A simple solution for evaluation of lubricants anti-wear properties

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Abstract. The present paper describes a simple four balls testing device adapted for a classical drilling machine, using standard methodology meant to evaluate the lubricating properties of lubricants. The advantage of the method consists in the possibility of using any type of balls and a special device adapted to a common drilling machine. The evaluation of anti-wear lubricants properties can be done by comparing the contact scar dimension obtained experimentally, following the procedure described in EN ISO 20623:2003 international standard. The contact scar diameter is measured using an optic microscope equipped with a camera and specialized software, by comparing the scar with a known body dimension. Some experimental results obtained for the contact between four 12.7 mm bearing balls lubricated with grease are presented as well. The contact scar dimension-load dependencies are similar to those presented in literature and therefore validate the experimental setup.

1. Introduction

Tribology failures determine about 30 percent of all failures in mechanical systems, [1]. This amount can be minimized by proper selection of lubricant, [2], the key element for proper system running. Knowledge of the anti-wear properties of lubricants is a very important aspect in system running. These properties can be determined by using special test machines and following a well specified procedure which involves specific testing equipment. This can be a real problem for small and medium factories, because it implies additional costs and investments that are unjustified if the low number of tests is considered. In such small manufactories, even to order of the tests from a specialized laboratory that owns the proper testing machine, raises costs and time problems. Usually, only comparing the anti-wear properties of two lubricants is required, in order to adequately choose the best suited one. This comparison is best done using the four balls test.

The four balls tests are used to measure the anti-wear and extreme pressure properties of lubricants by monitoring the evolution of wear scars. By comparing the results for different lubricants, it can be determined which is the best lubricant that can be used in certain conditions.

The test procedure is described in EN ISO 20623:2003 international standard, [3], and consists in a four balls special tester in which an upper rotating bearing ball is in contact with 3 lower bearing balls, fixed and immersed in lubricant. The upper ball is held in a steel chuck and rotated with 1450-1500 rpm by an electric motor. The lower bearing balls are held against each other in a steel cup. The ensemble is supported by a disc which rests on an axial bearing that allows horizontal displacements and self alignment between the upper rotating ball and the lower balls. The load is applied vertically by a load lever, in order to press the upper ball against the lower balls with a controlled load.
Frictional torque is measured by means of an arm attached to the cup and connected to the spring of a friction recording device.

The friction recording device consists of a spring with one end fixed by a wire attached to the steel cup arm and the other one anchored. The elongation of the spring is transmitted through a mechanism to a pen which records its movement on a rotating drum.

The testing procedure, presented by the international standard, [3], imposes to use only special balls and a special machine to run those tests. Chrome alloy steel balls of 12.7 mm±0.0005mm diameter, are used, conforming to the requirements of ISO 683-17 1999, type 1, [3]. Such balls are supplied by SKF with special destination, for four balls testing.

The procedure and the testing machine described in EN ISO 20623:2003 is difficult to be implemented in small factories because a testing machine must be purchased, even if rarely used, and a stock of standard bearing balls must always be assured.

There are situations when a lubricant must be replaced with another one and only qualitative and comparative assessment of lubricants is necessary. For such situations non-standardized tests can be conducted and simple and non-expensive devices could be used.

The experimental setup, presented further, is intended to help factories to evaluate lubricants, comparatively without use of special equipment and special testing balls.

2. Experimental setup
A simple four balls wear testing device was adapted on a classical drilling machine according with EN ISO 20623:2003 regulations (figure 1), [5].

![Figure 1. Experimental setup [5].](image)
The lower three balls are inserted in a special cage (figure 2) according with EN ISO 20623:2003 regulations. The cage has a threaded upper part, wherewith the balls are fixed.

Also, the cage is placed on an axial bearing and a force transducer which is seated on a drilling machine work table, to automatically align the balls system. The 4\textsuperscript{th} ball is fixed in the steel chuck and into the spindle of the drilling machine (figure 3). The contact load is generated by the drilling machine feed mechanism, adapted with a weights mounting system. Rotation is generated at 1450-1500 rpm by the drilling machine electric motor, through a V belt transmission (figure 1).

