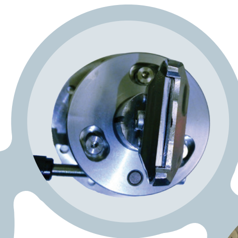

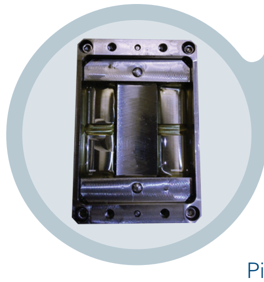

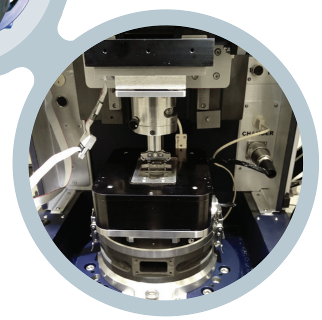

Application Note #1011

Understanding Engine Tribology: Performing Reciprocating Tests of a Piston Ring's Interaction with the Cylinder Liner

Tribological evaluation of a piston ring's interaction with the cylinder liner is an important step toward understanding engine tribology. It helps automotive manufacturers conform to the stringent specifications on fuel efficiency, emission, safety, and durability of automobiles. Traditionally, this kind of test is developed for a specific engine, and results gathered are not comparable from one test to the other. However, mechanical testing technology has advanced to the stage where it is now possible to perform standard tests for piston ring and cylinder liner frictional properties through high-speed reciprocating motion. This can assist automotive engineers, materials scientists, and lubricant manufacturers worldwide in the development of superior engine components and cost-effective lubricants.

Engine Tribology

The rapid growth of friction and wear studies of the various machine components in internal combustion engines is a direct response to the automotive industry's ever increasingly stringent specifications for fuel efficiency, safety, emissions, and general automobile durability. Specifically, engine tribology research has seen incredible changes over the last decade, with piston assemblies, valve train components, and internal bearings receiving the most attention as they are the major frictional components in any automotive engine. Of these, the piston assembly is the highest contributor of friction and is responsible for almost 45% of the overall frictional losses in a typical engine.[1] Reducing such frictional losses can immensely improve the brake thermal efficiency of an engine.

Naturally, a substantial amount of recent effort has been devoted toward studying the tribological characteristics of the piston ring's interaction with the cylinder liner to improve engine performance. Unlike engine bearings, the mechanism of piston rings and cylinder liners calls for a wide variation of service speed over an operating cycle. For a short time, at both ends of the stroke, i.e., at the top dead center (TDC) and bottom dead center (BDC), the speed of the piston ring is effectively zero. This condition provides virtually no chance of lubricant entering into the contact. Thus, a boundary lubrication regime is more applicable at TDC and BDC. On the other hand, the hydrodynamic or fluid-film lubrication condition prevails at the mid-stroke, where the speed is the highest. Near the dead centers, where velocity is low, squeeze film lubrication and elastohydrodynamic conditions of lubrication are expected to have a greater role in engine tribology. In essence, engine tribology encompasses all the regimes of lubrication.

Tribological testing of a piston ring assembly is inherently complicated. For example, studies of piston ring frictional characteristics have been attempted by using floating liners.[2] However, such application-oriented test fixtures require a separate design for each type of engine. These special test rigs are costly and unable to accommodate standard test specimens. The data obtained from such specially designed test methodologies also have a very limited scope of application. Such data can neither be effectively compared from test to test, nor do they have universal applicability.

The technology has now been developed to perform standard tests[3] on a piston-ring and cylinder liner. Today's most advanced mechanical testers can be configured for these tests and have the capability to compare results from test to test. In addition to contributing to better engine components, such comparative testing can also be used to develop cost-effective engine lubricants, and to perform quality control of these oils. For the comparative studies covered in this application note, we used a UMT TriboLab™ (Bruker Nano Surfaces, San Jose, CA) to perform high-speed reciprocating tests. These were done by examining and recording the tribological characteristics of piston rings against a cylinder liner segment, according to the ASTM G181 document,[3] with various combinations of test parameters, such as load, frequency, and stroke in lubricated conditions.

