THE PERFORMANCE OF EXPERIMENTAL GEAR OIL CONTAINING MOLYBDENUM DISULFIDE

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Abstract. *This experimental gear oil has been developed with Molybdenum Disulfide. Sliding and surface fatigue tests were performed to compare this product with commercial oil. The friction power and temperature were measured for sliding test and mean life, for fatigue test, using a Four Ball Machine. The Loads and velocities used in these tests were 80 kgf and 1200 rpm, for total sliding condition; 600 kgf and 3000 rpm, for contact fatigue condition. The sliding wear results showed that the wear and friction of this high performance lubricant lowered when compared with commercial oil. Reductions of 6.5ºC and 30 % of friction power were achieved, when the gear oil containing molybdenum disulfide was evaluated. Furthermore, the mean life for contact fatigue was 382 minutes for the new gear oil, thirteen times higher than that obtained with the simple oil. These results showed that, in a mechanic system, the lubricants can contribute significantly to save energy and increase the mean life of the parts and that molybdenum disulfide is an excellent boundary lubricant additive.*

Keywords: Gear Oil, Molybdenum Disulfide, Friction, Fatigue Contact, Reliability.

1. Introduction

The recent technological progress enables mechanical systems to work on conditions in which better contact mechanisms are necessary to operate, and thus require special lubricants for their successful operation.

In order to achieve high reliability and better performance for the new machines, solid lubricants have been used to improve additional functions, to act as supplementary additives. The typical solid lubricants are PTFE, graphite and molybdenum disulfide (Rapoport *et al*., 1999; Rapoport *et al*, 2003; Ruediger and Jungk, 2000; Campbel, 1973). Therefore, other solid compounds have been used with the same goal, like W_2S, BN and nanocopper powder (Tarasov *et al*).

Enclosed gear drives operate in three different regimes of lubrication: full fluid film, mixed film and boundary lubrication (Ludwig, 2004). At high loads and low speeds, the regimes of lubrication predominant are mixed and boundary conditions and the gear lubricants need to be prepared with extreme pressure additives containing P and S. The absence of water in this kind of oil also is very important, because it can accelerate the contact fatigue damage (Arimenzi et al, 1985a,b), the main wear mechanism for gears and ball bearings.

The MoS_2, P and S containing soluble additives can operate synergistically, improving the system reliability. The exact mechanism of action of MoS_2 is not yet well understood. The classical explanation of the effectiveness of molybdenum disulfide is based on the sliding process (Gansheimer and Holinski, 1972; Bartz and Muller, 1972), but some superficial analysis on the worn surfaces and frictional studies showed that a reaction product can be formed (Oliveira and Araújo, 2003; Gansheimer and Holinski, 1972; Bartz and Muller, 1972).

Some tests were performed using Sb_2S_4 and MoS_2 and the mixture presented a synergistic effect at high temperature. Small amounts of sulfur added to Sb_2S_4 with MoS_2 also improved the lubricating performance of MoS_2. It was proposed that sulfur improved MoS_2's tribological behavior (Sebenik, 1993).

If a rolling bearing in service is properly lubricated, well aligned, kept free from abrasives, moisture and corrosive reagents, the only cause of damage would be material fatigue (Arimenzi *et al*, 1985a). On the other hand, Scott proposed that the main retarding factor in damaging some rolling bearing is lubrication (Scott, 1972). As is widely known, the presence of a small amount of water in lubricating oil accelerates pitting failure of ball bearings (Arimenzi *et al*, 1985b). The action of water in ball bearing is not well understood, but it has been proposed that the presence of nascent hydrogen may lead to the occurrence of cracks that propagate and result in pitting damage on the surface contact.

The presence of 10 ppm of water in oil can reduce the fatigue life by 10%. When the content increases to 100 ppm, the decrease in life can be estimated to be between 32 and 48%. Finally, when the amount of water reaches 6%, the life can be decreased by around 80 or 90% (Arimenzi *et al*, 1985b).

In the present paper, the effect of MoS_2 in a gear oil lubricant on the mean life of ball bearings is discussed. Furthermore, the behavior of water in decreasing fatigue life is also evaluated.

2. Methods and Materials

The tests were performed in a four ball machine, in an accelerated condition. The configuration of the balls is shown on the Figure 1.

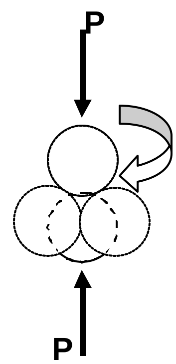


Figure 1. Schematic contact between the four spheres in a four ball tribometer.

The spheres were submitted to 80 kgf for the sliding test and the upper one rotated at 1200 rpm. The bottom balls were tightly clamped. The temperature was kept at 40 º C for ten minutes and after that the heater was turned off. Thus the test continued for 50 minutes more. During this time the behavior temperature and the friction torque were measured.

