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ANALYSIS OF RUNNING-IN PROCESSES IN TRIBOLOGICAL SYSTEMS

A brief analysis of the study of the running-in process is presented. The inconsistency of mechanistic representations of the running-in stage is established. An atomic and molecular model of tribological contact is presented. The mechanism of running-in is proposed, in which the main role is played by synthesis, in the process of which molecules, clusters, and nanosized particles are formed. By applying the Boltzmann transfer equation, an analytical expression for the evolutionary process of the exponential type of acclimation is obtained. The main characteristics of running-in are the running-in time and wear from the initial stage.

The level of characteristics can be controlled by external factors (increasing the load in the process) and internal factors (structure of solids and lubricant).

Keywords: *running-in, tribological contact, dissipative structures.*

Introduction. Each tribological system can be in one of three states: evolutionary - at the stage of running-in, stationary - normal operation, and abnormal - failure state [1].

The initial surface quality obtained during the processing of machine parts has characteristics that are usually different from those of the operating state that is formed during operation. Therefore, at the beginning of machine operation, processes of transformation and transition from the initial state of surface quality to the operational - stationary state occur, i.e., changes in the geometry and physical, chemical, and mechanical properties of thin surface layers occur, and dissipative structures are formed in contact. The transition from the initial state to the working state is called running-in, which occurs during the period of initial wear [2].

To achieve the desired effect, friction units are subjected to a specially selected operating mode in the initial period, which achieves the required quality in the shortest possible time.

This period of operation is based on complex mechanical, physical and chemical phenomena. By the end of this process, the main parameters of surface quality, such as roughness, microhardness, residual stresses, structure of the metal boundary layer, and others, interconnectedly acquire values that correspond to the given wear or operating conditions. In general, the surface quality parameters are self-sustaining during normal wear [3, 4]. That is, the running-in process largely determines the overall durability of parts.

Operational experience shows that the running-in process can be optimized through a combination of step or continuous running-in, as well as stages (cold run-in, hot run-in at idle and under load, and operational run-in). If we take into account that these factors can be in a variety of combinations, it will become clear how difficult it is to study the processes of running-in of friction surfaces of tribunals.

A large number of studies devoted to this issue of various units indicate that this technological operation plays an important role in increasing reliability and improving economic performance in operation, both in the manufacture of new parts and in repair.

In most papers, the authors aim to develop a methodology for optimal run-in. However, there are no well-defined patterns of influence of external and internal factors on this process.

The criterion by which the methodology is optimized is the quality of running-in of rubbing surfaces with their minimum initial wear. Also, the economic effect of reducing the cost of running-in is often used as an optimization criterion [5]. For example, the cost of running-in an engine is determined mainly by the duration of the running-in process and the amount of materials consumed (fuel, lubricants, etc.).

The purpose of running-in is to obtain a friction surface with such actual contact areas that can withstand operational loads. That is, mutual tribological treatment of friction units until sustainable wear. The realization of this goal is possible when determining the mechanism of running-in of tribological systems (TS). For example, after running-in, the engine will be prepared to deliver 100 % of its rated power. In the case of refusal to run-in and full load of the engine after factory assembly, after 100 hours of operation, cylinder wear reaches values equivalent to 10-20 thousand km of vehicle mileage [6].

However, the ways to realize this goal have not been sufficiently developed. Most studies consider a mechanistic approach to running-in of vehicles. However, stable operation is determined by the state of the surface layers of the friction pair formed during the running-in period.

The aim of this work is to analyze the running-in mechanism, taking into account both mechanistic and atomic-molecular approaches to the study of tribosystems.

Analysis of the mechanistic concepts of the running-in process. The evolutionary stage is divided into two phases: 1) intensive running-in at the macro level; 2) at the micro level. At the initial stage, roughness, plastic deformation, and system loading play an important role [7].

