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THE INFLUENCE OF BUSHINGS' PROCESSING DIRECTION UPON THE FRICTION COEFFICIENT AND THE STATISTICAL ANALYSIS OF THE RESULTS

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Abstract: *Knowing the friction coefficients has a very significant importance, especially when talking about friction couplings that have frequent starting and finishing points. Because of the multitude of factors that appear in the friction process, the calculus relation for the determination of the friction coefficients are very complex.*
It is known that any measurement process is accompanied by errors. In order to eliminate such errors, in the first stage, we determine the best values of the friction coefficient, then, with statistical indicators to determine the accuracy of the final results obtained by processing.
The present paper presents the results of the experimental research made by the authors in order to determine the influence of some parameters upon the friction coefficient within the bushings and the statistical analysis of the results.
Key words: *materials, friction bearings, statistical analysis.*

1. Introduction

In order to determine the influence of some parameters upon the friction coefficient, the researcher used the technology provided by the tribology laboratory belonging to "Transilvania" University of Brasov.

The precision required for the measuring of the friction coefficients has three digits; we also have to mention that in the technical literature, these coefficients are usually given with one or two final digits.

The devices used for these experiments were:
- a tribometer based on the measurement of the linear dimensions;
- a tribometer based on the measurement of the angular dimensions;
- a high precision tribometer that had prisms;
- a tribometer used for the measurement of the friction coefficients in the vibration fields;
- a portable device that could determine the sliding friction coefficient;
- a tribometer that used the slowing down of the oscillations of a pendulum that was gasostatically bushed;

2. Experimental results

Because when talking about the couplings made out of the same material, with the same rugosity, different values of the statically friction coefficients have been registered, another aspect has been taken into consideration, the one when during the relative movement, the direction between the couplings switches.

Determinations have been made on a number of six couplings made out of different materials used when making the bushings [e.g. an antifriction material based on Al-Sn (AS20) + steel OLC 45, anti friction material based on synthesized powders Cu-Pb (CP10S10) + steel OLC 45], the two semi couplings having the making direction of the parallel surface, then perpendicular [1; 2].

The determinations have been made on the high precision tribometer with a bushed mass on the prisms [2; 3]. When talking about the couple with an anti friction material based on Al-Sn (AS20) + steel OLC 45, ten determinations have been made for different rugosities of the mobile semicoupling, for the case in which the direction of the making of the semicoupling is parallel and ten determinations for the different rugosities of the mobile semicoupling, when the direction of the making is perpendicular. And also when the coupling has an antifriction material based on Cu-Pb (CP10S10) + steel OLC 45, there have been made ten determinations for the different types of rugositie of the mobile semicouplings order to establish the static medium friction coefficient.

In the following tables there are presented the experimental results for the friction coefficients when we are dealing with six plane couples, made out of different materials and having different rugosities, in the conditions of the dry friction of the translation motion.

Table 1 presents the scales of the static friction coefficient experimentally determined for the coupling made out of the anti friction material based on Al-Sn (sample 1) and steel OLC 45, depending upon the rugosities of the mobile semi coupling (having, in the making, a parallel direction with the motion direction).

Table 1

The static friction coefficient	***The rugosity, R_a=0.4***	***The rugosity, R_a=0.8***	***The rugosity, R_a=1.6***	***The rugosity, R_a=3.2***
The minimal value	0.3170	0.3732	0.2970	0.3158
The medium value	0.3610	0.4060	0.3180	0.3517
The maximal value	0.4370	0.4784	0.3673	0.3968

Table 2 presents the values of the static friction coefficient, values experimentally.

Determined when talking about the coupling formed from the anti friction material Al-Sn (sample 2) and OLC 45 depending upon the rugosity of the mobile semi couple (the making direction is parallel with the motion direction).

