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GENERALIZED COMPLEXES OF REPRODUCTION OF LUBRICATING LAYERS STATE IN A SIMULATIVE CONNECTION

Kubich V. I.

Zaporozhian National Technical University, Zaporozhye, Ukraine, reibung1@mail.ru

The article suggests approaches to stimulating an estimation criterion of lubricating layers functionality in tribological systems upon termination of the lubricant supply and step loading of a friction zone. The authors defined the regression equation that relates a specific time of minimum friction coefficient constancy in a tribounit "a movable disc – a fixed block" to generalized complexes that make conditions for transient processes in the contact layers of materials of different tribological activity and aggregative state. At that they used the results of tribotechnical tests of simulative tribological systems. It allows performing a preliminary predictive evaluation of functionality of lubricating layers in the process of elements interaction of conjugation. An approach to the definition of evaluation criteria classes for different tribological materials systems.

Keywords: generalized complex, lubricating layer, surface, functionality, time of loading, interaction toughness

Introduction

The integrated development of tribology, material science and technological aspects of improving the parametric reliability of friction assemblies in tribounits of which deterioration of lubrication conditions is possible, make it possible to form new approaches both to construction of new engineering facilities and upgrading of previously constructed ones. In this case, mathematical expressions, optimally representing multifactor impact of the whole complex of paramaters determines the possibility of tribological processes simulation at breakdown of lubrication modes. Insufficient knowledge of mechanisms of generation and regeneration of monomolecular layers of a lubricant with account for the impact of the surface activity of tribological systems materials without feeding them by the lubricant components makes tribological research in this direction neseccary. In this regard, it is important to develop criteria for evaluating the functionality of lubricating layers under a "film shortage" condition and to determine the regularities of their changes caused by a combination of dynamic loading parameters.

1. Formulation of the problem

Evaluation of the behavior of lubricating layers between the surfaces of materials with different chemical composition and mechanical properties are reported in [1-3], where the authors established a time ambiguity of the change in the boundary friction coefficient. Determination of only the friction coefficient while evaluating the functionality of lubricating layers, and thus the lubrication modes, certainly appears one-sided and does not fully show running tribological processes. So, a method for estimating the duration of the lubricating action of a plastic lubricant at sliding friction is known. In accordance with this method a set of indicators is determined, including the duration of action T_q sec, the dose of a lubricant in the amount of q_m m^3, equal to the total oil absorption of run-in friction surfaces. In this case the termination of the lubricating action is determined by the values of criteria, including a frictional force or moment, tribo EMF (electromotive force), PDP (pin difference of potentials) [4]. In [5,6] to investigate the processes of contact interaction of surfaces at friction of sliding and rolling the authors considered an integrated approach to the evaluation of a friction moment, the specific friction work, a lubricant temperature, a lubricant film thickness using the developed software for processing recorded simultaneously parameters. At that, as a criterion for evaluation the lubricating process quality at the the tribounit "a disk – a disk" they considered specific work of friction, which at the stage of the shift to the moment of the development of the base lubricant layer during start-up is determined by the expression (taking into account the kinetic energy of revolving samples):

$$E = \frac{\left[\int_0^{\alpha} Md\alpha - \frac{\sum J_i \omega_{в}^{2}}{2}\right]}{F} = \frac{\left[\int_0^{\alpha} Md\alpha - \frac{\sum_{i=1}^{n} J_i \omega_b^2 + \sum_{k=1}^{m} J_k \omega_o^2}{2}\right]}{F}, \quad (1)$$

where E is the specific work of friction, kJ/mm^2;

– F is Hertzian nominal contact area, mm^2;
– M is the moment of friction, N·m;
– α is the angle of rotation of the sample disc, grad;
– ω_b, ω_o are the angular rates of the advanced and left behind samples, respectively, rad/s;
– J_i, J_k are the inertia moments of the advanced and left behind samples, respectively, kg·mm^2.

Indeed, the resolved methods are multifaceted and more informative. However, in the above mentioned evaluation methods for manifestation of the effectiveness of the lubricating action, the properties of the sample materials, the surface tension of lubricants, and the approach rates of surfaces through the lubricant layers at lubricant structure discontinuity in local contact areas are disregarded. It is important for the more objective assessment of the lubrication mode duration, including the transition to film shortage. And statistics data on the integrated demonstration of the parameters taken into account make for obtaining mathematical expressions for simulation ofconsidered tribological processes.