Plastic deformation of the surface layers of tribosystem elements causes irreparable damage. Damage to individual structural components (mainly solid phases) located in certain areas of friction pairs; damage to most of the friction surface. The surface itself has an active surface layer, followed by a subsurface layer. The thickness of the active layer a ranges from fractions of a micron to tens of microns, and the subsurface layer is up to several millimeters. The layers represent a single ensemble of frictional interaction of the contacting bodies. Regardless of friction modes and materials, the active surface layer participates in physical and chemical triboreactions. In some cases, it provides a boundary lubrication regime [8].

If plastic deformation occurs in thin, easily movable surface layers, then the mated pair works without scoring. This is facilitated by specially applied coatings of soft metals, layers of solid lubricants, polymer coatings, or the use of self-lubricating alloys and composite materials. The peculiarities of self-lubricating materials involve the interaction of soft phases and a solid matrix in the process of elastic and plastic deformation. When heterogeneous alloys with a soft phase are used, this phase is extruded more intensively than during the stationary period due to the difference in yield strength of the components and different degrees of plastic deformation at stresses above the yield strength of the matrix and the soft phase. Thin protective films formed by the transfer of metal from the soft phase are capable of creating a kind of hardened zone on the mating surfaces.

One of the main conditions for completing the running-in process is the transition of the initial technological roughness to the operational one. Experimental studies [2; 9] have shown that after the end of the run-in process, a roughness is formed on the friction surface that does not depend on the initial one obtained during machining, but depends only on the wear conditions.

There are papers [2; 10] that study only the roughness formed during the run-in process and confirm the legitimacy of using the term “equilibrium roughness”.

The value of the equilibrium roughness depends on the load applied to the friction unit, sliding speed, and the properties of the friction pair materials [10]. The surface changes its roughness until it reaches a minimum friction coefficient corresponding to the minimum frictional energy. The initial roughness mainly affects the running-in time [11]. The regularities of formation and design characteristics of equilibrium roughness are presented in the works of I.V. Kragelsky et al.

Studies of changes in microhardness during running-in [10] showed that the running-in period ends when the friction surface reaches a certain degree of adhesion.

The running-in of a tribological system under conditions that are close to critical (according to I.I. Karasik, at the “jamming limit”) occurs with a decrease in the Sommerfeld index and friction coefficient in time according to the Hersey-Striebeck dependence. At the same time, the range of load and speed control does not go beyond semi-fluid lubrication. Depending on the type of friction pair, the bearing capacity differs significantly. Thus, it was found that at the end of the run-in period, the level of bearing capacity of aluminum alloys containing more than 9 % tin significantly exceeds the maximum loads before seizure of lead bronzes of BrS3O grades [12].

The operating time of a vehicle is determined by the degree of its completeness at each load-speed mode and after its completion. The completeness of the process is determined by the loading capacity of tribosystems, energy indicators (gear efficiency, reduced fuel consumption, friction losses, etc.), stabilization of wear intensity, frictional heat resistance, etc.

Changes in the properties of deformed surfaces are due to the very nature of friction and the peculiarities of converting mechanical energy into heat. The process of adjustment of friction pairs during the running-in period is energetic, since it proceeds with the absorption or release of energy by the contacting surfaces [7].

Atomic and molecular approach to the run-in process. From the point of view of thermodynamics, at the evolutionary stage, atoms located at the interface between two phases are “special” both in terms of their position in the asymmetric force field and their energy state. Indeed, the creation of a new surface requires the expenditure of work to break the bonds, a significant part of which accumulates in the form of excess potential energy at the interfacial boundary [12].

At the same time, as shown by M.A. Boucher, the tribological system is self-organized as a result of structural adaptability under friction. In the formation of substance flows, the main role is played by the processes of transfer and self-organization, which lead to the formation of tribological structures of the dissipative type in contact. The mechanism of formation of these structures is determined by the organizing effect of non-equilibrium states on the flows of matter [12]. The formation of substance flows in a tribological contact is determined by the phenomena of transfer at the atomic level.