Table 2

The static friction coefficient	***The rugosity, R_a=0.4***	***The rugosity, R_a=0.8***	***The rugosity, R_a=1.6***	***The rugosity, R_a=3.2***
The minimal value	0.3029	0.3520	0.3027	0.3154
The medium value	0.3364	0.4105	0.3354	0.3617
The maximal value	0.3877	0.5033	0.3855	0.4148

Table 3 presents a comparative study of the medium values obtained after the determinations made for the coupling made out of an anti friction material based on Al-Sn (AS20) and steel OLC 45, for different rugosities and also for the situation when the striations of the mobile coupling are parallel with the motion direction.

Table 3

The static friction coefficient	*The fixed coupling - anti friction material Al-Sn (AS20)*	*The mobile semi coupling– steel OLC 45*			
		The rogosity, *R_a=0.4*	**The rogosity, *R_a=0.8***	**The rogosity, *R_a=1.6***	**The rogosity, *R_a=3.2***
The medium value	sample 1	0.3610	0.4060	0.3180	0.3517
The medium value	sample 2	0.3364	0.4105	0.3354	0.3617

We can also notice that the medium values of the static friction coefficient in the case of the two samples of the same material are relatively close, having variations between 0.01-0.03, values that can be explained by the fact that on the surface of the anti friction material there can be found some faults resulted from the making, or that the determinations have been executed under different temperature and humidity conditions [1; 2].

In table 4 we have gathered all the values of the friction coefficient when talking about the coupling made out of the material Al-Sn and steel OLC 45, depending upon the rugosities of the mobile coupling.

Table 4

The static friction coefficient	*The rugosity, R_a=0.4*	*The rugosity, R_a=0.8*	*The rugosity, R_a=1.6*	*The rugosity, R_a=3.2*
The minimal value	0.3242	0.3076	0.2875	0.2913
The medium value	0.3513	0.4097	0.3201	0.3241
The maximal value	0.4072	0.5161	0.3374	0.4175

The determination have been made by reversing the motion direction of the mobile coupling so that the making direction to be perpendicular on the motion direction.

Table 5 gathers all the values of the friction coefficient, experimentally determined when talking about the coupling made out of the anti friction material Al-Sn and steel OLC 45, depending upon the rugosities.

Table 5

The static friction coefficient	*The rugosity, R_a=0.4*	*The rugosity, R_a=0.8*	*The rugosity, R_a=1.6*	*The rugosity, R_a=3.2*
The minimal value	0.3374	0.3261	0.3128	0.3064
The medium value	0.3738	0.3768	0.3688	0.3389
The maximal value	0.4251	0.4345	0.4077	0.3835

The numerical making of the experimental results has been made, and in table 6 we have presented together the results obtained in the two functioning situations.

Table 6

Crt. no.	*Sample no.*	*The semi coupling / The rugosity R_a*			*The value of the friction coefficient*	
		Fixed	*Mobile*	*The rogosity*	*The parallel direction of the production*	*The perpendicular direction of the production*
1	1	AS20	OLC 45	0.4	0.3610	0.3513
2		AS20	OLC 45	0.8	0.4060	0.4097
3		AS20	OLC 45	1.6	0.3180	0.3201
4		AS20	OLC 45	3.2	0.3517	0.3241
5	2	AS20	OLC 45	0.4	0.3364	0.3738
6		AS20	OLC 45	0.8	0.4105	0.3768
7		AS20	OLC 45	1.6	0.3354	0.3688
8		AS20	OLC 45	3.2	0.3617	0.3389

We can easily notice that, generally speaking, the value of the friction coefficient is higher when talking about the parallel direction of the production of the two elements belonging to the coupling. This can be easily explained regarding the micro geometry of the two surfaces. The real contact surface in this case is bigger when the direction of the production is perpendicular.

There are also exceptions from the rule. One of then appears when we have a contact between a surface with a higher durity and another surface with a lower one (e.g. OLC 45 with the anti friction material based on Al-Sn [AS20]). In this case the situation is being reversed. This could easily be explained by the fact that some plastically distortions of the mass of the softer material could lead to the increasing of the friction coefficient when the direction of production of the coupling is perpendicular.

