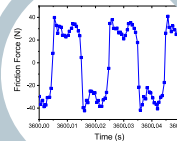
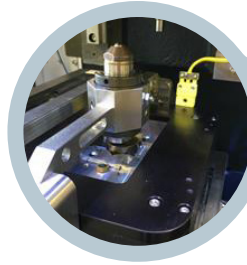
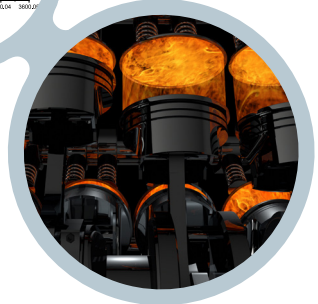


UMT TriboLab HFRR



Reciprocating Tests

Engine Tribosystem



## Application Note #1016

# Simulating the Friction of Lubricants and Materials with a High-Frequency Reciprocating Rig

Testing of surfaces and lubricants on reciprocating systems, such as engines and linear compressors, requires the use of laboratory-scale tribometers prior to final component testing. This application note discusses a tribometry setup that enables time-effective screening of lubricants and materials at the benchtop scale using a UMT TriboLab™ (Bruker, San Jose, CA). With this setup, the samples can be tested under simulated conditions to rank the performance of lubricants and surfaces, while monitoring small changes in friction with a piezoelectric-based force sensor. The material covers the technique and analyzes its effectiveness in simulating standard protocols, such as the ASTM D6245-17, and shows how. Also, of great importance the system offers unprecedented flexibility for a wide range of conditions and parameters, such as speed, stroke length, and temperature variation. Finally, we also present the critical importance of the calculation method employed to analyze the data obtained by high-frequency reciprocating tests.

### Evaluating the Behavior of Lubricants and Materials on Reciprocating Systems

Continuous development of lubricants and surfaces for reciprocating engine and compressors is needed to meet changing environmental regulations, improve automobile fuel economy, and extend component durability.

The precise understanding of component wear and friction in mechanical systems is vital to quantify energy losses and to predict the durability of such surfaces. Thus, the measurement of lubricant performance continues to be a critical factor in accurate fuel economy estimation. To do this successfully, one must account for various challenges in precisely mimicking the specific conditions and factors that might play a major role on the tribological performance of those systems. Fortunately, these measurements are possible with laboratory-scale tribometers.

Tribological evaluation of reciprocating systems can be effectively performed at the laboratory scale only by correctly implementing a motion and velocity profile that exactly simulates the actual motion of the real-world tribosystems. To properly simulate materials or lubricants in systems that reciprocate, it is critical to replicate the sinusoidal motion, typically produced by a slider-crank mechanism in which the lubrication regime could be varying along the stroke, and to monitor the small changes in friction. This requires high-speed, precise force transducers and displacement sensors.

A variety of standards are in use by the automotive and lubricants industry. Of particular interest here is the ASTM D6425-17 (Standard Test Method for Measuring Friction and Wear Properties of Extreme Pressure (EP) Lubricating Oils Using SRV Test Machine)<sup>1</sup>. This specific

protocol ranks lubricants using severe conditions of temperature, speed, and contact pressure.

### Performing Reciprocating Tribotests

To simulate the behavior of a reciprocating system, one must select the elements that play important roles on the tribological system. Such elements include:

- Material and geometry of the tested samples,
- Contact pressure between surfaces that is controlled by the load, geometry, and material of the contact surfaces,
- Reciprocating frequency and stroke length that will direct the motion and velocity profiles, and
- Controlled temperature that will activate tribo-chemical events on the tested surfaces.

Key resulting parameters that could be measured during the tests include:

- Friction changes along the stroke, since the friction is not steady in reciprocating systems,
- Temperature changes, and
- Wear measured after the test.

For the purposes of this study, we used a TriboLab system equipped with the new High Frequency Reciprocating Rig (HFRR). One main advantage of the use of a small-scale tribometer is that the lubricant and surfaces can be easily characterized after the test with other metrology tools, such as profilometers and chemical analyzers/spectrometers. Figure 1 shows the TriboLab setup for high-frequency reciprocating tests. The setup is equipped with a fast reciprocating stage, a piezo-based sensor, a normal-force sensor, and a 400°C heater. The sensor assembly has been designed with the capability of pivoting to allow the user to quickly replace lower samples and apply lubricant.

