PROCEDURE AND INVESTIGATION OF CONTACT POTENTIALS OF WEARRESISTANT COATINGS

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ABSTRACT

Tribological failures mostly related to wear affect strongly reliability and quality of mechanical systems. A way out of that situation is the deposition of wearresistant surface coatings. There are various tribological approaches to study the behavior of coatings.

The contact approach of tribology is based on the relationship or law of contact interaction. The interaction in each elemental contact system regarded as a functional atom is realized through multiplication of three potentials: active δ, reactive ω and contact potential η. The authors propose a procedure and investigation of the contact potentials for the process of wear of contact systems where the contacting surfaces include wearresistant coatings deposited by high velocity oxygen fuel (HVOF) thermal process. Experimental results have been obtained about the dynamics of the contact potentials in three regimes of operation of the tribological system: nonstationary regime of the running-in, stationary and pathological regime under conditions of abrasive wear.

KEYWORDS: wearresistant coatings, law of contact interaction, contact potentials

1. INTRODUCTION

Tribology as interdisciplinary science is based on four principles, most important of which is the principle of sustainable variation and evolution of each contact system. This principle is presented quantitatively by the general law of contact interaction, which is valid for all contact systems in nature, techniques and society.

The differential form of the law is as follows [1,2]:

$$\frac{dR}{R} = \eta \frac{dA}{A} \quad \text{or} \quad \frac{dA}{A} = \eta^* \frac{dR}{R} \qquad (1)$$

i.e.

$$\frac{dR}{dA} = \eta \frac{R}{A} \quad \text{or} \quad \frac{dR}{dA} = \eta^* \frac{A}{R} \qquad (2)$$

where:

A is the perturbation of the surrounding media upon the contact system;

R is the reaction of the contact system against this perturbation;

dA/A is the relative perturbation from outside toward inside;

dR/R is the relative reaction of the contact system from inside toward outside;

dR/dA is the rate of change of the reaction against the perturbation;

dA/dR is the rate of change of the reciprocate relation;

η is the communication potential of the interaction outside-in;

η^* - is the communication potential of the system inside-out.

Condition for equivalence of both directions (lack of hysteresis) is of the type:

$$\eta . \eta^* = 1 \qquad (3)$$

In the classical paradigm of tribology the linear character of the interactions is raised in absolute, hence also their reversibility. In that case the condition (3) will be in the form:

$$\eta.\eta^* = 1 \text{ and } \eta = \eta^* = 1 \qquad (4)$$

The multidisciplinary paradigm of tribology permits rupture of the second equation in (4), which means

$$\eta.\eta^* = 1 \text{ and } \eta \neq \eta^* = const \qquad (5)$$

The interdisciplinary paradigm of tribology contains above two paradigms as special cases in itself, and allows simultaneously break of (4) and (5),

$$\eta \neq \eta^* \neq const \text{ и } \eta.\eta^* \neq 1 \qquad (6)$$

The paper proposes a procedure for investigation of the communication potentials of wearresistant coatings.

2. EXPOSÉ

We shall consider the wearresistant coatings. Wear can be measured with the mass, volume or thickness of the worn part of the coating.

If m is the worn mass of the coating on a specimen with apparent working area 1 cm^2, the relationship for specimen's wear is mostly given in the form:

$$m = k.\tau.S = k.\mu.p.v.t = k.A \qquad (7)$$

i.e. the worn mass is proportional to the work of the specific nominal friction, so $A = \mu.p.S$.

According to the classical tribological paradigm the relationships of friction, wear and lubrication are expressed by linear functions [3,4,5].

Taking into account the interdisciplinary paradigm of tribology, the general law of contact interaction in those cases has the form:

$$\frac{dm}{m} = \eta \frac{dA}{A} \qquad (8)$$

where η is the communication potential of coating's wear. It is easy to see that the classical law of wear is a particular case of the general law – equation (8) [6,7]. In fact, after differentiation of equation (7), transformation and comparison with (8), we obtain:

$$\frac{dm}{m} = \frac{k.dA}{k.A} = \frac{dA}{A} \qquad (9)$$

i.e.

$$\eta = 1 \qquad (10)$$

which means that the classical law of wear is characterized by a constant communication potential with the value of 1.

The question is whether the communication potential of wear η remains constant for different coatings and different regimes of wear.

We seek the answer of this question further in the development of the work, related to the qualification of wearresistant coatings.

2.1. Variation of the communication potential of wear

Fig. 1 shows graphically the relationship between mass wear m and the sliding way S in its classical form.

