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## SOME QUESTIONS OF SELF-ORGANIZATION TRIBOLOGICAL SYSTEMS CONTAINING THIN LAYERS OF GREASE

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*The paper considers the question of self-organization of tribological systems in the presence of a thin film of grease. It is shown that the decisive role in the process of friction between two bodies is the surface tension at the interface. Examples of the assessment of the surface tension of pure metals and alloys. To assess the level of organization of tribological systems the criterion Aleksandrov-Bogolepov. It is shown that in the case of self-organization of tribological systems the number of control parameters decreases sharply, which facilitates both theoretical consideration of friction, so its practical use and management.*

Keywords: friction, lubrication, tribological system, self-organization, the surface tension

### Introduction

Under the self-organization of tribological systems refers to the presence of feedback, whereby tribosystem adapts to changing external factors. The basic principles of self-organization tribosystems described in [1]: 1) the system must exchange energy with the environment; 2) physical parameters describing tribosystems should be non-linear; 3) The system must be unstable to move into a new phase with the lowest kinetic energy. Strictly speaking, these principles form the basis of self-organizing systems, any [2, 3].

The lubricant that performs the function of reducing energy loss through friction, is an integral part tribosystem. Exceptions are space and vacuum systems where the prevailing dry friction. However, in this case, starting to use solid lubricants or anti-friction coating. Issues of self-organization of tribological systems large number of papers, a bibliography of which until 2000 is given in [4]. It is interesting and the work [5], which measured the thickness of the lubricant film, equal to about 1 nm. Despite the great diversity of approaches to self-organization of tribological systems that are not yet identified criteria to clearly assert the existence of self-organization in tribosystem no information on the control parameters variation which could be controlled and the process of self-organizing properties and tribological systems.

Considering that the process of the friction surfaces in contact with the layer of lubricant is complex and diverse in recent years began to develop methods of assessment and prediction of the criterion of wear of friction pairs based on the mechanical, physical, chemical and geometrical factors [6, 7]. These methods are based on the theory of similarity, which are well developed in the mechanics and hydrodynamics.

In this paper we consider the question of self-organization tribological systems with those positions that were not considered in the above mentioned works.

### 1. Surface tension in tribological systems with lubrication

In the simplest case tribological system consists of two solid surfaces, between which the lubricant. Friction is a superficial phenomenon at the interface and greatly depends on the state and properties of the surface. Start of development of modern surface physics dates from the beginning of the sixties of the last century, although the study of phenomena on the surface of solids began long before this, and many of the basic theoretical concepts to the point had already been developed [8]. The breakthrough came thanks to advances in ultra-high vacuum technology, the emergence of

methods of atomic force and tunneling spectroscopy, powerful high-speed computers and a number of other factors [9].

Surface tension is the main characteristic of the processes involving surfaces or interfaces between phases. Determination of surface tension of liquids (lubricants) is not difficult. Experimental determination of the surface tension of solids is complicated by the fact that their molecules (atoms) are unable to move freely. The exception is plastic flow of metal at temperatures close to the melting point - the method of "zero creep". As follows from the reviews [10-12], there is currently no method that could be reliably used for the experimental determination of the surface tension in the solid phase in a wide temperature range. Each of the described in [10-12] techniques practically limited to either the temperature or the amount that the experimentally determined with low accuracy. In [13] the proposed new methods for determining the surface tension on the basis of the size dependence of the physical properties of small particles and thin films.

The force of friction in the case of the molecular mechanism can be represented as:

$$F = \int_L \sigma dl \approx \sigma L, \quad (1)$$

where  $\sigma$  - the surface tension of the solid state,  $L$  - the length of the path traveled by the sliding.

