Development of a Bench Scale Performance Test Method for Lubricating Oils to Evaluate Wear and Extreme Pressure Properties for Lubes & Greases

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Introduction

Machinery operating under heavy loads, low speed, and high temperature conditions often require specially tailored lubricants and greases with exceptional anti-wear and Extreme pressure (EP) properties to provide protection against adhesion and friction wear. The most common method of measuring lubricant properties is the four-ball wear test. Particularly, the Four Ball Wear and EP Tester (K93170) is a reliable tool for assessing COF as well as WP and EP properties of lubricating oils. This instrument is designed as per ASTM standards to conduct tests that can be used as a tool for screening lubricating oils and narrowing down which gear oils should be further tested. The advantage of this instrument over the traditional dead weight loading technique is that the dynamic load control system with speed control can accurately control the load application and understand the Stribeck curve phenomenon.

Background Information

Testing Parameters

In order to advance the industrial applications of lubricating oils, three parameters can be used to evaluate the friction and wear properties of lubricants. The coefficient of friction (COF) is a quantitative measurement of the lubricity between contact surfaces. Wear preventive (WP) characteristics refer to the ability of a lubricating oil to prevent progressive loss of material due to mechanical interaction between two contacting surfaces under load. WP additives work by reacting with the surface material to deposit a protective barrier on the metal surface under extreme pressure. Furthermore, EP additives are usually used at heavier loads, high temperatures, and low speeds to prevent catastrophic failure or device blockage. EP lubricating oil produces a sacrificial coating that is softer than the unprotected base metal.

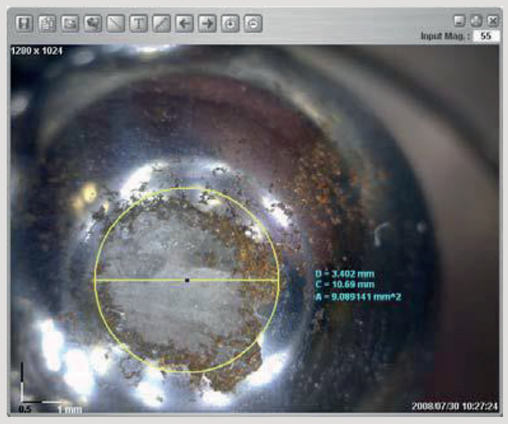

Figure 1. Digital Microscope for Wear Scar

General Testing Method

The Four-Ball Tester is used to characterize the properties of lubricants such as WP properties, EP properties and friction behavior. The test consisted of rotating a steel ball under load on three fixed steel balls. One ball rotates at a specific velocity, and three 12.7 mm diameter steel balls are clamped together and covered with the lubricant to be evaluated. The friction forces between the spinning ball and the three stationary balls are measured by a digital weighing sensor mounted at the precise location.

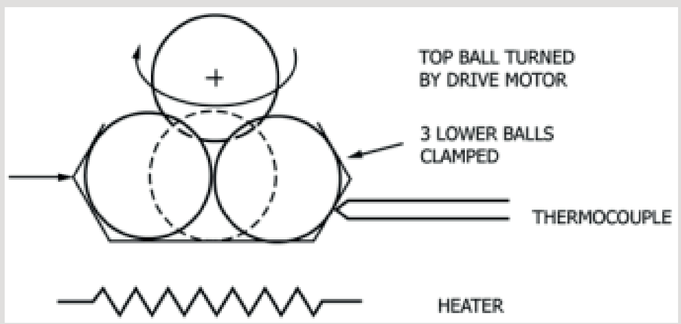

Figure 2. Schematic of a Four-Ball Wear Test Machine

Instrumentation

The K93170 Four Ball Wear and EP Tester is designed as per ASTM D2266, D2596, IP 239 and relative standards. According to this standard, the upper ball is rotated up to 2000 RPM and the lubricant can be heated up to 200°C. An axial force up to 1000 kg is applied through servo pneumatic close loop loading mechanisms.

