Journal of the Balkan Tribological Association *Vol. 25, No 2, 432–442 (2019)*

GENERAL METHODOLOGY FOR STUDYING THE TRIBOLOGICAL PROCESSES ON THE BASIS OF THE COMMUNICATIVE POTENTIAL

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ABSTRACT

The paper presents the authors general procedure for tribological processes study based on the communication potential and the general law of contact interaction in tribology. The procedure is applicable to arbitrary scope of perturbation influence, if the scope is divided into sectors, where the communication potential varies in a monotone.

The procedure was implemented for a concrete case of static friction study in a contact system containing high–strength cast iron with various tin micro–alloys. The obtained results are as follows:

– Procedure is developed and experimental relationship is obtained for the static coefficient of friction variation with the content of tin.

– The communication potential of the static friction is attained and its experimental variation is obtained for the content of tin in the interval 0% to 0,032%.

– The law for variation of the total communication potential with the content of tin in the interval 0% to 0,032% is obtained.

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– The law for the static coefficient of friction variation with the content of tin in the interval 0% to 0,032% is obtained.

Keywords: tribology, contact interaction, relationships and laws, friction, high–strength cast iron.

AIMS AND BACKGROUND

According to the paradigm of the classical mechanics, dominating now in the engineering tribology and in the overall engineering practice, a counteraction replies to each action. So, the contact between two alternative bodies in the systems is reduced to a constant and idealized formation. As a result, the contact is excluded as a factor in the dynamic behavior of the contact systems.

According to the interdisciplinary paradigm of tribology, each contact interaction in an elemental tribosystem is completed by three objects – two alternative bodies and a third functional object between them called contact. The contact is the most dynamical element in the system fulfilling three basic functions – dividing, unifying and realizing the alternative bodies in a unit[1,2,3,4,5].

It is known that the contact interaction does not result in linear reduction of the interaction relationships for the various processes – friction, wear, contact deformation, contact conductance, filtering, etc. The numerous results of testing in laboratory and production conditions show that there are nonlinear relationships exhibiting extreme variations and vibration components. They are related to structural, dynamic and process changes in contact under the various regimes of their exploitation[5–11].

The paper aims at development of a general procedure for contact interaction study under various conditions and taking into account the real contact behaviour of the contact as third functional body in each tribosystem.

GENERAL CHARACTERISTIC OF THE CONTACT INTERACTIONS THROUGH THE COMMUNICATION POTENTIAL

Quantitative expression of the model of three–unity of each tribosystem is the general law of contact interaction of tribology. According to that law, the current state of each contact system is determined by three potentials, and not by two, the three being: active, reactive and communication (contact) potentials. The relationship between the three potentials is represented as universal law in differential form as follows:

$$\frac{dR}{R} = \eta \frac{dA}{A} \tag{1}$$

where dR/R is the relative external perturbation (action) upon the system; dA/A –

the relative reaction of the system and η – the communication potential, by means of which the interaction between action and reaction is realized. The three variables in the law (1) are non–dimensional quantities and that reflects its universal character.

Three cases for quantitative measurement of the contact interaction communication potential are possible[12] .

CASE 1. $\eta = 1$

The law of contact interaction (1) is in the form:

$$\frac{dR}{R} = 1.\frac{dA}{A} \tag{2}$$

Integration of (2) and taking the antilogarithm give linear law for the contact interaction between action and reaction in the system:

$$R = k.A \tag{3}$$

The law (3) is a basic law for the contact interactions in accordance with the law of the classical mechanics for the equality between perturbation and reaction. Examples are the laws of friction and wear in a stationary regime of operation of tribosystems.

CASE 2. $\eta = const \neq 1$

The solution of equation (1) in this case leads to a non–linear law of contact interaction, which is observed in the contact deformation, contact displacements, etc.[10,11]:

$$R = k_1 A^{k_2} \tag{4}$$

where k_1 and k_2 are constants different from unity, k_1, $k_1 \neq 1$.

CASE 3. $\eta \neq const$ or

$$\eta = \eta(A_1, A_2, ...A_n) \tag{5}$$

i.e.η depends on the perturbations in a specific manner for each contact system.

In the general case, the relationship (5) is called *law for variation of the communication potential of the contact interaction.*

The third case is typical for the actual run of the tribological processes.

