USING THE BENCH SCALE FOUR BALL TEST TECHNOLOGY TO EVALUATE FLUIDS FOR ELECTRIC VEHICLES

The continuous release of harmful carbon emissions around the world has ignited increased awareness of climate change. One of the ways that people have found effective in lowering carbon emissions is through a focus on daily transportation. One of the ways of improving this is switching to electric vehicles which offer many positives. They provide both lower fuel costs as well as eliminating exhaust which lowers greenhouse gas emissions [1]. In addition, the batteries within electric vehicles are designed for extended life with several manufacturers offering an 8 year/100,000 mile warranty. The National Renewable Energy Laboratory states that today's batteries should last between 12 to 15 years [2] which is much better than internal combustion engine (ICE) vehicles that only last for around 3 years [3].

This has led to increased support for the development of electric vehicles (EVs) and the necessary components needed to construct them. Lubricants and greases are pivotal components to making an EV run efficiently. The use of lubricants and greases in EVs provide effects such as reducing the amount of noise produced, the efficiency of the vehicle, and the presence of electrical current and electromagnetic fields from electric modules, sensors and circuits [4]. As a result, there are various test methods used to determine different properties of these lubes and greases. All of these test methods and the equipment used within them must follow the standards issued by the American Society for Testing and Materials (ASTM International).

The primary instrument used for the test methods discussed later on in the paper is the K93170 Koehler Four Ball Wear and EP Tester. The K93170 Four Ball Wear and EP Tester is designed with ASTM standards in mind to conduct tests to determine the coefficient of friction of lubricants, wear preventative and extreme pressure properties of lubricating oils under a variety of test conditions. This instrument can also be used to determine load carrying properties by the load wear index and the weld point method which adds more usage to this exquisite model.

The test load is directly controlled through a software-based closed loop servo-pneumatic drive, which enables precise control over the load application. The user can choose between different loading sequences, such as constant load test, progressive loading in increment or decrement, and also step-wise loading in increment or decrement. This dynamic load control system with speed control can also be used for understanding the Stribeck curve phenomena, which is not possible with the conventional dead weight loading technique [5].

A machine's lifespan can almost be doubled due to the optimization of its different components., Tthis optimization can also lead to increased energy efficiency and sustainability [6]. There are various different methods used in order to test different qualifications that are needed in an EV. These qualifications are different from the standard ones used in the conventional ICE vehicles. These qualifications include, but are not limited to noise, efficiency, and the presence of electrical current and electromagnetic fields from electric modules, sensors and circuits

Figure 1: K93170 Koehler Four Ball Wear and EP Tester [5]

[4]. Each of these qualifications play an important role in the operation of EVs. Noise in EVs can be annoying to the driver, but it also is a perception of the quality of the EV. More importantly, the noise affects sensors that are progressively used in the vehicle's safety and guidance according to Chad Chichester, a member of Society of Tribologists and Lubricant Engineers (STLE). The energy efficiency is another crucial aspect of an EV. It must be raised in order to compensate for the range anxiety, the fear of not being near a charging station, that may be caused by EVs. Range anxiety is one of the main reasons why people hesitate to transition to EVs. This has called for automotive engineers to increase the efficiency of EVs by making vehicles lighter and decreasing the energy lost due to friction in all the components necessary for an EV. More than half of the power used by electric vehicles is used to reduce losses caused by friction [6].

The components in electric vehicles are different from previously used ICE's so the lubricants used can not be the exact same and new lubricants must be produced and tested for new types of engines and the new systems in electric vehicles.

In addition, the presence of electrical currents and electromagnetic fields calls for engineers to test the corrosion and material compatibility of these different greases and lubricants in order for the EV to function properly [4]. With increased corrosion resistance and material compatibility, the efficiency of the EV will also be optimized. The call for changes needed for greases and lubricants in EVs shows the necessity of different test methods. As seen in Table 1, there are a variety of test methods that test different kinds of properties in the greases and lubricants needed.