Keeping in mind the above mentioned, at this stage of the research the authors proposed to introduce the concept of "specific time of minimum friction coefficient constancy» and use it as a criterion for evaluating the lubricating layers functionality [7]. Certainly, this criterion will depend on a large number of parameters of influencing factors. For example, in [3] the functionality of the lubricating layer in the simulative tribounit "a fixed block – a movable disk" is assessed. In this case, a change in the tribological state of the tribounit "a shaft – a muft» of the friction unit that is the sliding bearing of the turbocharging assembly shaft in an internal combustion engine was simulated. Tribotechnical tests were carried out at the friction machine SMC -2 accordng to "a movable roll – a block" friction scheme. Then the experimenters analyzed the behavior of the friction coefficient for the test time at a step loading of the block without feeding the lubricant to the friction area. As a preliminary, the working surfaces of the roll and the block ran in at a constant rotational frequency of the roll and the step loading of the block. At that, from the list of experimental materials, graphitized steel alloys with a carbon content of 1.78%, 1.21%, 3.1% and copper of 3.19%, 3.95%, 1.18% respectively, as well as BrOTsS 4-4-4 bronze (tin content 4%, zinc content 4%, lead content 4%), L63 brass demonstrating anti-friction properties in a tribological system with 45HN2MFA steel in the lubricating medium of SAE 15W40 Lukoil-Super engine oil make conditions for a certain durability of boundary friction with minimal friction values for periods of time.

However, no investigators estimated impact parameters of manifestation, relevancy and independence that make for predictive assessment on the functionality of lubricating layers under considered conditions. It is possible when estimating values of the coefficients, which are presented in the form of members of certain orders of polynomials in the mathematical description of multifactor impact of arguments on the values of the response function in establishing regression dependence.

The work objective is to determine the type of mathematical expression, establishing a functional relationship between the specific time of constancy of the minimum friction coefficient and complex arguments of multifactor dimensionality, reproducing the tribological state of the investigated lubricants layers.

2. Research methods

In accordance with the proposed and discussed earlier methods [8-10] the authors proposed specific time dependence of the constancy of the minimum friction coefficient on the considered parameters presented as follows:

$$\frac{t}{\mu_{\min}} = A\Pi_1^{\alpha_1}\Pi_2^{\alpha_2}\ldots\Pi_k^{\alpha_k}, \tag{2}$$

where A is a constant factor, making provision for the impact of unaccounted factors; $(\Pi_1^{\alpha_1} - \Pi_k^{\alpha_k})$ are dimensionless complexes composed of impact parameters; $(\alpha_1 - \alpha_k)$ are coefficients determined experimentally; k is the number of complexes.

In view of the complexity of integrated accounting and behaviour description of interrelated mechanochemical, adhesion, cohesion, thermodynamic, hydrodynamic, electrochemical processes in establishing patterns of change in the tribological state of lubrication layers, some restrictions should be imposed. Accordingly, it is necessary to consider changes in the tribological state of the investigated tribounits defining and emphasizing a more significant process, from the perspective of the researcher. At this stage of the research it is consideredas follows. The force of friction that occurs at flat contact of elastically deformable sample surfaces to the extent of the contour areas of interaction causes tangential stresses. Dynamic loading stresses result in deformations breaking bonds between the molecules of the lubricant. Moreover, there may be both disruptions within its structure formed through its run-in and breaking of bonds with active centres of material samples. The weakening of the considered bonds will undoubtedly affect on the dynamics of change in the friction coefficient. As well as it will affect on the functionality of the lubricating layers.

At this stage of research as parameters affecting the functionality of the lubricant layers formed on friction surfaces the following ones are concidered:

– normal load in the friction zone N, H;
– the hardness of the sample material *HRB*;
– elasticity modulus of the sample material E, hPa;
– frequency of rotation of the disk n, min^{-1};
– the dynamic viscosity of the oil η_∂, cPs;
– the friction area of the block S_{fr_b}, m^2;
– the surface tension coefficient of the oil σ, N/m;
– the approach rate υ_a surface through lubricant layers, μm/sec;

Considering the complexes $(\Pi_1^{\alpha_1} - \Pi_k^{\alpha_k})$, as a set of combined parameters of the process under study, and expressing each complex in terms of the generic variable ($x_i = \Pi_i$), the expression (2) takes the form:

$$\frac{t}{\mu_{\min}} = Ax_1^{\alpha_1}x_2^{\alpha_2}\ldots x_k^{\alpha_k} = A\bigcap_{i=1}^{k} x_i^{\alpha_i}, \tag{3}$$

where x_i stands for the independent dimensionless generalized parameters (variables), which are used as controllable factors.

