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The Influence of the Surface Condensed Water on Friction in Microsystems

ABSTRACT

The water existing in the atmosphere condenses on the surfaces of elements in contacts in some molecular layers and water acts by capillary effect and lead to increases of the normal forces and of the rolling/sliding resistance. Authors consider important to determine the dimensional limits in micro rolling and sliding systems for what water condensed on surfaces increases the friction. Both rolling and sliding friction experiments was realized and some results regarding the limits for influence of the condensed water to the friction coefficient has been determined.

1. INTRODUCTION

In microsystems the tribological processes are developed between elements with relatively small mass under lightly loaded conditions. In this situation, negligible wear occurs and the surface properties dominate the tribological performance. As a result, friction is highly dependent on the surface interactions. In the microsystems a lot of interfacial forces as adhesion, van der Waals, electrostatic, capillary forces can be important and have an important contribution on the friction losses. Adhesion between two solid surfaces based on the thermodynamic interfacial free energy can develop attraction forces of (200 – 300)μN or more. As a result of adhesion, a micro contact can be loaded supplementary with normal force and the contact area increases.

The capillary forces are presents as a result of the condensed water from atmosphere on the solids. The most of the solids are hydrophilic surfaces and the atmospheric water cover these surfaces with molecular layers. In the contact zone between the two solids, by the capillary effect the adhered water lead to increase of normal force. A lot of experiences evidenced the influence of the pressure, temperature and humidity of air on the thickness of the condensed water films. In the last years a lot of researches was realized to determine the realistic friction forces in sliding microsystems. Some important effects regarding the sliding friction in microsystems can be observed: The water from the atmosphere adhere on the surfaces in contact and influences the friction forces. For high water layers (more than 10 nm) friction is dominate by capillary. The capillary bridges increases the normal force and imposes resistance against shear. High values for the friction coefficient was experimentally obtained (μ = 1…4 and more). For very low water films (less than 0.2 nm) the low values of the coefficient of friction was determined (μ = 0.3…0.4).

To investigate the influence of the condensed water on the rolling friction in microsystems, authors developed a new methodology based on the free oscillation of a ball on a spherical surface only on the influence of the gravity [1]. A free ball on a spherical surface microtribometer has been realised and rolling friction coefficient for small steel ball rolling on glass surface in dry and humidity conditions was determined.

To investigate the influence of the condensed water to the sliding friction forces in microsystems, a new pin disc microtribometer having the normal load between 5 mN to 100 mN has been realized [2]. Experimental investigations were realized in order to determine the friction coefficient between a steel ball and glass plane surface in dry and humidity conditions.

2. THE INFLUENCE OF CONDENSED WATER ON ROLLING FRICTION IN MICROSYSTEMS

To determine experimental the friction losses in a micro rolling tribosystem authors developed a methodology based on the free oscillation of a ball on a spherical surface only on the influence of the gravity. In Figure 1 is presented the principle of the methodology. Depending of the level of rolling friction torque Mr and of the start position (angle φ_0), the ball have a number of free oscillations over the spherical surface.