A certain statement is the one that says that the production direction also influences the static friction coefficient and we have to keep it in mind when making a friction coupling [1; 3].

The same tryouts have been made for the coupling made out of the anti friction material based on Cu-Pb (CP10S10) and steel OLC 45, for different rugosities of the mobile coupling. The final results of these determinations are presented as following.

In table 7 there can be noticed in a comparative way the medium values obtained after the determination made for the coupling made out of the anti friction material based on Cu-Pb (CP10S10) and steel OLC 45, for different rugosities of the mobile coupling.

Table 7

The static friction coefficient	*The rogosity, R_a=0.4*	*The rogosity, R_a=0.8*	*The rogosity, R_a=1.6*	*The rogosity, R_a=3.2*
Medium value–sample 1	0.2451	0.2286	0.2057	0.2451
Medium value–sample 2	0.2256	0.2342	0.2103	0.2055

We can notice that when talking about the anti friction material that is based on synthesized powder Cu-Pb (CP10S10), the values of the static friction coefficient or the two samples have variations between 0,01-0,04, thing that can be explained through the fact that the contact surface between the fixed semi coupling and the one of the semi-mobile are different. The difference is made depending on the rugosity, as well as through the fact that the determinations have been executed under different temperature and humidity conditions.

3. Processing measurements regarding the friction coefficient depending on sedge/roughness

It is known that any measurement process is accompanied by errors which can be summarized as follows: operator skills, performance and maintenance status of the used equipment, the environment [4].

In order to eliminate such errors, in the first stage, we determine the best values of the friction coefficient, then, with statistical indicators (empirical standard deviation of a single measurement, the arithmetic average of the average error of a single measurement, tolerance, maximum gap within the range of measurements), to determine the accuracy of the final results obtained by processing [4; 5].

Therefore, the relations used in the practice of processing the measurements [1] to estimate the accuracy of the reference values used as the arithmetic mean of the friction coefficient along the two directions, parallel to ($\overline{\mu}^{\|}$) and perpendicular ($\overline{\mu}^{\perp}$), which is considered to be the best value of the vector of measurements (relations 1 and 2):

$$\overline{\mu}^{\|} = \frac{\sum_{i=1}^{n} \mu_i^{\|}}{n} \tag{1}$$

$$\overline{\mu}^{\perp} = \frac{\sum_{i=1}^{n} \mu_i^{\perp}}{n} \tag{2}$$

where: $n = 8$, as well as the appropriate appearance and correction, calculated by the relationship 3 to 4:

$$v_i^{\|} = \overline{\mu}_i^{\|} - \mu_i^{\|}, \quad i = \overline{1,8} \tag{3}$$

$$v_i^{\perp} = \overline{\mu}_i^{\perp} - \mu_i^{\perp}, \quad i = \overline{1,8} \tag{4}$$

The validity of corrections is given by the conditions $\sum_{i=1}^{n} v_i^{\|} = 0.00$, respectively $\sum_{i=1}^{n} v_i^{\perp} = 0.00$.

There are situations when the second decimal is nonzero. Under these conditions the hundredth offset plus or minus (depending on the sign of the correction) over the components of the measurement vector, so that the sum is zero.

With apparent corrections we can calculate the empirical standard deviation (mean square error) of a single measurement on the two directions ($s_0^{\|}$, $s_0^{\perp}$) using the relations 5 and 6:

$$s_0^{\|} = \sqrt{\frac{\sum_{i=1}^{n} {v_i^{\|}}^2}{n-1}} \tag{5}$$

$$s_0^{\perp} = \sqrt{\frac{\sum_{i=1}^{n} {v_i^{\perp}}^2}{n-1}} \tag{6}$$

and then the average error of the arithmetic mean of the two directions ($s_m^{\|}$, $s_m^{\perp}$) using the relationship 7 and 8:

$$s_m^{\|} = \frac{s_0^{\|}}{\sqrt{n}} \tag{7}$$

$$s_m^{\perp} = \frac{s_0^{\perp}}{\sqrt{n}} \tag{8}$$

Then, we compare the maximum spacing (Δ_{max}) of tolerance (T) for the two-way set (relations 9, 10, 11 and 12):