Table 1. Table of Select Test Methods used for Lubricants in EVs [4]

Table 1. Selected Test Specifications Relevant to Wheel Bearing Lubrication in Electric Vehicles

Required characteristics	Test specifications
Superior wear properties under accelerated rolling contact fatigue	DIN 51819 - FAG FE8 (Wear of Rollers)
High-operating temperature	ASTM D2265 - Dropping Point
Excellent oil release properties	IP 121, ASTM D1742, ASTM D6184
Fretting resistance	ASTM D4170 - Fafnir Fretting Test, SNR FEB 2
Corrosion resistance	ASTM D6138 - Anti-Rust Test
Low-temperature torque	ASTM D1478 - Cold Start Torque
Consistency	ASTM D217 - NLGI Grade
Mechanical/work stability	ASM D217 - Worked Cone Penetration (100Kx)
Resistance to physical degradation	ASTM D1831 - Grease Roll Stability
EP properties	ASTM D2266, ASTM D2596 - 4 Ball Welding Test
Water resistance	ASTM D1264 - Water Washout Test
Grease life/oxidation stability	DIN 51821 - FAG FE9
Seal compatibility	ASTM D4289: Elastomer Compatibility

Courtesy of Kuldeep Mistry and The Timken Co.

There are about three primary test methods that are associated with the four ball tester. One of these test methods is known as ASTM D2266. ASTM D2266 is a standard test method that measures the wear preventive characteristics of lubricating greases. This test method is utilized to determine the relative wear-preventing properties of greases under the specified test conditions. The basic procedure for the ASTM D2266 Test Method starts when three 1⁄2 in. diameter steel balls are clamped together and covered with the lubricant to be evaluated as seen in Figure 2. A fourth 1⁄2 in. diameter steel ball, known as the top ball, is then pressed with a force of 392 N into the cavity formed by the three clamped balls for three-point contact. The temperature of the lubricating grease specimen is then regulated at 167°F and then the top ball is rotated at 1200 rpm for 60 min. Lubricants are compared by using the average size of the scar diameters worn on the three lower clamped balls [7].

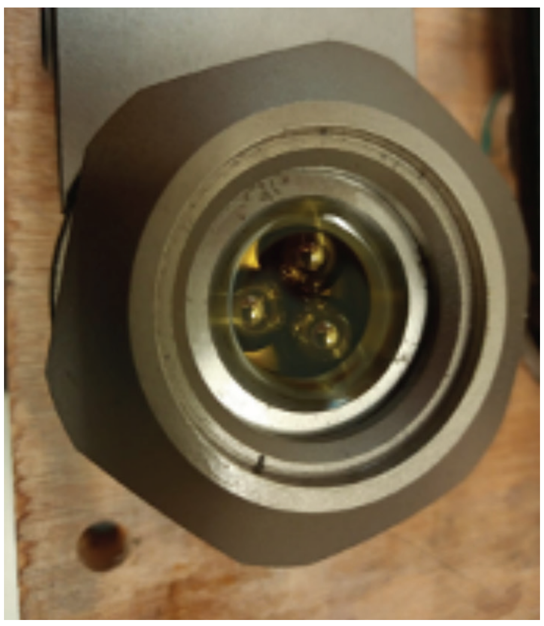
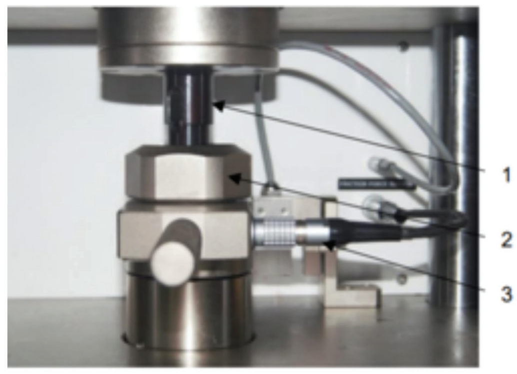


Figure 2. Arrangement of three 1/2 in. Diameter Steel Balls within K93170 Koehler Four Ball Wear and EP Tester [8]

Another of the methods used in the four ball tester is ASTM D5183. ASTM D5183 is a standard test method used for determination of the coefficient of friction of lubricants using the four-ball wear test instrument. The basic procedure of ASTM D5138 starts with the three steel balls being clamped together and covered with 10 mL of the lubricant. The fourth ball is then pressed with a force of 392 N into the cavity formed by the three clamped balls for three-point contact. The temperature of the wear-in lubricant is regulated at 75°C (167°F), and then, the top ball is rotated at 600 rpm for 60 min. Fluid is discarded and balls cleaned. The wear scar diameter on each of the lower three balls is examined. If the wear scars average 0.67 ± 0.03 mm, (0.026 ± 0.001 in.) then the 10 mL of test fluid is added to the ball cup with the worn-in test balls in place. The temperature of the test lubricant is regulated at 75°C (167°F) and the top ball is rotated at 600 rpm at 98.1 N (10 kgf) for 10 min. The load is then increased by 98.1 N (10 kgf) at the end of each successive 10 min interval up to the point where the frictional trace indicates incipient seizure. The coefficient of friction is



