# APPLICATIONS OF THE FOUR-BALL TEST METHODS AND COMPARISON WITH OTHER TESTS FOR FRICTION AND WEAR IN LUBRICANTS

Lubricants, including oils and greases, must always get tested for how they handle friction and wear on different types of surfaces under different operating conditions. Some lubricants will be more prone to allowing damage from friction and wear in certain applications than others and it is very important to see how different lubricants compare with each other in a given application. Many essential industries, such as automotive, aviation, marine, manufacturing, etc. rely on proper lubrication in machines in order to maximize efficiency and effectiveness in operation and tribology testing of lubricants is often the first step towards minimizing wear damage in machines. There have been different types of test methods developed for tribology testing and in particular, the four-ball method is used for measuring wear prevention and extreme pressure properties of lubricating oils and greases. In this article, we will discuss the importance of tribology testing of lubricants and explore how the four-ball testing compares with other types of testing.

Tribology testing of lubricants has been developed extensively over many years and will continue to be done to maximize the efficiency of industrial machines. This is done by decreasing friction and wear between sliding surfaces, reducing power requirements, and keeping direct contact between surfaces to a minimum. By reducing the amount of damage from wear, the longevity of machines can be almost doubled and this can increase energy efficiency, increase sustainability, and reduce emissions. It has been shown that emissions reduction potential can reach about 6 gigatons $CO_2$ just by optimizing wear protection. Along the lines of sustainability and the environment, there has recently been a large amount of research on the development of bio-lubricants, which are composed of biodegradable base oils, and also environmentally acceptable lubricants (EALs), which meet certain Sustainable Development Goals (SDGs) set forth by the United Nations. Because these new lubricants are made from non-traditional sources such as synthetic base oils and vegetable base oils, their tribological properties need to be tested to see how they compare with traditional mineral oil-based lubricants, and this is where the friction and wear testing comes in. It is very important to carry out accurate tribological tests on these new lubricants to see which ones should continue to be studied for further research and potential application [1]. Electric vehicles (EVs) present another area with a need to test tribological properties of lubricants. It has been determined that just over half of all the electric power delivered to an EV goes towards reducing losses from friction. It will be very important to analyze which lubricants can contribute to the lowest amount of frictional loss in an EV. Additionally, there are some differences in the EV driveline that friction and wear testing can address. These include the fact that lubricants for EVs must be adapted to high-speed reduction gears and also need to withstand high speeds of electric motors, which can reach up to 20,000 rpm [2].

To execute tribological testing, there are many different tests that have been developed and most of them are standardized with standard methods developed by organizations such as ASTM International and the former Institute of Petroleum. One type of test is called the twist compression test, which is meant to assess in what conditions will a lubricant breaks down and simulates lubricant starvation. This test measures the coefficient of friction by applying torque to a lubricated surface using a rotating cylinder under different pressures. This test generates different types of wear and is best as a comparative test. Another comparative test is the drawbead simulator, which measures coefficient of friction of a combination of lubricant in metal in a die cavity. It is meant to compare different lubricants under the same amount of load [3].

A test method that is popular for extreme pressure and coefficient of friction & wear determination is the SRV test instrument. This test analyzes the lubrication between a lubricant and two specimens, where the top specimen oscillates over the bottom specimen in either a linear or rotational fashion. One test method covered by this machine is ASTM D5706, "Standard Test Method for Determining Extreme Pressure Properties of Lubricating Greases Using a High-Frequency, Linear-Oscillation (SRV) Test Machine." In this method, load is increased until two specimens weld together and this is best for lubricating greases in constant velocity joints [4]. The other test method for the SRV machine is ASTM D5707, "Standard Test Method for Measuring Friction and Wear Properties of Lubricating Grease Using a High-Frequency, Linear-Oscillation (SRV) Test Machine." This method determines the coefficient of friction and also produces a wear scar, which is measured to determine the wear preventive properties of the lubricant. This method is also best for greases in both constant velocity joints and roller bearings [5,6].