Performing the Piston-Ring Test

The piston ring was tested with a reciprocating motion under a normal load (Fz) to measure the frictional force (Fx). The UMT TriboLab system has servo control of normal load and can measure and record several test parameters. These include Fx, Fz, and Stroke position (lvdt) as a function of time. Figure 1 shows representative plots of Fx, lvdt, and coefficient of friction (COF) as a function of time over four consecutive cycles during a reciprocating test. These data were obtained by performing the piston ring test with a normal load of 200 newtons at a frequency of 10 hertz. The lvdt plot shows that the test was performed over a stroke length of 25 millimeters. To some degree, the Fx plot mimics a square wave because of the change in direction of motion during every half cycle at the TDC and BDC positions. The Fx is found to be the highest at the dead centers because of the prevalence of boundary lubrication regime. The COF is reduced at the mid stroke due to the change in lubrication condition at higher speed. The COF was automatically calculated as a ratio of absolute value of Fx to Fz. The average COF is approximately 0.06, while the static COF at the dead centers is about 0.11.

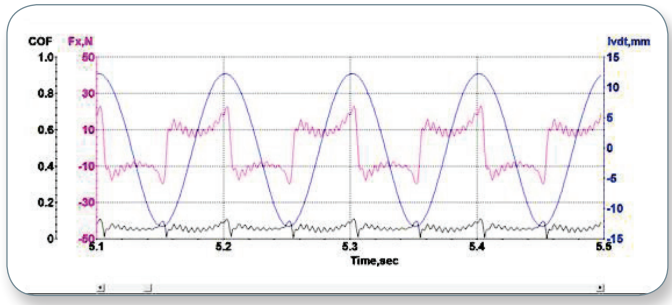

Figure 1. Plot of friction force (Fx), stroke position (lvdt), and coefficient of friction (COF) as a function of time for a test of piston ring on a cylinder liner segment with a normal load of 200N in lubricated condition.

Figure 2 shows a standard load profile during increasing and decreasing load cycles in an engine test.[3] The test was performed following a step-load profile at a frequency of 10 hertz over a stroke length of 25 millimeters using a high-speed reciprocating drive. COF data were obtained from each constant load step for increasing and decreasing load cycles (see Table 1). COF data show an increasing trend as the normal load was increased. Such frictional behavior was attributed to the change of lubrication regimes toward mixed, or boundary regions at higher load, where the COF tends to be higher. It can also be observed in Table 1 that there was some offset in COF in the same constant load steps between increasing and decreasing load cycles. This offset in COF was likely due to the insufficient run-in of the piston ring prior to the test, as suggested in the ASTM standard.[3]

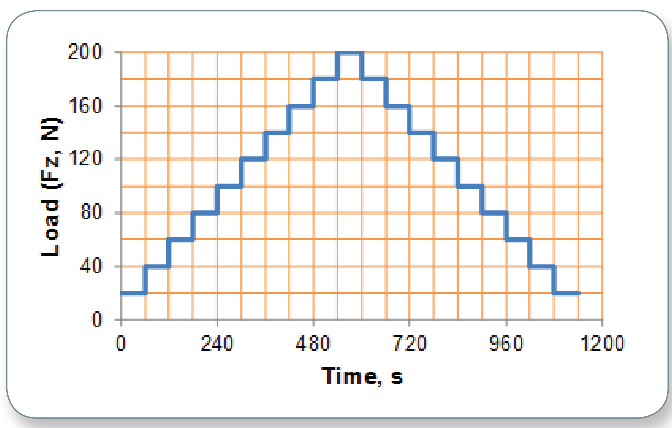

Figure 2. Normal load profile (Fz) as a function of time for an engine test.

Table 1. COF values at various loads during increasing and decreasing loading cycle.

Load	COF									
	Fz N									
	20	40	60	80	100	120	140	160	180	200
Increasing	0.053	0.056	0.055	0.055	0.058	0.060	0.063	0.065	0.069	0.071
Decreasing	0.055	0.059	0.061	0.062	0.064	0.065	0.066	0.069	0.071	0.071

The surface topography of the piston ring segment was evaluated using a Bruker ContourGT® optical profiler before and after the engine test to ascertain the comparative surface roughness parameters. Figures 3 and 4 show the representative topography of the piston ring surface before and after the test. Surface parameters, including arithmetical mean height (S_a), root mean square height (S_q), maximum peak height (S_p), minimum valley depth (S_v), and maximum peak-to-valley height (S_z) were obtained with the interferometric profiler (see Table 2). The parameters S_a, S_q, S_p, S_v, and S_z were found to have decreased after the test. This could be attributed to the initial run-in step prior to the actual engine test of the piston ring, which may have reduced the surface asperities and made the original surface smoother. Such reduction in surface asperity height can also be due to the boundary lubrication condition at the dead centers where the piston ring came in direct asperity contact with the cylinder liner segment.

