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RESEARCH

The Influence of the Contact Pressure on the Value of the Coefficient of Friction

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A B S T R A C T

Experimental research was carried out on the tribometer of high reliability of measurement. The paper discusses the impact of normal contact pressure on the value of the coefficient of friction. Elements that are in contact are filled steel rollers with different mass and diameters that slide on the hollow roller shaped like a ring. These contact elements are completely submerged in oil and have identical lubrication requirements. The results of this study indicate the significant influence of the level of normal load and contact pressure on the coefficient of friction.

1. INTRODUCTION

In addition to the required reliability of the measuring system, the latest methods of experimental research set a number of other complex demands and constraints. Tribology, as science and technology, to a large extent enables the solution of many global problems related to the consumption of materials, energy, cost reduction and the increase the reliability of the complex technical systems [1]. All this imposes a constant need for the development of new and the improvement of the existing measuring devices. For the purposes of the research presented in this paper a special device was developed. The developed device is characterized by ease of modification that provides the ability to physically affect a number of conditions of the process of measurement. Namely, it is necessary to interpret the results of tribological experiments, not from the point of view of a single material, but from the point of view of the material that is an integral part of the tribological system [2]. Friction characteristics of the tested contact pairs depend on the material of the contact pairs, design, tolerances, the surface, topography of the contact and lubricants [3]. According to research [3] the friction between cylindrical contact pairs is analysed both in dry and lubricating conditions until the moment the contact element starts to move. A significant number of papers in international journals treat the issue of the value of the coefficient of friction. In this regard it should be emphasized that research is moving in several directions, such as: a) The effect of moisture, vibration, and other factors on the bond capacity which was achieved by friction [4]; b) Calculation of the value of the coefficient of friction material regarding the development of the theoretical models [5]; c) The design of the topography of contact surfaces, which provides the maximum values of the friction coefficient [6]; d) Development of the tribological tests of composite biomaterials [7]; e) Identification and quantification of the impact of various factors on the friction coefficient in the systems of clamping tools for the processing of metal [8]; f) Development of devices for measuring the friction coefficient, the measurement of the adhesion force and the moment of detection of the start of movement [9]. Research related to the measurement of the coefficient of friction on the principle the inclined plane is very relevant [10] particularly in terms of comparing the results with those obtained by measuring the coefficient of friction by other methods. Friction is generated at the moment of macro tangential displacement of a body in motion with respect to the static body in contact [11,12]. The coefficient of friction depends on several factors, the contact surfaces, normal load, atmospheric pressure and temperature, the absorption of surfaces, the materials in contact and the state of processed surfaces [13]. The surface roughness and the state of the contact surface are of great importance in many applications which includes the flow of fluids. A large number of theories are based on the hypotheses and numerous considerations, which have been obtained in experimental data and explain the influence of different contact surfaces on the value of the coefficient of friction. In studies [14,15], the authors show that an increase in temperature of the body in contact has a significant impact on the increase in the coefficient of friction.

2. EXPERIMENTAL RESEARCH

Experimental research was carried out on the tribometer for the measurement of static friction coefficient of sliding and rolling. The scheme of the basic configuration of the tribometer is shown in Fig. 1.

On the stand (position 1) there are placed specially designed bolts (position 11) which are used for levelling the tribometer stand. The levelling is performed via a specially designed circumferentor for levelling in two planes.

