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ROLLING FRICTION EVALUATION IN DRY AND LUBRICATED CONTACT. PRELIMINARY RESULTS

BY

SORINEL TODERAŞ SIRETEAN and ILIE MUSCĂ[*]

“Ştefan cel Mare” University of Suceava, România,
Department of Mechanical Engineering

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Abstract. It is used a test rig based an outer bearing ring and a bearing ball, free placed on the ring raceway. The ring is driven in controlled rotational motion by an electrical motor. When the ring is in rotating motion, the ball has a translation movement from the initial position to another equilibrium position, deflected with an angle towards vertical axis, until it starts rotational motion on its own axis. The value of this angle it is correlated with the rolling friction coefficient. So, the static (ball not rolling) and the dynamic rolling friction coefficient, in dry and lubricated condition, can be evaluate by measuring this deflected angle.

This paper presents some preliminary results for the rolling friction coefficient using an originally experimental test rig in dry and lubricated condition.

Key words: friction; rolling friction.

1. Introduction

The rolling movement it can be affected by a series of factors acting individual or simultaneously such as: load and revolutions per minute, the losses through elastic hysteresis, the microslip from the contact, the

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[*] Corresponding author; *e-mail*: iliem@fim.usv.ro

hydrodynamic resistance of the lubricant, the state of the surfaces, the interactions between the parts in contact, the thermal regime.

Studies for decreasing the rolling friction, implicitly to evaluate the value of rolling friction coefficient were performed by many researchers including: Olaru *et al.* (2011), Lin *et al.* (2004), Muscă (2009), Stamate (Stamate & Olaru, 2007), Houpert (Houpert & Leenders, 1985), Biboulet (Biboulet & Houpert, 2010).

2. About Rolling Friction Coefficient

The forces acting on a contact between a ball bearing set free on raceway of a bearing outer ring and the bearing ring, given that the centers of rotation are arranged on the same vertical axis can be equaled with the contact between a ball and a plane, were the ball has just the tendency of rolling, Fig. 1.

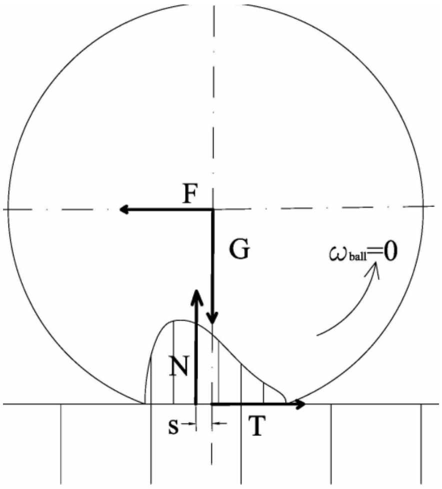

Fig. 1 − Forces system in contact ball – plane, the ball has just tendency of rolling (static equilibrium).

If the tendency of rolling occurs, in the center of the ball it can be considered the traction force, ***F***, which determines the occurrence, in the contact point, of a tangential force, ***T***. In these conditions we may presume that $F = 0$. But, experimental we remark that the system can be in equilibrium even if $F \neq 0$, in the conditions that the value of the force F does not exceed a certain value (Muscă, 2003).

The rotation of ring determine the rolling of the bearing ball and moving it from initial position to another position situated on a direction that forms an angle α with the vertical.

That’s why in the contact point we have a force couple, the ball having the tendency to roll, similar to the situation when it is on an inclined plane Fig. 2.

The point of application of the normal reaction, *N*, is moved from the contact point with distance *s*, in the direction of rolling of the ball. The value of this movement, *s*, is called rolling friction coefficient.

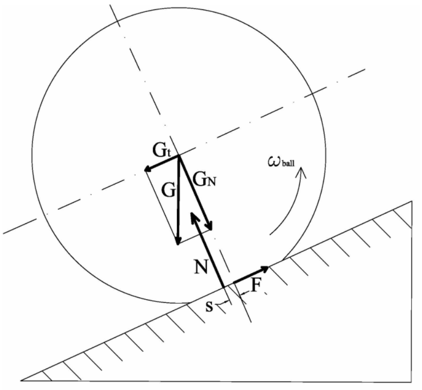

Fig. 2 – Forces system in ball – inclined plan contact.

The bearing ball, set free on the outer ring, can be in static (has just tendency for rolling) or dynamic (is rolling) equilibrium. That's why we can define, the *static rolling friction coefficient* as being the movement, *s*, in the conditions in which the ball is in static equilibrium (ball is not rolling) and denoted with s_s and the *dynamic rolling friction coefficient* as being movement, *s*, in the conditions in which the ball is in dynamic equilibrium and denoted with s_d.