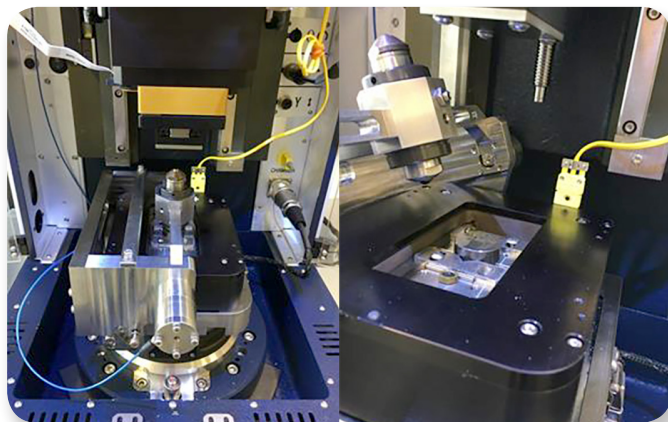


Figure 1. UMT TriboLab with HFRR setup. Left: Setup includes the reciprocating drive, HFRR sensor, 400°C heater, and load sensor. Right: Pivoting allows easy setup of the samples.

As an example, Figure 2 shows a typical result of 5W-30 engine oil tested using a reciprocating ball-on-flat (steel-on-steel) configuration and the ASTM D6425-17 conditions with the HFRR setup. Here friction changes were observed and plotted as a function of the time, data was collected and recorded in high resolution to monitor small variations of friction along the stroke. That variation of friction along the stroke is typically due to a combination of changes on the surface, transition on lubricating regime, and vibration generated from the mechanical motion. From the high-resolution data, it is easy to visualize changes in direction. This allows precise selection of the peak-to-peak friction (as suggested by the ASTM standard) or calculation of the friction in any way the user desires.

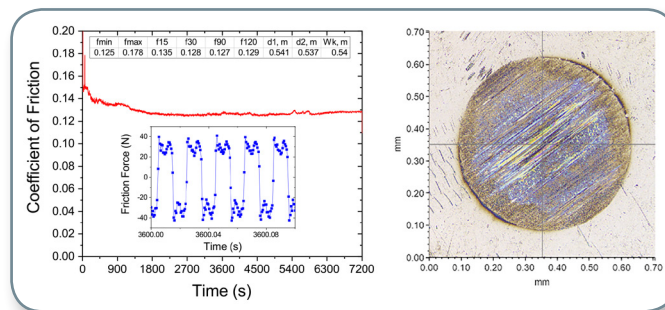


Figure 2. Friction and wear results of engine oil tested using ball-on-flat testing with the TriboLab HFRR setup under ASTM D6425-17 conditions (350 N, 50 Hz, 1 mm, 120°C, 2 h). Left: Calculated COF using 10% of the top points on each stroke, and inset showing the high-resolution data of the friction force at ~3600 s. Table shows the COF at 15, 30, 90, and 120 min, and the minimum and maximum COFs, as well as the wear diameter on the ball. Right: Wear scar after the test

### Analyzing the Results

Collecting good quality data by using a very precise system is an essential part of the experiment, but how the data is analyzed is equally critical. Figure 3 shows the coefficient of friction (COF) as a function of the position, since the velocity is sinusoidal rather than linear, this representation is more realistic of behavior along the stroke than data gathered only as a function of time. The HFRR system allowed precise recording of position due to the use of an LVDT (linear variable displacement transformer) incorporated in the fast reciprocating stage. The graph clearly shows how the friction maximizes in each extreme of the stroke and how the force decreased and dampened along the stroke until the next extreme in change of direction.

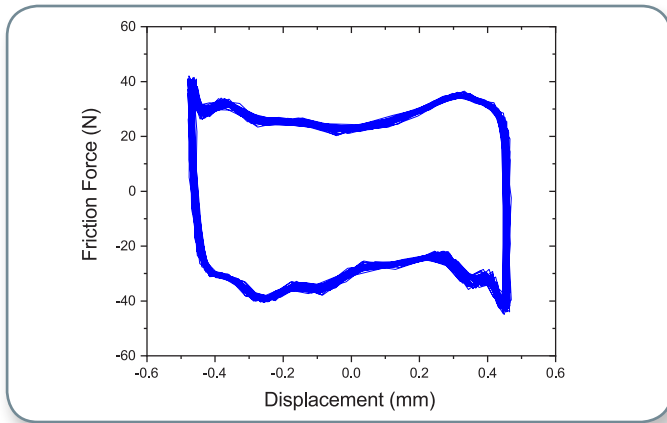


Figure 3. Friction force as a function of the displacement for data collected between 3600 and 3601 s.

