

## Application Note #1006

# Using the UMT TriboLab and Stribeck Curves to Evaluate Potential Applications of Lubricants

Lubricants are primarily used to reduce friction and tribological wear between contacting surfaces. They help transport wear debris out of contact zones, reducing further damage to bearing surfaces from abrasive wear. With an estimated current growth rate of about 2.5%, the value of the world lubricant market is expected to reach more than \$160 billion within a few years, dominated mostly by transportation and automotive sectors.<sup>1</sup> To leverage such market growth in the coming years, R&D and QC activities are going to be major areas of focus for lubricant manufacturers. The end-users of lubricants will be looking for the suppliers who can deliver products that are designed to reduce overall costs with improved performance and reliability. One of the most reliable and easy-to-use procedures for testing and evaluating lubricants for potential applications is obtaining a Stribeck curve. However, it is challenging to find a single tool that can cover all regions of the Stribeck curve. Bruker's UMT TriboLab™ is a universal tribometer that has been specifically designed to mitigate this challenge.

### Stribeck Curve

A Stribeck curve is a plot of the coefficient of friction (COF) as a function of the Stribeck parameter,  $\eta V/F_z$ , where  $\eta$ ,  $V$ , and  $F_z$  are the viscosity of the lubricant, the sliding velocity, and the normal load, respectively.<sup>2-4</sup>

Figure 1 is a schematic of a Stribeck curve showing three distinct regimes: (a) boundary, (b) intermediate or mixed, and (c) hydrodynamic. The load is carried by the surface asperities in boundary lubrication condition. In hydrodynamic lubrication, the load is entirely supported by a lubricating film that exists between the two contacting surfaces. The elastic deformation of the asperity and viscous resistance of the lubricant helps support the load in the intermediate regime of lubrication.

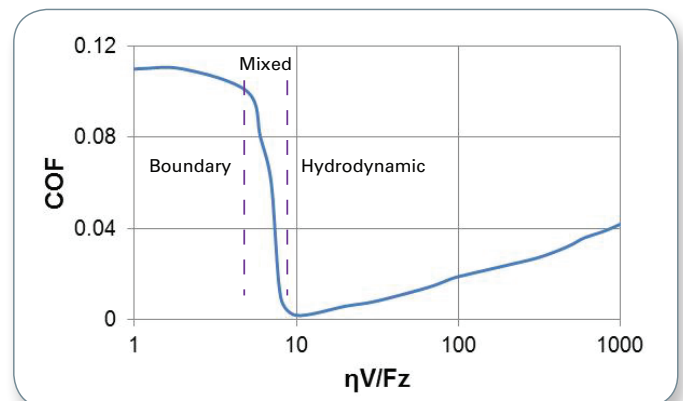


Figure 1. Schematic of a lubricant Stribeck curve showing three lubrication regimes.

Boundary and extreme pressure lubrication deals with direct asperities contact between two surfaces. Under such condition, the COF is the ratio of effective shear stress and the plastic flow stress of the contact materials.<sup>4</sup> Lubricant additives help reduce friction by forming a low-shear strength interface on hard metal contacts. At low temperature (100 to 150°C) and high pressure (up to 1GPa), covering the contacting surfaces with adsorbed mono-molecular and low-shear layer minimizes the friction. At high temperature, the formation of sacrificial films of inorganic materials due to reaction between lubricant additives containing sulphur, chlorine or phosphorus and the metal surface prevents metallic contact from severe wear.<sup>4</sup> The lubrication under such condition depends on a working temperature at which the rapidly forming film protects the contacts from damage. Boundary and mixed lubrication regimes represent situations in which bearing surfaces are not completely separated by a lubricant film but experience some degree of solid-to-solid contact, especially at high load and/or low velocity conditions.

A Stribeck curve for a lubricant is obtained under varying conditions of force, velocity, and temperature to encompass the three lubrication regimes. Generating a useful Stribeck curve requires a tribometer that is capable of operating at wide ranges of test parameters.

### Bruker's UMT TriboLab

The UMT TriboLab system is built on the Universal Mechanical Test (UMT) platform and its precision control of load, speed, and positioning. The modular design of TriboLab ensures the flexibility to cover test capabilities in wide ranges of force, speed, and temperatures, and a host of innovative features makes it easy to configure nearly any tribological test within minutes. Integrated intelligent hardware and software interfaces, such as Tribo ID™ and TriboScript™, make the instrument extremely user-friendly, versatile, and productive. Tribo ID not only automatically detects the various components attached to the main system that are necessary for its proper functioning, but it also configures them. Triboscript offers an enhanced and secured scripting interface for easy compilation of test sequences from the already created test blocks. Finally, the system is equipped with real-time control and data analysis software to ensure high accuracy and repeatability.

