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Rolling Friction in the Mechatronic Microsystems

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ABSTRACT

To determine the friction coefficient in micro rolling systems the authors developed a new microtribometer with a rotating disc by 3 micro balls. The angular position of the rotating disc is monitorized by a camera and friction coefficient was determined as a function of the angular acceleration of the rotating disc.

Experimental investigations was realised with the micro balls having the diameter of 1.97 mm and normal load of 8.7 mN. The friction coefficient between the steel microballs and the glass disc was experimentally obtained both in dray and water condensed conditions.

INTRODUCTION

The development at the world-wide level of the “new materials, micro- and nano-technology” fields is activated by the evolution in “nanotechnologies” field, which was enforced in the last period as the field of most interest , with the biggest dynamic and a “revolutionary” impact on industry and society for the next decades. The high brand-new level of the “nanotechnology” term determines the prognosis studies world-wide elaborated to pay attention to the definition of this new concept. The nanotechnology represents the science and the technology which have the capacity to understand, to control and to manipulate the matter at nanometrical dimensions, which represents a scale from atoms and individual molecules level to the “supramolecular” level of the molecules bunch up to the one hundred molecular diameters.

Taking into account the convergence of the micro- and nanotechnologies, there are multiple elements of interaction and convergence of these fields. The development of the Microsystems is determined by the nanocomponents, which is not a “concurrent which will eliminate micro”, but it is a major element of development in realization of mechatronical devices and systems with more and more complex functions.

An important category of microsystems is represented by the MEMS (Micro Electromechanical Systems) with a big applicability in mechatronics structures from the automobile industry, the medical instruments, informatics, aerospace technique, robotics, micro actuators, micro pumps, micro motors, micro transmissions with micro gears, micro grippers, walking systems for micro robots, micro sensors etc. Much of these microsystems have dimensions of 10^{-4} – 10^{-6}m. The reduction of dimensions of the elements from millimeters to microns represents a reduction of the surfaces with a 10^{6} factor and of the masses with a 10^{9} factor. In this context, the friction forces, which are in direct proportion with the contact surfaces, become with 3 order size bigger than the inertia forces, which are in proportion with the mass. As the consequence, the microelements are dominantly under the influence of the surface forces, each of them being a decisive factor in the functionality of these microsystems.

The friction in microsystems is caused by the simultaneous action of more surface forces of physics nature which act at nanoscale: van der Walls forces, electrostatic forces, capillarity forces caused by the water molecules which condense on surfaces.
The sliding movement at micro scale is characterized by high friction coefficients as a result of the micro capillary and adherence processes and through stick-slip phenomena.

In the last time researches are made related the replacement of the sliding movement with a rolling movement at some linear and rotating micro motors level. The use of the micro linear or rotating ball bearings in the MEMS applications implies the simplify in construction, low level of friction and high stability, so that the micro ball bearings seems promising for future MEMS applications. To determine the rolling friction coefficient in a linear micro systems, Ta-Wei Lin et al. [1], X.Tan et al. [2] used the inertial effect in oscillatory motion. Therefore, for a micro linear system with the steel micro balls of 0.285 mm rolling on silicon plates was obtained experimentally values of rolling friction coefficient between 0.006 to 0.05, depending of the normal load.
D. Olaru et.al. [3] elaborated an theoretical model for friction in a linear rolling micro system by including adhesion and capillary effects and obtained numerical values for rolling friction coefficient similar with [1,2]. Based on the free oscillations of a steel micro ball in a spherical surfaces, D. Olaru et. al. [4] elaborated a quasi analytically model to determine the rolling friction. Based on the experiments realised both in dry and water condensed conditions, D. Olaru et al. obtained values for rolling friction coefficient between 0.006 to 0.06 with micro balls having diameter of 1 to 3 mm.
Recently Ghalichechian, N. et al. [5] developed a micro motor supported on micro ball bearing with 0.285 mm diameter of balls and determined experimentally the friction torque and the friction coefficient by measuring angular position of the rotor during the deceleration process, from a rotational speed of 400 rot/min to zero.

To determine the friction coefficient in micro rolling systems the authors developed a new microtribometer with a rotating disc supported by 3 micro balls. The angular position of the rotating disc is monitorized by a camera, from start to the synchronism rotation and friction coefficient was determined as a function of the angular acceleration of the rotating disc.

Experimental investigations was realised with the micro balls having the diameter of 1.97 mm and normal load of 8.7 mN. The friction coefficient between the steel micro balls and the glass disc was experimentally obtained both in dray and water condensed conditions.