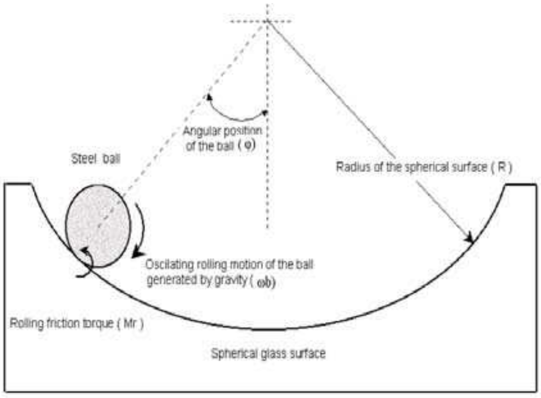

Figure 1: Oscillations of a ball over a spherical surface

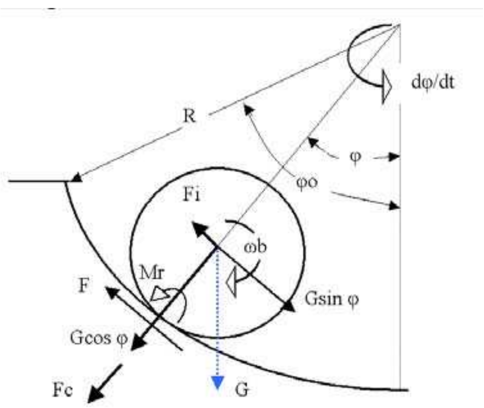

Figure 2: Forces and resistant moment acting on the rolling ball

When the ball rolling on a spherical surface from the angular position φ_0 to the angular position φ , as in Figure 2, the following energetic equation can be developed:

$$\Delta W + Mr \cdot \Delta\theta = G \cdot \Delta h \tag{1}$$

where :

ΔW - variation of the kinetic energy of the ball;

$Mr \cdot \Delta\theta$ - loosed energy in ball – race contact;

$G \cdot \Delta h$ - potential energy of the ball;

From equation (1) results differential equation for ball motion:

$$\frac{d^2\varphi}{dt^2} + k \cdot \sin\varphi \mp b = 0 \tag{2}$$

where $k = \sqrt{\frac{5 \cdot g}{7 \cdot R}}$ and $b = \frac{5}{7} \cdot \frac{Mr}{m \cdot r \cdot R}$

With the approximation $\sin\varphi \approx \varphi$ (for small oscillations), equation (2) have following solutions:

$$\varphi(t) = \frac{b}{2k^2} + (\varphi_0 - \frac{b}{2k^2}) \cdot \cos(k \cdot t) \tag{3}$$

when the ball rolling from position φ_0 to position $\varphi = 0$ and

$$\varphi(t) = -\frac{b}{2k^2} + \frac{b}{2k^2} \cdot \cos(k \cdot t) + \frac{v_0}{k} \cdot \sin(k \cdot t) \tag{4}$$

when the ball rolling on a spherical surface from the angular position corresponding to $\varphi = 0$ to the angular position φ when the ball speed is zero, as result of inertial effect.

According to Figure 2 the equilibrium of the forces acting on a rolling ball leads to following relations for tangential and normal forces, respectively:

$$F(t) = \frac{2}{7} \cdot m \cdot g \cdot \sin\varphi(t) + \frac{5}{7} \cdot \frac{M}{r} \tag{5}$$

$$N(t) = \frac{1}{7} \cdot m \cdot g \cdot \left[17\cos\varphi(t) - 10\cos\varphi_0\right] - \frac{10}{7} \cdot \frac{M}{r} \cdot \left[\varphi_0 - \varphi(t)\right] \tag{6}$$

A conventional friction coefficient in micro balls rolling was introduced according to following relation, when the acceleration of the ball is zero (position when $\varphi(t) = 0$):

$$\mu_r = \left(\frac{F(t)}{N(t)} \right)_{\varphi(t)=0} \tag{7}$$

Free oscillation of some steel micro balls on a spherical glass surface was registered with a video camera. The number of the balls oscillations and amplitude of the oscillations was determined for two conditions of temperature: 70^0 C and 10^0 C, both for balls and spherical surface. The atmospheric relative humidity was between (70 – 80)%. The experiments was made with steel balls having diameter of 1 mm, 3 mm, 5 mm and 9,525 mm. The spherical surface was made with the radius R = 75 mm and with the diameter of 70 mm. The maximum value of the angle φ was 20 degree. The variation of the ball position in the free oscillation given by equations (3) and (4) was used to determine the resistant friction torque between ball and surface. The following steps was used to simulated the free ball oscillations:

- For a given initial angular position of the ball, φ_0 and an imposed friction torque M, from equation (3) was determined the time t_1 when $\varphi(t_1) = 0$ (the ball arrive in the lowest level);
- For $t = t_1$ was determined the maximum angular speed of the ball $\frac{d\varphi(t)}{dt} = v_0$;
- From equation (4) was determined the time t_2 when the angular speed of ball is zero and ball position corresponding to the new higher level φ_1;
- The procedure was repeated with first step for the new position initial of the ball φ_1, with $\varphi_1 < \varphi_2$.

