FRICTION IN THE MICROTRIBOSYSTEMS. INFLUENCE OF THE CONDENSED WATER

Dumitru OLARU, Ciprian STAMATE, Alina DUMITRASCU, Gelu IANUS

Technical University “Gheorghe Asachi” of IASI, Romania, dolaru@mail.tuiasi.ro

ABSTRACT

To evaluate the influence of the condensed water on the rolling friction in the microtribosystems the authors used a microtribometer consist in a driving rotational disc in contact with 3 microballs which sustain an inertial driven rotational disc. The driving disc has a constant rotational speed and the rotational motion is transmitted from driving disc to the inertial driven disc by friction between the rolling contacts realized by the microballs and the two discs. A camera monitors the angular position of the inertial driven disc, from the start to the synchronism rotation and friction coefficient between the microballs and the inertial disc was determined as a function of the angular acceleration of the inertial disc

Experimental investigations were realized with the microballs having the diameter of 1.588 mm, 2 mm and 4.762 mm loaded with normal load of 9.42 mN both in dry conditions and in presence of condensed water on surfaces. Presence of the condensed water on the surfaces lead to increasing of the rolling friction coefficient, depending of the microballs diameter.

KEYWORDS: Rolling friction, microtribometer, microball, microsystem, condensed water

1. INTRODUCTION

The use of the micro linear or rotating ball bearings in the MEMS applications implies the simplification in construction, low level of friction and high stability, so that the microball bearings seem promising for future MEMS applications. Some experiments to determine the friction in the linear or rotating microball bearings was realized in the last period.

Lin et al. [1] determined the static and dynamic coefficient of friction for a microball linear system consisting of micromachined silicon V-grooves and stainless-steel microballs with diameter of 0.285 mm. Ghalichechian et al. [2] determined the coefficient of friction in an encapsulated rotary microball bearing realized by silicon microfabrication and stainless steel microballs with 0.285 mm diameter. The coefficient of friction was indirectly obtained by measuring the transient response of the rotor in the deceleration process from a constant angular velocity until it completely stops due to friction.

McCarthy et al. [3] experimentally investigated the dependence of speed and normal load on dynamic friction in a planar-contact encapsulated microball bearing having 0.285 mm diameter steel balls and silicon races. All the above mentioned experiments was realized in dry conditions, without water condensed on the surfaces.

Using the integration of the free oscillations equations of a microball on a spherical surface, Olaru et al. [4] determined the rolling friction coefficient both in dry conditions and in presence of water condensed on the surfaces. For a microball having a
diameter of 1 mm, Olaru et al. [4] obtained in dry conditions values for rolling friction coefficient up to 0.02 – 0.03 and in presence of the condensed water on rolling friction begin insignificant. Recently, Olaru et al. [5] presented a new methodology to determine the rolling friction coefficient between microballs and a rotational driven glass disc and obtained values of 0.0002 to 0.0004 in dry conditions.

To evaluate the influence of the condensed water on the rolling friction in the microtribosystems the authors used a microtribometer consist in a driving rotational disc in contact with 3 microballs which sustain an inertial driven rotational disc. The driving disc has a constant rotational speed and the rotational motion is transmitted from driving disc to the inertial driven disc by friction between the rolling contacts between the microballs and the two discs. A camera monitors the angular position of the inertial driven disc, from the start to the synchronism rotation and friction coefficient between the microballs and the inertial disc was determined as a function of the angular acceleration of the inertial disc

Experimental investigations were realized with the micro balls having the diameter of 1.588 mm, 2 mm and 4.762 mm, loaded with normal load of 9.42 mN both in dry and condensed water conditions.

2. EQUIPMENT AND PROCEDURE

In the figure 1 is presented the microtribometer used for experiments.

![Fig. 1 Micro tribometer disc on 3 balls](image)

The disc 1 is rotated with a constant rotating speed. Three micro balls are in contact with the race of the disc 1 at the equidistance position (120 degrees). All the three microballs sustain a glass disc 2 and are normal loaded with a force \( Q = \frac{G}{3 \cdot \cos \alpha} \), where G is the weigh of the disc 2 and \( \alpha \) is the contact angle between microballs and spherical surface of the disc 2.

When the disc 1 start to rotate with a constant speed \( \omega_1 \), the balls start to roll on the raceway of the disc 1 and start to rotate the disc 2, as a result of rolling friction forces between the balls and the disc 2. The tangential forces between the balls and the disc 2 are the traction forces for the disc 2 and can be expressed as:

\[
F = \mu \cdot Q
\]  
(1)

where \( \mu \) is the rolling friction coefficient between balls and disc 2.

