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COMPLEX STUDY OF SURFACE LAYERS AND COATINGS

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Abstract: *The paper presents theory and procedure for determination of the components of the communication potential* η_1, η_2 *and* η_3, *of their laws of variation and of the laws of linear wear for three typical situations and under three regimes of wear. The study is related to the first stage of the International Contract № ДНТС 02/12 of scientific-technical collaboration between Romania and Bulgaria for 2010 in the topic „Tribotechnological study and qualification of composite materials and coatings lubricated by biodegradable fluids".*

Keywords: *tribology theory and procedures, wear, coatings*

1. INTRODUCTION

As subject of machines' mechanics, the behavior of contact systems is described by one-parameter relationships with coefficient of proportionality between the external impact and the reactions in the joints related to friction, wear, lubrication, conductance, etc. contact processes [1], [2]. All these processes are based on contacts and contact interactions, thus the interdisciplinary science of tribology gives the central place and role to contact as a functional third body in the contact joints. This means that the contact as third body has to be presented through its individuality as complex distinct index in the law of contact interaction in general form, and, in particular, in the laws of friction, wear, etc. [3], [4].

This index is designated as communication (contact) potential η of the contact interaction in several papers of N. Manolov, M. Kandeva, et al. [4], [5], [6], [7].

According to the model of the functional atom, the interaction in contact joints and contact systems is described by the general law of contact interaction by the multiplication of three potentials: active potential λ, reactive potential δ and communication potential η in accordance with the equation:

$$\eta.\lambda.\delta = 1 \quad (1)$$

The same law (1) in its differential form has the form:

$$\frac{dR}{R} = \eta \frac{dA}{A} \quad (2)$$

where dA/A is the relative external perturbation acting on the joint; dR/R is its relative reflection; $\eta = \eta(A,R)$ is the communication potential.

In a first approximation the law in equation (2) can be presented in the form:

$$\frac{dR}{R} = \eta_3.R^{1-\eta_1} A^{\eta_2 - 1} \frac{dA}{A} \quad (3)$$

So that in the general case the communication potential η is expressed by three indices η_3, η_1 and η_2.

The original item introduced by tribology in the study and qualification of contact joints is the triune non-dimensional essence of the communication potential by means of the indices η_3, η_1 and η_2.

The paper aims to propose a procedure for formulation of tribological laws of contact interaction during friction and wear, which take into account the triune parametric nature of the contact potential.

2. EXPOSE

The three components η_3, η_1 and η_2 of the communication potential η are non-dimensional quantities and have their own structure formed by the model of the functional atom. Figure 1 shows the structure of the communication potential η and its components in a flat and in a three-dimensional form.

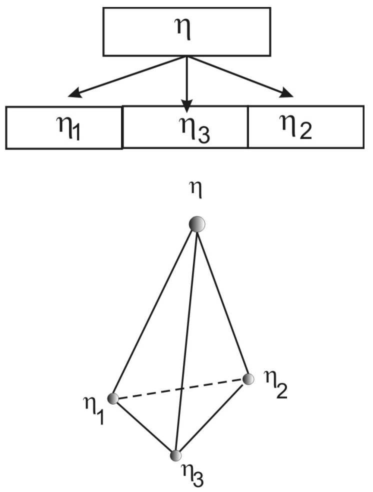

Figure 1. Structure of the communication potential in a flat and in a three-dimensional form

The parameter η_1 gives the reflection ability of contact, the parameter η_2 - the contact receptivity to external influence, and η_3 - the functional ability of contact as a third body in the tribosystem.

2.1 Communication components of wear during run-in, stationary and pathological regimes (Figure 2) [7]

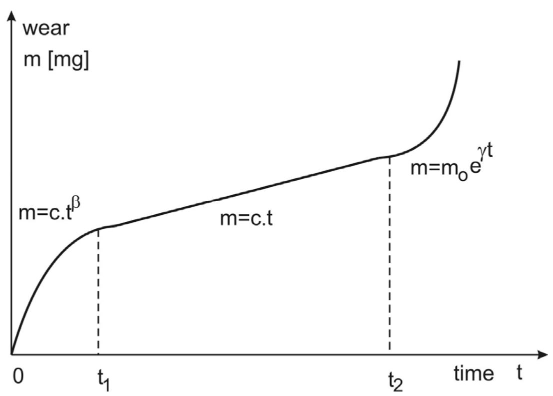

Figure 2. Curve of the three wear regimes – transient, stationary and pathological

The task is to calculate the components η_3, η_1 and η_2 of the communication potential η for the three regimes of wear and to present the obtained values in the form of Table 1.

Table 1.