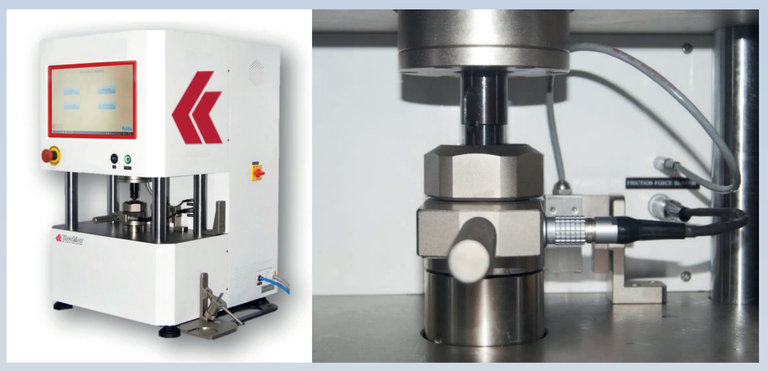

Figure 3. The K93170 Four Ball Wear and EP Instrument (left) and the testing chamber (right)

Compared to conventional dead weight loading technique, test load of K93170 Instrument can be controlled directly and accurately by a software-based closed-loop servo pneumatic drive. Tests can be selected between different load orders, such as constant load tests, incremental or decreasing load, and incremental or decreasing load.

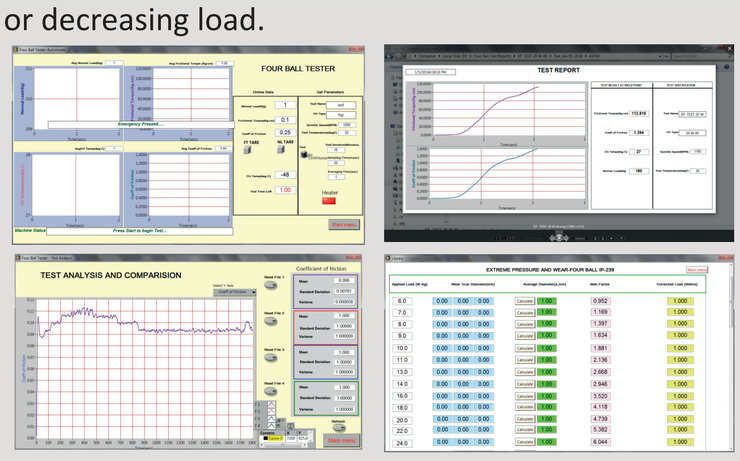

Figure 4. Data acquisition and analysis software interface

Tests and Results

Test for WP Characteristics of Lubricating Oil

WP properties tests are conducted on the lubricating oils below, implementing the K93170 Four Ball Wear and EP Tester, with the following restrictions:

- Pour the oil to be evaluated into a test oil cup until at least 3mm (1⁄8 in) above the top of the ball.
- Set temperature regulator to produce a test-oil temperature of 75 °C ± 2 °C (167 °F ± 4 °F).
- Set up the drive of the machine to obtain a spindle speed of 1200 r⁄min ± 60 r⁄min.
- When an automatic timer is used to terminate a test, it should be checked for the required ±1 min accuracy at 60 min elapsed time.

The precision data were derived from cooperative testing by 13 laboratories on 5 oils:

Sample		Scar Diameter, mm	
Number	Description	147 N	392 N
LXI2-1	Mineral Oil, 46 cSt at 40 °C	0.56	0.72
LXI2-2	LXI2-1 plus 1 % wt ZDT[A]	0.27	0.42
LXI2-3	LXI2-1 plus 2 % wt S/P[B]	0.28	0.35
LXI2-4	Synthetic hydrocarbon	0.53	0.76
LXI2-5	Tricresyl phosphate	0.54	0.59

[A] ZDT = zinc O, O-dialkylphosphorodithioate.
[B] S/P = additive containing sulfur and phosphorus.

Figure 5. Table of the summary of cooperative testing for 5 different oils

This test method has high repeatability and reproducibility.

Repeatability=0.12 mm scar diameter difference
Reproducibility=0.28 mm scar diameter difference

Another advantage of this instrument is that the procedure in this test method minimizes bias. In other words, the apparatus eliminates incorrect estimations in measuring the value of ball scar width because it can only be defined in terms of a test method.

Test for EP Characteristics of Lubricating Oil

In the EP test, there are two parameters are significant to measure, load-wear index and weld point. Load-wear index refers to the ability of a lubricant to reduce wear under applied load. Under the conditions of this test, it is measured as the average value of the modified load sum determined for the ten loads applied before the welding. Weld point is the minimum applied load exceeding the lubricating force, indicating the extreme pressure levels.