The force system for the new position of the ball is presented in Fig. 2.

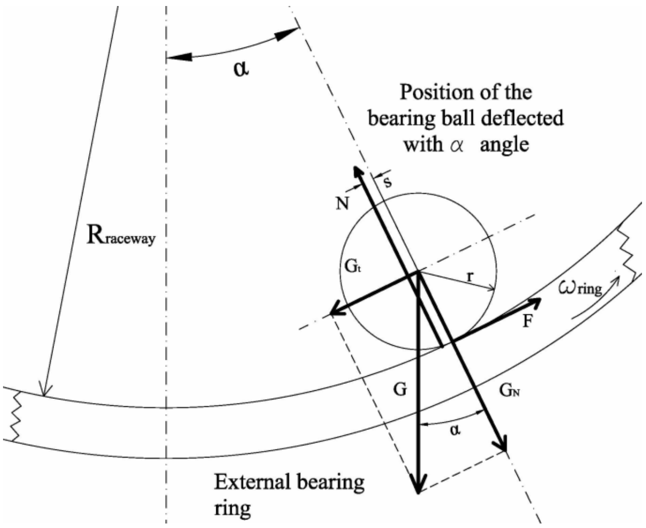

Fig. 3 – Forces system that acts on the ball in the position deviated with the angle α, (Siretean & Muscă, 2015).

The rolling friction coefficient can be evaluated (Siretean & Muscă, 2015) by:

$$s = r \cdot \mathrm{tg}\, \alpha \tag{1}$$

This equation shows that the rolling friction coefficient is directly correlated with the angle of deviation adequate to the position of relative equilibrium of the ball.

3. Experimental Process

For the evaluation of the static (ball not rolling) and dynamic rolling friction coefficient we use the test rig described by (Siretean & Muscă, 2015).

By the method of experiment shown in (Siretean & Muscă, 2015), it was obtained a video of the experiment which allows precise localization of the ball and ring, on each frame. The execution method of image analysis is presented below.

The video camera is mounted so that the axis of the camera lens to be situate on the same axis with the rotation axis of the bearing ring. On the axis of the engine was mounted solidary with this one, an auxiliary metal disc on which was marked a circle, concentric with the bearing ring. The marked circle it is useful in image analysis process to determine the rotation center. Given the fact that the bearing ring and auxiliary metal disc are fixed mounted on the motor shaft, it can be said that the centers of rotation of those two elements coincide. Also we make a diametrical mark on the bearing ball with which we determine the frame when the ball starts to roll. For determining the vertical and horizontal of the device, it has being used an optic device, with plane calibrated laser fascicules which projects two laser beams plane perpendicular on the metal disc (Siretean & Muscă, 2015).

The ball is positioned free on the raceway of the bearing ring, at zero speed. Rotation of the bearing ring will determine the translation of the ball without rolling, in a new angular position deflected to the vertical with an angle α_s, Fig. 4, until the ball starts to roll. In this moment the bearing ball just has the tendency to roll, it is in static equilibrium (ball not rolling).

After the ball starts to roll it will reach an another angular position, deflected from the vertical with an angle α_d, Fig. 5. In this case the bearing ball it is in dynamic equilibrium.

With an image processing software we extract the images, frame by frame, at the speed of recording of the camera of 30 frames/sec.

The selected frames are imported in Autodesk Inventor. By overdrawing the circles centers line and vertical direction, angular ball deviation can be evaluated.

Here, drawing three segments of lines tangent on the helpful disc and using the function “Circle tangent at three lines” we mark the circle inscribed by the three tangents and determining by this way, the center of rotation of the bearing ring.

In the same manner it is located the ball center too.

The vertical and the horizontal are represented by two segments of line overlapping the beams projected by the optic device.

The angles of deviation, α_s and α_d, are obtained through direct measurement, between the segment of line that passes through the two centers of rotation and the vertical. Image analysis enables us to obtain direct measurement of the angle of deviation with an accurate assessment of the order of seconds but in evaluation of rolling friction coefficient we round these values to the order of minutes.

Using the eq. (1) and knowing the radius of the bearing ball, we can evaluate the value of the static rolling friction coefficient (ball not rolling).