For the fatigue tests, the loading on the samples was 600 kgf and the speed was 3000 rpm. In this case the temperature was monitored. The bottom balls, in this case, were free to rotate. The rig was equipped with an accelerometer in order to identify the first pitting and turn off the electrical motor.

The balls were made of AISI 52100 steel and their surfaces were extra polished. Their hardness was between 64-66 HRC.

The lubricant used was a commercial ISO VG 460 gear oil, denominated here as Common Oil or CO. A new lubricant oil was prepared with 5000 ppm of MoS_2, maintaining the same viscosity at 40 ºC. The MoS_2 containing oil is considered a high performance oil, or HPO. The typical molybdenum disulphide size was 800 nm. Its lamellar character is shown on Figure 2.

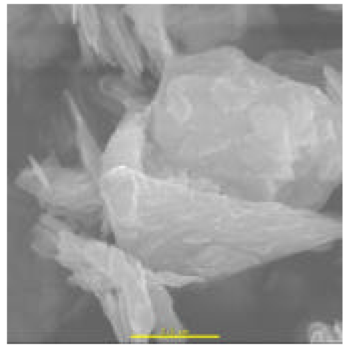


Figure 2. Particle of Molybdenum Disulphide – 10.000x.

The main properties of the lubricant used are shown in Table I.

Table 1. Properties of the gear lubricant, ISO VG 460

PROPERTIES	VALUE
Pour Point, ºC	- 6
Viscosity at 40 ºC, cSt	472.0
Viscosity at 100 ºC, cSt	31.80
Viscosity Index	98
Flash Point, ºC	290

The sliding tests were performed for the CO and HPO without water. For fatigue testing, the mean life and reliability of the balls were measured for CO, HPO and HPO contaminated with 1020, 5000, 10000 and 20000 ppm of water.

3. Results and Discussion

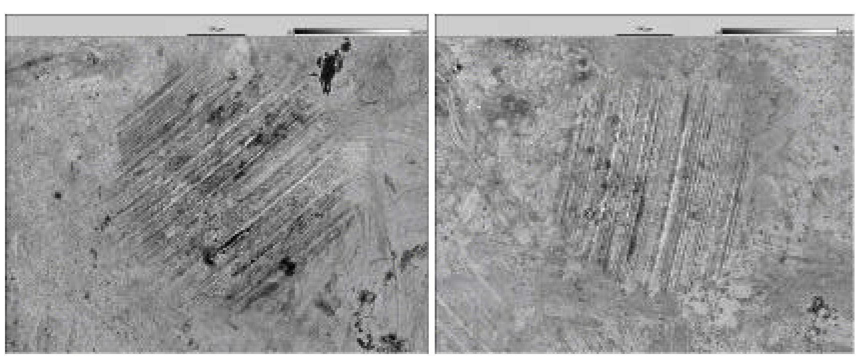
3.1. Sliding Tests

The friction Torque and final temperature are presented in Table 2.

Table 2. Result of the friction torque and final temperature.

TESTED OIL	FRICTION TORQUE (Nm)	FINAL TEMPERATURE (ºC)
Common Oil	1135	46
High Performance Oil	795	39.6

To illustrate the different behavior of the tested oil, Fig. 2 shows the contacted worn surfaces.



(a) (b)

Figure 2. Worn surfaces for each tested oil. (a) Common Oil (CO). (b) High Performance Oil (HPO).

The results of Tab. 2 point out to a high performance of HPO. The results obtained with HPO showed that the friction torque is about 30% lower and the final temperature is lower 6.4 °C. These results are the direct effect of a better friction mechanism and in the Figure 2 are shown photos that support this affirmative. The worn surface for HPO is smoother than that for CO, indicating the predominance of the lower friction. The same reasoning can be used for the final temperatures.

3.2. Contact Fatigue Tests

The mean lives and reliabilities of the tested spheres are shown in Table 3.

Table 3. Mean lives of the CO and HPO.

TESTED OIL	MEAN LIFE (minute)
CO	28.9
HPO	382.6
HPO + 1000 ppm of H2O	282.3
HPO + 5000 ppm of H2O	215.3
HPO + 10000 ppm of H2O	326.7
HPO + 20000 ppm of H2O	368.5

To illustrate the effects of the kind of lubricant on the mean lives of the spheres, the pitted surface is shown on Figure 3.

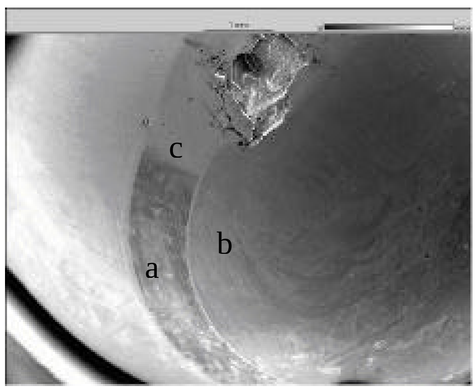


Figure 3. Contact surface and pitting damage for HPO.