A NEW MICRO TRIBOMETER DISC – 3 BALLS

In fig. 1 is presented the new micro tribometer. The disc no.1 is rotated with a constant rotating speed (20 rpm to 120 rpm). Three micro balls are in contact with the disc 1 and the disc no.2 and are normal loaded with a force Q = G/3, where G is the weigh of the disc 2. The geometrical characteristics are: R=14.25mm; r =8.4mm; balls diameter d_b =1,97mm, and normal load on a ball is Q= 8.7mN.

When the disc 1 start to rotate with a constant speed, the balls start to rolls on the raceway of the disc 1 and start to rotate the disc 2, as a result of rolling friction forces between balls and disc 2. The rolling forces between balls and disc 2 (F_t) can be expressed as:

$$F_t = \mu_r \cdot Q \tag{1}$$

where μ_r is 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). Considering only friction between disc 2 and the three balls, the rotating of the disc 2 is governed by following inertial equation:

$$J \cdot \frac{d\omega_2}{dt} = 3 \cdot \mu_r \cdot Q \cdot r \tag{2}$$

where J is the disc 2 moment of inertia determined by relation: $J = 0{,}5 \cdot \frac{G}{g} \cdot R^2$ and $\frac{d\omega_2}{dt}$ is angular acceleration of the disc 2.
Equation (2) lead to the following equation for rolling friction coefficient μ_r:

$$\mu_r = \frac{R^2}{2 \cdot g \cdot r} \cdot \frac{d\omega_2}{dt} \tag{3}$$

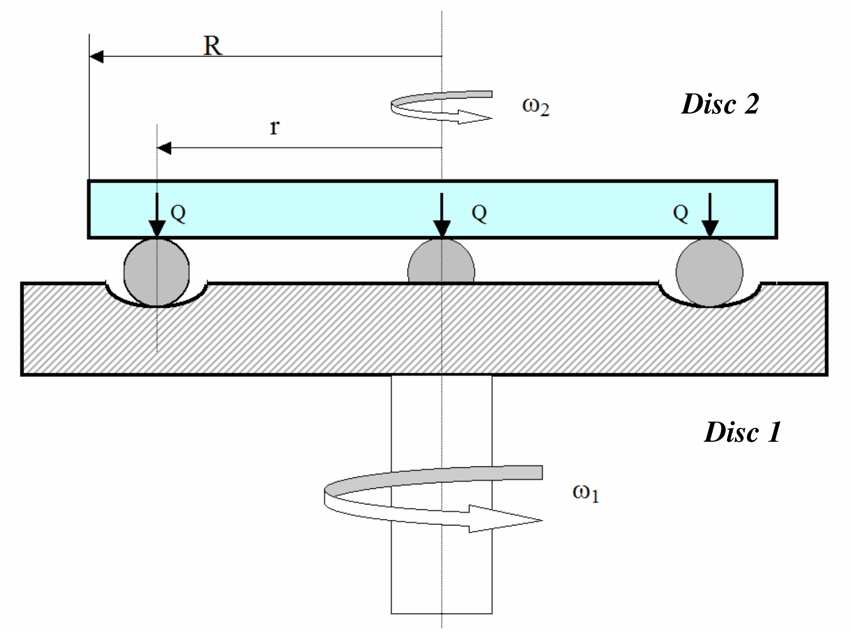

Figure 1: The new micro tribometer disc – 3 balls

From equation (3) results a linear dependence between rolling friction coefficient and angular acceleration of the disc 2.

To determine the angular acceleration of the disc 2 a high – speed camera with 90 frames/seconds was used to registred the angular position of the disc 2 from start to the syncronism rotation. In figure 2 is presented the registered positions of the disc 2, of a ball and of the disc 1, respectively φ_2, φ_b, and φ_1 at a time t.

