Improving measurement precision and informativity under testing antifrictional materials with Timken machine

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Abstract. The expediency of modernization of well-known Timken machine is proved. The way of modernizing Timken machine with a two-lever friction pair loading system is given. The measurement precision and test results informativity under antifriction testing of lubricating and engineering materials are improved. The testing of lubricants using the modernized equipment shows high sensitivity to small changes of mechanical losses, as well as extended informativity of short-term test results.

1. Introduction
One of the most pressing challenges in minimizing friction and wear processes is reliable express experimental evaluation of antifriction properties of construction materials and tribological compositions [1-4]. Today this evaluation can be assessed only on the basis of a correctly designed experiment. A typical task of tribological express-test is to identify the material with best antifrictional properties among a number of alternatives [5-7]. Notably the time needed to conduct single test is important while comparing a large number of test objects. The significant number of special equipment for tribological testing materials implies sufficient test duration (of 1 hour or more), including preparation of test objects and a friction pair, the experiment itself and the processing of received results.

Among the methods and equipment for tribological testing materials, well-known Timken extreme load friction machine is widely used for evaluating the extreme pressure, anti-wear, and anti-friction properties of liquid lubricants and tribological compositions according to ASTM D2782-17 [8].

The disadvantage of the Timken method and the measuring device of the corresponding friction machine is the low accuracy and fidelity (repeatability and reproducibility) of the test results due to indirect measurement of the friction force in "roller - rotating ring" pair via the current intensity in the motor winding. The contributing distortion factors include the friction in the drive shaft bearings furthermore aggravated by misalignment of the shaft axes and bearing supports, which increases significantly while increasing load on a friction pair under test. An additional error in the friction force measurement is caused by the power grid voltage fluctuations and the non-linear dependence of the current on the load of the electric motor.
2. Purpose and objectives of research
The purpose of this work was to improve the accuracy and reliability of friction force measurement while reducing the testing time of lubricants and structural materials on a Timken friction machine. The following plan was implemented to achieve this purpose:

- designing and manufacturing of a special measuring unit based on the modernization of the main lever of the double-lever loading system of the Timken machine;
- checking and (if necessary) debugging the operation of the measuring unit, auxiliary equipment, devices and software for data acquisition and processing;
- creation and testing test methods;
- conducting a series of parallel experiments with measuring the force and other friction parameters, ceteris paribus test conditions;
- evaluation of the effectiveness of using both the method and the device for measuring friction force according to the criteria of accuracy and reliability.

3. Objects, equipment and test methods
The paper [9] presents a description of a new method for measuring friction force based on the use of the modernized Timken machine. To implement this method the main lever of the double-lever loading system was structurally changed so that the fixed roller of the "roller - rotating ring" friction pair placed in this lever was provided with free axial movement under the effect and in the direction of the friction force applied to it from the ring side. The measurement of this friction force was implemented by using a standard strain gauge rigidly mounted in a specially made channel of the main lever. A rod made of antifriction material cinematically links the roller and the strain gauge.

The developed device for friction force measurement (Figure 1) includes a frame 1, electric motor (not shown for simplicity), drive shaft 2, rotating ring 3, oil bath 4, roller 5, main lever 6; ball 7, rod 8, strain gauge 9, thrust ball bearing 10, screw 11, nut 12, load 13, auxiliary lever 14.

Figure 1. General view of the designed device for friction force measurement.

To record the signals of the strain gauge located in the main lever, as well as to implement the applied method, Timken machine was equipped with additional original measuring equipment and instruments, including a weight indicator, a semiconductor temperature sensor for the lubricant in the oil bath, a signal converter and a computer (Figure 2).

During a single experiment the signal from the strain gauge flows to the weight indicator, passes through the signal converter, and after the conversion into the friction force dimension (H) it is processed by special software and saved into an array of friction force. Additionally data from the temperature sensor for the lubricant in the oil bath is sent to the computer.
Figure 2. Measuring equipment: 1 - main lever with a strain gauge; 2 - cable from lubricant temperature sensor to signal converter; 3 – computer; 4 - monitor; 5 - weight indicator; 6 - signal converter.

Colorimeter temperature indicators serve as an additional indirect estimate of the magnitude and nature of the friction process in the lubricated pair. The processing software automatically builds the real-time dependence of the lubricant temperature and the friction force on the test duration for improving clarity and operational evaluation of the acquired data (Figure 3).

Figure 3. Screenshots of the software with the results of automated data processing: a - the interface of the processing software; b - graphs of the lubricant temperature change and the friction force in the lubricated friction pair during the test.

4. Results of the experiment
After tuning the measurement system, a series of nine parallel experiments was conducted. The duration of a single experiment was no more than 60 sec. This duration derives from the stabilization time for the friction force levels. Each experiment was carried out on a new friction pair (a new ring and roller surface) with a new lubricant in the oil bath.

The object of the test was a lubricant - synthetic motor oil Lukoil SAE 5W-40 API SN / CF. In all experiments the load on the auxiliary lever reached 1050 g in total; the gain ratio of the double-lever loading system was 16. The systematic error in friction force measurement of a standard strain gauge
MLB20-50 and the associated weight indicator SH-20E-R2 was ±0.5H (±2.2%); the error in the lubricant temperature measurement with a semiconductor sensor (thermistor) did not exceed ±0.5°C (±1.9%).