The communication potential can obtain three different values in the process of operation of the tribosystems, namely: $\eta = 0$; $0 < \eta \leq 1$; $\eta \geq 1$. For example, the curve of the wear rate as a function of the duration of friction between the two partners is in the form given in Fig. 1.

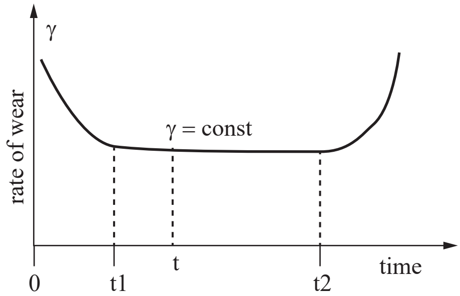

Fig. 1. Wear rate versus time

Three stages are observed, which are known in tribology as: regime of running–in, regime of stationary contact interaction and regime of pathological interaction.

Each stage is characterized by different communication potential according to Table 1.

Table 1. Communication potential in the regimes of contact interaction in tribosystems

Stage of contact interaction	Running-in $0 < t \le t_1$	Stationary $0 < t \le t_2$	Patological $t > t_2$
Communication potential	$1 \le \eta(t) \le 0$	$\eta(t) = 0 = \text{const}$	$\eta(t) \ge 1$

It is generally accepted that the stationary stage of the interaction is the basic one, determining the resource of the system. That is related to the stability of the tribological processes related to the stationary wear rate of the elements, where $\eta(t) = 0 = const$. The attention of tribologists is mainly focused on the study of the dependence of the wear rate on various factors – materials and operation regimes during this stage, as well as to the improvement of the duration of the stage.

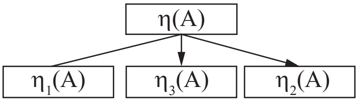

Fig. 2. Functional atom of the communication potential of contact interaction

As it is known from the literature, the notion of *functional atom* (FA) reflects the three–unity of each entity – object, body, process, state, etc. on each level and each cross–section. FA is structured by two alternatives supplemented by a third functional object between them, the *contact* [1,2,3].

Being general characteristic of the current contact state, the communication potential η is a quantity that changes dynamically. According to the model of FA, the communication potential of FA as an entity is represented by three components: $\eta_1(A)$– current communication, $\eta_2(A)$– nominal communication and $\eta_3(A)$– creative communication (Fig. 2).

According to the general law (1) and Figure 3, the communication potential is given as:

$$\eta(A) = \frac{dR}{R} : \frac{dA}{A} = \frac{dR}{dA}\frac{A}{R} = \frac{tg\alpha(A)}{tg\beta(A)},$$

or

$$\eta(A) = \frac{tg\alpha(A)}{tg\beta(A)} \tag{6}$$

where $\alpha(A) = (\vec{T}, \overline{OA})$ is the angle between the tangent in point M and the axis *OA*, and $\alpha(A)=(\vec{F},\overline{OA})$ is the angle between the cutting line $\vec{F}$ and the axis $\overline{OA}$. The relationship (6) is called *law for variation of the total communication potential of the contact interaction.*

The current communication $\eta_1(A)=\mathrm{tg}\alpha(A)$ expresses the current velocity of the contact interaction, the nominal communication $\eta_2(A) = \mathrm{tg}\alpha(A)$ expresses the average velocity of the contact interaction, and the creative communication $\eta_3(A)$ reflects the equalizing creative function of the contact. This is the hidden component of the total communication potential.

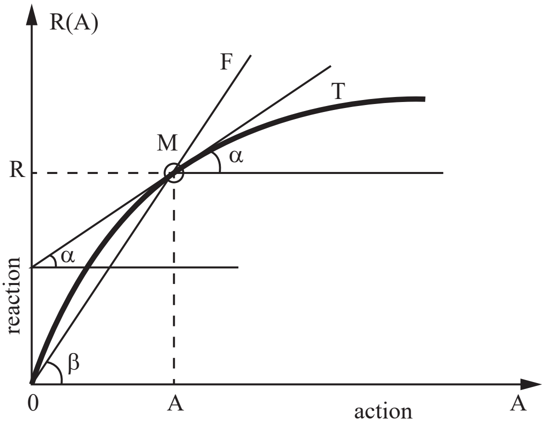

Fig. 3. Curve of the на contact interaction between perturbation A and reaction R

INFLUENCE OF TIN CONTENT IN HIGH STRENGTH CAST IRON ON THE STATIC COEFFICIENT OF FRICTION IN THE TRIBOSYSTEM ‘HIGH STRENGTH CAST IRON – STEEL’

It is well known that microalloying of high strength cast iron by various elements influences its mechanical and tribological characteristics. The present paper focuses on the influence of tin content in high strength cast iron upon the static coefficient of friction in the case, when the interaction is with steel conterbody.