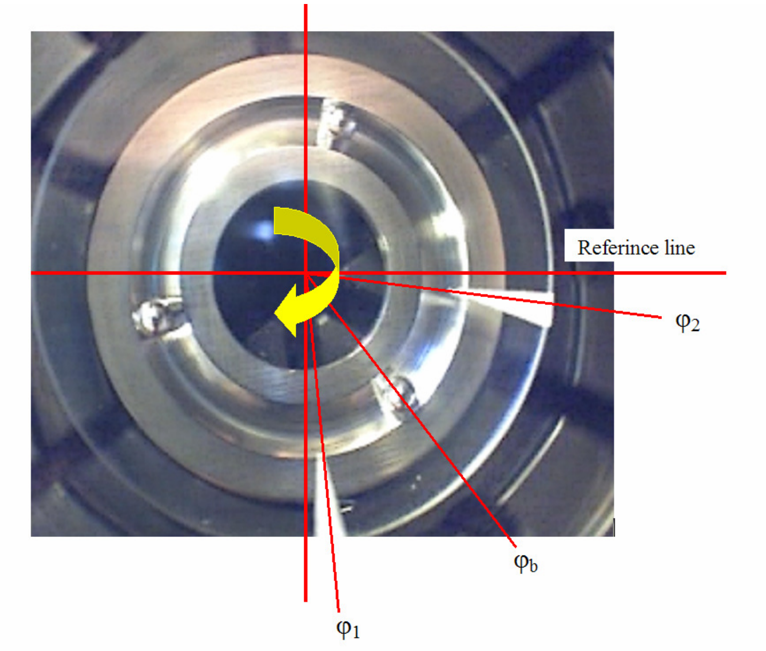

Figure 2: Determination of the angular positions of the disc 2

The angular positions of the disc 2, of the balls and of the disc 1 are registered from start to the time when the angular speed of all three elements is the same (synchronism speed).

In figure 3 are presented the typically registration of the three angular positions, when the disc 1 is rotate with 22 rot/min. It can be observed that angular position of the disc 1 is a linear function of the time: $\varphi_1(t) = \omega_1 \cdot t$, where ω_1 is angular speed of disc 1. The angular position of the ball, $\varphi_b(t)$ and of the disc 2, $\varphi_2(t)$ are non linear functions of the time and can be obtained by curve fitting of the experimental results.

The angular speeds of the balls and of the disc 2 can be obtained as derivate of the functions $\varphi_b(t)$ and $\varphi_2(t)$, respectively: $\omega_b = \dfrac{d\varphi_b(t)}{dt}$ and $\omega_2 = \dfrac{d\varphi_2(t)}{dt}$.

In pure rolling conditions between balls and discs, the following relation between the three angular speeds can be developed:

$$\omega_2 = 2 \cdot \frac{d\varphi_b(t)}{dt} - \omega_1 \qquad (4)$$

The difference between the theoretical angular speed of the disc 2 - equation (4) and the real angular speed $\omega_2 = \dfrac{d\varphi_2(t)}{dt}$ suggest the amplitude of the sliding between balls and disc 2.

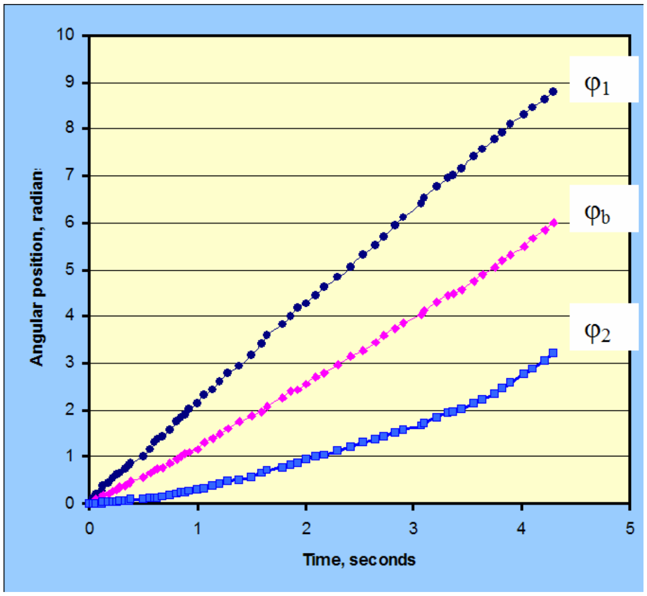

Figure 3: Variation of the angular positions φ_1 , φ_b and φ_2 for angular speed of the disc 1 of 22 rpm and for dry conditions

The real angular acceleration of the disc 2 is obtained by relation: $\frac{d\omega_2}{dt} = \frac{d^2\varphi_2(t)}{dt^2}$.

Finally, rolling friction coefficient μ_r is obtained by equation (3) as a function of time.

NUMERICAL RESULTS

A lot of experiments was performed using the new micro tribometer disc – 3 balls, both in dry conditions and with water condensed on the disc. The curve fitting of the angular position of the disc 2 presented in figure 3 leads to following equation:

$$\varphi_2(t) = 0.022 + 0.102 \cdot x + 0.535 \cdot x^2 - 0.173 \cdot x^3 + 0.021 \cdot x^4 \qquad (5)$$

Rolling friction coefficient results as a function of time and is presented in figure 4. It can be observed that values between 0.0005 to 0.0023 have been obtained, in good agreement with other experimental results.

In figure 5 are presented the experimental values of angular positions φ_1 , φ_b and φ_2 for angular speed of disc 1 of 66 rpm in dry conditions.