### Evaluation of Lubricants for Potential Applications

Stribeck tests were performed with TriboLab using SAE 52100 balls and disks. Each set of tests was preceded by a break-in step. Four different lubricants (A, B, C, and D) were used to generate Stribeck curves for the determination of the potential applications of the lubricants, and to provide performance-based ranking in each lubrication regime. TriboLab allows for simultaneous changing of the velocity and normal force to maintain a particular V/Fz ratio. Stribeck tests to evaluate the four lubricants were conducted in the V/Fz ratio of 0.01 to 20,000 to cover all the three lubrication

regimes. Friction force (Fx) and normal force were measured during the test. Electrical contact resistance (ECR) values between the ball and the disk were also measured and recorded. The measure of ECR data yields qualitative indication of the thickness of the lubricant film between the ball and the disk.

Figure 2 shows the Stribeck curve of Lube-A along with an electrical contact resistance plot. It exhibited boundary, mixed, and hydrodynamic regimes. Because of contribution from the viscosity of the lubricant, COF was found to be substantially high in the hydrodynamic zone. The COF showed an increasing trend at the boundary compared to the mixed regime because of direct metal-to-metal contact. The COF is really low at the initiation of the hydrodynamic regime. The electrical contact resistance data, as shown in Figure 2, also exhibited three regions, corroborating the friction results. ECR signal was substantially high in the hydrodynamic regime. It showed a decreasing trend at the start of the mixed region corresponding to a V/Fz ratio of about 200. At the start of the boundary regime at about a V/Fz ratio of 1.3, the ECR shows a drastic reduction, confirming metal-to-metal contact. Lube-A was found to have the best performance in boundary and mixed regions. Hence, the other three lubes were compared directly with Lube-A. Figure 3 compares Stribeck curves of Lube-A and Lube-B. In the boundary and mixed regimes, Lube-B exhibited higher values of COF than Lube-A. Comparative Stribeck curves of Lube-A and Lube-C are shown in Figure 4, confirming that Lube-C showed higher COF in the mixed lubrication regime. Although Lube-C showed similar friction behavior as Lube-A in the boundary regime, it exhibited substantially lower COF than Lube-A in the hydrodynamic regime because of differential contribution of viscosity. Figure 5 depicts the comparative Stribeck curves of Lube-A and Lube-D. Lube-D showed higher COF than Lube-A except in the hydrodynamic regime.

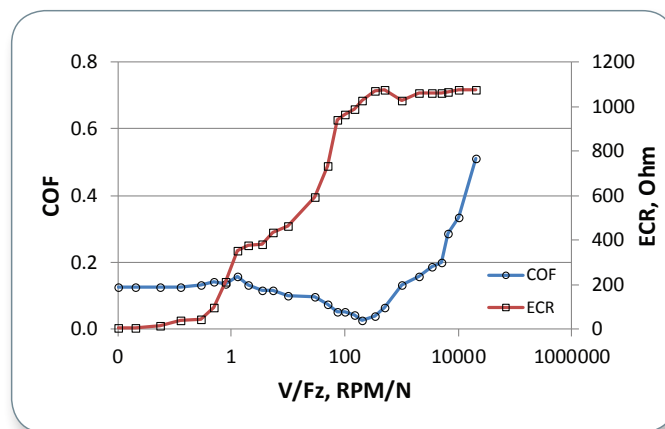


Figure 2. Stribeck curve of Lube-A along with an ECR plot showing three lubrication regimes.

It is generally accepted that a lubricant is expected to perform better when it exhibits a lower coefficient of friction. Based on the COF data, the four lubricants are ranked from 1 to 4, corresponding to each regime; 1 having the highest performance and 4 being the lowest. The ranking of the lubricants are shown in Table I. Lube-A and Lube-C exhibited the best performance in the boundary regime, whereas Lube-D had the worst. In the mixed regime, Lube-A was found to be the best and Lube-D was the worst. Lube-B ranks second in boundary and mixed regimes. On the hydrodynamic side, Lube-D performed the best and hence ranked 1 whereas Lube-C placed in the second. Lube-A and Lube-B hold the last rank in hydrodynamic regime. Electrical contact resistance measurement corresponded well with the friction measurement during the Stribeck test.