With the coordination number of the crystal lattice equal to eight, surface atoms have from seven to one bond with the internal atoms of the solid and from one to seven free bonds, the energy of which forms the excess surface energy of solids. In contact, from one to seven bonds can be formed between an atom of one surface and the atoms of a counterbody. If the number of bonds with the atoms of the counterbody exceeds the number of internal bonds, then the atom is transferred to another surface during the relative motion of the solids. During friction, there is a continuous transfer of atoms between surfaces, these active atoms enter into a chemical bond with the atoms of the counterbody and lubricant. Interatomic bonding is not considered in the sense of a real physical object, but as a result of the dynamic redistribution of the probability density of electronic states, which results in electric forces of attraction, repulsion, or neutral state.

The evolutionary stage is dominated by the desire to minimize free energy. In the contact, the transferred particles aggregate, the internal flows of matter are aimed at forming a tribostructure and increasing its volume, and the flow of matter out of the system decreases until it reaches a stationary level. In the steady state, the tribostructure fluctuates around the mean value. During one fluctuation, part of the substance leaves the system in the form of wear products, and then the tribostructure is restored.

Thus, tribological structures are formed during the running-in process, then the process fluctuates in a stationary mode with constant mean and variance, excessive growth is limited by entropy, and the lower level is limited by free energy [12]. The formulas for the wear rate it = dI/dt and the wear I(t) as a function of time t are as follows:

$$i_t(t) = (i_0 - < i_t >)\exp(-t/T) + < i_t > \qquad (1)$$

$$I(l) = (i_0 - < i_t >)T[1 i_t - \exp(-t/T)] + < i_t > t \qquad (2)$$

where i0 and <it> are the initial and average stationary values of the wear rate: T is the running-in relaxation time; I(t) is wear.

Replacing time t in formulas (1) and (2) with the friction path l, we obtain the formula for the wear rate il and the wear I(l) along the friction path. The exponents on the left-hand side describe the evolutionary process of running-in, with the duration of running-in estimated by the relaxation time T, and the contribution of running-in to wear by the functional I0 = (i0 - < it >)T[l it - eqr(-t/T)]. At the evolutionary stage of running-in, tribosystems move from the state set by the technology to the state determined by the process itself.

Conclusions. In the traditional mechanistic approach, the running-in mechanism is determined by deformation and fracture of the surface layers of the contacting solids. This does not correspond to the real conditions of tribological contact in antifriction systems. In operation, all types of surface destruction and the appearance of metal particles in wear products are considered as signs of failure.

Wear products consist of nanoscale particles, the end products of physical and chemical transformations: oxides, sulfides, phosphates, cokes, and others.

A mechanism of working-in is proposed, in which the main role is played by synthesis, in the process of which molecules, clusters, and nanosized particles are formed.

In non-equilibrium conditions of tribological contact, in the process of exchange with the environment, substance, energy, particles are formed into dissipative structures that determine the level of tribological processes.

An exponential expression for the running-in time is obtained using the Boltzmann transfer equation. The main characteristics of running-in are determined.

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АНАЛІЗ ПРОЦЕСІВ ПРИПРАЦЮВАННЯ В ТРИБОЛОГІЧНИХ СИСТЕМАХ

Представлено короткий аналіз дослідження процесу припрацювання. Встановлено невідповідність механістичних уявлень етапу припрацювання. Представлена атомно-молекулярна модель трибологічного контакту. Запропонований механізм припрацювання, в якому основну роль відіграє синтез, в процесі якого формуються молекули, кластери, нанорозмірні частинки. Застосувавши рівняння переносу Больцмана, отримано аналітичний вираз для еволюційного процесу припрацювання експоненціального типу. Основними характеристиками припрацювання є час припрацювання та зношування від початкового етапу.

Управління рівнем характеристик, можливе з допомогою зовнішніх факторів (збільшення навантаження в процесі) та внутрішніх (структурою твердих тіл та мастила).

Ключові слова: припрацювання, трибологічний контакт, структури дисипативного типу.

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