FROM LOAD STEPS TO LOAD RAMPS: DEVELOPMENTS IN FASTER FOUR-BALL TESTING FOR LUBRICANT DEVELOPMENT

Introduction

The four-ball test has long been used to compare the wear and extreme-pressure performance of lubricants. Recent work is focused on making some four-ball determinations faster by replacing a series of individual load steps with a continuous load ramp. ASTM International is currently balloting WK100071, a proposed new method for measuring the extreme-pressure properties and load-carrying capacity of greases using four-ball geometry and a constant load-ramp rate [14]. The proposed method has not yet been published as an ASTM standard.

At the 2025 STLE Annual Meeting, researchers from Valvoline Global Operations and Falex Tribology presented a programmable variable-load four-ball procedure using a one-minute run-in at 40 kg, followed by a fixed-rate normal-load ramp until failure or the machine limit [16]. The authors compared the results with ASTM D2596 data and described the procedure as a possible rapid screening method [16].

Figure 1. Koehler K93170-PN/K93179-PN Benchtop Four Ball Wear and EP Tester with software-controlled, closed-loop pneumatic loading. Image courtesy of Koehler Instrument Company, Inc.

Faster extreme-pressure testing is one area in which the four-ball method is advancing. A second area concerns the growing need to evaluate lubricants under electrical conditions. No matter how much the automotive industry changes, lubrication remains an important part of keeping core components, such as drivetrains, operating properly. The transition from internal combustion engines (ICEs) to electric vehicles (EVs) creates new demands for lubricants. Higher rotational speeds and electrical currents passing through lubricated contacts [1] create additional factors to consider, including electrically induced bearing damage (EIBD) caused by stray and circulating currents generated by inverter switching [2].

When an electrical current passes through a conductive vehicle component, it can produce surface damage that differs from the mechanical wear normally observed. Craters can develop, and the lubricant can also change chemically. A standard sliding steel-on-steel wear test may therefore give only part of the picture of how a lubricant will perform in an electric drivetrain. This review evaluates the established four-ball methods, recent work intended to make extreme-pressure testing faster, and research in which electrical current has been introduced into the four-ball apparatus.

How the Four-Ball Test Functions

The four-ball test is a method used to compare how well different lubricants prevent wear. ASTM D4172 covers a procedure for making a preliminary evaluation of the anti-wear properties of fluid lubricants in sliding contact [3]. In the normal setup, three 12.7 mm steel balls are held together inside a cup and submerged in the test lubricant. A fourth ball is brought into contact with the three lower balls and rotated under a specified load, speed, and temperature. Under ASTM D4172 Condition B, the mechanical baseline used in the electrified work discussed below, the test was conducted at 1200 r/min for 60 minutes at 75 °C under a 40 kgf (392 N) load [3]. After the test, the wear-scar diameters are measured under a microscope, and a smaller scar indicates better protection under the specified conditions.

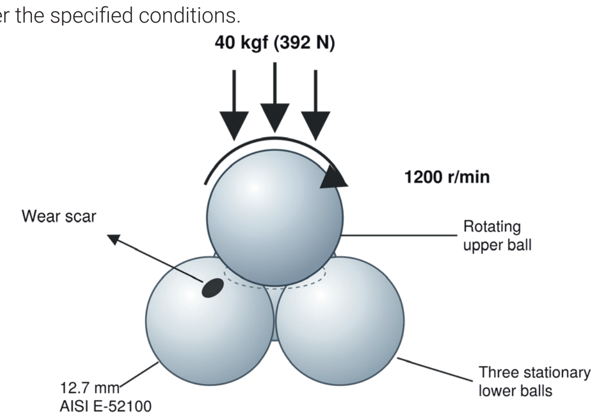

Figure 2. Schematic of the four-ball wear test configuration under ASTM D4172 Condition B [3].

The four-ball apparatus can also be used for other types of lubricant testing. When testing for wear, the load is held at one specified value and the resulting wear-scar diameter is reported. Extreme-pressure testing takes a different approach by progressively increasing the load until the contacting balls weld to one another. ASTM D2783 determines the load-wear index and weld point for lubricating fluids [4]. ASTM D2596 covers greases and reports the load-wear index, weld point, and last nonseizure load [5]. ASTM D5183 determines the coefficient of friction of lubricants under prescribed four-ball conditions [6]. ASTM D2266 covers the wear-preventive characteristics of greases [7]. These methods make the four-ball machine useful because only a small amount of lubricant is needed, the conditions are controlled, and the same basic apparatus can be used for several test objectives.

Moving from Load Steps to Load Ramps

Traditional ASTM D2596 extreme-pressure testing is performed through a series of 10-second runs at increasing loads. A complete determination can require several runs, with the test balls removed, cleaned, measured, and replaced between stages [5]. A continuously ramped test uses one programmed loading sequence instead. Singh and colleagues evaluated a related procedure for oils and greases, using the coefficient-of-friction peak to identify the last nonseizure transition. Within their test program, they identified 30 N/s for oils and 60 N/s for greases as suitable load-ramp rates [17]. These figures are loading rates, not complete test durations.

