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MEASUREMENT INSTRUMENTATION FOR DETERMINATION OF STATIC COEFFICIENT OF ROLLING FRICTION

Petar Todorović[1], Ivan Mačužić[1], Branislav Jeremić[1], Marko Đapan[1], Branko Tadić[1]

[1]Faculty of Engineering Kragujevac, Serbia, petar@kg.ac.rs, ivanm@kg.ac.rs, bane@kg.ac.rs, djapan@kg.ac.rs, btadic@kg.ac.rs

Abstract: *This paper is considering the influence of temperature, at normal load and bend radius of contact elements on the coefficient of rolling friction. Contact pairs are made of steel DIN 17230 (100Cr6). Measurement results in a condition of high temperatures, variation of the normal load and bend radius of contact element indicate complex influence of temperature in this specific test condition. Authors' future research would be in direction of determination of static friction coefficient on the higher temperatures of contact pairs made of different materials.*

Keywords: *Measurement instrumentation, coefficient of rolling friction, high temperatures, inclined plane*

1. INTRODUCTION

For every engineer and constructor, who is engaged in design and development of mechanical constructions, knowledge of friction coefficient is very important and crucial. However, there are multiple issues, doubts and problems regarding using of friction coefficient values during experiments. These problems occur primarily because of poor applying of standard tables and under which conditions these values are measured. This is all because friction coefficient values are different from laboratory to laboratory, and depend on equipment, measuring methods and a number of other parameters that may influence on diversity of measured values. Peter J. Blau [1] has represented review of friction force and ways of its measurement. He made a list of standard measurement methods for static and dynamic friction coefficient as well as the way of its potential use.

As we know, friction occurs when two bodies are in contact and based on velocity of relative motion, friction can be static or kinetic. The static friction coefficient depends on many different parameters, primarily from surface contact, normal load, atmosphere conditions and temperature, surface absorption, quality of processing and material in contact [2-5]. There have been several studies regarding the influence of surface roughness parameters with the static friction coefficient and concluded that the coefficient of static friction will increase if surface roughness coefficient increases [3, 4]. Also, some of them concluded that some roughness parameters, like skewness and kurtosis, have a greater influence on coefficient of static friction compared to other parameters [6, 7]. Complete understanding of the coefficient of static friction is impossible without various analyses of mechanisms under which this is occurring. This issue is a goal for numerous research efforts [8-10].

As a start, some authors represented conditions under which the value of static friction is greater than the dynamic friction value, in terms of temperature influence on creep motion. Generally, at temperature above zero, static friction coefficient is higher compared to kinetic friction coefficient due to different heat activated processes. But, we cannot say that the static friction coefficient has only one value because it depends on contact and initial velocity. In order to determine static friction coefficient, Chang et al. [8] analyzed adhesion force and load in contact at rough metal surfaces. The study showed that the coefficient of static friction depends on characteristics of the material and topography of the surface in contact as well as that depends on external load versus general defined friction law. In this paper, researchers were experimentally determined that for specific external load, coefficient of static friction will decrease if plastic characteristic of material increases and surface energy decreases. D.-H. Hwang et al [11] concluded that the coefficient of static friction is higher if contact pair is made of different material - steel/alumina, while the lower value is determined for similar materials (steel/steel). This result is consequence of “stick-slip” effect. Also, one of conclusions was that the influence of surface roughness has less influence for similar materials in contact pair, as well as the increasing value of normal load affects on increasing coefficient of static friction in contact pair of different materials, while there is no significant influence for contact pairs of the identical materials.

Etsion and Amit [12] experimentally researched the influence of normal load on coefficient of static friction with very smooth metal surfaces in a controlled laboratory conditions. Dramatically increasing coefficient of static friction was noticed when the normal load is on the lowest level. Behaviour like this is assigned to adhesion forces which have more important function regarding small normal loads and surface smoothness.

A small number of papers deal with coefficient of static friction under influence of temperature [13-16]. The most important conclusion that authors made in this papers is that the coefficient of static friction will increase if temperature is increased, which is resulted of increasing plastic characteristics of the most contact material at increased temperature. Reviewing the literature is noticed that experimental tests of coefficient of static friction were performed on experimental equipment with different design, construction and different contact geometry. Also, very interesting are measurement instruments for static coefficient of rolling friction [17-19]. Friction characteristics of rolling bearing elements depend on contact pair material, design, tolerance, topography of contact surfaces and lubricants. Authors in this paper noticed, during literature review, that there are no any papers which based their research attempts on static coefficient of rolling friction, while in conditions at higher temperature referring to issue above, there was no paper found (when this paper is written).