A test method that is important specifically for extreme pressure

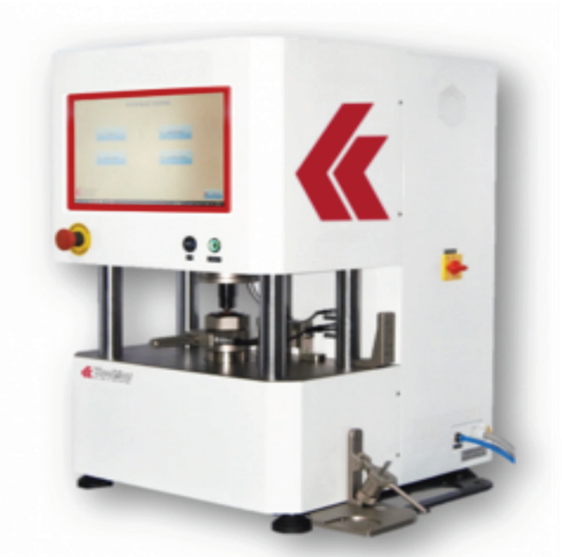

*Figure 1. Benchtop Four Ball Wear and EP Tester from Koehler Instrument Company*

(EP) properties of greases is the Timken method, carried out by a Timken tester. In this method, a tapered roller bearing cone is loaded against a steel block and the test runs for 10 minutes at 2.05 m/s with a constant grease feed into the system. The test stops when either the time has run out or when scuffing occurs and the steel test block is inspected afterwards for the extent of scuffing. The load reported from the test is defined as the highest load where scuffing did not occur. This method is standardized as ASTM D2509, "Standard Test Method for Measurement of Load-Carrying Capacity of Lubricating Grease (Timken Method)." It is best used to determine the degree of extreme pressure characteristics for a given grease, determined to be either low, medium, or high levels of extreme pressure characteristics. Usually if a grease has a 40 lb load from the Timken test, it is determined to be an EP grease [7,8].

In addition to all the methods above, one of the most important tests for EP properties and wear prevention characteristics is the four-ball method. The four-ball method is set apart from other friction and wear tests by the very unique arrangement of four steel test balls that are clamped together in the form of a tetrahedron. The four test balls are submerged in either oil or grease and the single top ball is rotated while in contact with three stationary balls beneath it. Because of the steel balls applied in the tests, the four-ball method is specifically applicable for sliding steel-on-steel applications. A study published in 1983 by Richard Gates and Stephen Hsu [9] was able to show sufficient correlation between four-ball wear tests and wear data gathered for automotive engine oils, so the method has proven very useful for automotive applications.

The first four-ball test method is done for wear prevention characteristics and is standardized as ASTM D2266 for greases and ASTM D4172 for oils. The conditions for these tests are as follows: a ball cavity which contains three 12.7 mm steel balls clamped together is filled with the test specimen (oil or grease) and then a fourth 12.7 mm steel ball is introduced on top of the three balls in the ball cavity, for a three-point contact. During the test, the top steel ball is rotated at 1200 rpm for 60 minutes and is pressed down against the three stationary balls at a constant 40 kgf force. The test specimen is also regulated at a constant temperature of 75°C. After the test is completed, the wear scar on each of the three stationary balls is measured and the final value is reported as the average of the three wear scars [10,11].

The four-ball method also includes tests for EP characteristics of lubricants and these are standardized as ASTM D2596 for greases and ASTM D2783 for oils. For these methods, the three stationary balls are covered in the test lubricant and the fourth top ball is rotated at a certain speed and a certain temperature and the load is increased in intervals of 10 seconds until welding of the steel balls occurs. In the case of D2596, the speed is around 1770 rpm and the lubricant temperature is around 27°C. For D2783, the speed is around 1760 rpm and the lubricant temperature is anywhere between 18 and 35°C [12,13].