Results of the reciprocating tests can be compared among different piston rings, cylinder liners, and lubricant materials. Such studies can be used to evaluate tribological

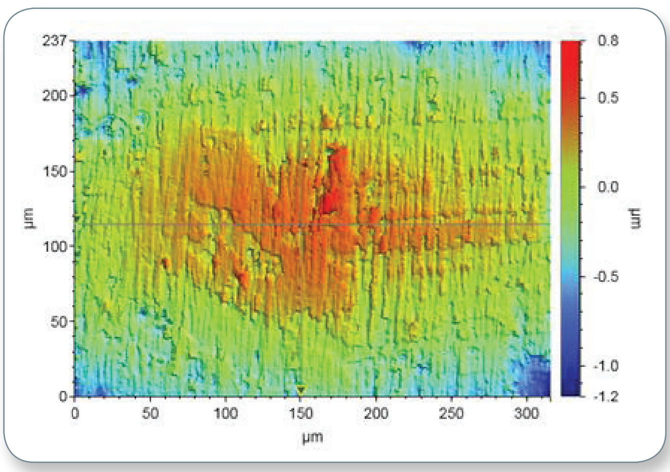

Figure 3. Surface topograph of the piston ring before performing the engine test, obtained with a Bruker ContourGT interferometer.

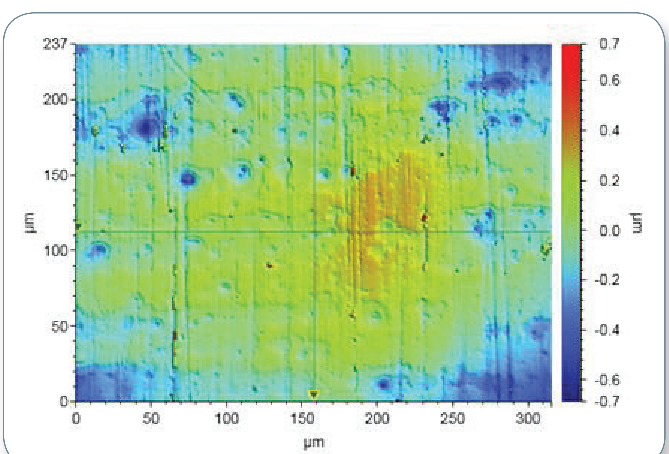

Figure 4. Surface topograph of the piston ring after performing the engine test, obtained with a Bruker ContourGT interferometer.

Table 2. Surface parameters of the piston ring before and after the engine test.

Surface	Surface Parameters, µm				
	S_a	S_q	S_p	S_v	$S_z=\|S_p-S_v\|$
Before Test	0.205	0.249	0.821	-1.176	1.997
After Test	0.123	0.157	0.746	-0.688	1.434

characteristics of piston ring and cylinder liner segments across a very wide range of engine types, and to develop and test new materials for engine components, as well as help in the development of more efficient and cost-effective lubricants.

Conclusions

Engine tribology is important in the research, development, and quality control of various machine elements for internal combustion engines. As piston assemblies are the highest contributor toward frictional losses in an engine, tribological study of piston ring and cylinder liner components in the presence of lubricants is considered to be the most beneficial activity in improving energy efficiency of an automobile. Bruker's UMT TriboLab test system is capable of performing such tribological evaluation to assist automotive engineers, materials scientists, and lubricant manufacturers toward achieving their fuel efficiency, emission, and durability objectives.

About UMT TriboLab

The UMT TriboLab system is built on Bruker's historic Universal Mechanical Test (UMT) platform and its precision control of load, speed, and positioning. The modular design of TriboLab ensures the flexibility to enable a wide range of force, speed, stroke length, and temperature test capabilities.

The UMT TriboLab is easy to reconfigure for nearly any tribological test, typically within minutes. Integrated "intelligent" hardware and software interfaces, such as TriboID™ and TriboScript™, make the instrument extremely user-friendly, versatile, and highly productive. TriboID not only automatically detects the various components attached to the main system necessary for its proper functioning, but it also configures them for operation. TriboScript offers an enhanced and secured scripting interface for easy compilation of test sequences of the already created test blocks. The TriboLab system is equipped with real-time control and data analysis software to ensure highest accuracy and repeatability.

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