The aim of this paper is to determine influence of temperature on static coefficient of rolling friction on contact elements made of steel. Experimental measurements were performed on instrumentation that authors designed, developed and constructed regarding very precise determination of static coefficient of rolling friction at higher temperatures and relatively small values of contact pressure with changing radius bends of contact elements.

2. THEORETICAL CONSIDERATION

According to literature, the static coefficient of friction increases with increasing temperature. It is found that temperatures above 200°C lead to increasing of coefficient of friction which can be interpreted as a result of increasing plastic characteristics of material at increased temperature. The static coefficient of rolling friction tested in condition of increased temperature has not been subject of either theoretical or experimental research. The authors will determine the influence of temperature, normal load and radius bend of contact elements on coefficient of rolling friction by experimental methods. According to that, measure instrumentation is designed and constructed, based on inclined plane principle.

In the case of rolling friction (contiguous case – figure 1), coefficient of rolling friction is determined from formula 1 and 2:

$$M_{\mu} = N \cdot e \quad (1)$$

$$M_{P} = F \cdot R \quad (2)$$

where are:

M_{μ} – moment of resistance and

M_{P} – rolling moment.

From equations 3 and 4:

$$F = N \cdot \frac{e}{R} = f \cdot N \quad (3)$$

$$f = \frac{e}{R} = \tan\alpha \quad (4)$$

and from the body balance at inclined plate (figure 2), we get the following equation:

$$N = G \cdot \cos\alpha \quad (5)$$

$$\sin\alpha \cdot R = N \cdot e = G \cdot \cos\alpha \cdot e \Rightarrow \frac{e}{R} = \tan\alpha \quad (6)$$

where are:

f – static coefficient of rolling friction;
N – normal force;
e – coordinate that defines resultant reaction position N;
R – radius of rolling body;
G – the force of gravity;
α – angle of inclined plane.

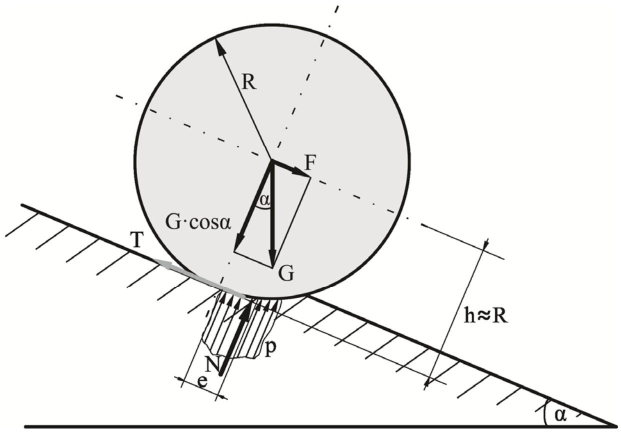

Figure 1 – The balance of rolling body at inclined plate

The authors' starting point was from theoretical assumption that the contact between ball and flat surface in laboratory conditions will be achieved on the small number of unevenness in a regard a number of unevenness at higher temperatures. Further, it is assumed that due to thermal expansion of material in the contact zone, will result as increasing of value e (figure 1). This means that as a consequence we will have an increase of rolling moment resistance and a parallel increase of the coefficient of rolling friction. The authors believe that there is some correlation between static coefficient of rolling friction and the value of thermal dilatation of contact pair. If we have in mind the stochastic nature of real contact area and nonlinear temperature field, it is hard to theoretically quantify the influence of temperature on coefficient of friction. Hence, in order to quantify the influence of various parameters on coefficient of friction, authors will provide relative extensive experimental research.

3. EXPERIMENTAL TESTS

Experimental tests were performed on a special designed and constructed tribometer. The complete measuring instrument is showed on figure 2. Also, all positions are marked with numbers and described in following text. The tribometer consists of three bigger parts, as follows:

1 – Thermoregulator. The main aim of this part is to vary a temperature (in our case is 200°C). There are two small screens; one is showing desired temperature and another current temperature.

2 – Block with thermocouple. Inside of this block, beside thermocouple, there is a system for heating and probe for temperature measurement. Also, in this part of tribometer the contact between object and block is made.

3 – Counterweight. This part enables to make rotating of the block with thermocouple with very good precision.

The tribometer operates in principle of inclined plane. Contact pair together with system for heating and probe for temperature measurement is rotated from horizontal to the desired angle α. The rotated angle of inclined plane is measured with reading precision of one minute, which for a wide interval of possible values of the coefficient of rolling friction causes the measurement error less than 3%.