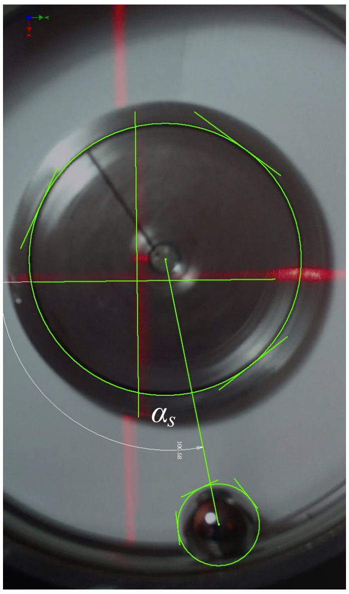

Fig. 4 – Determining the angle of deviation of the ball in lubricated (3 drops) and static equilibrium conditions (ball not rolling).

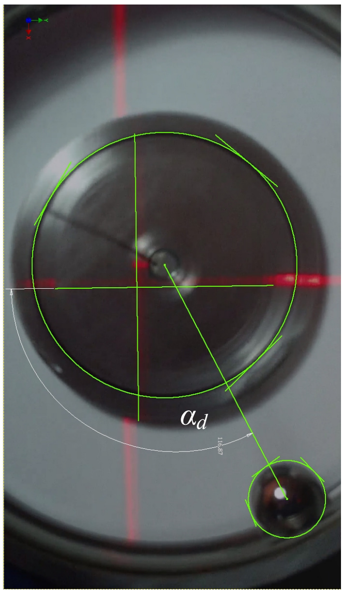

Fig. 5 – Determining the angle of deviation of the ball in lubricated (3 drops) and dynamic equilibrium conditions.

4. Experiment and Preliminary Results

Experiments were performed to determine the static (ball not rolling) and dynamic rolling friction coefficient in contact between an outer bearing ring, code 6014, and a ball bearing with radius r = 6.1 mm, in dry friction conditions and in the presence of different amounts of lubricant, quantified in 1 or 3 drops.

For lubricated experiments video recordings were made after a longer period of time to ensure a uniform distribution of lubricant on the rolling path of the bearing ring.

The preliminary results obtained in dry conditions (no lubricant) and lubricated conditions, respectively 1 drop and 3 drops of lubricant are presented in Figs. 6,…,9.

5. Conclusions

In this paper it is presented a method which allows the assessment of rolling friction coefficient in both situations, static (ball not rolling) and dynamic, in dry (no lubricant) and lubricated conditions with different amounts of lubricant.

Preliminary results obtained, show a higher of the ball bearing deviation angle in static friction (0.8° – 0.9°) compared to the dynamic one (0.3° – 0.4°).

For a quantity of one drop of lubricant were observed angular deviations of the ball bearing of 8° – 9° when the ball is in static friction and 19° – 21° compared to the dynamic one.

Variations of the deviated angle of the ball in case of using three drops of lubricant were between 10° – 11° when the ball is in static friction and 24° – 27° compared to the dynamic one.

A reduced deviation of the experimental results reported to the mean value can be observed. The means values, calculated from all ten experiments give as rolling friction coefficient:

$$s_{sm\,dry} = 0.0000949 \text{ m}$$
$$s_{dm\,dry} = 0.0000402 \text{ m}$$
$$s_{sm\,1drop} = 0.0009375 \text{ m}$$
$$s_{dm\,1drop} = 0.0021886 \text{ m}$$
$$s_{sm\,3drops} = 0.0011344 \text{ m}$$
$$s_{dm\,3drops} = 0.0029274 \text{ m}$$

These values increase with the quantity of the lubricant and the lubricant viscosity. Increased levels of deviated angle of the ball may be due to lubricant adhesion to surfaces, the friction of the ball bearing with the lubricant and also due to the viscos effect. Also, experimental was observed that the value of dynamic rolling friction coefficient increase once with increasing rotation speed of the bearing ring.

The results of this paper were determined for a bearing ring rotation speed of about 1 m/s and are in good agreement with the results presented by other authors (Domenech *et al*., 1987).

Influence of rotational speed on friction rolling and especially the lubricated one, will be treated in a forthcoming paper.