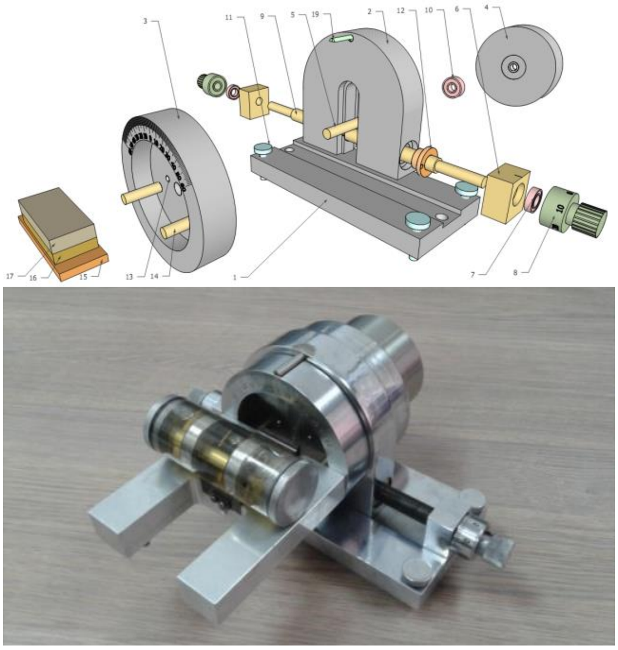

Fig. 1. Schematic representation of a tribometer.

The bearing plate (position 2) slides on the groove built on top of the stand. On the support plate (position 2) are attached tightly both a screw nut (position 12) and a zero position indicator (position 19). On the stand (position 1) are fixed the carrier plates (position 6) which hold the axial-radial bearings inside them (position 7) Helical spindle (position 9) on a 1 mm step is coupled with a screw nut (position 12) and with a nonius calliper (position 8) through which the reading of displacements is measured with an accuracy of one minute. On the bearing plate (position 2) a groove has been dug, through which it is possible to move in vertical direction the bolt (position 5), that has two ball bearing attached on each of its sides (position 10) Ball bearings are pressed into discs (positions 3 and 4). On the disc (position 3) there is engraved an angular scale in degrees and two clamped pins (position 14). On the inner side of the disc (position 3) are attached two limit beads (position 13). Contact pairs (positions 15 and 16) with a weight (position 17) with a detachable fixing to the sample (position 16) are placed on the pins (position 14). Turning the nonius (position 8) linearly moves the support plate (position 2) while the discs (positions 3 and 4) roll on the stand (position 1), and so rotate the plane of overlap of the contact pairs (positions 15 and 16) for the desired angle. An additional burden is added via removable weights (item 17).

For the implementation of programs of experimental research, the basic configuration of the tribometer (shown in Fig. 1.) was supplemented by a module (Fig. 2.) which is through the pins (Position 14 – Fig. 1) attached to the disk with a scale (Position 3 – Fig. 1).

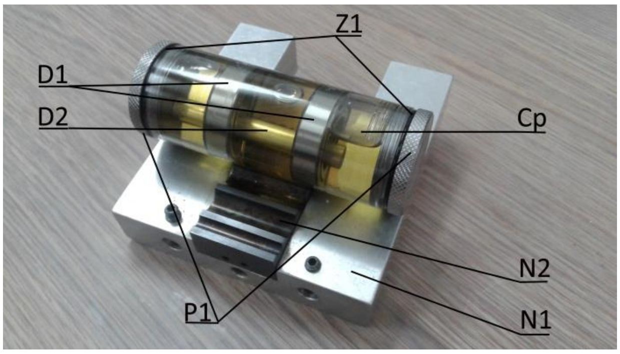

Fig. 2. Photographic example of the auxiliary module.

The additional module consists of: sub-assembly supports (position N1) and the sub-assembly of the carrier contact pairs (position N2). The carrier of the contact pairs (position N2) is mechanically fastened to the sub-assembly carrier (position N1). The sample holder is a transparent plastic tube (Position CP) in which on a specified distance are fixed two shell shaped hollow cylinders (bearings) forming the first contact element (position D1) A transparent plastic tube is filled with hydraulic oil HIDROL 46 for the lubrication of the contacts and, after insertion of the second contact element shaped like a full cylinder (pin or rod) (position D2), is hermetically sealed through gaskets (the position Z1) and lids (position P1).