The above equation (3) is the basis for determining a mathematical expression in the form of regression dependence.

3. Results and discussion

In accordance with the first similarity theorem the authors suggest grouping the considered parameters and representing them in the form of three generalized dimensionless complexes.

The first complex is presented in the expression (4).

$$x_1 = \frac{N}{S_{fr_к} \eta_\partial n} \tag{4}$$

The complex x_1 indicates the proportion of the specific normal force accounted for the resistance force of lubricating layer to shear deformations, resulting in disturbance of their operational condition during the dynamic-strength loading surfaces of the simulative tribounit "a roll – a block" (in this case, the frequency of rotation and the load are interrelated parameters). Proceeding from the above mentioned, the presented complex causes tangential impact on the lubricating layers.

For many materials, there has been found a correlation between the modules of volumetric deformation and the shear on the one hand and hardness on another hand [11]. Under considered tribotechnical test conditions, at film shortage there will obviously be a fragment manifestation of an elastohydrodynamic lubrication mode. Thus, to assess the impact of mechanical properties of the material on the lubricating layers behavior the authors propose to develop the second complex x_2 as follows:

$$x_2 = \frac{E_к E_p (HRB_p + HRB_к)}{(E_к + E_p) HRB_р HRB_к} \tag{5}$$

However, taking into account the correlation between the physical quantities in order to simplify calculations they propose to use for materials only one physical quantity instead of two of them. In this case the value of the quantity of a numerical measure will not change. For example, the expression (4) can be represented as follows:

$$x_2 = \frac{E_к (HRB_p + HRB_к)}{(E_к + E_p) HRB_р}$$

The authors propose to consider the complex x2 as a measure of the interaction toughness between lubricating layers, caused by the viscoelastic deformation of surface fragments of materials of different hardness that results in a failure of their functionality.

When changing normal loading in the friction zone, the layerwise suppleness of ordered structures of the lubricant components will definitely affect on the surfaces approach rate. To assess this impact the authors propose to use the third complex x_3 that is the rate of reduction of the lubricating layer thickness υ_l between the surfaces of tribounit elements affected by normal loading at elastic deformation of its gradient near-surface parts in one revolution at thermal states of the contact. For example, it is proposed to take into account the thermal states of tribological contact at temperatures of 25°C and 80°C. This complex makes provision for the normal initial impact on the structure of the formed lubricating layers, thus causing the outflow of the hydrodynamic buildup. This proposition takes into account the following:

– inoperable state of the contact, during which there may be a "film shortage" because of the lubricant lag with respect to the motion start of one of the elements;

– operational condition, under which re-sets in motion of one of the elements are possible.

The third complex is proposed to present as follows [4]:

$$x_3 = \frac{\upsilon_l \sigma}{Nn} \tag{6}$$

At that, the rate of approach υ_l, surface tension coefficient σ for the corresponding lubricant, in this case for the motor oil is determined by experiment. For example, for SAE 15W40 Lukoil-Super motor oil σ_1=0.0498±0.001N/m, and for SAE 5W-40 Special Plus motor oil σ_2=0.0465±0.001 N/m.

With regard to the introduced complexes, their influence on the response function that is the specific time of constancy of the minimum friction coefficient, to determine the coefficients in the expression (2), the authors proposed to use the method of factorial experiment planning and determination of the regression coefficients of an equation [12]. For this purpose, the system of algebraic equations for the number of unknown regression coefficients was made (7). In this case in order to establish the extended boundaries of the factor influence they proposed to use a polynomial of the first order.

$$y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_1 x_2 + b_5 x_1 x_3 + b_6 x_2 x_3 \tag{7}$$

For the expression (3) coefficients (α_1-α_k) = (b_1 - b_4). In this equation, taking into account the experimental data, there are seven unknowns. It will be possible to define factors by solving a system of seven equations. When making a system of equations it must be borne in mind that their forms will be prepared taking into account the logarithmation of the left and right sides of the expression (3).