The purpose is to develop a procedure based on the communication potential and the general law of contact interaction and to obtain the law for variation of the static coefficient of friction due to the content of tin.

The procedure includes the following phases:

- Obtaining experimental relationship between the coefficient of friction and the content of tin in high strength cast iron.
- Establishment of the law of variation of the communication potential of the static friction due to the content of tin.
- Obtaining the law of variation of the static coefficient of friction due to the content of tin.

EXPERIMENTAL RELATIONSHIP BETWEEN THE COEFFICIENT OF FRICTION AND THE CONTENT OF TIN IN HIGH STRENGTH CAST IRON

Figure 4 shows the laboratory device for the study of static friction. The studied cast iron specimen 1 is fixed in the holder 3 and it forms contact with the

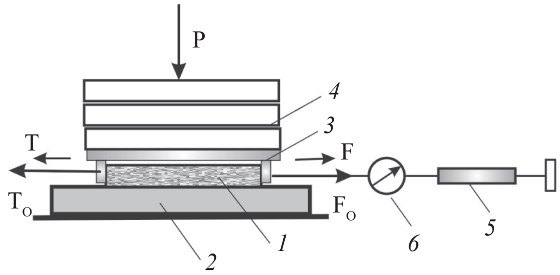

Fig. 4. Scheme of the device for static friction study

counterbody 2. The normal load P made through the weights 4 is homogeneously distributed. The specimen 1 is connected by the dynamometer 6 and micrometric screw 5 by means of an elastic yarn fixed to the holder 3 on 2 mm level from the contact surface[13].

All specimens are in the form of prism with equal dimensions 30 mm × 20 mm × 6 mm and roughness Ra = 0.189 μm. The counterbody 2 is of steel with HB 450 and roughness Ra = 0.225 μm. Roughness is measured by the profile meter TESA Rugosurf 10–10G.

Static friction force T_o is measured as follows: specimen 1 is fixed in the holder 3; the load P is given by the weights 4. The dynamometer is reset 6 and the tangential force F is given on the specimen 1 through slow rotation of the screw 10 μm/s) and it is measured by the 6. F tries to move the specimen 1 to the right on the surface of the counterbody 2. For the small values of F, the specimenът remains at rest. This results from the action of the tangential reaction T in the contact, which neutralizes the action of the force F; it is known as *incomplete friction force* T. At the boundary value F_o, the specimen is under boundary condition, when the minimal increase of the force brings it in motion.

The boundary friction force is determined by the condition of equilibrium of the contact system in boundary state of the transition from preliminary displacement to motion:

$$T_o = F_o \tag{7}$$

It is known as *friction force at rest (static friction force).*

The static friction force T_o is measured with the maximal reading on the dynamometer, then the value decreases giving the value of the T during the motion of the specimen. Figure 5 shows the classical curve of the friction force, respectively the coefficient of friction versus the sliding way S.

The static friction force T_o and the static coefficient of friction μ_o are determined by Leonardo–Amontons's law:

$$T_o = \mu_o P \tag{8}$$

Hence for the static coefficient of friction it follows:

$$\mu_o = T_o/P = F_o/P \tag{9}$$

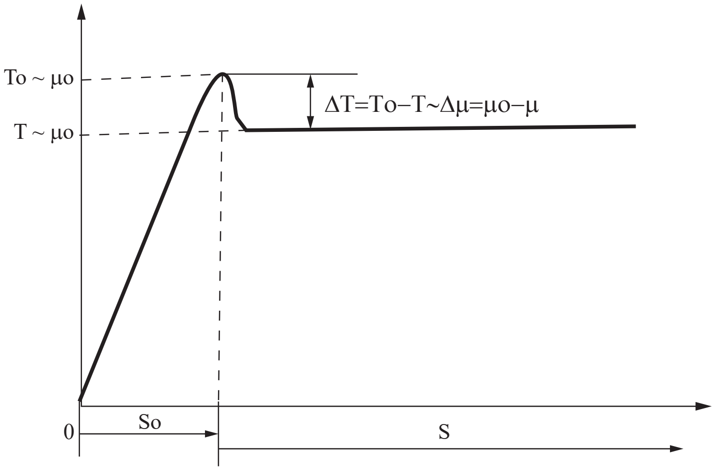

Fig. 5. Friction force and COF vs sliding way (classical)

Table 2 shows information of the content of tin in percents and the hardness of the tested specimens of cast iron, and Table 3 – the elemental content of the counterbody.

