used in the scanner life test. Since no fluorine was detected in the deposit, the possibility exists the outer race could have resulted from an oxygen reaction at the wearing surfaces.

CONCLUSIONS

Analysis of a spacecraft instrument ball bearing unit by high pressure liquid chromatography and energy dispersive x-ray analysis (EDX) subjected to a scanning life test, revealed an ineffective transfer of lubricant from a phenolic retainer to the ball bearings. This information helped to explain why several ball bearing assemblies, aboard satellites, have developed rotational problems.

Analysis of the liquid lubricant, a perfluoroalkylether fluid, led to a novel HPLC size exclusion method, that was capable of separating not only the perfluoroalkylether but a variety of other fluorocarbons as well. This method consisted of using 1,1,2-trichlorotrifluoroethane as a mobile phase in conjunction with silica based size exclusion columns.

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TABLE I. - THE PERFLUOROALKYLETHER PROPERTIES

Property	Test procedure	Typical value
Specific gravity	Mohr Westphal	1.8430 (20 °C)
Pour point	ASTM 97/66	-6 °C
Vapor pressure	Knudsen	6×10^{-3} torr (20 °C)
Kinematic viscosity	ASTM 445	250 cSt (20 °C)
Kinematic viscosity	ASTM 445	45 cSt (99 °C)
Viscosity index	ASTM 2270	345
Surface tension	Du Nouy	25 dynes/cm (20 °C)
Evaporation rate	ASTM 972	0.1 percent (149 °C)
Average MW	Viscometric	9 500

	Size exclusion separation	Retention time, min
1	Fomblin Z25, MW 9500	9.40
2	DuPont E-11, MW not available	12.26
3	DuPont E-1, MW not available	13.74
4	Unknown	-----
5	Hexafluorobenzene, MW 186	14.60
6	Fluorobenzene, MW 96	16.80

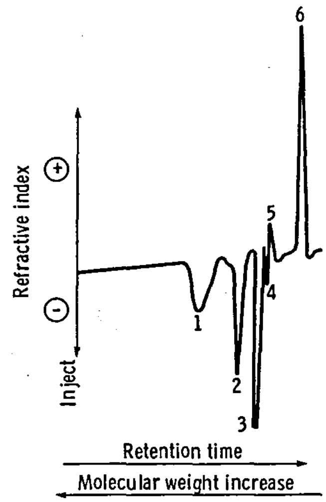

Figure 1. - Size exclusion separation of fluorocarbon substances.

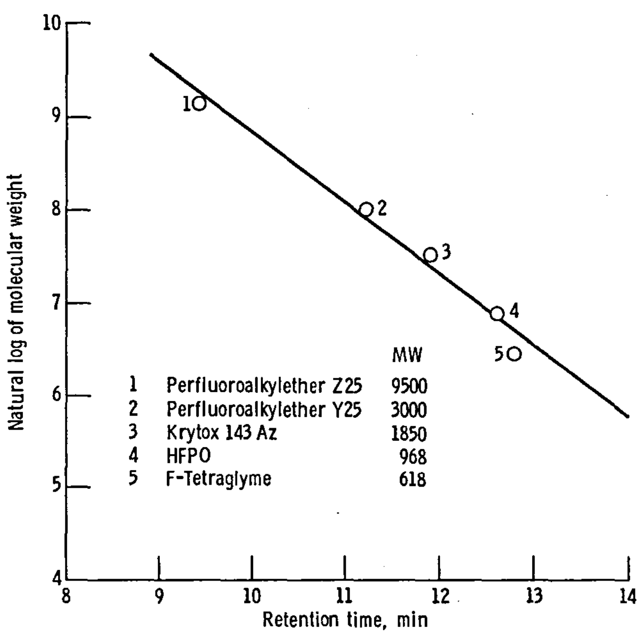

Figure 2. - Molecular weight distribution chart.

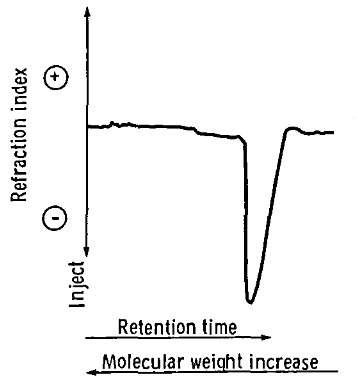

Figure 3. - Size exclusion separation of spacecraft liquid lubricant; retention time, 9.40 minutes.

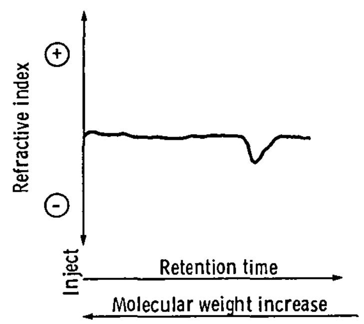

Figure 4. - Size exclusion separation of the phenolic retainer extract; retention time, 9.40 minutes.

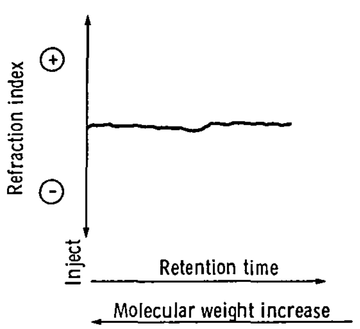

Figure 5. - Size exclusion separation of the ball bearing extract.

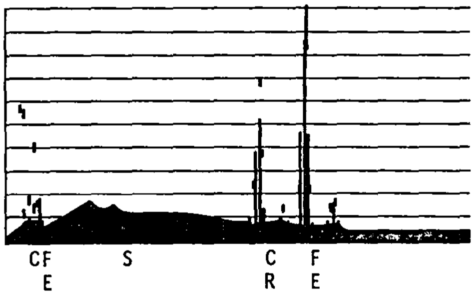

Figure 6. - EDX analysis of outer race.

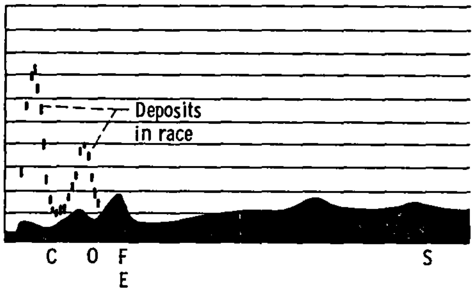

Figure 7. - EDX analysis of deposit.

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16. Abstract

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