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 \( \eta \), \( \eta_2 \) and \( \eta_3 \), 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 \( \check{\nu} \AA \check{C} \check{A} \mathcal{L} 02/12 \) 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 \( \eta \) 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 \( \lambda \), reactive potential \( \delta \) and communication potential \( \eta \) in accordance with the equation:

\[
\eta \lambda \delta = 1
\]  

(1)

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

\[
\frac{dR}{R} = \eta \frac{dA}{A}
\]  

(2)

where \( dA/A \) is the relative external perturbation acting on the joint; \( dR/R \) 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:

\[
\frac{dR}{R} = \eta_3 R^{1-\eta_1} A^{\eta_2-1} \frac{dA}{A}
\]  

(3)

So that in the general case the communication potential \( \eta \) is expressed by three indices \( \eta_3, \eta_1 \) and \( \eta_2 \).

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 \( \eta_3, \eta_1 \) and \( \eta_2 \).

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 \( \eta_3, \eta_1 \) and \( \eta_2 \) of the communication potential \( \eta \) 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 \( \eta \) 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](image)

The parameter \( \eta_1 \) gives the reflection ability of contact, the parameter \( \eta_2 \) - the contact receptivity to external influence, and \( \eta_3 \) - 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](image)

The task is to calculate the components \( \eta_3, \eta_1 \) and \( \eta_2 \) of the communication potential \( \eta \) for the three regimes of wear and to present the obtained values in the form of Table 1.

### Table 1.

<table>
<thead>
<tr>
<th>Regime of wear</th>
<th>Transient regime ( 0 \leq t \leq t_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wear law</td>
<td>( m = c_1 \beta, \beta &lt; 1 )</td>
</tr>
<tr>
<td>Components of ( \eta )</td>
<td>( \eta_1 = 1 ), ( \eta_2 = 1 ), ( \eta_3 = \beta )</td>
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<th>Regime of wear</th>
<th>Pathological regime ( t &gt; t_2 )</th>
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<td>( m = m_0 e^{\gamma t} )</td>
</tr>
<tr>
<td>Components of ( \eta )</td>
<td>( \eta_1 = 1 ), ( \eta_2 = 2 ), ( \eta_3 = \gamma )</td>
</tr>
</tbody>
</table>

#### a) Transient regime (running-in) \( 0 \leq t \leq t_1 \)

From equations

\[
\frac{dm}{m} = \eta \frac{dt}{t} \quad \text{and} \quad m = c_1 \beta \tag{4}
\]

follow

\[
dm = c_1 \beta t^{\beta - 1} dt; \quad \frac{dm}{m} = c_1 \beta t^{\beta - 1} \frac{dt}{t} = \eta \frac{dt}{t}
\]

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.

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

For the components of \( \eta \) it follows:

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

#### b) Stationary regime \( t_1 \leq t \leq t_2 \)

From

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

We obtain

\[
\frac{dm}{m} = c.t \frac{dt}{c} = \eta \frac{dt}{t}
\]
Comparing (2) with (3) in this case gives:
\[
\frac{dm}{m} = \eta \frac{dt}{t} = 1, \quad \frac{dt}{t} = \eta_3 m - \eta_1 \int^t_{t_2 - 1} dt
\]
i.e. \( \eta_3 = 1; \quad \eta_1 = 1; \quad \eta_2 = 1 \) \( \quad \) (10)

c) Pathological regime \( t > t_2 \)

From \( \frac{dm}{m} = \eta \frac{dt}{t} \) and \( m = m_0 e^{\gamma t} \)

follows \( \frac{dm}{m} = \frac{m_0 \gamma e^{\gamma t} dt}{m_0 e^{\gamma t}} = \eta \frac{dt}{t} \)

Hence
\[
\eta = \gamma \cdot t \quad (11)
\]

The comparison of (2) and (3) gives:
\[
\frac{dm}{m} = \eta \frac{dt}{t} = \gamma \cdot t \frac{dt}{t} = \eta_3 m - \eta_1 \int^t_{t_2 - 1} dt
\]
or
\[
\gamma \cdot t = \eta_3 m - \eta_1 \int^t_{t_2 - 1} dt
\]

Then we can determine:
\[
\eta_3 = \gamma; \quad \eta_1 = 1; \quad \eta_2 = 2 \quad (12)
\]

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 \( \eta_3 \).

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:
\[
\frac{dh}{h} = \eta_3 h \eta_1 t \eta_2 \frac{dt}{t} \quad (13)
\]

As in this case \( \eta_1 = \eta_2 = 1 \), it follows:
\[
\frac{dh}{h} = \eta_3 h \cdot dt \quad (14)
\]
or
\[
\frac{dh}{h^2} = \eta_3 dt \quad (15)
\]

In a very short time interval \( \Delta t = t_2 - t_1 \) the component \( \eta_3 \) can be assumed as a constant, thus the integration of equation (15) in that narrow time interval leads to:
\[
\int_{t_1}^{t_2} \frac{dh}{h^2} = \eta_3 \int_{t_1}^{t_2} dt = 0 \quad (16)
\]
or
\[
-1 \frac{h_2}{h_1} = \eta_3 (t_2 - t_1); \quad \frac{1}{h_2} + \frac{1}{h_1} = \eta_3 \Delta t \quad ,
\]
i.e.
\[
\eta_3 = \frac{\Delta h_i}{\Delta t_i (h_1, h_2)} \quad (17)
\]

The law of variation of \( \eta_3 \) 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 \( \Delta t_i \) 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:
\[
\int_{h_0}^{h} \frac{dh}{h^2} = \int_{0}^{t} \eta_3(t) dt \quad (18)
\]

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
\[
\eta_3 = k \cdot t \quad (19)
\]
and having in view (18), the law of linear wear takes the form:
Let consider the particular case \( \eta_3 = k t^{-\nu} \), where \( \nu = \text{const} < 1 \). After substitution in (23) and integration we have:

\[
\int_{h_0}^{h(t)} \frac{dh}{h} = \int_0^{t} k t^{-\nu} dt; \quad t \ln \frac{h}{h_0} = \frac{k t^{1-\nu}}{1-\nu}
\]

i.e.

\[
h(t) = h_0 e^{1-\nu} t^{1-\nu} \quad (24)
\]

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 \( h = h(t) \):

\[
h(t) = h_0 \left( 1 + \frac{k}{1-\nu} t^{1-\nu} \right) \quad (25)
\]

3. CONCLUSION

Wear processes on fundamental level in tribology are analyzed through the non-dimensional communication potential \( \eta \); they are described by the law of its variation \( \eta = \eta(t) \) and the existing law of linear wear \( h = h(t) \). If \( \eta = \text{const} = 1 \), 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 \( \eta_1, \eta_2 \) and \( \eta_3 \). 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 communication potential \( \eta_1, \eta_2 \) and \( \eta_3 \), 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-technological 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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