Then, for the expression (7) known values will be determined as follows:

$$y = \ln \frac{t}{\mu_{\min}}, \quad b_0 = \ln A, \quad x_1 = \ln \frac{N}{S_{\text{тр}_\text{к}} \eta_\text{д} n}, \quad x_2 = \ln \frac{E_k \left(HRB_k + HRB_\text{р}\right)}{\left(\text{E}_\text{k} + E_\text{р}\right) HRB_\text{р}}, \quad x_3 = \ln \frac{\upsilon_c \cdot \sigma}{N \cdot n}, \text{ etc.}$$

To calculate the logarithms of specific time of minimum friction coefficient constancy the values can be taken from Table 1. These values are marked by boldface characters.

The theoretical estimate of the numerical value of the proposed criteron, under condition of lubricating layer supply to the bottom of the boundary lubrication of the tribounit surfaces μ_{tmin}=0.01 during the time t=10 min is t/μ_{tmin}=1000 nominal units, and respectively, to the upper bound μ_{tmax}=0.1 will be 100 nominal units. The experimental values are in the range between 0.8 and 108. Based on the above, it is possible to determine the class of the evaluation criteria for various tribological material systems in the future.

Further, in accordance with the experimental data logarithms of specific time of constancy of minimum friction coefficient and the numerical values of its defining complexes were calculated. For that purpose, of all of the factor space the values of the response function at variable maximum and minimum values of the complex logarithms were selected.

For convenience, the table of experiment planning matrix was drawn 2^2. To calculate appropriate levels of complex factors, the values of the strength and dynamic loading modes as well as the experimental data were used. For example, summarized data on the results of tribotehnichal tests described in [3] are given in Table 1.

Table 1 – Summarized data on the tests of model tribological material systems

№	Tribological system	The values of the tribotechnical test parameters						
		HRB_p / HRB_k	N=165 H		N=250 H		N=350 H	
			μ_{min}	t, min	μ_{min}	t, min	μ_{min}	t, min
1	45HN2MFA -L63	1.32	0.08	6.5	0.132	0.08	0.2	0.08
2	45HN2MFA - GS (C-1,21%; Cu-3,95)	0.89	0.06	1.0	0.11	0.08	0.1	0.08
3	45HN2MFA -ACHS-2	1.01	0.08	2.0	0.12	0.08	0.2	0.08
4	45HN2MFA - GS (C-1,78%; Cu-3,18)	0.83	0.08	6.5	0.1	0.08	0.15	6.5
5	45HN2MFA - GS (C-1,95%; Cu-1,94)	0.9	0.06	6.5	0.03	0.08	0.15	0.08
6	45HN2MFA - BrOTsS 4-4-4	1.18	0.06	6.5	0.12	3	0.18	6

Based on the computation data (solved by S_7LAE that is system of seven linear algebraic equations by Cramer method,) the numerical values of the coefficients b_0-b_6 are determined. After making appropriate transformations the expression (3) will be presented as follows:

$$\frac{t}{\mu_{\min}} = e^{b_0}\left(\frac{N}{S_{\text{тр}_\text{к}}\cdot\eta\cdot n}\right)^{b_1}\left(\frac{E_\text{к}\left(HRB_\text{р}+HRB_\text{к}\right)}{(E_p+E_\text{к})HRB_p}\right)^{b_2}\left(\frac{\upsilon_c\cdot\sigma}{N\cdot n}\right)^{b_3}\left(\frac{N}{S_{\text{тр}_\text{к}}\cdot\eta\cdot n}+\frac{E_k\left(HRB_p+HRB_k\right)}{\left(E_p+E_k\right)HRB_p}\right)^{b_4}\times$$
$$\times\left(\frac{N}{S_{\text{тр}_\text{к}}\cdot\eta\cdot n}+\frac{\upsilon_c\cdot\sigma}{N\cdot n}\right)^{b_5}\left(\frac{E_k\left(HRB_p+HRB_k\right)}{\left(E_k+E_p\right)HRB_p}+\frac{\upsilon_c\cdot\sigma}{N\cdot n}\right)^{b_6} \quad (8)$$

Conclusion

The proposed approaches made it possible to define the type of the mathematical expression that can be used for tentative predictive estimate of functionality of lubricating films in the mentioned process of change in their tribological conditions. The deduced patterns can be the basis of the algorithm of computer simulation of tribological processes under study. The computer stimulation will be one of the problems set for future studies.

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