Regime of wear	Transient regime $0 \le t \le t_1$		
Wear law	$m = c.t^{\beta}$, $\beta < 1$		
Components of η	$\eta_1 = 1$	$\eta_2 = 1$	$\eta_3 = \beta$

Regime of wear	Stationary regime $t_1 \le t \le t_2$		
Wear law	$m = c.t$		
Components of η	$\eta_1 = 1$	$\eta_2 = 1$	$\eta_3 = 1$

Regime of wear	Pathological regime $t > t_2$		
Wear law	$m = m_o e^{\gamma.t}$		
Components of η	$\eta_1 = 1$	$\eta_2 = 2$	$\eta_3 = \gamma$

a) Transient regime (running-in) $0 \le t \le t_1$

From equations

$$\frac{dm}{m} = \eta \frac{dt}{t} \quad \text{and} \quad m = c.t^{\beta} \tag{4}$$

follow

$$dm = c.\beta.t^{\beta-1}dt \; ; \quad \frac{dm}{m} = \frac{c.\beta.t^{\beta-1}dt}{c.t^{\beta}} = \eta \frac{dt}{t}$$

Where from the communication potential is:

$$\eta = \beta < 1 \tag{5}$$

The law of contact interaction (2) is compared with its form (3), i.e.

$$\frac{dm}{m} = \eta \frac{dt}{t} = \beta \frac{dt}{t} = \eta_3 . m^{1-\eta_1} t^{\eta_2 - 1} \frac{dt}{t} \tag{6}$$

For the components of η it follows:

$$\eta_3 = \beta < 1 ; \quad \eta_1 = 1 ; \quad \eta_2 = 1 \tag{7}$$

b) Stationary regime $t_1 \le t \le t_2$

From

$$\frac{dm}{m} = \eta \frac{dt}{t} \quad \text{and} \quad m = c.t \tag{8}$$

We obtain

$$\frac{dm}{m} = \frac{c.dt}{c.t} = \eta \frac{dt}{t}$$

or

$$\eta = 1 \tag{9}$$

Comparing (2) with (3) in this case gives:

$$\frac{dm}{m} = \eta\frac{dt}{t} = 1.\frac{dt}{t} = \eta_3.m^{1-\eta_1}.t^{\eta_2 - 1}\frac{dt}{t}$$

i.e. $\eta_3 = 1$; $\eta_1 = 1$; $\eta_2 = 1$ (10)

c) Pathological regime $t > t_2$

From $\frac{dm}{m} = \eta\frac{dt}{t}$ and $m = m_o e^{\gamma.t}$

follows $\frac{dm}{m} = \frac{m_o \gamma.e^{\gamma.t}dt}{m_o.e^{\gamma.t}} = \eta\frac{dt}{t}$

Hence

$$\eta = \gamma.t \tag{11}$$

The comparison of (2) and (3) gives:

$$\frac{dm}{m} = \eta\frac{dt}{t} = \gamma.t\frac{dt}{t} = \eta_3.m^{1-\eta_1}.t^{\eta_2-1}\frac{dt}{t}$$

or

$$\gamma.t = \eta_3.m^{\eta_1-1}.t^{\eta_2-1}$$

Then we can determine:

$$\eta_3 = \gamma\,;\ \eta_1 = 1;\quad \eta_2 = 2 \tag{12}$$

2.2 Theoretical study of contact wear of rough surface layers

In the considered general case the link between rough surface layers and the basic bodies is perfect (ideal) and is characterized by the components $\eta_1 = \eta_2 = 1$. So the dynamics in the process of wear is concentrated entirely in the dynamic processes in the contact as autonomous body by means of the variation in the parameter η_3.

If the current linear wear is designated by $h(t)$, where t is the duration of wear with fixed values of sliding velocity and nominal contact pressure, then in accordance with the law of contact interaction in the form (3) we obtain:

$$\frac{dh}{h} = \eta_3.h^{\eta_1}t^{\eta_2}\frac{dt}{t} \tag{13}$$

As in this case $\eta_1 = \eta_2 = 1$, it follows:

$$\frac{dh}{h} = \eta_3.h.dt \tag{14}$$

or

$$\frac{dh}{h^2} = \eta_3.dt \tag{15}$$

In a very short time interval $\Delta t = t_2 - t_1$ the component η_3 can be assumed as a constant, thus the integration of equation (15) in that narrow time interval leads to:

$$\int_{h_1}^{h_2}\frac{dh}{h^2} = \eta_3\int_{t_1}^{t_2}dt \tag{16}$$

or

$$-\frac{1}{h}\Bigg|_{h_1}^{h_2} = \eta_3(t_2 - t_1);\quad -\frac{1}{h_2} + \frac{1}{h_1} = \eta_3\Delta t\,,$$

i.e.

$$\eta_3^i = \frac{\Delta h_i}{\Delta t_i.(h_1.h_2)_i} \tag{17}$$

The law of variation of η_3 is determined by the graphical relationship $\eta_3 = \eta_3(t)$ drawn by the experimental data according to formula (17) by means of measurement of the difference in the linear wear $\Delta h_i = h_2 - h_1$ around the current moments t_i and the corresponding wear values h_1 and h_2 in the time intervals Δt_i around these moments.