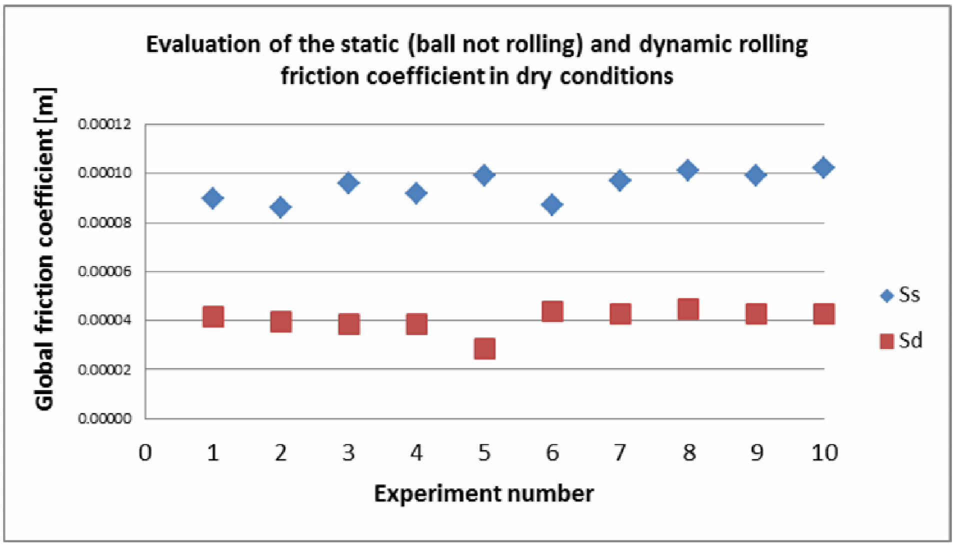

Fig. 6 – Preliminary results on evaluation of the static (ball not rolling) and dynamic rolling friction coefficient in dry conditions.

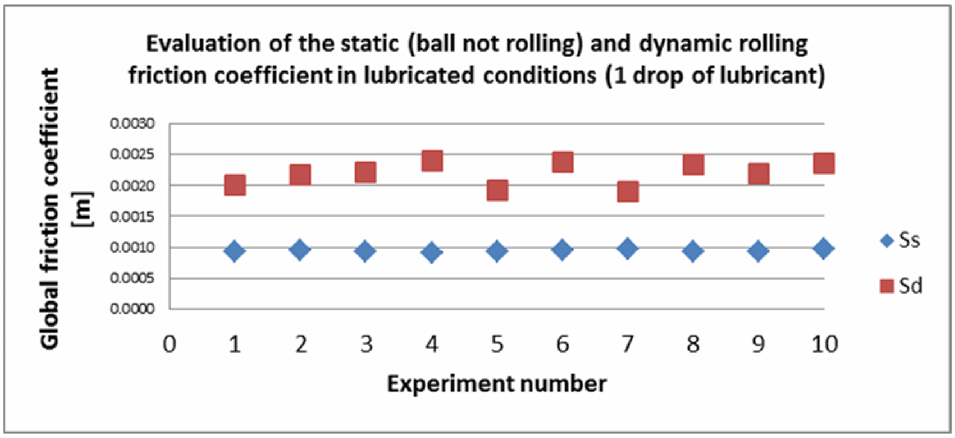

Fig. 7 – Preliminary results on evaluation of the static (ball not rolling) and dynamic rolling friction coefficient in lubricated conditions (1 drop of lubricant).

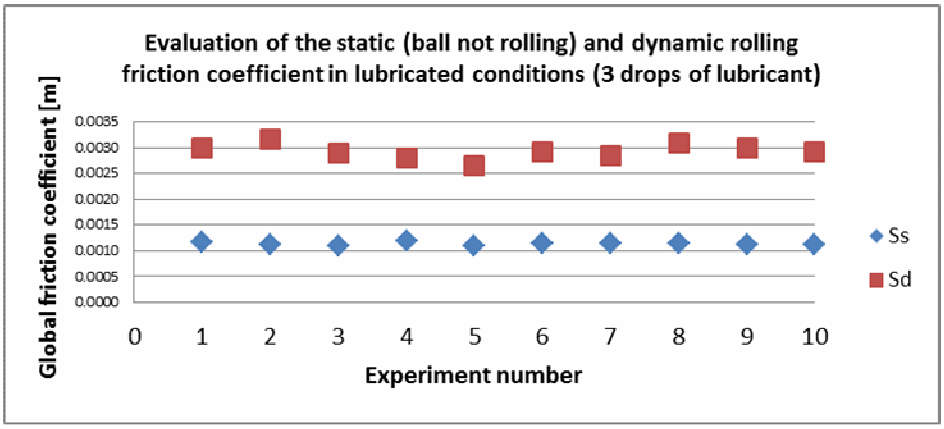

Fig. 8 – Preliminary results on evaluation of the static (ball not rolling) and dynamic rolling friction coefficient in lubricated conditions (3 drops of lubricant).

