

Optimization of method a load cell calibration for the measurement of coefficient of friction

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Abstract. The instrumentation of equipment for mechanical testing is used to optimize the time to deliver a result, besides minimizing errors associated with manual measurements. Given this context, this work aims to present a calibration method for a load cell to determine the measurement results of force and friction coefficient, developed from on rotary pin-on-disk tribometer. The results indicate that the procedure provides measurements reliable for the tribological phenomena, resulting in with proximity the values provided by the ASTM G99-04.

1. Introduction

The friction and gravity forces are the variables with which engineer mechanic finds more often throughout the development of projects, however, these are still the least understood forces of nature. Besides energy, friction also performs a vital role in systems that requiring motion. The science and technology that focuses on the study of the interaction between surfaces in relative motion and related practices, is referred tribology, including wear and lubrication phenomena [1]. Although the friction is extremely useful in most cases, much of the in tribology study, is concentrated in order to minimize its effects.

As a way to study the phenomena resulting from surface interactions, the American Society for Testing and Materials (ASTM) presents the method designated "Pin on Disk". It uses two test bodies, a pin or ball, and the other in the form of a thin disk (figure 1) [2]. The machine that performs the test is called tribometer, which is able to measure the friction coefficient between the two materials what will be in sliding.

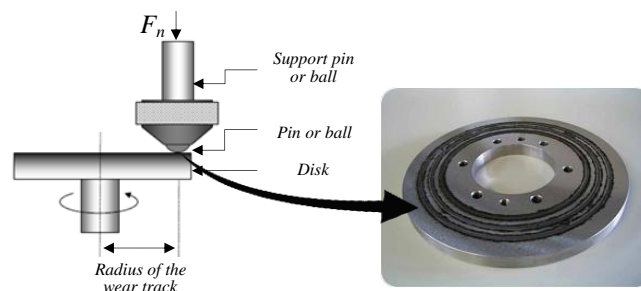


Figure 1. Schematic drawing pin on disk [2].

The fundamental laws of the friction in solid bodies are quite simple and are based on principle of Coulomb (1785) where the friction forces (F_a) is given by the following equation 1 [3]:

$$F_a = \mu \cdot F_n \quad (1)$$

Where:

μ : Friction coefficient [---]

F_n : Normal force [N]

The standard guide this study it is ASTM G99-10, which differs from the other on Tribology, not determining which instrumentation technologies or even automation to be implemented for performing the test and determination of the friction results.

Basically there are two principles of devices for measuring the frictional force, the piezoelectric dynamometer, and the load cell designated strain gauge [4]. In this project was used a resistive load type cell, because makes the dynamic measurement and having a lower cost.

2. Experimental procedure

2.1 Definition and load cell calibration

For the selection of the load cell capacity was used the largest value of the normal force (F_n) of 30 N, suitable to design mechanic of tribometer and in accordance with the highest expected value for the coefficient of friction between the no lubricated materials, that is 0.8 [2]. The selected load cell was of 33 N.

The selected load cell is of the type single point model PW4MC3 manufactured by HBM. The sensitivity is 2.0 ± 0.2 mV/V and the maximum load allowed is 30 ± 3 N. In order to position the load cell in the tribometer, necessary was fabricating an articulation system, called arm of the lifting. To meet the proportional amounts of voltage to each load, the load cell calibration was performed using standard weights (figure 2). This procedure was done to verify the values specified by the load cell manufacturer and thus, performing the friction tests.

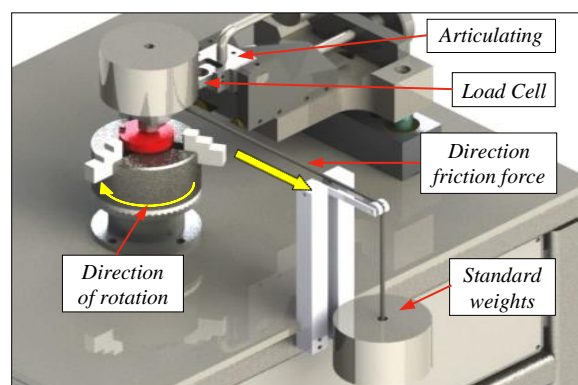


Figure 2. Methodology used for calibration.

Through the standard weights, the voltage was related. The voltage was collected by a data acquisition system and with the voltmeter, allowing the values can be stored and compared. Table 1

presents the basic characteristics for each measurements instrument, where the accuracy data supplied by manufacturers refer to full scale (FS).