Table 2. Content of tin and hardness of the specimens of high strength cast iron

x, mass % Sn	0	0.01	0.018	0.02	0.032	0.051
Hardness, HB	179	186	197	203	262	277

Table 3. Chemical content in the counterbody, mass %

Element	C	S	Mn	P	Si	Cr	Ni	Fe
Percentage	0.41	0.035	0.58	0.55	0.20	0.41	0.35	Balance

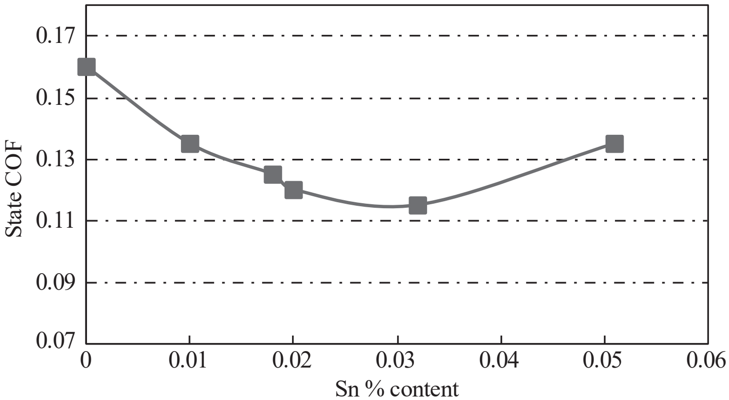

Fig. 6. Variation of the static coefficient of friction with the content of tin in high strength cast iron

The tests are carried out under the same normal load P=98.1N=const and nominal contact pressure p_a=16.3 N/cm^2.

Figure 6 gives the graph of the experimental relationship of the static coefficient of friction μ_o with the content of tin *x*.

The presence of tin results in decrease of the static coefficient of friction. The relationship is non–linear. The friction coefficient is minimal at tin content x_o = 0,032%, then it increases and reaches the values lower than the values of cast iron without tin (Fig.6).

LAW OF VARIATION OF THE COMMUNICATION POTENTIAL OF STATIC FRICTION

The experimental curve in Fig. 6 is used, divided into two sections: $0 \le x \le 0{,}032\%$ and $0 < x \le 0{,}051\%$. Limit is the value of tin x_o= 0,032%, where the static coefficient of friction changes direction.

The variation of the static coefficient of friction is studied within the interval $0 \le x \le x_o$. The curve is given in Fig. 7. The coordinate system (x, y) with beginning μ_o – the value of the static coefficient of friction of high strength cast iron without tin is selected.

The perturbation – the action *(A)* is the content of tin designated by *x*, and the reaction *(R)* – the static friction coefficient $\mu_o(x)$, varying within the interval $\mu_o \le \mu_o(x) \le \mu_o(x_o)$.

The communication potential is calculated according to equation (6) for each current state M of the experimental curve, and formula (6) is written as:

$$\eta(x) = \frac{tg\alpha(x)}{tg\beta(x)} \tag{10}$$

The results for $\eta(x)$ are given in Table 4. Figure 8 shows the graphic relationship between the communication potential and the content of tin.

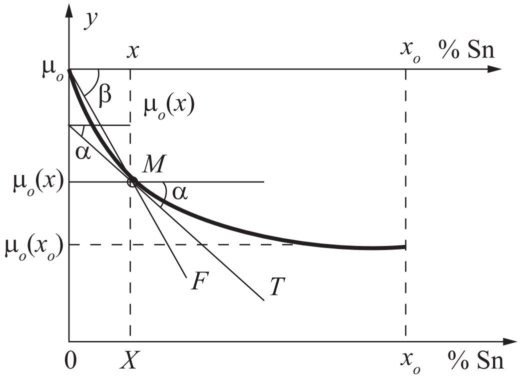

Fig. 7. Variation of the static coefficient of friction in the interval $0 \le x \le x_o$=032%