1. **Spindle Unit.**
2. **Ball Pot Assembly.**
3. **Heater & Thermocouple Cable.**

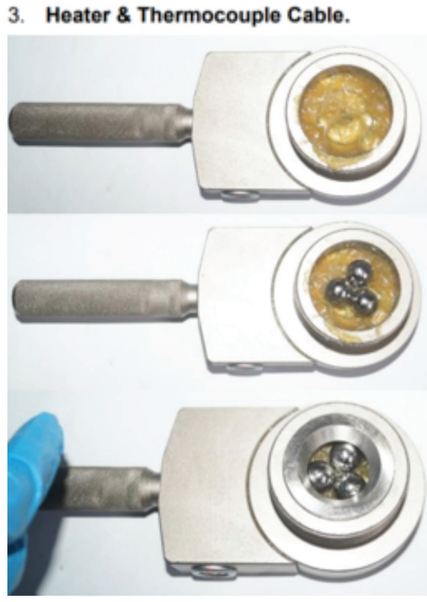


Figure 3. Setup of K93170 Koehler Koehler Four Ball Wear and EP Tester(Left) and Preparation of the Apparatus for Testing(Right) [11]

measured at the end of each 10 min interval [9]. The coefficient of friction can then be calculated using the data obtained and equation 1 as seen below.

*μ=0.00227*fL/P (Eq. 1) [9]*

The equation is formatted so thatμis the friction factor, f is the friction force in Newtons, L is the length of the lever arm in cm and P is the test load in kg.

The final test method of the four ball tester is known as ASTM D2596. ASTM D2596 is a standard test method that is used for specification purposes and differentiating between lubricating greases having low, medium, and high level of extreme-pressure properties. The basic procedure of ASTM D2596 starts when the tester is operated with one steel ball under load rotating against three steel balls held stationary in the form of a cradle. The rotating speed is 1770 ± 60 rpm. Lubricating greases are brought to 27 ± 8°C (80 ± 15°F) and then subjected to a series of tests of 10-s duration at increasing loads until welding occurs [10].

The four ball test method is a very important test method for lubricants and greases for electric vehicles for determining the wear prevention characteristics. All of the test methods mentioned are crucial within the four ball test and a special instrument is needed in order to measure all the properties.

This specific apparatus is very versatile and is able to test different properties for lubricants that apply in many different fields and systems, providing information on the coefficient of friction of different lubricants and greases, their weld load and other types of information. It is no surprise that researchers frequently use this test method to test the properties of different substances before they can be used as lubricants in their machinery. A research study was conducted on the ramp up time to simulate the ramp up time of these substances for experience in actual motors. Using test method ASTM D2596 they were able to calculate the weld load, and friction coefficient of the greases tested.

The data shown in Figure 4 shows real world data of a grease tested using the four ball test method. While the data would seem inconsequential it proves that even the slightest change in the startup time of a motor has a huge impact on the friction between the moving parts of the motor and the grease. The more startup time the grease is given the lower the friction is. The data shows a change in time from 0.15 seconds to 0.95 which is just a 0.8 second difference which is barely anything but it has a huge difference. On an EV or even an ICE engine that would be running for tens of thousands of miles, this small change in the friction coefficient could decrease the possible efficiency and sustainability of the vehicle by a huge amount. Minor differences in the many properties of lubricants and greases can have a bigger impact than one can imagine because of the total lifetime and use of each instrument.

Another study tested whether or not certain greases and lubricants could handle varying loads for a set amount of time.

This study while not directly related to the study of EV's still shows another very important property being tested. Electric vehicles accelerate much faster than cars with ICE's and all around are faster [14]. This increase in speed would mean that the engines in electric vehicles would be under more stress in a shorter period of time than current vehicles are in. This means that it's important to test how much the friction fluctuates with differing amounts of