The contact pairs, hollow cylinders and the full cylinder (rod) are made of stainless steel EN 1.4021. The inner diameter of hollow cylinders is Du = 28mm, and the width of the hollow cylinders is Bd = 11mm. Hollow cylinders are in the course of execution of two independent experiments in contact with the cylinders (pins or rods) of diameter: dv= 3 mm and 6 mm, and of length: b1 = 75m.

Based on the given geometric values of the diameter and the width/length of the contact elements, the values of the theoretical Hertz pressure can be determined based on a pattern:

Based on the known value of the normal load F_n, as well as the known type of contacts (of the cylinder in the inner cylinder), the value of the contact pressure can be calculated using the expressions known from the theory of elasticity:

$$p = 0{,}798 * \sqrt{\frac{q}{\nu(k_1 + k_2)}} ; \quad \text{where:}$$

$$\nu = \frac{D_1 * D_2}{D_1 - D_2},\ k_1 = \frac{1-\mu_1^2}{E_1},\ \text{and}\ k_2 = \frac{1-\mu_2^2}{E_2} \quad (1)$$

where p is the contact pressure, q is a load per length unit of the cylinder, D1 is the diameter of the cylinder bearing, D2 is the diameter of the rods (pins), μ1 is the Poisson's ratio of the pin material, μ2 is the Poisson's ratio of bearing material, E1 is the modulus of elasticity of the material of the pin and E2 is the modulus of elasticity of the material of the bearing. Since the pin and the bearings are made of the same material, $\mu_1 = \mu_2$ and $E_1 = E_2$.

Table 1. The measured values of angles and coefficients of friction.

Cylinder (pin) Ø 3mm Stainless steel			Cylinder (pin) Ø 6mm Stainless steel		
N	α°	μ=tgα	N	α°	μ=tgα
1	15,87	0,284	1	16,63	0,299
2	19,33	0,351	2	18,03	0,325
3	15,77	0,282	3	17,80	0,321
4	18,70	0,338	4	16,73	0,301
5	17,38	0,313	5	16,93	0,304
6	16,03	0,287	6	17,26	0,311
7	15,50	0,277	7	16,83	0,302
8	19,63	0,357	8	16,20	0,291
9	18,42	0,333	9	14,58	0,260
10	15,68	0,281	10	15,20	0,272
11	18,70	0,338	11	16,46	0,295
12	14,68	0,262	12	16,08	0,288
13	15,33	0,274	13	16,58	0,298
14	23,38	0,432	14	15,01	0,268
15	15,72	0,281	15	17,75	0,320
16	17,45	0,314	16	20,88	0,381
17	16,53	0,297	17	15,08	0,269
18	16,80	0,302	18	15,66	0,280
19	20,72	0,378	19	15,36	0,275
20	19,51	0,354	20	17,21	0,310
21	16,03	0,287	21	14,55	0,260
22	15,98	0,286	22	18,91	0,343
23	19,86	0,361	23	16,53	0,297
24	17,16	0,309	24	16,20	0,291
25	22,98	0,424	25	16,60	0,298
26	15,73	0,282	26	18,38	0,332
27	16,18	0,290	27	16,56	0,297
28	18,31	0,331	28	15,56	0,278
29	16,96	0,305	29	16,66	0,299
30	16,68	0,300	30	17,88	0,323

The measured values of the angle of rotation of the inclined plane and the value of the friction coefficient calculated based on a pattern: $\mu = tg\alpha$ are given in Table 1. In order to increase the reliability of measurements and the determination of the middle values and the dispersion of the coefficient of friction, the measurements were repeated 30 times for both contact pairs.