The EDS (Dispersive Energy Spectroscopy) analysis reveals that the presence of a film lubricant supplied by MoS_2 can be the responsible for higher mean lives of the HPO oils. The molybdenum content at the analyzed surface is shown in Table 4.

Table 4. Results of EDS analysis on the surface tested.

Region Analyzed	Molybdenum content (wt. %)
A	5.34
B	0
C	3.65

Point (a) is far from the pitting damage. It can be considered that all ring of contact, before the failure, was like point (a), containing a high level of Molybdenum. Region (b) is out of contact, containing no amount of molybdenum, as expected. At region (c), near the pitting, molybdenum content decreases, showing that the effect of molybdenum, like a film lubricant formed, is fundamental for improving the lubricants behavior.

The effect of the oils as regards reliability is shown on Figure 4.

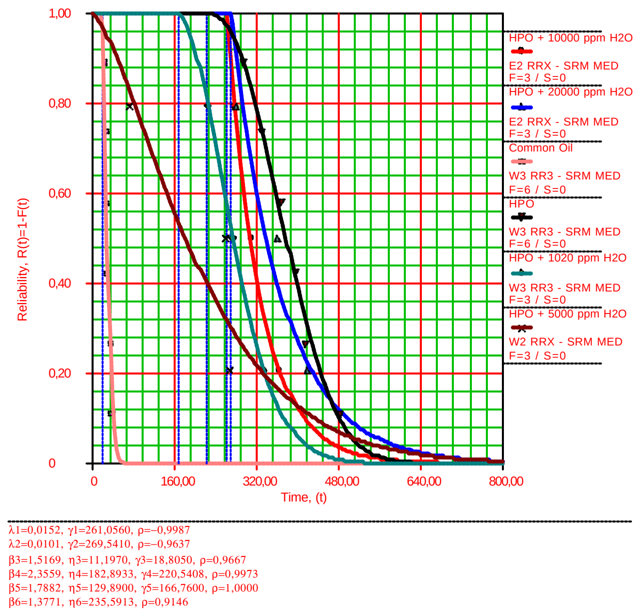


Figure 4. Tribosystems Reliability Results.

The reliability curves indicate the superior behavior of HPO. The CO curve decreases abruptly, showing the high dependence of the reliability with time. Anomalous results were presented for the HPO oil contaminated with water, since as water content raises the mean lives and reliability increases, except for 5000 ppm of water sample, because its mean life decreases quickly. This phenomenon is not well understood; therefore new tests must be performed in order to clarify it.

In spite of the bad behavior of HPO with 5000 ppm of water, the reliability of the system remains satisfactory, as can seen on Figure 5.

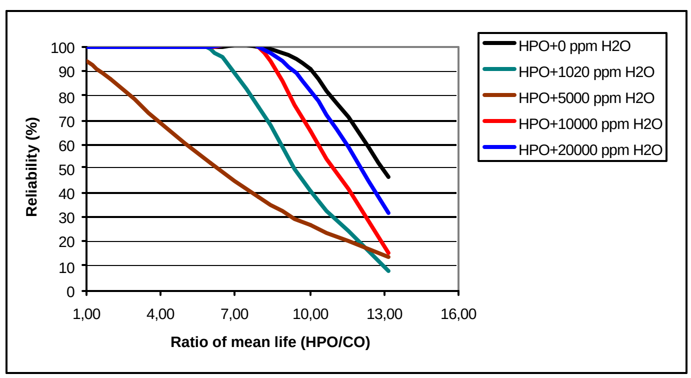


Figure 5. Mean lives ratio between HPO and CO.

The general behavior of the several tested oils is shown on Figure 5. In spite of worst mean life for HPO + 5000 ppm H_2O, when compared with the other water content, its mean life is about 95 % for same mean life of CO, or ratio equal 1. For the other level of contamination, HPO presents a reliability of 100 % in six times the mean life of CO.

The presence of MoS_2 under high test loads resulted in a strong superficial lubricant film. The lubricant film was the responsible for decreasing the friction coefficient, while reducing the contact temperature and avoiding severe reaction between water and metallic surface, resulting in high mean lives and high tribosystems reliability.

4. Conclusions

Molybdenum Disulphide containing gear oil improves the mean lives of ball bearings. The tribosystems reliability is substantially increased. The proposed mechanism of protection is a strong lubricant film formed on contact surfaces.

In spite of the water contamination, the HPO had a superior performance, as compared to CO. The MoS_2 can retard the action of water on small superficial cracks, reduces friction coefficient and improves the general performance of mechanical systems.

5. Acknowledgements

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