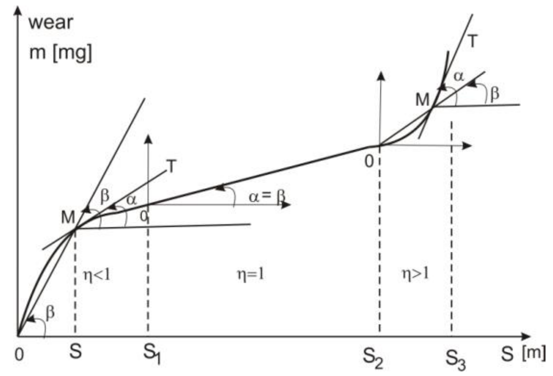

Fig. 1. Geometrical diagram of the communication potential η of wear in the three stages: run-in, stationary and pathological

Mass wear m is considered for arbitrary sliding way S, which corresponds to the point M of the curve at constant nominal contact pressure $p = const$. After differentiation of (7) and according to (8) we obtain for the perturbation A (in this case the sliding way S):

$$\frac{dA}{A} = \eta \frac{dS}{S} = \eta(S) \frac{dS}{S} = \eta_S \frac{dS}{S} \qquad (11)$$

where η_S is the partial communication potential of the sliding way.

According to (8) and (11) the mass wear law in differential form takes the form:

$$\frac{dm}{m} = \eta_S \frac{dS}{S} \qquad (12)$$

From (12) and from Fig. 1 we obtain for the partial communication potential:

$$\eta_S = \frac{dm}{dS} : \frac{m}{S} = \frac{tg\alpha_S}{tg\beta_S} = \eta_S(S) \qquad (13)$$

where: $\alpha_s = \left(\vec{T}, \overrightarrow{OS}\right)$ is the angle between the tangent in point M and the axis S ; $\beta_s = \left(\overrightarrow{OF}, \overrightarrow{OS}\right)$ is the angle between the cutting line $\overrightarrow{OF}$ and the axis $\overrightarrow{OS}$.

Equation (13) gives the variation of the communication potential η_s .

As per Fig. 1 and equation (13) we obtain the following statements for the communication potential:

- during running-in (section OS_1) - $\eta_s < 1$;
- in stationary regime (section S_1S_2) - $\eta_s = 1$;
- in pathological regime (section S_2S_3) - $\eta_s > 1$,

i.e. the communication potential η_s is an indicator, which varies in the process of wear and takes into account the complex contact interaction between the perturbation (S) the reflection (m) of the coating.

The transition zones between the wear regimes – run-in, stationary, pathological in S_1 and S_2 are characterized with transient zone in the variation of the communication potential η_s .

Experimental results have been obtained for the mass wear of composite coatings deposited through the technology of the HVOF-process under conditions of friction on surface with fixed abrasive according to the scheme pin-on-disk.

Tables 1 and 2 give the data of the mass wear m and the communication potential of wear η_s varying with the sliding way S .

Table 1: Coating **602P**

S $[m]$	50	116	232	348	464	580
$m[mg]$	90	154	181	200	215	217
η_s	0,81	0,39	0,25	0,12	0,09	0,04

Table 2: Coating **WC/Co**

S $[m]$	50	116	232	348	464	580
$m[mg]$	0,45	0,6	0,8	1	1,4	1,6
η_s	0,8	0,79	0,66	0,49	0,45	0,35

Figures 2 and 3 show graphically the variation of mass wear and communication potential of wear with the sliding way.

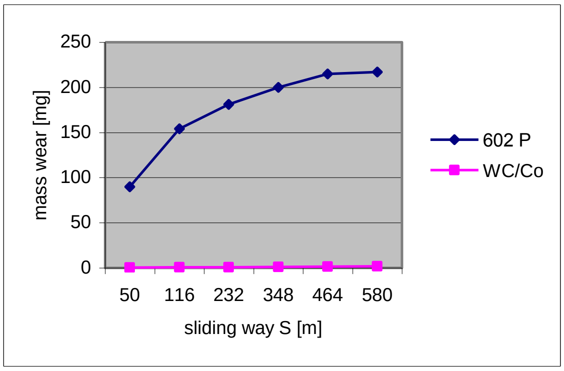

Fig.2 Mass wear versus sliding way for both types of coatings

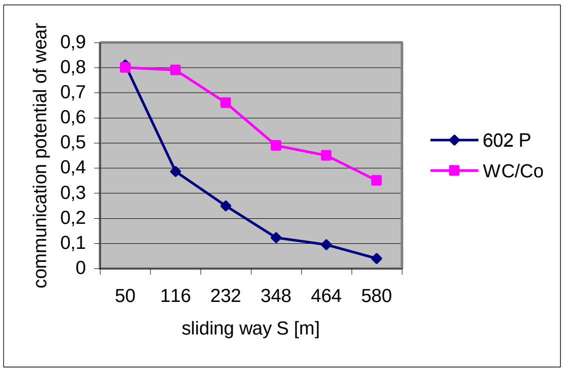

Fig. 3 Variation of the communication potential of wear with the sliding way
for both types of coatings

The classical paradigm excludes run-in and pathological regime as transient regimes and reduces the whole wearing process to stationary regime.

In fact, in all regimes of wear the communication potential varies. The process of wear needs to be studied deeply taking into account influence of the other partial and total potentials – of pressure, of time, of speed η_p, η_t, η_v .