Speed is not the only reason for this work. A separate ASTM work item, WK86025, addresses spindle speed ramp-up time, or the time required to reach 1770 r/min, which its rationale identifies as a source of variation between instruments [15]. The related WK100071 effort examines whether constant load ramping can provide a shorter method for determining the extreme-pressure properties of greases [14].

Programmable loading is important for this type of work. The Koehler K93170-PN/K93179-PN Benchtop Four Ball Wear and EP Tester uses software-controlled, closed-loop pneumatic loading and supports user-defined test sequences [8]. It records applied load, frictional force, coefficient of friction, temperature, speed, and time. These capabilities provide a basis for evaluating proposed load-ramp procedures while continuing to run established four-ball methods. Compatibility with any final ASTM method would need to be confirmed after its requirements have been approved and published.

What Standard Four-Ball Methods Measure

The four-ball method is widely used because it provides a controlled way to compare lubricant samples. ASTM D4172 is intentionally a test for wear prevention in sliding contact and notes that it was not developed to establish correlation with balls operating in rolling contact [3]. This clarification is important when the result is being used to understand an EV bearing. Standard D4172 prescribes load, speed, temperature, and duration but does not include electrical loading [3]. Electrified test equipment is being developed for research [9], although a standardized procedure for evaluating base oils, additives, or fully formulated lubricants under electrical conditions has not yet been established [10].

Wear results are typically reported as the diameters of scars observed on the balls, which provide a straightforward way to compare samples. Electrical damage, however, may also appear as pitting, frosting, and fluting. These are surface changes that are not described completely by scar diameter alone [11]. For this reason, wear-scar measurements can be supplemented with surface imaging and electrical measurements when the application requires them.

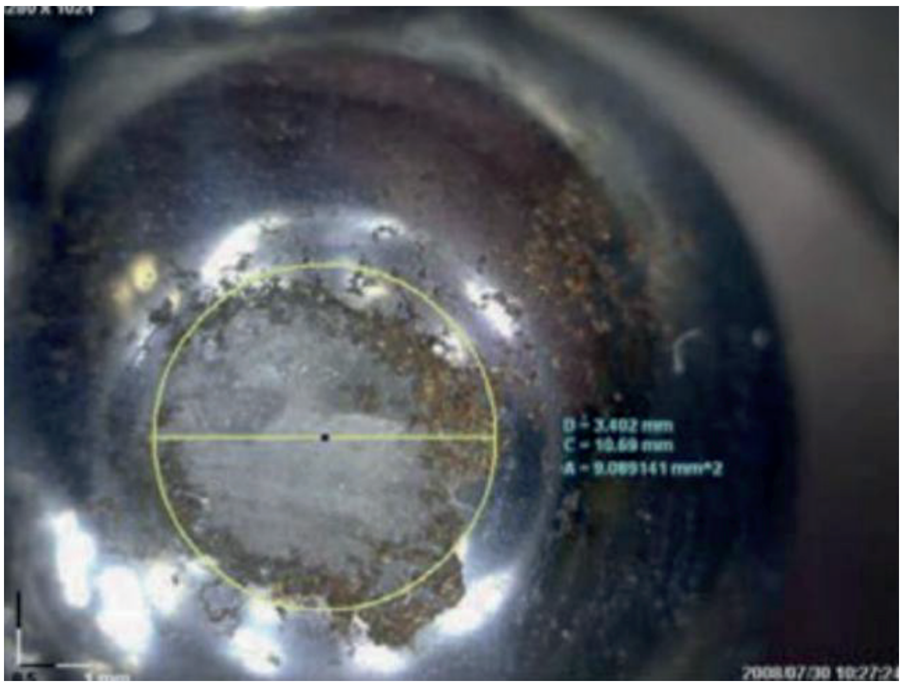

Figure 3. Conventional four-ball wear scar produced under standard sliding steel-on-steel conditions. Reproduced from Koehler Instrument Company, Inc. internal micrograph (Yu, Shah, & Gashi, 2008) [12].

The type of motion and the materials in contact should also be considered when interpreting the result. The four-ball test creates a point contact in which the upper ball slides against the three stationary lower balls. Gears have line contact with sliding, while bearings operate mainly through rolling motion [13]. The test also uses steel-to-steel contact, whereas EV lubricants may interact with copper, electrical insulation, aluminum, and other materials. These differences define the intended role of the four-ball result; they do not reduce its value as a controlled comparison.

The method remains widely used because of its simple design, small lubricant requirement, relatively low testing cost, and established precision. ASTM D4172 has been evaluated across multiple laboratories. Thirteen laboratories tested five oils and reported a repeatability of 0.12 mm and a reproducibility of 0.28 mm in wear-scar diameter [3]. Standard four-ball testing therefore provides a repeatable mechanical baseline that can be supplemented with electrical loading, surface characterization, temperature, resistance, and chemical analysis when those measurements are needed.