Table 1. Characteristics of the instruments (mV)

| Instrument | Model | Accuracy | Resolution |
|-------------------|----------|----------------|------------|
| Voltmeter | F106 | $\pm 0.3\%$ +3 | 1.0 |
| Acquisition board | USB 6008 | ± 7.7 | 9.7 |

For the loading of the load cell was used mass of 0.01, 0.02, 0.05, 0.1, 0.2, 0.5 and 1 kg, with uncertainty of 1×10^{-5} kg, employing a USB6008 data acquisition system and software LabVIEW®. The acquisition rate for obtaining measurements was set to 1 kHz, performing a time of 10 s, giving an average value that was compared to the voltmeter.

The excitation of the load cell was made with a voltage of 10 V, allowing an output proportional to the deformation of 0 to 10 V. After measuring and analyzing the data, the voltage (V) was converted in force ($F = m.g$), generated by the product of mass (m) with acceleration of gravity ($g = 9.81 \text{ m/s}^2$). From the data, we performed the calculation of the average and standard deviation for each force obtained with accumulative loads by standard weights, ending with the curve trend shown in figure 3. With the calibration data, introduced the trend line and equation in order to demonstrate the coefficient of determination R^2 , which indicates the quality of the regression. A value of 1 indicates a total correlation between the measurements and the linear behavior of the regression. In figure 3 the equation $y = 0.2988x + 0.0175$ represents data regarding USB-6008 and $y = 0.2987x + 0.0192$ corresponds to the voltmeter. In figure 4 the error curve related to the load cell calibration is displayed.

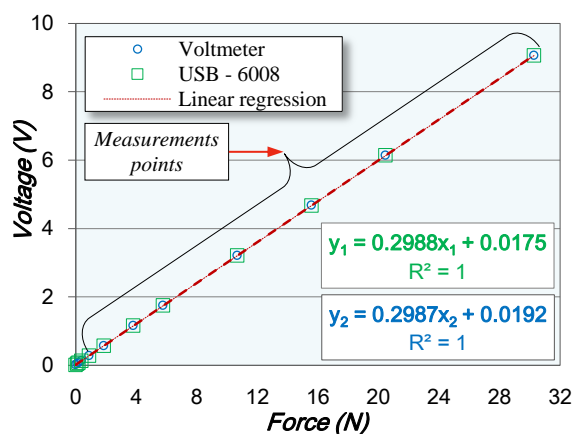


Figure 3. Curve de calibration load cell.

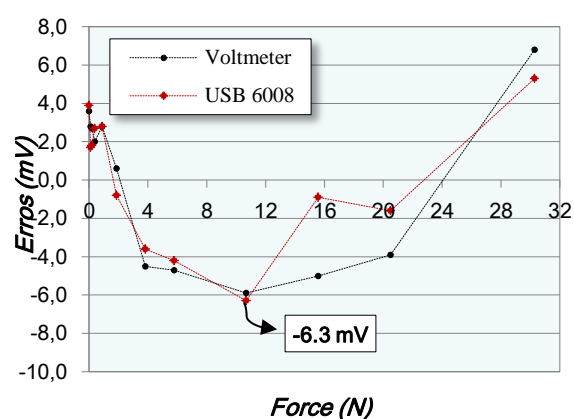


Figure 4. Errors curve.

According to the manufacturer of load cell, the sums of the errors are in the range of $\pm 0.03\%$ of the value of the sensitivity, meaning a $\pm 0.045 \text{ N}$ error for a full scale value (FS). In figure 4 it is still possible to identify the difference between the theoretical and experimental values, determining the how much the equations in figure 3 approaches the true value. Through the data, the biggest found was error of 6.3 mV, corresponding in a 0.021 N force. According to the data shown to maximum error of $\pm 0.045 \text{ N}$ of the cell, the maximum values determined by calibration are within its characteristic scale.

3. Results and discussion

The results of the calibration will be presented for the friction determination in the tribometer.

3.1 Procedures for friction testing

After calibration of the load cell, were performed the tribometer dynamic tests, where was established a number of six tests. In order to make a comparison between the experimental tests with standard ASTM G99, we used a sphere of aluminum oxide (Al_2O_3) (pin) and a steel disc AISI 52100 and a load by dead weight to a normal force (F_n). To perform tests under the same conditions and compare with the standard was followed by the data as Table 2.

Table 2. Input data for tests

| v_d [m/s] | R_m [m] | F_n [N] | H_r [%] | Δs [m] |
|-------------|--------------|-----------|-----------|----------------|
| 0.27 | 17.10^{-3} | 10 | 44 a 65 | 1000 |

Where:

v_d is the sliding speed, R_m is the average radius, F_n is the normal force applied, H_r is the relative humidity and Δs refers to the total sliding distance.