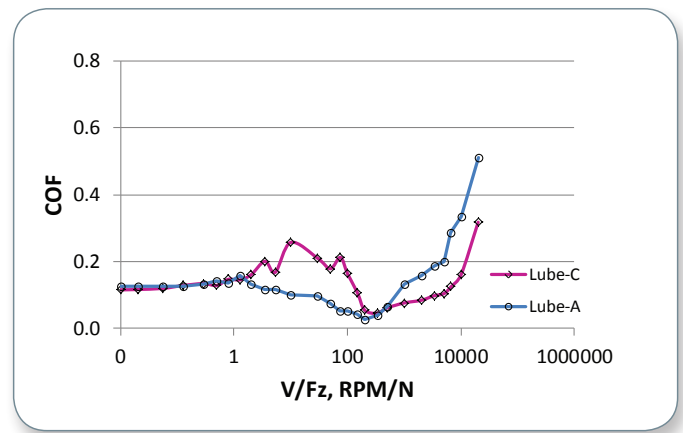


Figure 4. Comparative Stribeck curves of Lube-A and Lube-C.

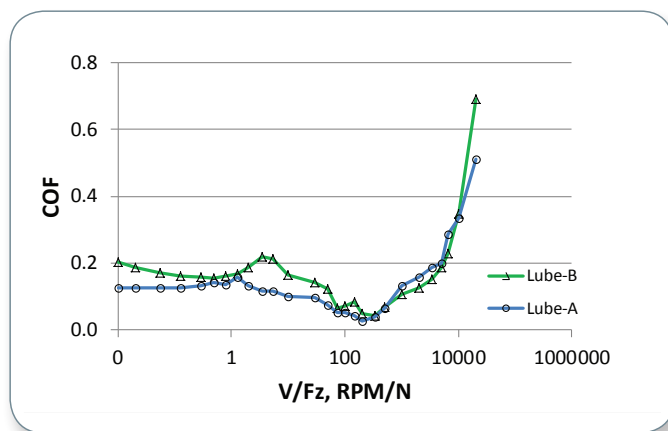


Figure 3. Comparative Stribeck curves of Lube-A and Lube-B.

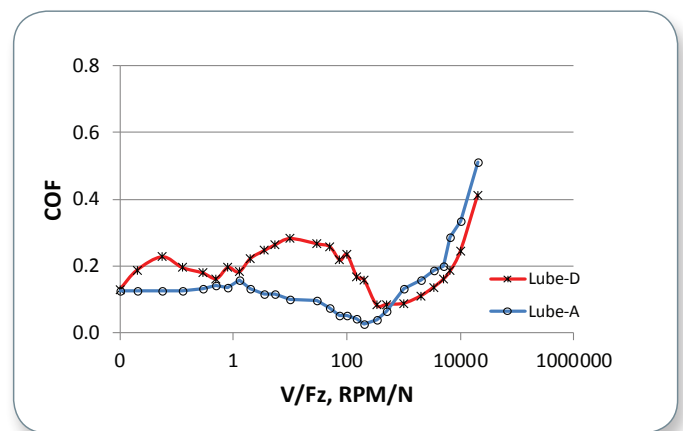


Figure 5. Comparative Stribeck curves of Lube-A and Lube-D.

Lubricant	Boundary	Mixed	Hydrodynamic
Lube-A	1	1	3
Lube-B	2	2	3
Lube-C	1	3	1
Lube-D	3	4	2

Table 1. Ranking of the lubes in three lubrication regimes.

## Conclusions

For comprehensive tribological characterization, lubricants need to be tested and compared in all three lubrication regimes over a wide range of test parameters, such as force, velocity, and temperature. Lube-A and Lube-C exhibited the best performance in the boundary lubrication regime. Lube-B ranks second in boundary and mixed regimes. In the hydrodynamic condition, Lube-D was found to be the best. The UMT TriboLab is capable of performing Stribeck tests to differentiate lubricants for their specific applications and rank them based on their performance in various lubrication regimes. It is important to test a lubricant in conditions that encompass all the three regimes of lubrication to explore its full application potential.

## References

1. "Global Lubricants Market Expected to Reach \$162.3 Billion by 2019," *Machinery Lubrication*, accessed September 11, 2015, <http://www.machinerylubrication.com/Read/29991/>.
2. Jacobson, B., "The Stribeck Memorial Lecture," *Tribology International*, 36 (2003): 781-89.
3. Jones, M.H. and D. Scott, eds., *Industrial Tribology: The Practical Aspects of Friction, Lubrication and Wear* (Amsterdam: Elsevier, 1983), 227.
4. Stachowiack, G.W. and A.W. Batchelor, *Engineering Tribology* (Oxford: Butterworth Heinemann, 2000), 183.

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