In the presence of lubricants and surface tension will be equal to (for thin films when the contact angle can be neglected)  $\sigma_{is} = \sigma_s - \sigma_l$  where  $\sigma_{is}$  - the surface tension at the interface - the solid-liquid interface;  $\sigma_s$  - surface tension of the solid state and  $\sigma_l$  - fluid (lubricant). In the presence of a third body, sliding over the surface of the first, the value of  $\sigma_{is}$  will double. Natural conditions, optimization of friction units are relations:

$$\sigma_{is} \rightarrow \min, \quad \sigma_s - \sigma_l \rightarrow \min. \quad (2)$$

As already indicated, to determine the surface tension of the liquid lubricant is not difficult. For pure metals  $\sigma_{is}$  with great accuracy is [13, 14]:

$$\sigma_s = 0,7 \cdot 10^{-3} \cdot T_m, \quad (3)$$

where  $T_m$  - the melting temperature of pure metal, which is known for all metals.

For alloys have a surface tension value of the additive (as opposed to the bulk properties), so that the following relation holds:

$$\sigma_T = X_1 \sigma_{T_1} + X_2 \sigma_{T_2} + \dots \quad (4)$$

where  $\sigma_T$  - the surface tension of the alloy;  $X_i$  - the contents of  $i$ -th metal components in the alloy.

Table 1 shows the values of  $\sigma_T$  for 56 pure metals, calculated by formula (3).

In [15] measurement of the surface tension of coatings Zn-Cu-Al. The results of the calculation according to the stoichiometry of the XPS gave the following results:  $Zn_{0,59}Cu_{0,01}Al_{0,40}$ . The mean value of the surface tension, resulting in the experiment was equal to:  $\sigma_{Zn-Cu-Al} = 0,351 \text{ J / m}^2$ . Calculated using the formula (4), the theoretical value was found to be:  $\sigma_{Zn-Cu-Al} = 0,412 \text{ J / m}^2$ , which is in good agreement with experiment. Thus, the balance of (4) to evaluate the surface tension of the solid elemental composition of the surface that is not currently experimental difficulties. Further, the need to use the criterion (2) in order to optimize friction units. This means that it is necessary to increase the surface tension of the lubricant. In most cases this is achieved by adding to the lubricant additives from various powdered metals, alloys, etc. [16].

Table 1. Surface tension of pure metals at T = 300 K

Metal	$\sigma_T, \text{J/m}^2$	Metal	$\sigma_T, \text{J/m}^2$	Metal	$\sigma_T, \text{J/m}^2$	Metal	$\sigma_T, \text{J/m}^2$
Li	0,152	Si	1,386	W	3,373	Dy	1,380
Na	0,071	Ge	0,931	Mn	1,217	Ho	1,434
K	0,037	Sn	0,205	Tc	2,173	Er	1,470
Rb	0,012	Pb	0,300	Re	3,123	Tm	1,518
Cs	0,002	Se	0,193	Fe	1,508	Yb	0,797
Be	1,258	Te	0,425	Co	1,463	Lu	1,625
Mg	0,623	Cu	1,056	Ni	1,426	Ac	1,023
Ca	0,818	Ag	0,934	Ce	0,777	Th	1,723
Sr	0,730	Au	1,036	Pr	0,908	U	1,105
Ba	0,683	Zn	0,399	Nd	0,998	Np	0,613
Al	0,633	Cd	0,294	Sm	1,025	Pu	0,610
Ga	0,003	Hg	0,070	Eu	0,875	Am	0,973
In	0,129	Cr	1,873	Gd	1,285	Bk	0,998
Tl	0,276	Mo	2,573	Tb	1,331		

## 2. The level of organization of tribological systems

In 1968, Aleksandrov and Bogolepov [17] proposed a method for assessing the level of organization of systems based on the criterion of Forster, is a measure of redundancy K. Shannon:

$$R = \frac{S_{\max} - S_t}{S_{\max}} = 1 - \frac{S_t}{S_{\max}}, \quad (5)$$

$S_{\max}$  - the maximum entropy of the system;  $S_t$  - the current value of the entropy at a given time t.

This test characterizes the relative organization of the system; the absolute level of organization at any given point in time is estimated structural information  $I_t$ , characterizing the system. Without considering the details of this approach, we present only the main conclusions that have been made by the authors.

