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## **EFFECTIVE TRIBOLOGY TESTING OF LUBRICATING OILS**

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### **ABSTRACT**

There are several solutions suggested to develop the unified approach to tribological testing of oils. For evaluation of the coefficient of friction and wear, it is suggested to monitor friction force, normal load, and in-situ wear dynamics, as well as to clearly distinguish the running-in and stable-wear components. Tests on lab-bench testers are recommended to start from obtaining a Stribeck curve in a wide range of loads and speeds. During the tests, monitoring additional parameters of contact acoustic emission and contact electrical resistance is beneficial for sensitive and comprehensive characterization of oils and greases.

### **INTRODUCTION**

There are numerous techniques known to study tribological properties of oils and greases. A common problem in tribological literature, however, is the wide scatter of test results obtained by different authors on different testers for different applications.

We recommend several solutions to overcome data fluctuations and develop the unified approach to the tribological testing of oils, namely:

- To evaluate friction and wear characteristics on the lab-bench tester, it is important to start from obtaining a Stribeck curve in a wide range of loads and speeds, so that to clarify whether the test conditions correspond to boundary, mixed or hydrodynamic regime, and to modify them to ensure the regime fully corresponding to the one in the target practical application (instead of performing "blind" tests in the unknown lubrication regime and so neglecting the dramatic friction and wear changes at different zones of the Stribeck curve).

- When evaluating the coefficient of friction, it is important to measure both its friction force and normal load components (instead of assuming a static normal load and so neglecting flatness of test samples and runout of the motion).

- For wear evaluation, it is important to monitor its actual dynamics during the test and clearly distinguish its running-in and stable components (instead of taking into account only the

post-test final wear depth and so neglecting the fact that most of it could be due to the initial test period).

- Additional parameters of contact acoustic emission and contact electrical resistance are beneficial for more sensitive characterization of oils and greases, monitoring bonding and debonding processes, formation and destruction of tribo-films, initiation and propagation of wear tracks.

### **EXPERIMENTAL APPARATUS**

The tests were performed on the Universal Tribometer, which can be configured either as a micro-tribometer UMT-2 or a macro-tribometer UMT-3. It can accommodate test samples of various shapes and dimensions (up to 150 mm in both lateral and vertical directions) and perform all common lubricant tests, including ball/pin-on-disc, disc-on-disc, block-on-ring, nut-in-screw, drill-in-hole, mill-on-block, shaft-in-bushing, 4-ball, etc. Easily interchangeable compatible rotary and linear drives allow for almost any combination of rotary and linear motions (including fast oscillations) of test specimens. Oils can be applied either continuously with a peristaltic pump or in the beginning of the test into corrosion-resistant containers.

The applied loads are servo-controlled (with a closed-loop feedback) from 1 mN to 1 kN. The speeds (from 0.001 to 5,000 rpm), accelerations and positions are also precisely controlled. The loads and speeds can be programmed to have different values on different areas of the test specimens consistently during the test, allowing for wear evaluation and comparison on those areas as if they were obtained after a whole battery of tests. In case of start-stop cyclical tests, both the load-unload and acceleration-deceleration profiles can be either programmed or downloaded from the real machine, allowing for the full simulation of target application.

During testing, up to 16 parameters are monitored, displayed and stored in the computer for further analysis: up to three forces (in all 3 axes), three torques (around all 3 axes), wear depth, temperature, humidity, electrical contact resistance, high-frequency contact acoustic emission, audible noise, etc.

An integrated digital optical microscope allows for both precise samples positioning and imaging of the wear track.

**EXPERIMENTAL PROCEDURES**

Prior to friction and wear testing, it is crucial to find out what lubrication regime is targeted (boundary, mixed or hydrodynamic) and to perform the tests in the correct regime. All tribological parameters differ dramatically in different regimes. These regimes, in turn, depend on the lubricant thickness and viscosity, surface roughness, speed, load, temperature, etc. Therefore, comparison of oils by their friction and wear characteristics has to be done within the same lubricating regimes. For example, oils with viscosity modifiers may show advantages in the hydrodynamic regime and easier change from the mixed to hydrodynamic regimes, but no advantages in boundary lubrication. Oils with wear reducing additives may exhibit better characteristics in boundary lubrication, but no advantages in a hydrodynamic regime.

The best way to compare frictional properties of lubricating oils is to obtain their Stribeck curves and determine their friction levels in all three regimes. Our automatic procedure includes testing at different speeds and loads, each ranging by 3 orders of magnitude, so that the total speed-to-load ratio ranges by 6 orders of magnitude; it allows for detection of all three lubrication regimes. The test on each level takes 1 minute; the software calculates average friction coefficient during the last 15 seconds and automatically plots the Stribeck curve.