The disc 2 is accelerated from zero to the rotational speed of the disc 1 in a time \( t \) (seconds) as a result of inertial effect. Considering only friction between disc 2 and the three balls and using the dynamic equilibrium of the disc 2, following equation for rolling friction coefficient between the microballs and disc 2 is obtained:

\[
\mu = \frac{J \cdot \cos(\alpha)}{G \cdot r} \cdot \frac{d^2 \phi_2}{dt^2}
\]  
(2)

where: \( J \) is the moment of inertia for the disc 2, \( \frac{d^2 \phi_2}{dt^2} \) is angular acceleration of the disc 2 and \( \phi_2 \) is angular position of the disc 2 as a function of the time \( t \).

To determine the angular acceleration of the disc 2 a high – speed camera with 90 frames/seconds was used to capture the angular position of the disc 2 from start to the synchronism rotation. Also, the angular positions of the balls and of the disc 1 are captured by camera from start to the synchronism time. In figure 2 are presented the registered positions of the disc 2, of a ball and of the disc 1, respectively \( \phi_2 \), \( \phi_b \) and \( \phi_1 \), at a short time \( t \) after the start of the rotation.

![Fig. 2. Angular positions of the disc 1, 2 and of the balls after the time t](image)
time \((t = 0)\) the marks on the two discs and one of the three balls was placed at zero position corresponding to reference line.

**3. EXPERIMENTAL RESULTS**

The disc 1 was mounted on the rotational table of the pin on disc machine CETR type UMT-2 having servo-controlled rotational speed. The disc 2 and the balls have the following dimensions:

- Radius of the disc 2: \(R = 14.25\, \text{mm}\)
- Radius of the spherical surface of the disc 2: \(R_s = 70\, \text{mm}\)
- Weight of the disc 2: \(G = 28.05\, \text{mN}\)
- Normal load on every ball: \(Q = 9.42\, \text{mN}\)
- Steel ring of an axial ball bearing (series 51100) with a curvature radius of 2.63 mm and having the radius of the rolling path for the three microballs: \(r = 8.4\, \text{mm}\).

The roughness of the active surfaces of the two discs and of the balls was measured with Form Talysurf Intra System. Following values of roughness parameter \(R_a\) were obtained:

- Surface of the disc 2: \(R_a = 0.028\, \mu\text{m}\)
- Rolling path of the disc 1: \(R_a = 0.030\, \mu\text{m}\)
- Balls surfaces: \(R_a = (0.022-0.03)\, \mu\text{m}\)

The contact angle \(\alpha = 70^\circ\).

Three microballs, diameter 1.588 mm, were used in the experiments.

To evidence the influence of the condensed water on the friction coefficient, experiments were realized both in dry conditions and in presence of the condensed water on the surface of the disc 2.

**3.1. Experimental results in dry conditions for microballs having 1.588 mm diameter**

The measurements were performed in steady room environment at a temperature of \((22-24)^\circ\, \text{C}\) and a relative humidity of \((40-60)\%\, \text{RH}\). The surfaces of the disc 1, disc 2 and microballs were cleaned with white spirit to assure dry conditions for rolling contact between microballs and the two discs.

In Figure 3, the registrations of the angular positions of the disc 2, \(\varphi_2\), when the disc 1 has rotational speed of 40, 60, 90 and 120 rpm, are presented for dry conditions.

The angular position of the disc 2, \(\varphi_2(t)\), are non-linear functions of the time and analytical expressions were obtained by curve fitting of the experimental results. The following exponential function was proposed for the angular position of the disc 2:

\[
\varphi_2(t) = e^{a + b ln(t)} + c ln(t)^2
\]

where \(a, b\) and \(c\) are constants obtained by curve fitting of the numerical values.

Angular acceleration of the disc 2 was obtained by derivative process from fitted function of angular position described by equation (3). Also, by equation (2) was obtained the friction coefficient between balls and disc 2 as a function of the time \(\mu(t)\). In the figure 4 are presented the variations of the friction coefficient between balls and disc 2, \(\mu(t)\), for rotational speeds of 40, 60, 90 and 120 rpm of the disc 1, in dry conditions.

The variation of the friction coefficient with the time, from start to the synchronism rotation, is in accord with physical phenomena. That means a rapid increasing of the friction coefficient at the start to a maximum value and followed by a decreasing to a low constant value, when is attained the synchronism of rotation for all 3 elements (disc 1, disc 2 and balls).