The medium values of the coefficient of friction and the corresponding dispersion are:

- for the cylinder contact with a diameter of dv=3 mm per cylinder:
  μ_{sr}=0,317; σ=0,04276

- for the cylinder contact with a diameter of dv=6 mm per cylinder:
  μ_{sr}=0,2996; σ=0,02593

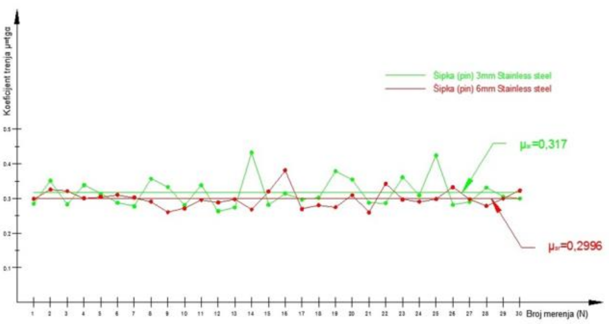

Fig. 3. A diagrammatic representation of the value of the coefficient of friction.

On the Fig. 3, a diagrammatic representation of the coefficient of friction is shown for all of the 30 measurements of the both contact pairs.

3. DISCUSSION

Based on the analysis of the literature sources it can be concluded that the research in the field of the coefficient of static friction is very relevant. The researches presented in this paper were performed in order to determine the impact of the Hertz contact pressure on the value of the coefficient of static friction. In order to achieve the identical testing conditions, the contact pairs are made of the same material and using the grinding pre-treatment brought to approximately the same value of the surface roughness (Ra=0,62-0,73 μm). Creating identical test conditions can largely be contributed to achieving contact in the enviroment filled with fluid (oil). As from the aforementioned, it can be concluded (Fig. 2), that the contact pairs were fully submerged in oil. That was contributed by a specially designed module which was effectively upgraded to the basic configuration of the tribometer for measuring the coefficient of static friction and the coefficient of the rolling friction. The tests were carried out at a theoretical maximum value of the contact - Hertz pressure p = 29,8 MPa in the case of the contact rod with the diameter of Ø3mm and cylinder, and p = 56,3 MPa in the case of a contact rod of a diameter of Ø6 mm and the cylinder.

Based on the experimental results it can be concluded that lower contact pressure values correspond to higher values of the coefficient of sliding friction. Also, the dispersions of the coefficient of friction are considerably higher at lower contact pressures. As it is written for the rod with the diameter of Ø3mm, the middle value of the coefficient of friction is as follows: μ_{sr} = 0,317 at σ = 0,04276 and for the rod of the diameter Ø6mm the middle value of the coefficient of friction is μ_{sr} = 0,2996 at σ = 0,02593, which is in accordance with the literature sources. At low contact pressures the contact is achieved mainly on the tops of bumps with great influence from the micro-geometry of the surface itself. In addition to that, the share of the adhesion effect of the presence of a lubricant at low values of load is much higher.

4. CONCLUSIONS

Research in the field of tribology as a science and tribology as a technology is well represented in the modern world. In particular, the current field of tribology is represented by tribometry. Tribometry specializes in finding new and improving the existing methods and devices for quantifying parameters of friction and wear. For the needs of the study from which the results were presented in this paper, a specially designed and implemented module was mounted on the basic configuration of the tribometer to measure both the coefficient of static friction and the coefficient of the rolling friction. The projected module allows for the measurement of the friction coefficient to be carried out in a controlled environment to allow for complete lubrication of the contact pairs which are immersed in oil. This opens up the opportunity to explore not only the impact of the Hertz contact pressure on the value of the coefficient of friction, which was done in this paper, but also examine the effect of viscosity and the general quality of the lubricant. The results of the research described in this paper point to the significant impact of the level of normal load, or contact pressure, on the value of the coefficient of friction, which is consistent with the data in the literature.

Future research should be directed to upgrading the designed module by using the elements that allow testing of contact pairs in the controlled gas environment (vacuum, argon and other gases). The authors of this paper believe that from a technical point of view there is no problem in terms of upgrading the existing module, so this will most certainly be the subject of future research of the authors of this work in the field of tribometry.

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