EP properties tests are conducted on the lubricating oils by using K93170 with different restrictions:

- Set up the temperature of test oil and cup to 18°C to 35 °C (65 to 95°F).
- When the measured wear scar remains 5% above the compensation line, continue this process until a total of 10 runs.

Several useful parameters are derived from the data obtained by the tester. The load-wear index can be calculated by averaging the corrected loads determined by the 10 loads prior to the welding point.

Sample	L-XI-1-2-A	L-XI-1-2-B	L-XI-1-2-C	L-XI-1-2-D[A]	L-XI-1-2-E	L-XI-1-2-F
Number of cooperators	11	11	11	8	8	10
Grand average, LWI, kg	16.08	26.87	71.23	76.8	53.7	51.25
Number of runs	30	30	30	19	29	29
Repeatability, kg	1.93	1.26	5.02	3.14	3.04	3.34
Reproducibility, kg	7.25	6.66	11.95	18.55	27.1	20.2

[A] Wear scar values above compensation line.

Figure 6. Table of precision data for load-wear index of 6 different oils

Laboratory	1	2	3	4	5[A]	6	7	8	9	10	11A	11B	12
Sample L-XI-1-2-A													
Run 1 Weld Point, kg	100	...	126	100	126	100	126	100	126	126	126	126	100
Run 2 Weld Point, kg	100	...	100	100	126	100	126	100	100	...	126	126	100
Run 3 Weld Point, kg	100	...	100	...	126	100	126	100	100	...	126	126	100
Sample L-XI-1-2-B													
Run 1 Weld Point, kg	160	...	160	160	200	160	200	160	160	160	160	200	160
Run 2 Weld Point, kg	160	...	160	160	200	160	200	160	160	...	160	200	160
Run 3 Weld Point, kg	160	...	160	...	200	160	200	160	160	...	160	200	160
Sample L-XI-1-2-C													
Laboratory	1	2	3	4	5[A]	6	7	8	9	10	11A	11B	12
Run 1 Weld Point, kg	620	...	500	500	620	500	620	500	500	500	500	500	500
Run 2 Weld Point, kg	500	...	500	500	620	500	620	500	500	...	500	500	500
Run 3 Weld Point, kg	500	...	500	...	620	500	800	500	500	...	500	500	500
Sample L-XI-1-2-D													
Laboratory	1	2	3	4	5[A]	6	7	8	9	10	11A	11B	12
Run 1	500	...	...	400	800	400	...	500	500	500	500	500	...
Run 2	500	...	...	400	800	400	...	400	500	500	...	...	...
Run 3	500	...	...	...	800	400	...	500	500	500	...	...	...
Sample L-XI-1-2-E													
Laboratory	1	2	3	4	5[A]	6	7	8	9	10	11A	11B	12
Run 1	...	...	...	250	315	...	315	250	250	250	250	250	250
Run 2	...	...	...	200	315	...	315	250	200	250	250	250	250
Run 3	...	...	...	...	315	...	315	250	250	250	250	250	250
Sample L-XI-1-2-F													
Laboratory	1	2	3	4	5[A]	6	7	8	9	10	11A	11B	12
Run 1	315	...	...	315	315	250	315	250	250	315	315	315	400
Run 2	315	...	...	250	315	250	400	315	250	315	315	315	315
Run 3	315	...	...	...	315	250	400	315	315	315	315	315	315

[A] Four-ball EP tester run at 1500 rpm.

Figure 7. Table of laboratory test results welding point of 6 different oils

Also, this test method has high repeatability and reproducibility.

Load-wear Index:
Repeatability=17 % of the mean value
Reproducibility=44 % of the mean value
Weld point:
Repeatability= more than one increment loading
Reproducibility=more than one increment loading

According to the experimental procedures, continuous results were obtained throughout nineteen out of the twenty experimental cases using the same test lubricant and conditions. Moreover, the difference between the two independent results obtained by different research groups working in different laboratories is greater than the repeatability values only one in twenty cases.

Conclusion

The results convey that the K93170 Four Ball Wear and EP Tester can exceptionally analyze the WP and EP properties of lubricating oils. These test results are important indicators of lubricant behavior when used in practical applications which can guide engineers to make better decisions on the use of lubricating oil. This instrument has high repeatability and high reproducibility, meaning that measurements made by a single instrument or individual under the same conditions have minimal interference, and the entire test can be reproduced consistently. Therefore, K93170 can be used as pre-selection for further field trails.