The experimental values of the friction coefficient obtained by proposed method suggest a dominance of the rolling process between balls and disc 2 with maximum values between 0.0002 to 0.0004. The values of the rolling friction coefficient obtained in dry conditions by the presented method are smaller.
that the rolling friction coefficient obtained by [1,2,3,4] in linear and rotational microball bearings, especially as a result of the pure rolling friction obtained with our method. So, in [1, 2] the friction coefficient experimentally determined in a microball linear system has values between 0.007 and 0.015 in the presence of the microslip caused by pivoting motion of the microballs on contact surfaces. Also, in [3,4] the friction coefficient experimentally determined in an encapsulated microball bearing varied between 0.0005 and 0.025, depending of the rotational speed and normal load. All the experiments presented in [1, 2, 3, 4] was realized with stainless steel microballs and micromachined silicon surfaces.

3.2. Experimental results in presence of condensed water on surfaces for microballs having 1.588 mm diameter

To obtain condensed water on contact surfaces, disc 2 was maintained initially some minutes at low temperature (about 4-5°C), then was brought to ambient temperature of 24°C and start the experiment. In the presence of atmospheric humidity of (40 – 60) %RH, water condensed on the surfaces of the disc 2. Some experiments was repeated with condensed water on the surfaces of the disc 2 when the driving disc 1 was rotated with 30, 60, 100 and 150 rpm. In figure 5 are presented the registrations of the angular positions of the disc 2, $\varphi_2$, when the disc 1 has rotational speed of 30, 60, 90 and 150 rpm, for condensed water on surfaces.

![Fig. 5. The variation of the angular positions of the disc 2 for microballs having 1.588 mm and for angular speed of the disc 1 of 30, 60, 90 and 150 rpm for condensed water on surfaces.](image)

It can be observed that presence of the condensed water on contact surfaces lead to important increasing of the rolling friction with about one order of magnitude compared to dry conditions. So, presence of the condensed water leads to maximum values of the friction coefficient between 0.003 to 0.007.

![Fig. 6. The variation of the friction coefficient between the microballs having 1.588 mm and the disc 2 when the driving disc 1 was rotated with 30, 60, 100 and 150 rpm, in presence of condensed water on surfaces](image)

3.3. Experimental results for microballs having 2 mm and 4.762 mm diameter

By increasing of the microballs diameter it is assumed to decreases the influence of the condensed water on the rolling friction. A new lot of experiments, both in dry conditions and with condensed water on surfaces was realized, the three microballs having 2 mm diameter and 4.762 mm diameter. In figure 7 are presented the variation of the friction coefficient between the disc 2 and the microballs for the microballs having 2 mm diameter in dry contact and with condensed water on surfaces, for a rotational speed of the disc 1 of 60 rpm. In figure 8 are presented the variation of the friction coefficient between the disc 2 and the microballs for the microballs having 4.762 mm diameter in dry contact and with condensed water on surfaces, for a rotational speed of the disc 1 of 60 rpm.

As it can be observed in figures 7 and 8, by increasing of the microballs diameter, the influence of the condensed water on rolling friction is decreasing. So, if for microballs of 1.588 mm diameter presence of the condensed water increases the rolling friction with about one order of magnitude, for balls of 4.762 mm diameter presence of the condensed water increases the rolling friction with about (20 – 30) %, for the same load and rotational conditions.
For dry conditions, rolling friction coefficient between 3 steel microballs with diameter of 1.588 mm and a glass disc is about 0.0002 – 0.0004, for a rotational speed between 40 to 120 rpm, for a normal load of 9.42 mN and for dry conditions.

Presence of the condensed water on the contact surfaces lead to increases of the rolling friction between microballs and the disc. So, for microballs with diameter of 1.588 mm presence of the condensed water on surfaces lead to increasing of the friction coefficient with about one order of magnitude.

By increasing the diameter of the microballs from 1.588 mm to 4.762 mm the influence of the condensed water to the friction coefficient is decreasing. So, for microballs having 4.762 mm diameter, in the same operating conditions, the increase of the friction coefficient as result of the condensed water is about of (20 – 30)%.

So, if in macro tribosystems water acts as lubricant, in micro scale tribosystems water is an important factor for increasing of the friction.

Acknowledgements
This work was supported by CNCSIS Grant ID_607 No. 381/1.10.2007.

REFERENCES