The number of the simulated oscillations was compared with experimental values registered by video camera and correction for friction torque M was realized in order to corresponds to the simulated oscillations of the ball with experimental oscillations. The experiments realized at 70^0C was considered as rolling oscillations in dry conditions and only the effect of adhesion was evidenced. With relation (7) was calculated the conventional rolling friction coefficient μ_r for all balls diameter and for every position with maximum speed. In Figure 3 are presented the values of rolling friction coefficient for the ball with 1 mm diameter. In Figure 4 are presented values of rolling friction coefficient for the ball with 9.525 mm diameter. The diameter of 9.525 mm was used to evidence the differences between micro and macro scale.

The results evidence that if for a macro ball (ball diameter of 9.525 mm) the rolling friction coefficient has an average value of 0.004, for a micro ball (ball diameter of 1 mm) the rolling friction coefficient has an average value of 0.025.

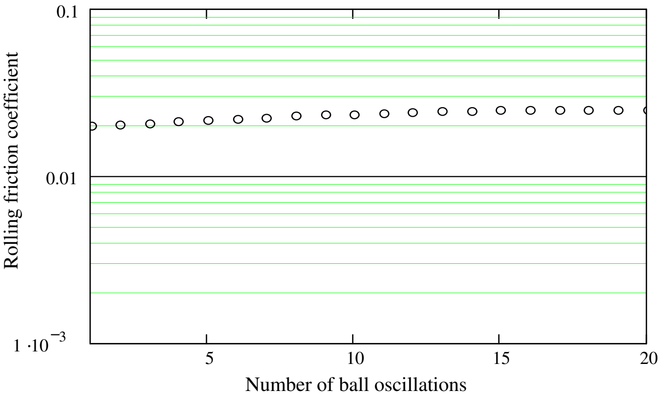

Figure 3: Friction coefficient for the ball with 1mm diameter (dry conditions)

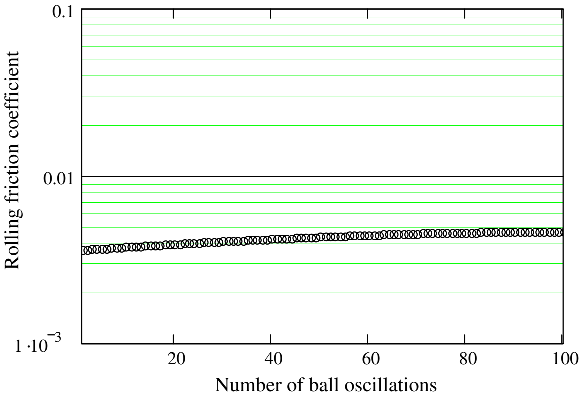

Figure 4: Friction coefficient for the ball with 9.525 mm diameter (dry conditions)

To evidence the capillary effects on rolling friction was realized the similar experiments at a temperature of 10^0C with water condensed on surfaces. In Figure 5 are presented the values of rolling friction coefficient for the ball with 1 mm diameter and in Figure 6 are presented values of rolling friction coefficient for the ball with 9.525 mm diameter

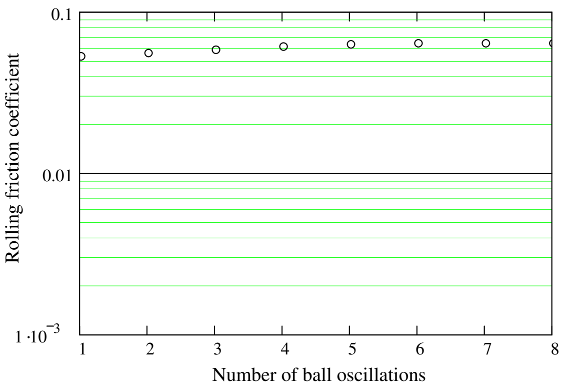

Figure 5: Friction coefficient for the ball with 1 mm diameter (capillary effects)