Table 4. Values of the communication potential for specimens with various tin content

x, % Sn	0	0.01	0.018	0.02	0.032
η(*x*)	1	0.76	0.60	0.40	0

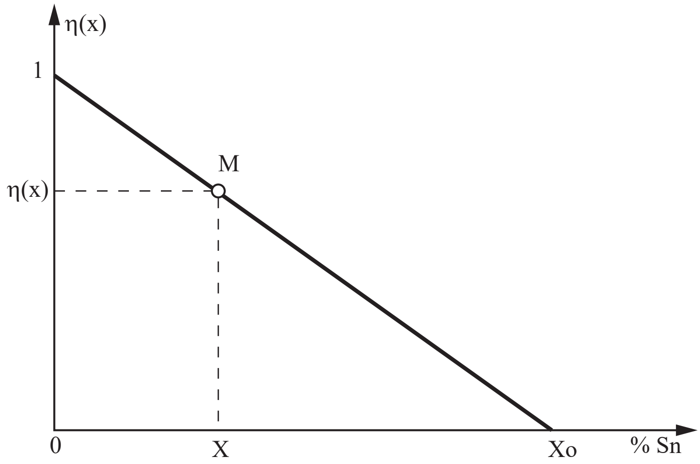

Fig. 8. Communication potential versus tin content

According to Fig. 8 the law of variation of the communication potential of the static friction is presented in the form:

$$\eta(x) = 1 - \frac{x}{x_o} \tag{11}$$

and for the boundary values one obtains: at $x = 0 \rightarrow \eta(0)=1$ and at $x = x_o \rightarrow \eta(x_o) = 0$.

LAW OF VARIATION OF THE STATIC COEFFICIENT OF FRICTION WITH THE PERCENTAGE CONTENT OF TIN IN HIGH STRENGTH CAST IRON

The general law for contact interaction (1) obtains the form:

$$\frac{d\mu_o(x)}{\mu_o(x)} = \eta(x)\frac{dx}{x} \tag{12}$$

Substituting equation (11) in (12) gives:

$$\frac{d\mu_o(x)}{\mu_o(x)} = \left(1 - \frac{x}{x_o}\right)\frac{dx}{x} \tag{13}$$

The following equation is obtained after integration, transforming and taking antilogarithm of (13):

$$\mu_o(x) = \mu_o\left(1 - cx_o e^{-x/x_o}\right) \tag{14}$$

The formula (14) is the law for variation of the static coefficient of friction with the content x of tin in microalloyed high strength cast iron for the interval $0 \leq x \leq 0.032\%$.

The constant c is determined by the boundary condition at $x = x_o$ namely $\mu(x) = \mu(x_o)$ substituted in (14), which is:

$$c = \left[1 - \frac{\mu_o(x)}{\mu_o}\right]\frac{e}{x_o} \tag{15}$$

For the considered case $c = 23.8$.

The comparison between experimental $\mu^e_o(x)$ and theoretical $\mu^t_o(x)$ results of the static coefficient of friction shows maximal relative error of 4%.

CONCLUSIONS

The presented work reveals the developed universal procedure for investigation of tribological processes based on the communication potential and the general law of contact interaction in tribology. The procedure is applicable to arbitrary scope of the study of the influence of the perturbation, if the interval of study is divided into sections, where the contact potential changes in a monotone.

The procedure is implemented in the case of study of the static friction in contact systems containing high strength cast iron microalloyed with various percentage of tin. The following results were obtained:

– Procedure is developed and experimental relationship is obtained for the static coefficient of friction variation with the content of tin.

– The communication potential of the static friction is attained and its experimental variation is obtained for the content of tin within the intervall 0% to 0.032% .

– The law for variation of the total communication potential with the content of tin within the interval 0% to 0.032% is obtained .

– The law for the static coefficient of friction variation with the content of tin within the interval 0% to 0.032% is obtained.

ACKNOWLEDGEMENTS

This study and the results are related to the implementation of tasks:

(a) Contract: DN 07/28–15.12.2016 ‘Research and creation of new wear–resistant coatings using composites and nanomaterials’, funded by the National Science Fund at the Ministry of Education and Science, Bulgaria;

(b) CEEPUS III Network: CIII–BG–0703–07–1819 ‘Modern Trends in Education and Research on Mechanical Systems – Bridging Reliability, Quality and Tribology’.

(c) Project FSI–S–17–4415 from the Ministry of Education, Youth and Sports of Czech Republic.

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Received 2 January 2019
Revised 20 February 2019