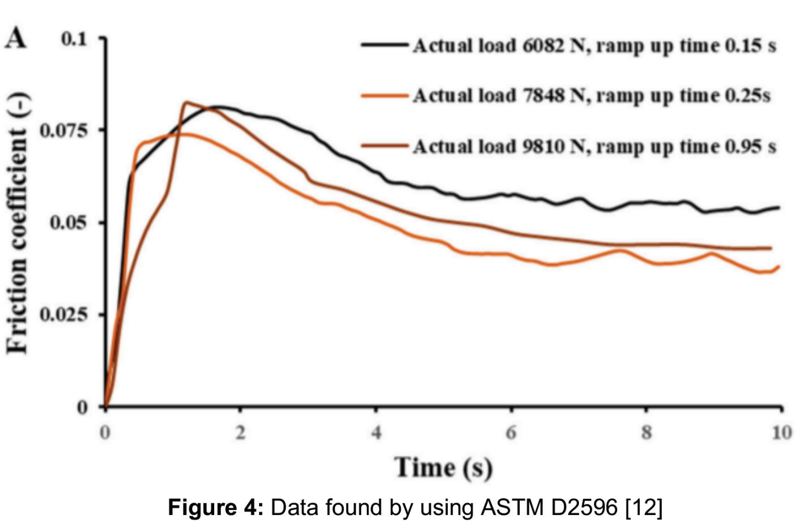


Figure 4: Data found by using ASTM D2596 [12]

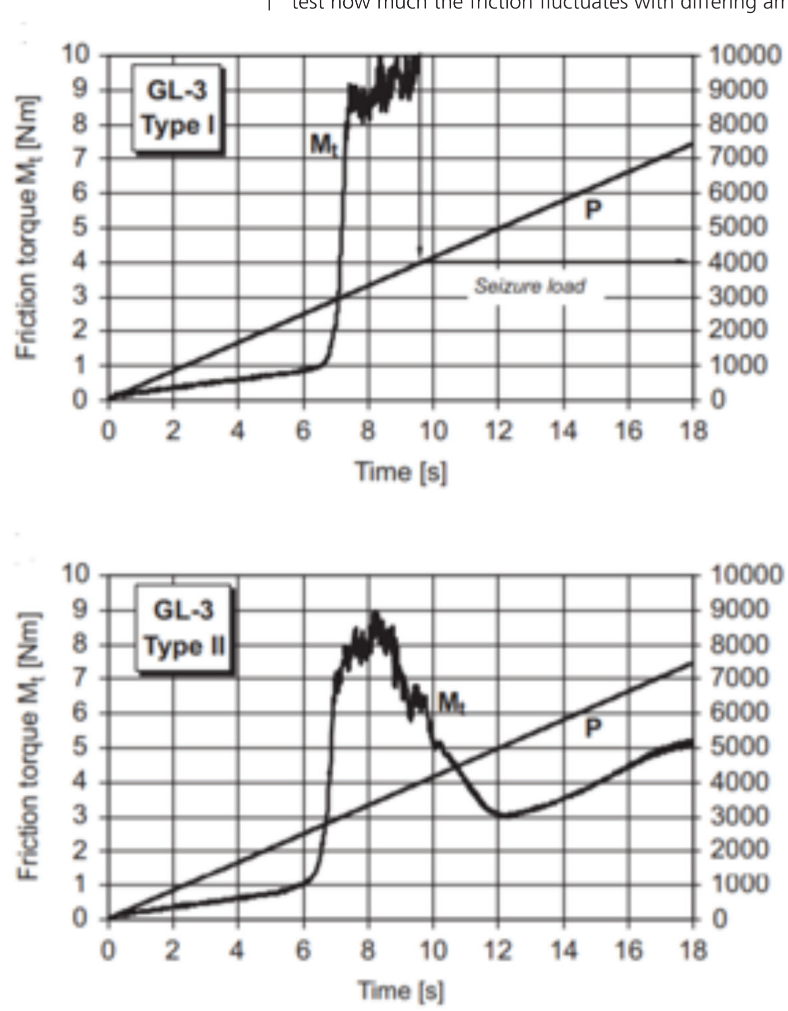


Figure 5: Graphs showing the load applied versus the time and the friction [13]

load over the course of time. If something as niche as this is not tested then something as simple as a person accelerating their vehicle could result in a huge loss to the lifespan in their vehicle, decreasing the range and reliability of their vehicle.

Electric vehicles not only provide consumers with an eco-friendly alternative to current vehicles that run with ICE engines but also a more efficient vehicle. Electric vehicles use about 77% of the electrical energy provided to them and with the optimization of their properties they may be able to use them more efficiently [15]. To optimize their properties they must first be tested. A test method as versatile as the four ball test method would not only be useful for making EV's more efficient but in many other industries that use lubricants and greases, not only increasing the efficacy of these other industries but also their sustainability.

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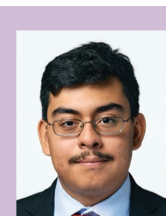
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