After the Stribeck curves are obtained and all three regimes are determined, the test conditions are chosen that correspond to the target application lubrication regime. In these conditions, a wear test is run with simultaneous monitoring of normal load, friction force and coefficient COF, wear depth W and rate, contact electrical resistance ER and acoustic emission AE. Humidity and temperature are monitored, if needed – controlled within 5 to 100 %RH and -20 to +1000 °C.

**RESULTS AND DISCUSSION**

Comparative tests of oils 1 and 2 were performed. Quick testing on 10 speed and load levels with monitoring the COF and ER versus the speed-to-load ratio produced two different Stribeck curves (Fig. 1). A higher-viscosity oil 1 showed higher

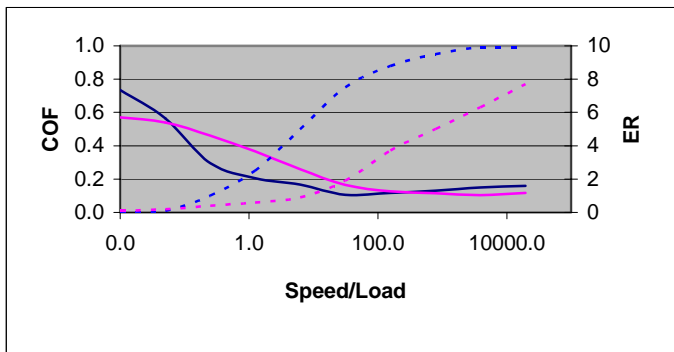


Figure 1. Stribeck curves for oils 1 (blue) and 2 (red):

COF (solid lines) and ER (broken lines) data friction and near-zero ER. In boundary lubrication at very low speed/load ratio (as it did not form protective layers separating the surfaces) and slightly higher friction in the hydrodynamic lubrication at high speed-load ratio, but lower friction and more dramatic ER increase in the mixed lubrication regime (as its higher viscosity allowed for a hydrodynamic effect at lower speed/load levels than for the lower-viscosity oil 2).

Based on the oil target application, a speed/ratio of 6 was chosen for a durability test. The durability results are shown in Figure 2. Oil 1 failed, its friction and wear increased sharply

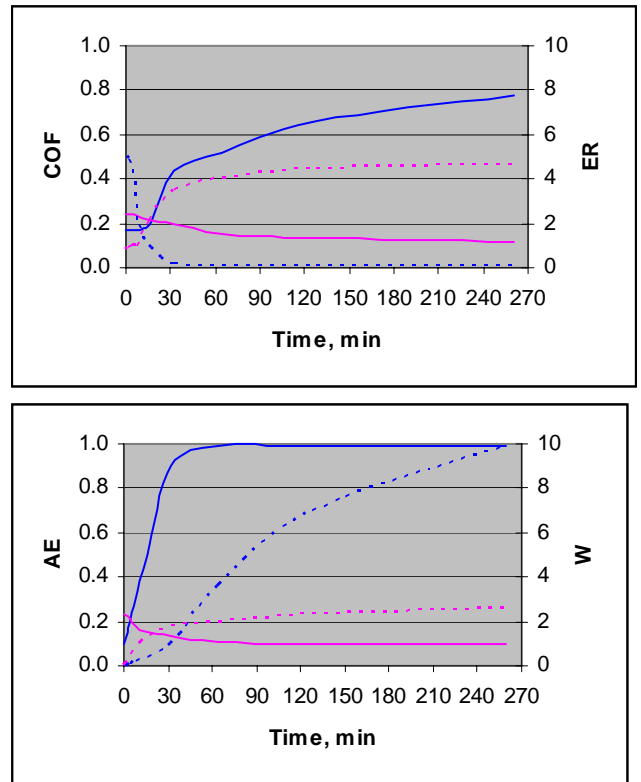


Figure 2. Durability test for oils 1 (blue) and 2 (red): COF and AE - solid lines, ER and W – broken lines.

after 20 minutes, with ER dropping and AE increasing about 10 minutes earlier. Oil 2 performed well and formed a protective film, reflected in an ER increase and AE decrease after about 20 minutes, followed by reduction in both friction and wear rate.

**CONCLUSIONS**

The multi-sensing technology is effective for tribology testing of oils. For comprehensive frictional characterization, oils have to be tested and compared in all three lubrication regimes. For durability characterization, wear testing should be performed in the application-specific lubrication regime. The UMT tester with multiple sensors, automated test procedures and data presentation is suitable for sensitive and practical oils tests.