Figure 1 shows an image of the Benchtop Four Ball Wear and EP Tester from Koehler Instrument Company. The large 15-inch touchscreen on the front of the instrument allows for precise user control of the test parameters and ease of use. This tester combines all of the typical four-ball test methods into one machine, including ASTM D5183 for coefficient of friction, through predefined built-in test protocols and also allows for the input of custom test parameters. All of the major test parameters, such as normal load, frictional force, test specimen temperature, rpm, and coefficient of friction are measured by data acquisition software and displayed on the screen. The tester allows for very precise control of the load up to 1000 kg using a closed-loop servo pneumatic drive. A dynamic load control system is also featured, which allows for a constant load test (for wear testing), progressive loading (for EP testing), or step wise loading. An AC servo motor provides accurate control of speed. The control of the speed and the dynamic loading allow for an analysis of the Stribeck curve which shows the type of lubrication regime in the system.

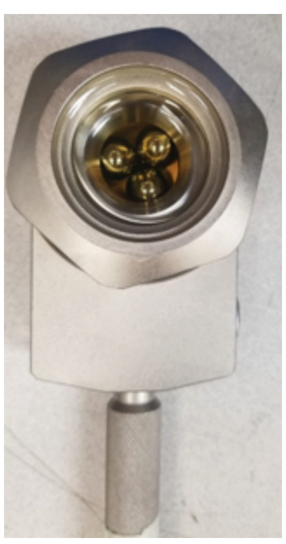

*Figure 2. A typical four ball test setup before test specimen is placed in the cavity*

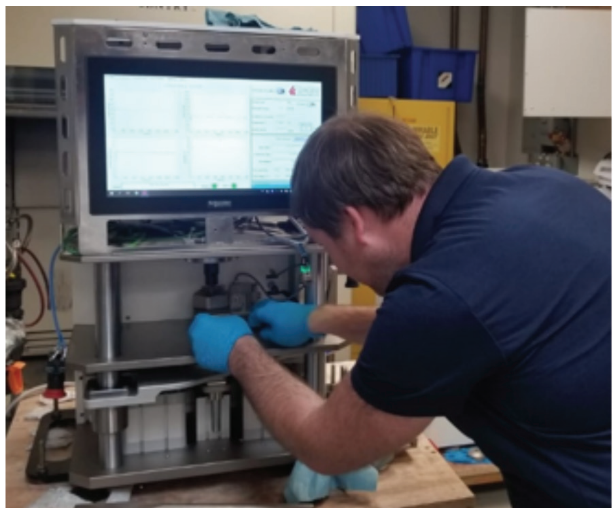

*Figure 3. The Koehler Benchtop Four Ball Tester during the manufacturing stage*

In conclusion, friction and wear testing of lubricants has always played a prominent role in ensuring that the proper lubricants are used for maximum protection against damage from wear. Many different tests exist, ranging from the SRV test to the Timken test and the twist compression test, with each test used to predict performance in specific applications. The four-ball method is a test specifically for steel-on-steel contact and has shown the greatest correlation with automotive lubricants. The National Lubricating Grease Institute (NLGI) has recently worked to update the traditional GC-LB specifications for automotive greases due to advancements over time in different materials and technologies. The new specifications for automotive greases are known as HPM, or High Performance Multiuse. The HPM specifications include more rigorous testing standards for greases to ensure that they perform even better than before, and new greases formulated today are already being tested against the new HPM standards. The four-ball test methods play a prominent role in HPM specs and now the need for more accurate tribological testing is required. Four-ball testers, such as the one from Koehler Instrument Company, will be sure to carry the next-generation of greases into the future.

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https://www.astm.org/DIGITAL_LIBRARY/MNL/SOURCE_PAGES/MNL37-2ND_foreword.pdf

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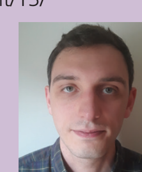

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