Bringing Current into the Test

In addition to improving the speed of four-ball testing, researchers have begun modifying the apparatus to include electrical current. One example is the work of Aguilar-Rosas and colleagues, who added a DC power supply and resistance data logger to a conventional four-ball tester and conducted tests at current levels of 0, 1.5, and 3 A [10]. The apparatus used ASTM D4172 Condition B as the mechanical baseline and then added a nonstandard DC circuit. It should therefore be understood as a research modification rather than an electrified ASTM D4172 procedure. It did not reproduce rolling-bearing contact, inverter pulse-width-modulated waveforms, high-frequency common-mode voltage, or complete EV drivetrain operation. The study compared a neat mineral base oil, two automatic transmission fluids, and one gear oil.

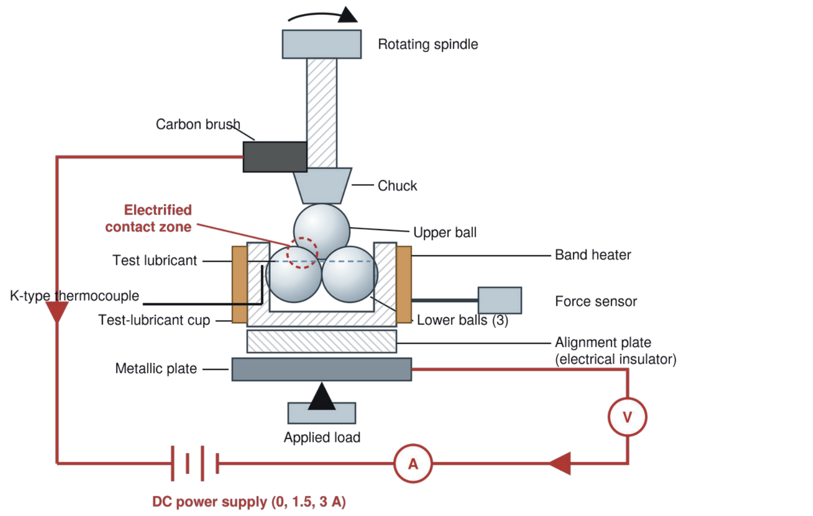

Figure 4. Schematic of the modified four-ball apparatus with DC circuit, based on the configuration described in [10].

In addition to average wear-scar diameter, the modified apparatus recorded coefficient of friction, electrical contact resistance, and contact temperature. Post-test infrared spectroscopy assessed chemical changes in the lubricants. The results indicated that applying current could alter friction and wear in ways that are not described by wear-scar diameter alone. In one of the transmission fluids, for example, the electrified wear track contained scratches and occasional small craters. Wear-scar diameters measured across the three lower balls remained within 30 µm of one another, and the standard deviation remained below 120 µm for all tested fluids and conditions [10]. The results show that the modified apparatus can be used for laboratory research. Repeatability and interlaboratory reproducibility for a standardized electrified procedure still need to be established. ASTM D4172 also notes that stated precision may not apply when the prescribed test parameters are changed [3].

Electrical contact resistance provides an indirect indication of electrical continuity and contact separation during the test, although it does not directly measure lubricant-film thickness. Wear-scar measurements describe the condition of the surface after the test, while infrared spectroscopy can indicate whether the lubricant changed chemically compared with the baseline. On its own, however, infrared spectroscopy cannot show that current was the only cause of those changes. Used together, these measurements extend the four-ball apparatus from a simple wear comparison into a configuration that can also report electrical, thermal, surface, and post-test chemical changes.

Current Work and Outlook

Current work on the four-ball method is moving in two directions. The first is the development and balloting of a constant-load-ramp procedure for faster grease EP testing [14]. The second represents the ongoing development of electrified test configurations. There is currently no standardized ASTM electrified four-ball procedure with agreed electrical input, waveform, polarity, contact geometry, insulation, and reporting requirements. Published testing indicates that current can affect lubricant performance and wear, but researchers use different methods and conditions [10]. Common test parameters and reporting practices would allow results to be compared more directly between laboratories. A combination of wear-scar measurement, surface characterization, contact resistance, temperature, and lubricant chemistry can then provide a more complete picture of the lubricated contact.

Conclusion

Four-ball testing continues to be a practical method for comparing lubricant wear, extreme-pressure performance, and friction under controlled conditions. The proposed constant-load-ramp approach could make early EP screening faster, while electrified configurations can provide additional information about how current affects friction, wear, temperature, resistance, and lubricant chemistry. These developments build on the standard mechanical methods rather than replace them. For electrified testing, future standardization would require defined electrical parameters, insulation and safety controls, reporting requirements, interlaboratory precision, and validation against representative component-level tests.

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Abhinav Pagidi is a second-year Mechanical Engineering student at Michigan State University. His academic interests include automotive systems and emerging electric vehicle technologies. Through coursework and independent exploration, he enjoys learning about principles that influence the performance, durability, and efficiency of modern transportation systems. Abhinav is particularly interested in the continued evolution of electric vehicles and the technologies that support them. After his research at Koehler, he looks forward to exploring advanced vehicle technologies and next-generation solutions in the future.

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