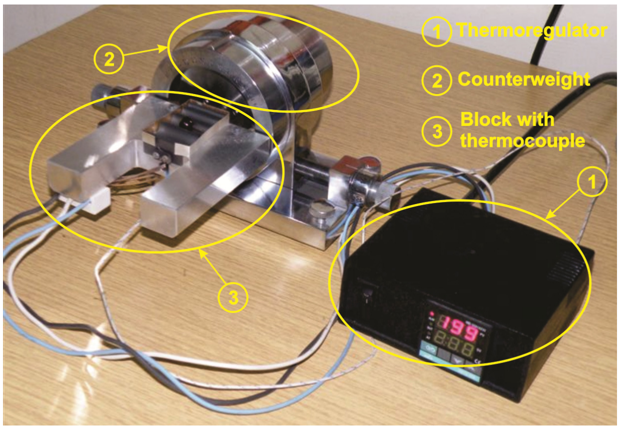

Figure 2 – Measurement instrumentation (1-Thermoregulator, 2-Counterweight, 3-Block with thermocouple)

The tests were performed with rolling balls of different diameters over channels with different radius bends. Balls weight and balls diameter were in a range from 0.04 to 0.08N and from 2.32 to 13mm respectively. Bend radius of the block covered a range from 2.5 to 8 mm. Balls and block were heated on selected temperatures, 20, 100, 150 and 200°C. Chosen material for balls and block was steel DIN 17230 (100Cr6) with hardness 62-66HRC. Hardness is achieved by quenching and tempering process. Ball roughness is Ra=0.002µm. The roughness of the block channels surface was in a range between: Ra=0.8-1µm. The figure 3 is a diagrammatic representation coefficient of rolling friction dependence regarding temperature and normal load.

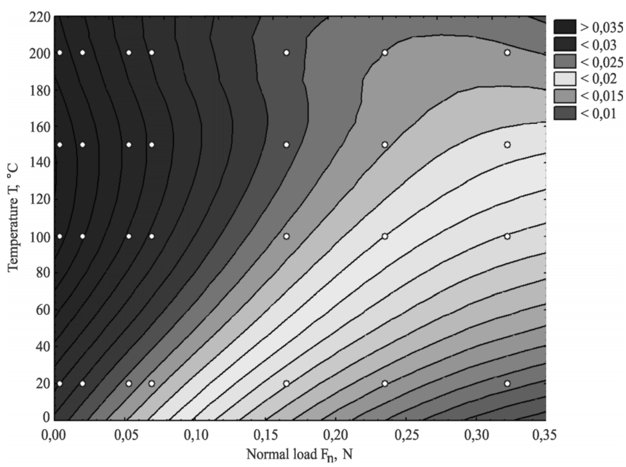

Figure 3 – Coefficient of rolling friction dependence regarding temperature and normal load

4. DISCUSSION

According to the theoretical consideration, physical principle and characteristics of inclined plane for coefficient of static friction measurement can be applicable in the conditions with higher temperatures. The measurement error is function of the angle α and value of friction coefficient, as follows:

$$\varepsilon = \frac{\tan(\alpha + \Delta\alpha) - \tan\alpha}{\tan(\alpha a} \cdot 100 \quad [\%] \qquad (7)$$

where are:
ε - measurement error and
Δα – measurement error of angle.

Measured coefficient of friction is in the range from 0.01 to 0.05 and reading precision is one minute based on computation, the measurement error is less than 3%. This result is totally acceptable. The results of experimental tests enable global overview of how larger number of parameters influence on coefficient of rolling friction. Besides variations of temperature and level of normal load, variations were made to block channel radius (the second contact element).

From diagram (figure 3) we can conclude that temperature, which is selected for contact pair heating and normal load (ball weight) has large influence on changing trend of coefficient of rolling friction. The bend radius has indirect influence on real contact surface, meaning that larger radius corresponds to 10% of lower values of friction coefficient. If we have in mind that increasing radius of block bend increases contact pressure then it can be concluded that results correspond with literature. In conjunction with above stated, it can be concluded that to lower coefficient of friction corresponds higher contact pressure.

Based on analyses of experimental results, generally it can be stated that contact temperature has significant influence on coefficient of rolling friction. However, level of temperature influence on coefficient of rolling friction is highly dependent from normal load value, especially in an area of lower values of normal load.

5. CONCLUSION

The research in the field of static friction is spread in a number of directions. The topic explored by authors aimed to draw attention that research in a field of static coefficient of rolling friction have not been carried out in order to quantify complex influence of normal load, contact surface and temperature on coefficient of rolling friction. Through theoretical consideration presented in this paper, authors hypothesized that there is necessary thermal potential in a contact zone for redistribution of contact pressure and increase of rolling moment resistance at temperatures around 200°C. The instrumentation used for static coefficient of rolling friction measurement in a condition of high temperatures functions as inclined plane and enables satisfactory determination results of static coefficient of rolling friction. In this paper the measurement error is less than 3%, for performed program of experimental research, and regarding problems of measurement of very small friction forces this is completely satisfactory. The measurement results of static coefficient of rolling friction for selected materials, in a condition of high temperatures, normal load and bend radius of contact elements variation, indicate a complex influence of temperature in the testing conditions.