$$\Delta^{||}_{max} = \mu^{||}_{max} - \mu^{||}_{min} \quad (9)$$

$$\Delta^{\perp}_{max} = \mu^{\perp}_{max} - \mu^{\perp}_{min} \quad (10)$$

$$T^{||} = 3s^{||}_{0} \quad (11)$$

$$T^{\perp} = 3s^{\perp}_{0} \quad (12)$$

If $\Delta^{||}_{max} \le T^{||}$, namely $\Delta^{\perp}_{max} \le T^{\perp}$, when the measurements are within the specified tolerances. Otherwise, the answer is negative.

The processed results (precision indicators for friction coefficient) are summarized in table 8.

Table 8

Crt. no.	***Friction coefficient,*** μ		***Apparent corrections***		***Precision indicators***
	Parallel direction $\mu^{\|\|}$	***Perpendicular direction*** $\mu^{\perp}$	$v^{\|\|}_{i}$	$v^{\perp}_{i}$	
1.	0.3610	0.3513	0.00	0.01	(5) $\Rightarrow s^{\|\|}_{0}$ = 0.033
2.	0.4060	0.4097	-0.05	-0.05	(6) $\Rightarrow s^{\perp}_{0}$ = 0.030
3.	0.3180	0.3201	0.04	0.04	(7) $\Rightarrow s^{\|\|}_{m}$ = 0.013
4.	0.3517	0.3241	0.01	0.03	(8) $\Rightarrow s^{\perp}_{m}$ = 0.011
5.	0.3364	0.3738	0.02	-0.02	(9) $\Rightarrow \Delta^{\|\|}_{max}$ = 0.093
6.	0.4105	0.3768	-0.05	-0.02	(10) $\Rightarrow \Delta^{\perp}_{max}$ = 0.090
7.	0.3354	0.3688	0.02	-0.01	(11) $\Rightarrow T^{\|\|} = 3s^{\|\|}_{0}$ =0.099
8.	0.3617	0.3389	0.00	0.02	(12) $\Rightarrow T^{\perp} = 3s^{\perp}_{0}$ =0.091
	$\overline{\mu}^{\|\|} =$ 0.3601	$\overline{\mu}^{\perp} =$ 0.3579	$\sum_{i=1}^{n} v^{\|\|}_{i} = 0.00$	$\sum_{i=1}^{n} v^{\perp}_{i} = 0.00$	

At the end of the statistical study we can determine empirical correlation coefficient (r_{12}), using relation 13:

$$r_{12} = \frac{s_{12}}{s^{||}_{0} \cdot s^{\perp}_{0}} = 0.001, \quad (13)$$

where: s_{12} is the empirical covariance (relation 14):

$$s_{12} = \frac{\sum_{i=1}^{n} v^{||}_{i} v^{\perp}_{i}}{n-1} = 1.34 \text{ X } 10^{-6}. \quad (14)$$

Empirical correlation coefficient shows statistical dependence (independence) of two measurements as follows:

- $r_{12} \in [-0.2; 0.2]$ insignificant dependence;
- $r_{12} \in [-0.4; -0.2] \cup [0.2; 0.4]$ very low dependence;
- $r_{12} \in [-0.6; -0.4] \cup [0.4; 0.6]$ low dependence;
- $r_{12} \in [-0.8; -0.6] \cup [0.6; 0.8]$ moderate dependence;
- $r_{12} \in [-1; -0.8] \cup [0.8; 1]$ strong dependence.

4. Conclusions

From the experimental research already made we find out the variations met in the case of the friction coefficient of the anti friction materials used in the process of the making of the bushings.