2.2. Procedure for evaluation of the partial wearresistance of coatings accounting the communication potential

Let have to our disposal an experimental curve of the relationship between mass wear m and the friction way for a given sliding way S_o (Fig. 4).

We want to determine the formula for assessment of the wearresistance taking into account the communication potential.

Equation (12) is presented in the form:

$$\frac{dS}{dm} = \frac{1}{\eta_S} \frac{S}{m} \qquad (14)$$

where:

$$\bar{I}_S = \frac{dS}{dm} \qquad (15)$$

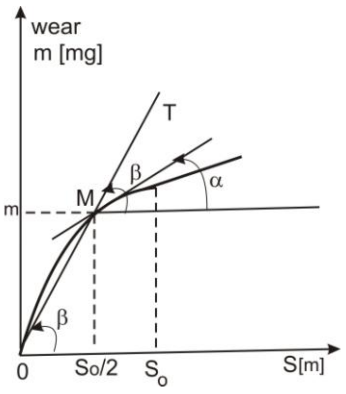

Fig. 4. Mass wear m curve for a given sliding way S_o

is the local wearresistance, which is reduced to the wearresistance of the coating in the middle point M with coordinates $(S_o/2; m)$, and

$$\bar{I} = \frac{S}{m} \qquad (16)$$

is the average wearresistance of the coating in the point M of that interval.

The relationship between local $\bar{I}_S$ and average $\bar{I}$ wearresistance is obtained after substitution of (15) and (16) in (14) and appears in the form:

$$\bar{I}_S = \frac{1}{\eta_S} \bar{I} = \frac{\cot g\alpha}{\cot g\beta} . \frac{S}{m} \qquad (17)$$

because

$$\frac{1}{\eta_S} = \frac{tg\beta_S}{tg\alpha_S} = \frac{\cot g\alpha_S}{\cot g\beta_S}$$

The known formula for assessment of the wearresistance of coatings through the ratio S/m is corrected by the multiplier $1/\eta_S$, which in this case (running-in) is bigger than 1. For the linear relationship between m and S (stationary regime) $1/\eta_S = 1$, and in the pathological regime $1/\eta_S < 1$.

2.3. Partial communication potentials of wear

If we express the friction path S with the sliding velocity v, equation (7) obtains the form:

$$m = k.\mu.p.v.t = k.A \qquad (18)$$

where $A = \mu.p.v.t$.

According to (8) and (18) will follow the equation:

$$\frac{dm}{m} = \eta \frac{k.d(p.v.t)}{k.p.v.t}$$

And after differentiation:

$$\frac{dm}{m} = \eta_p \frac{dp}{p}\frac{vt}{vt} + \eta_v \frac{dv}{v}\frac{pt}{pt} + \eta_t \frac{dt}{t}\frac{pv}{pv}$$

we obtain the equation:

$$\frac{dm}{m} = \eta_p \frac{dp}{p} + \eta_v \frac{dv}{v} + \eta_t \frac{dt}{t} \qquad (19)$$

Formula (19) gives the relative mass wear as function of the individual influence of the parameters p, v and t by means of their partial communication potentials η_p, η_v and η_t.

Having in view equation (13), the partial communication potentials of pressure η_p, speed η_v and time η_t are determined with the following equations:

$$\eta_p = \frac{tg\alpha_p}{tg\beta_p} \text{ at } v = const \text{ and } t = const \qquad (20)$$

$$\eta_v = \frac{tg\alpha_v}{tg\beta_v} \text{ at } p = const \text{ and } t = const \qquad (21)$$

$$\eta_t = \frac{tg\alpha_t}{tg\beta_t} \text{ at } p = const \text{ and } v = const \qquad (22)$$

In the case (22) we obtain from equation (19) the relationship of the wear rate with the participation of the communication potential of time η_t, i.e.

$$\dot{m} = \frac{dm}{dt} = \eta_t \frac{m}{t} = \dot{m}(t) \qquad (23)$$

3. CONCLUSION

The contact zones are mediators between the alternative bodies, so they are carriers and generators of the complex nonlinear behavior of the systems. The general law of contact interaction in tribology takes into account this complex behavior by means of a system of parameters called communication potentials. The communication potentials are variable and the relationships of their variation determine the spontaneous and nonlinear character of the contact processes.

The main results of above exposed study are as follows:

1. We have shown that the total communication potential of wear in a given tribosystem is characterized by different equations of variation depending on the regime of operation of the system – running-in, stationary or pathological.

2. The current value of the communication potential in the different regimes was shown by means of the ratio of trigonometric functions characterizing an arbitrary profile of the process of wear.

3. A procedure and relationships have been developed for evaluation of the partial wearresistance of coatings taking into account the partial communication potentials.

4. It has been proved that the multiplier for correction of the classical formula of the wearresistance of coatings is the reciprocated value of the corresponding total or partial communication potential.

5. A relationship has been derived for the wear rate accounting the communication potential.

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