The test results presented in Figure 4 show that the relative deviation from the arithmetic mean of the final values of the friction force at the end of the test (final friction force \( F_e \)) did not exceed 3.2% of its arithmetic mean (\( F_m \)). This deviation indicates the repeatability of parallel measurements.

Since the method and the device showed high sensitivity, reliability and speed of measurements, a third-party laboratory involved in testing various lubricants and tribological compositions for automotive ICEs (hereinafter Laboratory No. 2 in relation to our Laboratory No. 1) showed interest in these results. At their request, we made an exact copy of the upgraded main lever and provided similar instruments, equipment and processing software for their Timken machine.

Afterwards the laboratory No. 2 independently conducted a series of tests of three lubricants using our method and measuring device: 1) Lukoil SAE 5W-40 API SN / CF synthetic motor oil; 2) the same oil, but with the introduction of 1% (vol.) synthetic anti-friction metal conditioner FENOM; 3) the same as 2), but with 3% (vol.) of FENOM. Similar tests were carried out in our laboratory No. 1 to evaluate the reproducibility of the antifriction properties test results. The Timken machines in laboratories No. 1 and No. 2 differed in the gain of the lever loading system, as well as in the mass of a single load. To eliminate the distorting effect of this difference on the quantitative measurement result the comparison of the test results of two laboratories was performed not by the final friction force, but by the final friction coefficient.

Figure 5 shows the pattern of change in the friction coefficient averaged over four parallel experiments when testing synthetic motor oil Lukoil SAE 5W-40 API SN / CF. The data shown in these graphs show satisfactory qualitative similarity of the compared dependences of the friction coefficient \( f \) on time \( t \). We also note a very good quantitative coincidence of the results from both laboratories, which manifested itself while evaluating the final friction coefficient \( f_e \) corresponding to time \( t = 60 \) s (the divergence was 11% - Table 1).
Figure 5. Comparison of the dependences of the average friction coefficient \( f \) over four test runs on the test duration \( t \) for testing of engine oil Lukoil SAE 5W-40 API SN/CF in laboratory No.1 and laboratory No.2.

Table 1. Assessment of reproducibility of independent testing results for similar lubricants.

| Testing lubricant                  | The average value of the final friction coefficient \( f_e \) corresponding to time \( t = 60s \) over four parallel experiments | Laboratory No.1 | Laboratory No.2 | The relative difference of the compared measurements |
|------------------------------------|-----------------------------------------------------------------------------------------------------------------|-----------------|-----------------|------------------------------------------------------|
| Engine oil Lukoil SAE 5W-40 API SN/CF |                                                                                                                                 | 0.107           | 0.119           | +11%                                                 |
| Same + 1% FENOM                    | 0.105 (-1.87%)                                                                                                 | 0.116 (-2.52%)  | +10%            |
| Same + 3% FENOM                    | 0.086 (-19.63%)                                                                                               | 0.105 (-11.76%) | +22%            |

Table 1 presented comparison of the results of the antifriction efficiency of the FENOM metal conditioner in synthetic motor oil Lukoil SAE 5W-40 API SN/CF. These results were obtained in two different laboratories by different people on different basic equipment (Timken machines) at different times, but using one method. As a result, a comparable decrease in the coefficient of friction of a lubricated pair after the introduction of the FENOM metal conditioner into the above engine oil (by 1.87% in laboratory No. 1 and by 2.52% in laboratory No. 2) is detected. Also, a tendency to a decrease in this coefficient was revealed with an increase in the concentration of the conditioner in oil (by 19.63% in laboratory No. 1 and by 11.76% in laboratory No. 2). However, the divergence between the quantitative estimates of the final friction coefficient average values obtained from similar lubricants by laboratories No. 1 and No. 2 ranged from 11 to 22%.

The level of relative difference in the quantitative indicators being compared (22%) is quite high. After a thorough analysis it can be explained by at least two violations of the well-known principle of other equal conditions when conducting comparative tests. Firstly, the chemical composition of the test objects was not identical. Motor oils and metal conditioners were of different years of production (2 years difference). During this time, the composition of the package of functional additives of the compared objects could change. Secondly, the difference in the ring friction surface preparation before each experiment: in laboratory No. 1 a new ring was used in each new experiment, while in laboratory No. 2 the same ring was used in all parallel experiments (the friction track on the ring, left from a previous experiment, was removed with sandpaper, after which the ring was washed and dried), only the surface of the roller was fresh in each new experiment. Thus, this quantitative divergence once
again confirmed the high sensitivity and truth of tribometry methods for observing the principle of equality of other equal conditions when conducting comparative tests.

5. Conclusions
The verification of our own and independent third-party results show the viability of developed method and device for measuring friction force. The scatter of values from the arithmetic mean did not exceed 3.2%. This indicates the repeatability of the results and insignificance of a random measurement error. The duration of a single experiment in accordance with the developed method does not exceed 60 s.

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