After the experimental measurements we can draw the following conclusions:

- the variations of the static friction coefficient are quite high even if the velocity in sliding was kept relatively constant, for the same material, situation that can be explained through the fact that on the surface of the anti friction materials there can be some faults as well as through the fact that the determinations have been executed under different temperature and humidity conditions;

- the differences in temperature are noticeable at the level of the sliding surfaces, of the bushings, due to the friction between the axel and the bushing;

- the static friction coefficient is influenced by the temperature, the working conditions as well as by the relative sliding velocity;

- in appreciatively the same conditions of trying out the anti-friction material based on Cu-Pb (CP10S10) we obtain a lower static friction coefficient then the one of the anti-friction material based on Al-Sn (AS20), so the conclusion is that we can get a better friction behavior of the anti-friction material based on the sinthetized powder Cu-Pb (CP10S10) than the one of the anti-friction material based on Al-Sn (AS 20);

- because of the existance of the tiny soft layer (anti-friction metal) on the steel structure (when talking about the bushings) the values of the friction coefficient are lower than when using the couplings made out of the same soft material;

- the friction coefficient is influenced by the interaction of the microrugosities of the mobile semicoupling with the tiny soft layer of anti-friction material put on the steel structure, because the resistance during the shearing is determined by it.

In the case of the couplings made out of the same anti-friction material based on Al-Sn (AS20) with the same rugosity, there have been registered different values of the static friction coefficients in the moment when the relative movement between then changes its processing direction.

The value of the static friction coefficient is influenced by the material of the semicouplings as well as by the direction and the way of producing the materials out of which the friction coupling is being made.

The value of the friction coefficient is greater when the processing direction of the elements of the coupling is paralel. This can be explained by the fact that the contact surface of this particular case is bigger than in the case when the direction of the processing is perpendicular.

There are also exception s from this rule, exceptions that can be explained by the fact that when the contact between a surface with a greater durity and a softer one is produced [for e.g. when OLC 45 and the anti friction material Al-Sn (AS20) meet] the situation is being reversed and so there may appear some distortions in the mass of the softer material. This kind of transformation may lead to an increased friction coefficient in the case when the processing direction of the mobile coupling is perpendicular.

The friction coefficient is also influenced by the micro geometry of the surfaces that get in contact during the friction.

As the conditions on the validity of the apparent corrections have been completed without the plus or minus offset of a hundredth, it confirms that the friction coefficient measurements were correctly read, not being accompanied by significant errors.

The fact that the maximum spacing along the two directions does not exceed the relevant tolerance leads to the following statement: The measurements along the two directions (parallel and perpendicular) *fall within the specified tolerance.*

As an empirical correlation coefficient (r_{12}) corresponds to the interval $[-0.2; 0.2]$, the measurement of the friction coefficient along the parallel direction are statistically independent in relation to the measurement of the friction coefficient along the perpendicular direction.

References

[1]. Bardocz, G., Dinescu, I. *Cercetări experimentale privind proprietăților de rezistență ale materialelor bimetal pe bază de Cu-Pb şi Al-Sn*, SESIUNEA DE COMUNICĂRI ŞTIINȚIFICE CU PARTICIPARE INTERNAȚIONALĂ „EDUCAȚIE ŞI CERCETARE ŞTIINȚIFICĂ LA STANDARDE EUROPENE", 11-12 mai 2007, Editura Academiei Forțelor Aeriene "Henri Coandă", ISBN 978-973-8415-45-4.

[2] Cozma, R. *Elemente fundamentale de tribologie – frecare-ungere*, MATRIX ROM, Bucureşti, 2004.

[3] Dinescu, I., Bardocz, G., Oprescu, M. *Proprietăți fizico-mecanice ale materialelor utilizate la fabricarea lagărelor cu alunecare*, A X-a sesiune de comunicări ştiințifice cu participare internațională, Academia Forțelor Terestre „Nicolae Bălcescu" Sibiu, noiembrie 2005.

[4]. Ghițău, D. *Prelucrarea măsurătorilor geodezice*, Editura Topoexim, Bucureşti, 2009.

[5]. Wolf, H. *Ausgleichungsrechnung nach der Methode der kleinsten Quadraten,* Dummlers Verlag, Bonn-Hannover-Munchen, 1968.