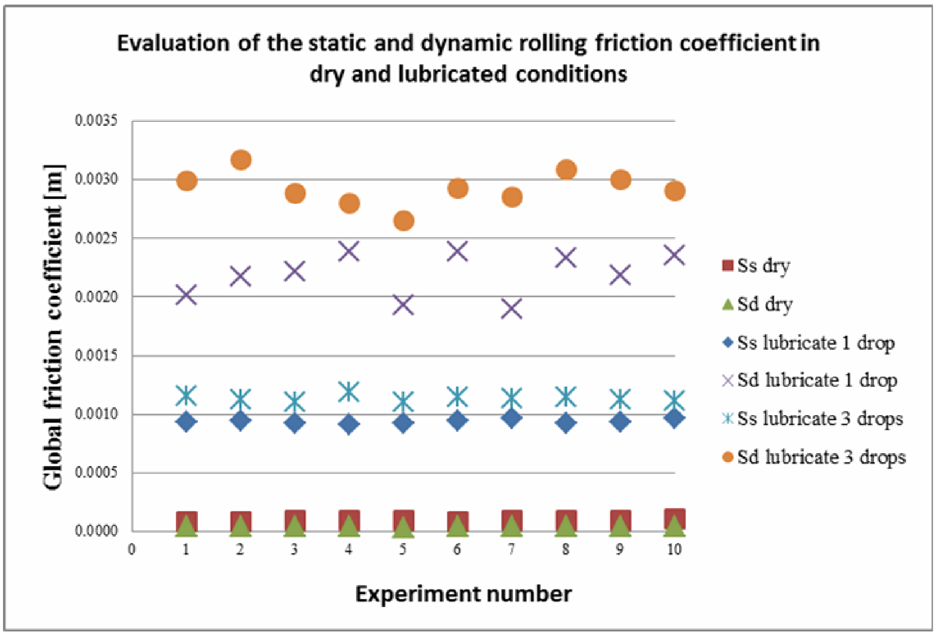

Fig. 9 – Preliminary results on evaluation of the static and dynamic rolling friction coefficient in dry and lubricated conditions (1 and 3 drops of lubricant).

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STUDIUL FRECĂRII DE ROSTOGOLIRE ÎN CONDIȚII USCATE ŞI LUBRIFIATE. REZULTATE PRELIMINARE

(Rezumat)

Pentru studierea frecării de rostogolire în condiții uscate şi lubrifiate se utilizează un dispozitiv alătuit dintr-un inel exterior al unui rulment care este antrenat în mişcarea de rotație de un motor comandat de un variator electronic de turație, o bilă de rulment aşezată liber pe calea de rulare, un disc de metal montat concentric cu axul motorului, pe care s-a marcat un cerc concentric cu inelul de rulment, pentru a putea determina în procesul de analiză şi prelucrare a imaginilor, centrul de rotație a inelului de rulment şi un marcaj radial pentru determinarea vitezei unghiulare şi periferice a inelului de rulment precum şi o cameră video de înaltă definiție capabilă să realizeze captură de imagine la o viteză de înregistrare de circa 30 cadre/sec montată astfel încât centrul obiectivului să fie situat pe aceeaşi axă cu axa inelului de rulment. Rotația inelului de rulment cu o viteză controlată va determina translația bilei fără ca aceasta să se rostogolească, într-o nouă poziție unghiulară deviată față de poziția verticală cu un unghi α_s şi, după ce bila începe mişcarea de rostogolire, aceasta se va deplasa într-o altă poziție, deviată față de verticală cu unghiul α_d. Determinarea unghiurilor poziționale α_s

sau α_d se realizează prin prelucrari de imagine cu ajutorul unor programe specializate în captură şi prelucrare video. Evaluarea unui coeficient de frecare de rostogolire denumit static (când bila nu se rostogoleşte) şi a unuia dinamic (când bila se rostogoleşte) în condiții uscate respectiv lubrifiate cu diferite cantități de lubrifiant se realizează prin introducerea succesivă a valorilor unghirilor de deviație α_s şi α_d determinate experimental, pentru fiecare condiție în parte, în relația matematică. Sunt prezentate rezultate preliminare pentru coeficientul de frecare de rostogolire bila-inel de rulment, static (când bila nu se rostogoleşte) şi dinamic în condiții uscate şi în condiții de lubrifiere cu o picătură respectiv 3 picături de lubrifiant.