

EFFECT OF TEST ENVIRONMENT ON LIFETIME OF A VACUUM LUBRICANT (Extended Abstract)

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ABSTRACT

The relative destruction rate of Krytox 143AC molecules subjected to rolling contact with 440C steel has been evaluated as a function of test environment. The rates in ultrahigh vacuum, 1.6 Torr oxygen and 760 Torr dry nitrogen were about the same. However, water vapor in the test environment – a few ppm in 760 Torr nitrogen – reduced the destruction rate by up to an order of magnitude.

1. INTRODUCTION

The liquid lubricant of a bearing system operating in the starved or boundary lubrication regime is subject to tribochemical degradation that can deplete the lubricant supply and cause bearing failure. The destruction rate of the lubricant molecules is a function of both lubricant and substrate chemistry. It can also depend on the test environment. In this paper, the relative destruction rates of Krytox 143AC™, a popular perfluoropolyether (PFPE) vacuum lubricant, in rolling contact with 440C stainless steel are studied for test environments of ultrahigh vacuum (UHV), dry oxygen, dry nitrogen, nitrogen containing water vapor and pure water vapor. The destruction rate is expressed as the lifetime of a finite charge of lubricant in a test.

2. EXPERIMENTAL

The test instrument is a Spiral Orbit Tribometer (SOT), a retainerless thrust bearing with one ball and flat races whose kinematics have been described [1]. The SOT was used to observe the tribochemical destruction of lubricants in vacuum [2]. The stainless steel, conflat-flanged test chamber could be evacuated to $<1 \times 10^{-8}$ Torr with a turbomolecular vacuum pump. A gate valve between the test chamber and the turbopump could be closed to permit the evacuated chamber to be back-filled with a particular gas. The nitrogen and oxygen supply bottles were specified to have a water vapor content of < 1 ppm and these gasses were admitted into the test chamber through an evacuated and baked stainless steel transfer line and a variable leak valve. Pure water vapor was admitted into the test chamber through a variable leak valve from a water supply that had been thoroughly degassed by the freeze-pump-thaw method. Water vapor concentration in the test environment was determined

with a thin film hygrometer (Kahn Cermet II) inserted directly into the test chamber. The hygrometer's readout in dewpoint temperature, T_d , could be converted to either partial pressure of water vapor in millitorr or concentration of water vapor in ppm through the Magnus formula. Test chamber total pressure P was determined by a cold cathode ionization gauge for $P < 8 \times 10^{-3}$ Torr, a Pirani gauge for 8×10^{-3} Torr $\leq P \leq 2$ Torr and a diaphragm gauge for $P > 2$ Torr. A lubricant charge of $\sim 25 \mu\text{g}$ was deposited on a ball from a gas-tight syringe containing a dilute solution of the lubricant. All tests were run at a Hertz pressure of 1.5 GPa and a ball orbit rate of 30 rpm. Tests with these small lubricant charges result in "friction traces" such as the one illustrated below, where the coefficient of friction for a given ball orbit, CoF, is plotted against ball orbit number.

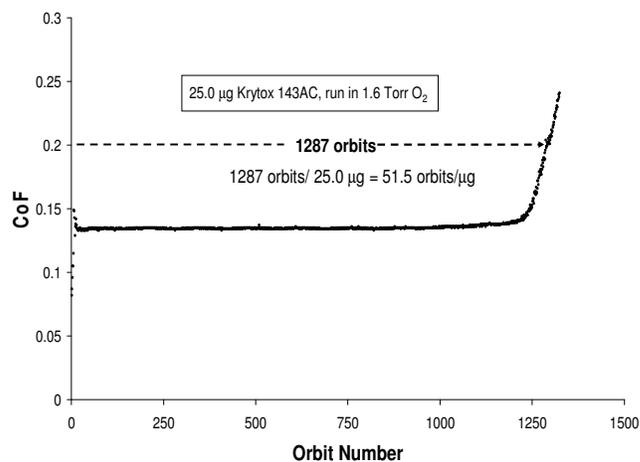


Figure 1. Typical friction trace in SOT tests

The trace exhibits constant $\text{CoF} = 0.134$ until an abrupt increase at ~ 1230 orbits. $\text{CoF} = 0.2$ is considered here as the point at which the lubricant is totally consumed and is taken as the criterion of failure. In this test, this corresponds to 1287 orbits and a lifetime normalized to the initial $25 \mu\text{g}$ lubricant charge is obtained as 51.5 orbits/ μg . Normalized lifetimes (inversely proportional to the molecular destruction rate) obtained in this manner were obtained for all tests reported here.