1). For any closed system:

$$\frac{dS_t}{dt} = -S_{\max} \frac{dR}{dt}. \quad (6)$$

This expression is a formalized record of fundamental provisions of the duality of all organizational processes. They are always self-contradictory: in addition to ordering processes, improve internal organization of the system always works just the opposite trend - the rise of disorganization, disordered systems.

2). For any of the relation:

$$I_t = S_{\max} \cdot R. \quad (7)$$

That is, at any given moment of time information in the system is proportional to the maximum entropy and level of organization.

3). For two dependent systems in the states a and b ( $\alpha = 1,2,3 \dots m$ ;  $\beta = 1,2,3, \dots n$ ) at any given point in time of the absolute level of organization is given by:

$$I_{\alpha\beta t} \geq I_{\alpha t} + I_{\beta t}. \quad (8)$$

The equality in equation (8) is possible only when the system independent.

It follows the basic property of organized systems: absolute organization system as a whole is always greater than the algebraic sum of absolute organized elements of its constituent parts; information about the system over the combined aggregate information on both systems, are regarded as independent.

From all this leads to the following conclusions:

Expression (8) indicates that when the two independent systems of  $\alpha$  and  $\beta$  in the combined system appears some additional structural information, equal to:

$$\Delta I_{\alpha\beta} = I_{\alpha\beta} - (I_{\alpha} - I_{\beta}) \quad \text{or} \quad \Delta I_{\alpha\beta} = (S_{\alpha} - S_{\beta}) - S_{\alpha\beta}. \quad (9)$$

The close connection between the thermodynamic characteristics and information systems led to the conclusion that the introduction of information into the system results in an increase of its internal energy, which corresponds to the commission her work on the outside. [17].

In [18] to change the tribological system entropy obtained by:

$$\Delta S = \alpha \frac{G^0}{2NT}, \quad (10)$$

where  $\alpha = \exp[-(E_m + E_a)/kT] \sim 1$ ,  $G^0$  - Gibbs energy of the thermostat (for the surface  $G^0 = \sigma S$ ,  $\sigma$  - the surface tension,  $S$  - surface area,  $N$  - number of actual contact with the friction.

The change in entropy of the object is inversely proportional to the amount of  $\Delta I$  information about it, i.e.:

$$\Delta S = \frac{k \ln 2}{\Delta I}, \quad (11)$$

where  $k \ln 2$  - the energy equivalent information.

On the other hand, information on the tribological properties of the object it carries some factor, for example,  $J_h = dh/dL$  - the intensity of linear wear,  $h$  - the value of linear depreciation,  $L$  - the path of friction, i.e.:

$$\Delta I = J_h. \quad (12)$$

From equation (13) shows that the level of organization of the tribological system can be improved ( $R \rightarrow 1$ ) by reducing the number of contacts  $N$  (roughness) and the wear rate.

If there is a thin film of grease instead  $J_h$  better use of the Rayleigh number. where  $g$  - acceleration of free fall,  $L$  - characteristic size,  $b$  - coefficient of volume expansion,  $dT$  - temperature gradient,  $\nu$  - kinematic viscosity, and - the thermal diffusivity of the medium. Because the kinematic viscosity  $\nu \sim 1 / \sigma_{sl}$ ,  $\sigma_{sl}$  - interfacial tension, we finally have:

$$R = 1 - F \cdot \frac{\sigma_{sl}}{\sigma_s}, \quad (14)$$

where  $F$  - function of the above parameters.

Here again we come to the equation (2). Note that the Rayleigh number is a control parameter in the self-organization of liquid (Benard cells) [19].

## Conclusion

Thin-film facilities are subject to the friction zone complicated the process of destruction, recovery is not consistent with traditional principles of thermodynamics equilibrium systems. This comes against the backdrop of the most powerful concentrations of specific energy microcontacts resulting material into the "magma plasma" [5] to the particular properties of the substance. In the case of self-organization of tribological systems the number of control parameters decreases sharply [20], which facilitates both theoretical consideration of friction, so its practical use and management. In this paper we consider only one aspect of the whole variety of issues of modern tribology. Nevertheless, we can conclude that one of the control parameters of tribological systems in their self-organization should take the surface energy (surface tension) tribosystems.

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