![Figure 2. Cage for lower balls.](image)

![Figure 3. Steel chuck with the 4\textsuperscript{th} ball [5].](image)

The load is measured with a manufactured force transducer based on four strain gauges mounted on the drilling machine work table. The strain gauges are wired to a strain gauge indicator connected in full bridge configuration. The force transducer was calibrated prior and the correlation between force - indicated values was found to be linear.

In order to assure equal periods of testing time, a command system was conceived based on an electronic timer. The electronic timer output circuit is connected to an electro-mechanical relay which starts and stops the electric motor of the drilling machine.

3. Test methodology
The tests are conducted according standard-EN ISO 20623:2003. Previously, the balls are cleaned with hydrocarbon solvent. Then, the testing balls are inserted in the cage and blocked. After fixing, the lower cage is filled with tested grease. The supports are arranged on the drilling machine. The contact is loaded with the prescribed level load, controlled with the force transducer, the testing time is set by the timer at 10 seconds and the machine is turned on.

After every 10 seconds, the wear test process is stopped, the balls are cleaned and the cage assembly is observed using an optical microscope with camera. An image of the contact scar, together with a reference body, which has an easily measurable and precise enough dimension, such as a wire is captured, in order to evaluate the scar diameter. The image is captured such as the complete scar and the known body width dimension to be recorded into the same picture.

A simple method to do the evaluation of the scar diameter was used, by comparing the scar dimension from the captured image with the dimension of the known body placed into the optical microscope visual area before image capture.

The ratio between the real dimension of the reference body and its dimension from the captured image is similar to the same ratio between the scar diameter and its image.

By measuring the scar diameter from the image and known body image dimension from the image, using a CAD software, the contact scar diameter can be evaluated.

For the present work, Autodesk Inventor was used for image processing and a simple copper wire, as known body.

4. Device validation
In order to validate the testing method, two tests were conducted with similar balls and the same type of lubricant.

The tests were done using 12.7 mm common bearing balls, procured from a local bearing factory. A larger number of balls were bought to assure enough test pieces for a long period of time. So, in this
way, when we need a test to compare the performances for two different lubricants, only the lubricant is the different parameter from one test to another.

As lubricant was used U90C03 commercial grease.

The load levels vary from 400 N up to 2200 N in 100 N steps, following the methodology prescribed in EN ISO 20623:2003, [3].

Using a microscope with camera, images of the scar and reference body of known dimension were captured and processed after each load level step. Examples of the wear scar processed images are presented in figure 4.

![Figure 4](image)

(a) 

(b)

**Figure 4.** The wear scar at: (a) 1400 N, (b) 1700 N, [5].

The correlation between wear scar dimension and load is represented in figure 5. Literature presents a similar variation between scar dimension and contact load, [3,4].

![Figure 5](image)

**Figure 5.** The correlation between contact scar diameter and load (first test).

A second test was conducted in similar conditions in order to validate the accuracy of the experiments. The results are represented in figure 6.

By comparing the results obtained experimentally, a close agreement between tests was found. This demonstrates that the method can be used as an alternative solution for small factories that do not have special machines for lubricant testing and they do not need more than a result with local applicability. In both cases the scar dimension increases rapidly at loads over 1500N. This phenomenon can be explained by taking into account seizure phenomena.
5. Conclusions
Using a common drilling machine and a simple device, the quality of different types of greases can be comparatively evaluated. For experiments, common similar bearing balls and a manufactured device, adapted on a classical drilling machine were used. Following EN ISO 20623:2003 procedures, the contacts between four balls were investigated and the contact wear scar images were captured using an optical microscope with camera and a CAD software. The diameter of the contact scars was measured by comparing its images to the image of a reference body of known dimension. The results revealed that the contact scar radius increases with load and has an evolution in agreement with the international standard and literature references. For the tested grease, at high loads (larger than 1500N), scuffing phenomenon appears and the scar diameter increases rapidly. Similar evolutions of the dependency between the contact scar diameter and load are presented in literature, [3, 4, 6]. This demonstrates that the method can be used as an inexpensive and local alternative solution, only for results with limited applicability in factories that do not have special machines for lubricant testing. This method can be applied for comparative evaluation of the anti-wear quality of lubricants.

6. References
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