The law of variation $\eta_3 = \eta_3(t)$ is determined by the experimental procedure described in an earlier publication [5].

The law of linear wear $h = h(t)$ is found by substitution of (17) in (16) and integration in arbitrary limits:

$$\int_{h_o}^{h}\frac{dh}{h^2} = \int_0^t \eta_3(t)dt \tag{18}$$

where $\eta_3(t)$ is the law of structural and functional change of contact as a third autonomous body in the regime of wear.

In the particular case

$$\eta_3 = k.t \tag{19}$$

and having in view (18), the law of linear wear takes the form:

$$-\frac{1}{h}\Bigg|_{h_o}^{h} = \frac{k.t^2}{2}; \; \frac{h-h_o}{hh_o} = \frac{k.t^2}{2}; \; h-h_o = \frac{h.h_o.k.t^2}{2}$$

Where from we obtain:

$$h(t) = \frac{h_o}{\left(1 - \frac{h_o.k.t^2}{2}\right)} \tag{20}$$

2.3 Theory and procedure for the abrasive wear of tribological coatings

In the particular case when the abrasive is fixed on a plastic substrate, the components of the communication potential are $\eta_1 = 1$; $\eta_2 = 1$ and $\eta_3 = \eta_3(t)$, where η_1 characterizes the penetration of the reactive signal in the coating; η_2 - the penetration of the active signal in the coating; and η_3 characterizes the generative ability of the coating as separate object.

From the law of contact interaction in the form (3), where

$$\frac{dR}{R} = \frac{dh}{h} \text{ and } \frac{dA}{A} = \frac{dt}{t},$$

is obtained

$$\frac{dh}{h} = \eta_3 t \frac{dt}{t} \tag{21}$$

Integration is done in a very short interval $\Delta t_i = (t_2 - t_1)_i$

$$\int_{h_1}^{h_2} \frac{dh}{h} = \eta_3^i \int_{t_1}^{t_2} dt; \; \ell n\left(\frac{h_2}{h_1}\right)_i = \eta_3^i (t_2 - t_1)_i$$

or

$$\eta_3^i = \frac{1}{\Delta t_i} \ell n\left(\frac{h_2}{h_1}\right)_i \tag{22}$$

The law of variation of η_3 is determined by equation (22) in different intervals Δt_i by means of the experimentally obtained results.

After finding the law $\eta_3 = \eta_3(t)$ it is substituted again in formula (21) and is integrated in arbitrary limits from 0 to t, i. e. in the general case we obtain:

$$\int_{h_o}^{h} \frac{dh}{h} = \int_0^t \eta_3(t) dt = \psi(t) \tag{23}$$

Let consider the particular case $\eta_3 = k.t^{-\nu}$, where $\nu = const < 1$. After substitution in (23) and integration we have:

$$\int_{h_o}^{h} \frac{dh}{h} = \int_0^t k.t^{-\nu} dt; \; \ell n \frac{h}{h_o} = \frac{k.t^{1-\nu}}{1-\nu}$$

i.e.

$$h(t) = h_o.e^{\frac{k}{1-\nu}.t^{1-\nu}} \tag{24}$$

If we use development in Taylor series and neglect the small quantities of second and higher order, we obtain for the law of linear wear $h = h(t)$:

$$h(t) = h_o\left(1 + \frac{k}{1-\nu}.t^{1-\nu}\right) \tag{25}$$

3. CONCLUSION

Wear processes on fundamental level in tribology are analyzed through the non-dimensional communication potential η; they are described by the law of its variation $\eta = \eta(t)$ and the existing law of linear wear $h = h(t)$. If $\eta = const = 1$, the approach and the result of wear study is purely mechanical.

On the first essential level of tribology, contact wear is identified by the three components of the communication potential - η_1, η_2 and η_3. The values of these components are found through the selection of test conditions and the type of interaction in concrete contact joints and wear regimes.

The paper proposes theory and procedure for determination of the components of the на communication potential η_1, η_2 and η_3, of their laws of variation and the laws of linear wear in three typical situations and three regimes of wear.

The study in above paper is related to the first stage of the International Contract № ДНТС 02/12 of scientific-technical collaboration between Romania and Bulgaria for 2010 in the topic „Tribotechnological study and qualification of composite materials and coatings lubricated by biodegradable fluids" supported by the fund "Scientific Research" at the Bulgarian Ministry of Education and Science.

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