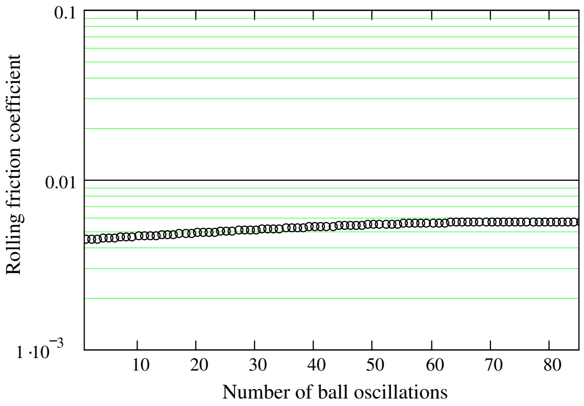

Figure 6: Friction coefficient for the ball with 9.525mm diameter (capillary effects)

It can be observed important increasing of the rolling friction coefficient for the ball with 1mm diameter as result of capillary effect. So, the rolling friction coefficient can increase to 0.06. A comparison between the gravitational force of a micro ball and the capillary force acting on the same ball is presented in Figure 7 and evidences that exist a limit of 3 mm diameter over that the gravitational force exceeds the capillary force.

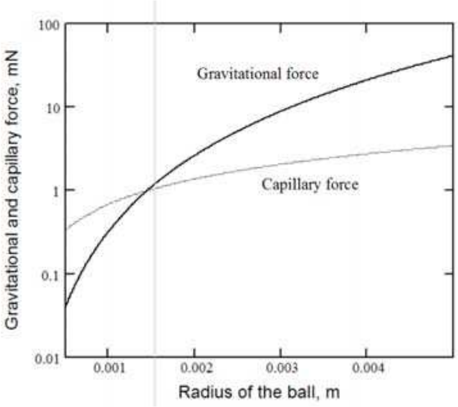

Figure 7: Gravitational and capillary force depending of the micro balls' radius

By similar experiments realized with ball having diameter of 9.525 mm was not observed important influence of capillary on rolling friction coefficient (the friction coefficient has an increasing from 0.004 to 0.005). As a first conclusion we consider that, in rolling friction the influence of the water condensed on surfaces must be considered for the balls having the diameter smaller that (3 – 5) mm.

3. THE INFLUENCE OF CONDENSED WATER ON SLIDING FRICTION IN MICROSYSTEMS

In Figure 8 is presented a new pin disc microtribometer developed by authors to determine the influence of condensed water on friction in sliding Microsystems. A small pin with diameter of 3 mm and with various length generated a normal force G with values between 5 mN and 25 mN. Supplementary, with additional loads attached on the pin can be increased the normal force G to 100mN (equivalent of aprox. 10 grams). A glass disc having a diameter of 200 mm is rotate with speed of 33 rpm and 48 rpm. The position of the pin on the disc can be modified with a radius between 10 mm to 90 mm, and can be obtain sliding speed between 0,03 m/s to 0,7 m/s.