Scientists' future research in this field should be directed to experimental tests of different materials in contact and optimization in order to determine minimal values of static coefficient of friction at high temperatures.

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REFERENCES

[1] P. J. Blau, *The significance and use of the friction coefficient*, Tribology International, Vol. 34, No. 9, pp. 585–591, 2001.

[2] B. Ivkovic, M. Djurdjanovic, D. Stamenkovic, *The Influence of the Contact Surface Roughness on the Static Friction Coefficient*, Tribology in Industry, Vol. 22, No. 3&4, pp. 41-44, 2000.

[3] U. Muller, R. Hauert, *Investigations of the coefficient of static friction diamond-like carbon films*, Surface and Coatings Technology, Vol. 174-175, pp. 421–426, 2003.

[4] B. Polyakov, S. Vlassov, L. M. Dorogin, P. Kulis, I. Kink, R. Lohmus, *The effect of substrate roughness on the static friction of CuO nanowires,* Surface Science, Vol. 606, No. 17-18. pp. 1393-1399, 2012.

[5] N. Tayebi, A. A. Polycarpou, *Modeling the effect of skewness and kurtosis on the static friction coefficient of rough surfaces*, Tribology International, Vol. 37, No. 6, pp. 491-505, 2004.

[6] B. Bhushan, S. Sundararajan, W.W. Scott, S. Chilamakuri, *Stiction analysis of magnetic tapes*, IEEE Magnetics Transactions, Vol. 33, No. 5, pp. 3211-3213, 1997.

[7] J. S. McFarlane, D. Tabor, Relation between friction and adhesion, in: *Proceedings of the Royal Society of London. Series A,* Mathematical and Physical Science, Vol. 202, No. 1069, pp. 244-253, 1950.

[8] W.R. Chang, I. Etsion, D. B. Bogy, *Static friction coefficient model for metallic rough surfaces,* Journal of Tribology, Vol. 110, pp. 57-61, 1988.

[9] B.N.J. Persson, O. Albohr, F. Mancosu, V. Peveri, V.N. Samoilov, I.M. Sivebaek, *On the nature of the static friction, kinetic friction and creep*, Wear, Vol. 254, No. 9, pp. 835-851, 2003.

[10] J. M. Galligan, P. McCullough, *On the nature of static friction*, Wear, Vol. 105, No. 9, pp. 337-340, 1985.

[11] D.-H. Hwang, K.-H. Zum Gahr, *Transition from static to kinetic friction of unlubricated or oil lubricated steel/steel, steel/ceramic and ceramic/ceramic pairs*, Wear, Vol. 255, No. 1-6, pp. 365-375, 2003.

[12] I. Etsion, M. Amit, *The effect of small normal loads on the static friction coefficient for very smooth surfaces,* Journal of tribology, Vol.115, No. 3, 1993.

[13] H. Kumar, V. Ramakrishnan, S. K. Albert, C. Meikandamurthy, B.V.R. Tata, A.K. Bhaduri, *High temperature wear and friction behaviour of 15Cr-15Ni-2Mo titanium-modified austenitic stainless steel in liquid sodium*, Wear, Vol. 270, No. 1-2, pp. 1-4, 2010.

[14] P. Mosaddegh, J. Ziegert, W. Iqbal, Y. Tohme, *Apparatus for high temperature friction measurement*, Precision Engineering, Vol. 35, No. 3, pp. 473-483, 2011.

[15] A. Chaikittiratana, S. Koetniyom, S. Lakkam, *Static/kinetic friction behaviour of a clutch facing material: effects of temperature and pressure*, World Academy of Science, Engineering and Technology Vol. 66, 2012.

[16] M. Worgull, J. F. Hetu, K. K. Kabanemi, M. Heckele, *Hot embossing of microstructures: characterization of friction during demolding,* Microsyst Technol, Vol. 14, pp. 767-773, 2008.

[17] K. G. Budinski, *An inclined plane test for the breakaway coefficient of rolling friction of rolling element bearings*, Wear, Vol. 259, No. 7-12, pp. 1443-1447, 2005.

[18] Ta-Wei Lin, A. Modafe, B. Shapiro, R. Ghodssi, *Characterization of Dynamic Friction in MEMS-Based Microball Bearings*, IEEE Transactions on instrumentation and measurement, Vol. 53, No. 3, pp. 839-846, 2004.

[19] D. N. Olaru, C. Stamate, A. Dumitrascu, G. Prisacaru, *New micro tribometer for rolling friction*, Wear, Vol. 271, No. 5-6, pp. 842-852, 2011.