Bruker's UMT TriboLab software allows the user complete flexibility in how to analyze the data obtained from a fast reciprocating test. To calculate the COF the user can choose between different methods; a simple method using a certain percentage of the top values of friction in each stroke (Figure 4, left), or an advanced method that selects a percentage of points in the middle of the stroke (Figure 4, right). This capability allows the user to customize the data collection and analysis, providing friction values that can enhance understanding of small differences between lubricants.

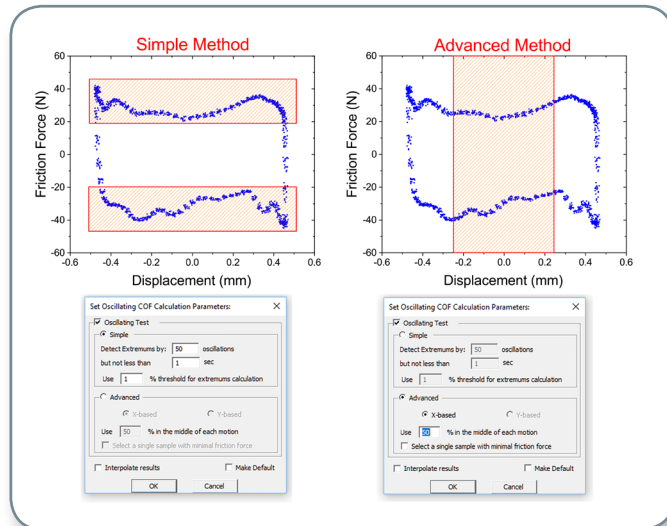


Figure 4. Simple and advanced methods to make calculations using the change between positive and negative friction in each stroke.

To better understand the implications of the calculation method, Figure 5 presents the differences between the overall COF calculation when using different methods for the same engine oil. When calculating the COF by different methods, it is possible to see how the value dramatically changes, from overall values of  $\sim 0.14$  when using the simple method with 1% of the points, down to  $\sim 0.11$  when employing 30% of the top points, and lower ( $\sim 0.10$ ), when using the advanced method with 50% of the

points in the middle of the stroke. The advanced method tends to be more consistent, with 50% and 80% of the points overlapping.

It is clear that the simple method is less consistent than the advanced method, but it is available because it is necessary to calculate the peak-to-peak (small percentage of the top points) friction that is required by the ASTM standard.

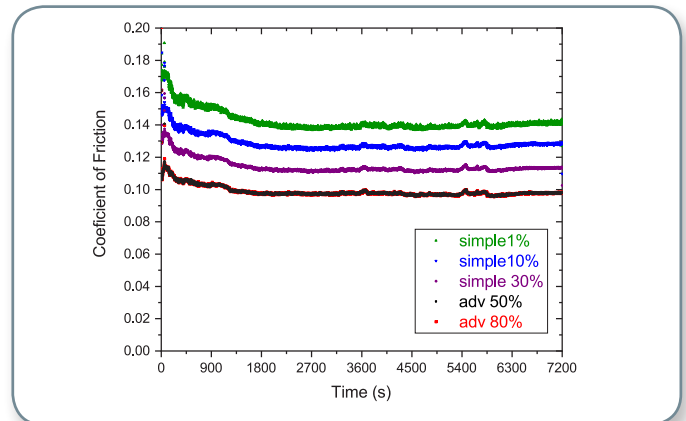


Figure 5. Results of engine oil tested under ASTM D6425 conditions. Calculations could change the reported value of the COF.

The method that is selected to calculate the COF is highly important when comparing lubricants that are very close in performance. It is not just a simple absolute value when referring to friction of reciprocating systems, but rather is very dependent on the analysis method. To better explain the effect on lubricant ranking/comparison, Figure 6 presents the results of the test performed using ASTM D6425-17 in two lubricants (oil A: 5W-30, oil B: 0W-20) that are very close in performance, and how the data differs between the methods.