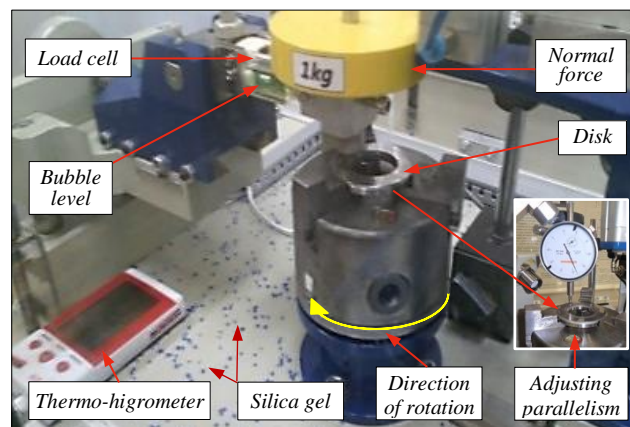


Figure 5. Friction testing procedures.

To maintain the relative humidity within the standards set by the standard (range of 12 to 70%), it was added a small amount of silica gel with a particle size of 1 to 4 mm. During testing, was observed through a thermo-hygrometer (figure 5), the decrease in humidity of 65 to 43%, justified also by the enclosure caused by acrylic protection and the natural warming of the atmosphere due to the testing.

Each test was also checked disk parallelism through measurement dial indicator to what the displacement of the load cell occur in a single direction. Furthermore, each test was adjusted arm of the level of articulation, made with the aid of a bubble level as shown in figure 5.

3.2 Friction measurement results

Although the values were recorded by the voltmeter, only the equation obtained by the data recorded by the USB 6008 was used, because this system would be fixed in the tribometer. From these data we determined the coefficient of friction for each test. The figure 6 shows the results of coefficient of friction versus distance for the six tests in the tribometer.

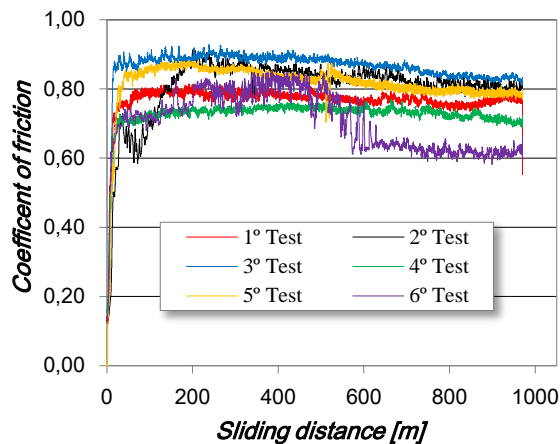


Figure 6. Friction results tribometer.

Table 3. Six tests of the coefficient friction

| | Experimental tests | | | | | | Mean |
|--------------------|--------------------|------|------|------|------|------|-------------|
| | 01 | 02 | 03 | 04 | 05 | 06 | |
| Average | 0.76 | 0.81 | 0.86 | 0.73 | 0.79 | 0.71 | 0.78 |
| Standard deviation | 0.06 | 0.09 | 0.06 | 0.05 | 0.08 | 0.09 | 0.07 |

Through the values shown in figure 6, are observed with greater clarity the individual values of each test for the input conditions (Table 2) and at the end the final mean value and standard deviation for the friction coefficient for the developed test in rotary tribometer (Table 3).

The mean final value (six measurements) for the friction coefficient was 0.78 with a standard deviation of 0.07. According to Table 3, we can see a variation between the mean of each test, typically influenced by factors characteristic to the tests, as oxide formation, roughness changes, vibration, and others. However, making a comparison with the standard (ASTM G99) what indicating a value of 0.76 ± 0.14 for 60 tests, it is clear that the calibration process and the methodology defined for the load cell measurement were consistent, validating measurement of the friction.

For all tests, the temperature and speed were also monitored. These were within the permissible variation and no significant influence to all results. The tests started with the average temperature of 19 °C and ended at about 28 °C. According to the results reported by Kim, 2014 [5], this difference of 7 °C is not sufficient to modification considerable in friction.

4. Conclusion

The application of the methodology used for the load cell calibration showed good results, since results were within the uncertainty values determined by the load cell manufacturer. Moreover, the procedure adopted for comparing the voltage values, using the acquisition system (USB-6008) and voltmeter, brought more reliable calibration results.

The measurements conducted in order to determine the strength and average coefficient of friction for the tribometer using equation 1, was satisfactory on the results supplied by the ASTM G99, with a mean small difference of 3%, relevant to a destructive type of test.

References

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