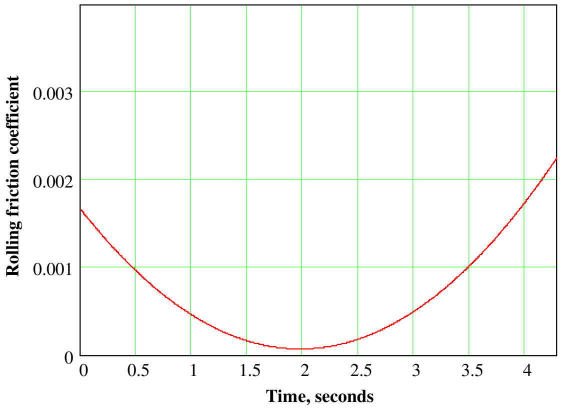

Figure 4: The variation of the rolling friction coefficient for dry conditions and for angular speed of disc 1 of 22 rpm

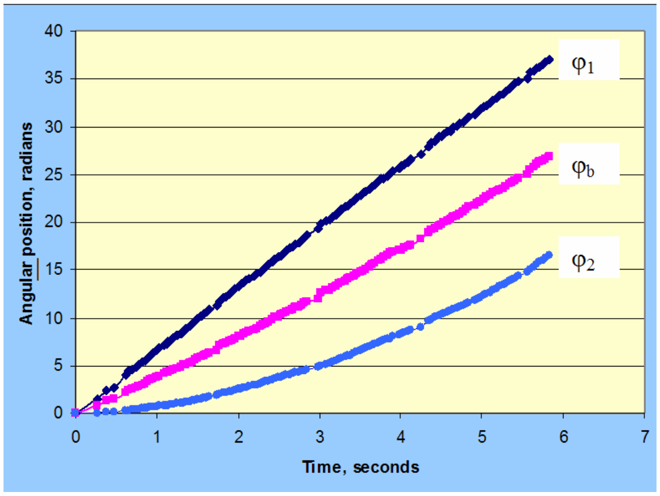

Figure 5: Variation of the angular positions φ_1 , φ_b and φ_2 for angular speed of the disc 1 of 66 rpm and for dry conditions

By curve fitting the values presented in figure 5 and derivate the function $\varphi_2(t)$, rolling friction coefficient with values between 0.0015 to 0.003 have been obtained, also.

Presence of the water condensed on the disc 2 leads to the increases of the rolling friction coefficient. In figure 6 are presented the experimental values of angular positions φ_1 , φ_b and φ_2 for angular speed of disc 1 of 66 rpm in water condensed conditions. If in dry conditions the disc 2 obtain the synchronism rotational speed in about 6 seconds, in water condensed conditions, the same rotational speed is obtained in about 1.8 seconds that means the increasing of the rolling friction coefficient. By curve fitting the values presented in figure 6 and derivate the function $\varphi_2(t)$, rolling friction coefficient with values between 0.003 to 0.005 have been obtained.

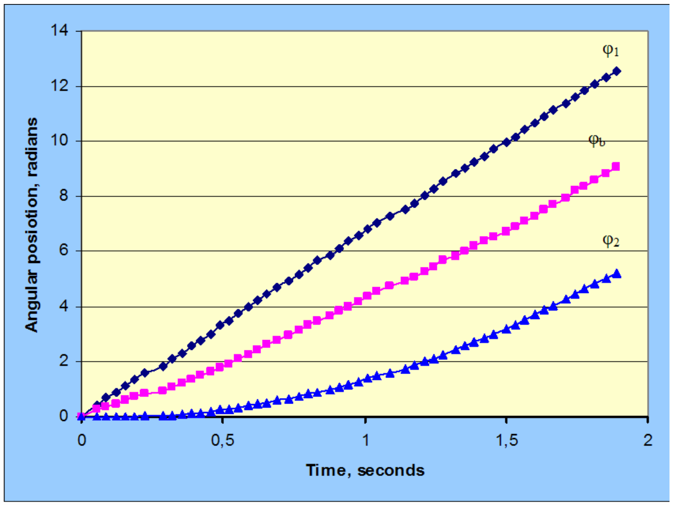

Figure 6: Variation of the angular positions φ_1 , φ_b and φ_2 for angular speed of the disc 1 of 66 rpm and for water condensed conditions

CONCLUSIONS

It is possible to estimate rolling friction coefficient by monitoring the variation in time of angular position for a rotating disc in contact with 3 micro balls. A new micro tribometer based on monitoring of the transient motion of a rotating disc has been realised.

For dry conditions rolling friction coefficient between 3 steel micro balls (1.97 mm diameter) and a glass disc with 2.6 grams is about 0.0015 – 0.003, for a rotational speed between 22 rot/min to 66 rot/min.

Presence of the water condensed on the surfaces lead to increasing of the rolling friction coefficient. So, the rolling friction coefficient between 3 steel micro balls (1.97 mm diameter) and a glass disc with 2.6 grams is about 0.003 – 0.005, for a rotational speed between 22 rot/min to 66 rot/min.

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