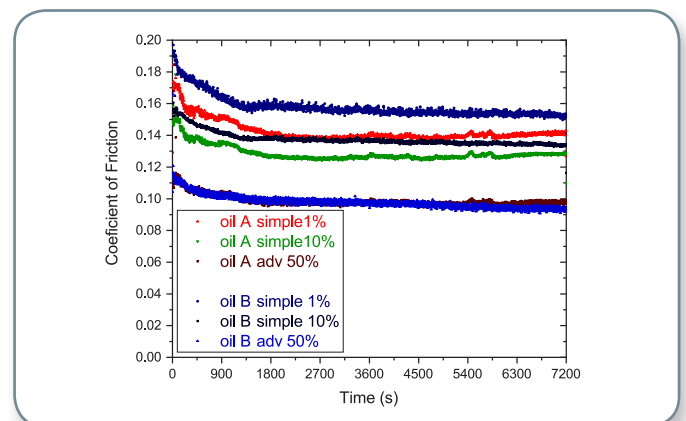


Figure 6. Comparison of oils A and B. The COF changes depending upon the method of calculation.

When using the simple method with 1% of the top points, the difference between oils A and B is considerably more noticeable than when using the advanced method with 50% of the points in which the lubricants overlap their behavior. These differences are not just numerical

differences, but could represent how different the lubricants behave along the stroke, meaning they behave in a different way mechanically depending on the regime or lubricant properties.

### Studying Lubricants and Surfaces with Superior Flexibility

The presented setup/rig has been designed with unprecedented flexibility, and not exclusively for protocols. It allows researchers to perform measurements at different conditions, which is essential in understanding performance differences of lubricants at different regimes. The TriboLab's reciprocating stage can move at very slow speeds of 0.01 Hz and below, as well as at speeds as high as 60 Hz. At high speeds, the piezoelectric-based force sensor does not drain the current, and the sensor is able to precisely record quasi-static or very slow-motion systems. The normal force that can be applied is likewise flexible due to TriboLab's selection of 11 distinct sensors covering ranges between a few millinewtons to kilonewtons. The variable stroke is capable from 10s of microns to 25 mm. Figure 7 presents the quality of the data capture by the piezoelectric-based sensor for tests conducted at different speeds, illustrating how the test can be conducted to understand mechanical and tribochemical events occurring in very different regimes.

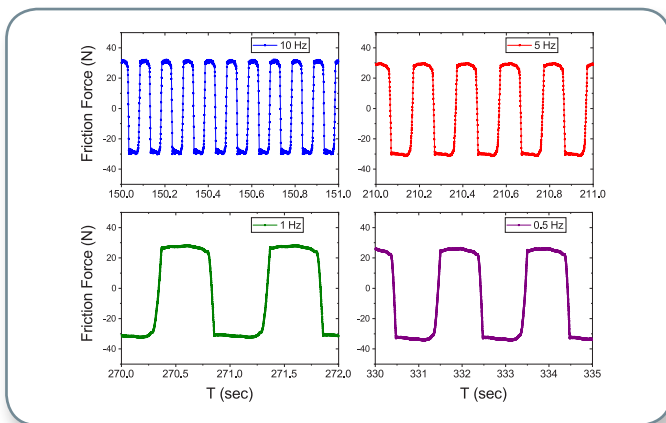


Figure 7. Oil B tested at 10 Hz, 5 Hz, 1Hz, and 0.5 Hz.

### Conclusions

The high-frequency reciprocating rig of the UMT TriboLab has been proven as a reliable technique for screening of materials and lubricants employed on reciprocating applications, such as engines and compressors. The flexibility of the system allows evaluation of lubricants at different regimes and with the advantage of having full control of the data analysis. The UMT TriboLab is capable to perform similar protocols to the ASTM 6425 to evaluate friction of lubricants, and can help make important distinctions in a wide range of tribosystem functions.

### References

1. ASTM D6425-17, Standard Test Method for Measuring Friction and Wear Properties of Extreme Pressure (EP) Lubricating Oils Using SRV Test Machine, ASTM International, West Conshohocken, PA, 2017, [www.astm.org](http://www.astm.org)

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