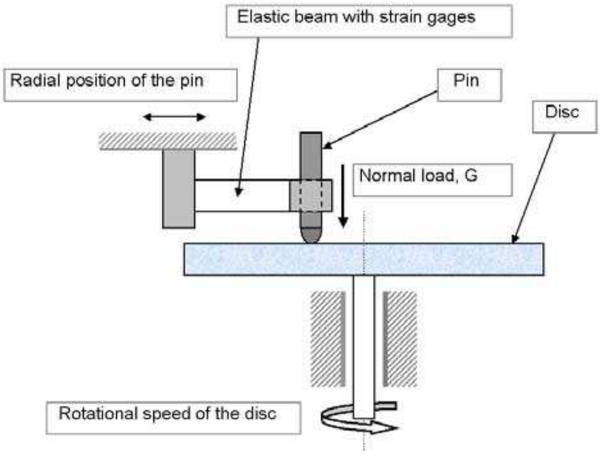

Figure 8: Pin/ball – disc microtribometer

The friction force is measured by a Futek Force Sensor model FBB350 (elastic beam with strain gages). Data acquisition is realised by a Vishay P3 Strain Indicator and Recorder and the results are saved in computer. The measurement system was calibrated with loads between 0,5 grams to 5 grams (5 mN to 50 mN). The measurement precision is about 0.2 mN. The pin is mounted in his support and is free in the direction of the normal load G. The friction force F_f is determined directly during the experiment and the coefficient of friction is determined as ratio between F_f and normal load G. In the top of the pin, directly in contact with disc is mounted a micro ball having the diameter of 3 mm. A lot of experiments was realized to determine the friction coefficient in dry and water condensed conditions for steel pin/ball – glass disc. In Figure 9 is presented the variation of friction coefficient with the time for dry and water condensed conditions with a normal load of 10 mN and a sliding speed of 0.06 m/s .

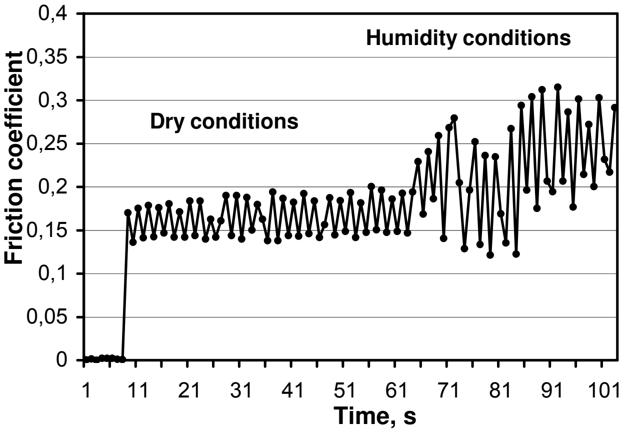

Figure 9: Friction coefficient in dry and humidity conditions for a normal load of 10mN

It can be observed that if in dry conditions the friction coefficient has values between 0.15 – 0.2, the presence of condensed water on the glass surface leads to increases of friction coefficient to 0.2 – 0.3 and important friction instabilities was developed. In Figure 10 is presented the variation of friction coefficient with the time for dry and water condensed conditions with a normal load of 30 mN and a sliding speed of 0.06 m/s .

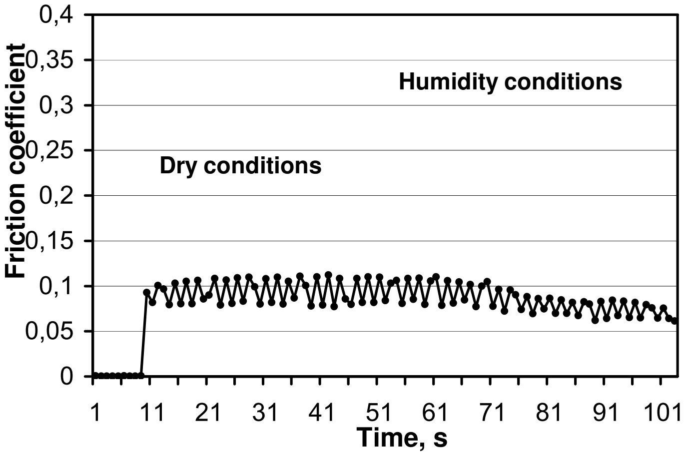

Figure 10: Friction coefficient in dry and humidity conditions for a normal load of 30mN

It can be observed that by increasing of the normal load, the effect of water condensed on surface is similar to a lubricant and leads to reduce the friction coefficient from 0.1 to 0.06 – 0.07.

CONCLUSIONS

As a first conclusion we consider that, both in rolling and sliding microsystems it can be obtained by experiments the limits for what the water condensed on surfaces can be “brake” or “lubricant”.

Based on the experiments two conclusions are obtained:

1. Presence of the condensed water leads to increase of the friction coefficient in micro rolling systems up to the diameter of about 3-5 mm.
2. Presence of the condensed water leads to increase of the friction coefficient in micro sliding systems up to the normal load of (10-20) mN

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