3. RESULTS

The results of four tests run in each of the five specified environments are presented in Figure 2. The shortest lifetimes are exhibited by tests run in UHV. The longest lifetimes are observed by running in the presence of water vapor. Only a few ppm water vapor in an atmosphere of nitrogen is sufficient to extend the lifetime by an order of magnitude relative to testing in UHV. Pure water vapor itself, without its being present in nitrogen gas, also leads to lifetimes much longer than testing in UHV. In contrast to the effect of water vapor, testing in one atmosphere of dry nitrogen has only a small lifetime-enhancing effect, and even this small effect may be due to trace amounts of water vapor below the level detectable by the hygrometer. Testing in 1.6 Torr dry oxygen, corresponding to $\sim 0.2\%$ trace contamination of oxygen in a nitrogen supply, also has little effect on lifetime.

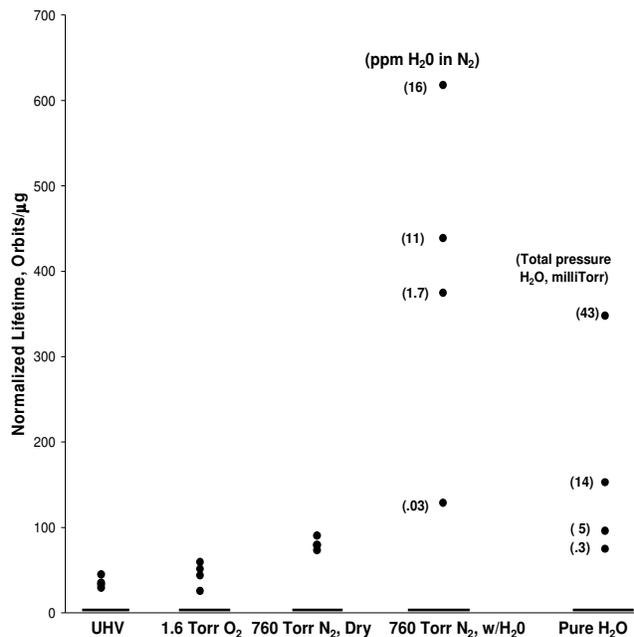


Figure 2. Lifetimes when testing in different environments

The results presented here indicate that water vapor in the test environment exercises a “protective” effect, permitting a longer life of the bearing before failure.

4. DISCUSSION

The first comment concerns an apparent quantitative inconsistency between the effect of pure water vapor and the effect of water vapor present in nitrogen. A partial pressure of 43 milliTorr in nitrogen corresponds to a concentration of ~ 57 ppm. Yet, the lifetime running in an *absolute* pressure of 43 milliTorr is *less* than the lifetime running in 16 ppm in nitrogen.

There thus may be a mechanism enabling water vapor to be more effective within a matrix of a background gas (nitrogen in this case) than by itself alone.

The null result of running in 1.6 Torr oxygen certainly establishes that such trace amounts of oxygen in nitrogen cannot be responsible for protecting the PFPE lubricant against tribochemical attack. This result also relates to a current idea that tribological stress exposes clean metal by removing the native oxide, allowing the clean metal to play a principal role in initiating tribochemical attack on the lubricant. However, such clean metal would be immediately oxidized by exposure to 1.6 Torr oxygen and quench any tribochemical attack by clean metal. Since there is no effect of running in 1.6 Torr oxygen, it is concluded that this “exposure” mechanism is not operative here and that the ball is probably rolling on the native oxide of the steel throughout the test.

Testing in a full atmosphere of dry nitrogen raises the question of the possible role of a kinetic knock-on effect by incoming atoms of the cover gas. Although such chemically neutral arrivals may conceivably affect the chemical reactions of the tribochemical process, the lack of a significant effect on either the CoF or the lifetime indicates that such concerns are not warranted.

There are two approaches that may be considered in understanding the mechanism by which water vapor retards tribochemical degradation. The first is that of specific chemistry, in which water vapor plays a direct role in the chain of chemical reactions proposed, for example, by Carré and coworkers [3]. The second approach is that of physical adsorption, in which water vapor adsorbs on either the bearing surface or the lubricant and simply physically separates these reactants. Physical adsorption of water is, of course, well known [4]. The purely tribological results presented here do not indicate a preference for either approach. Thus the responsible mechanism remains a matter for further study.

This lubricant/substrate combination is a popular choice for bearings in spacecraft mechanisms. The implication of these results for testing of space mechanisms is two-fold: first, testing in a nitrogen environment to simulate vacuum is permissible in the absence of water vapor and second, the local environment of the mechanism may contain water vapor contributed by its surroundings that can greatly extend its lifetime beyond that observed in a test environment that was free of water vapor.

ACKNOWLEDGMENTS

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