Problems of Tribology, V. 25, No 4/98-2020, 13-19

Problems of Tribology
Website: http://tribology.khnu.km.ua/index.php/ProbTrib
E-mail: tribosenator@gmail.com

DOI: https://doi.org/10.31891/2079-1372-2020-98-4-13-19

New approach to elucidating the physical nature of the processes that occur in the friction zone of mates of machine parts

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Abstract

It has been found that during frictional contact in separate local areas of a thin surface layer of parts under significant loads and deformations and high contact temperatures, the material of the tribocontact zone of parts transforms into a special activating unstable state of magma-plasma or triboplasma. General issues in which the nature of the processes of friction and wear of mating parts is clarified are considered at a higher fundamental level with the involvement of nanotribology.

A number of processes that accompany interactions of triboconjugations of parts are analyzed: mechanoemission, mechanochemical, gas-discharge, etc., tribochemical reactions, fluxes of high-energy particles: excited molecules, atoms, ions, fast electrons, phonons (sound quanta and quanta of electromagnetic radiation).

Regularities of additivity of elastic and magnetic aftereffect in the volumetric parts and surface layers of tribo-interface parts made of ferromagnetic materials and alloys have been revealed. Also, the regularity of the additivity of the diffusion aftereffect in their surface layers has been established. A tribophysical model of self-organization is built on the basis of a carbon-nitrogen cycle of tribochemical reactions that have the content of thermonuclear fusion reactions and which can be considered at the nanoscale. In these reactions, the carbon atom plays the role of a catalyst for the process of fusion of protons with subsequent transformation into a radioactive isotope, which decays into ordinary carbon and helium. It has been established that the mechanism of nuclear fusion reactions in the surface layers of triboconjugation parts is due to the directional movement of dislocations in the crystal structures of materials with the implementation of the proton cycle and the conversion of hydrogen into helium.

It has been shown that this makes it possible to change the idea of the mechanocaloric effect, the process of friction and wear, and to substantiate a number of effects and processes from the physical positions of nanotribology. This will allow the creation of competitive tribotechnologies in various industries.

Key words: mating parts, friction criteria, wear resistance, reliability of systems and units

Introduction

The interaction in the movable interfaces of parts of systems and machine assemblies causes, first of all, the occurrence of processes of friction and wear, as well as the failure caused by them, amounting to about 90%. Losses from the processes of friction and wear in developed countries reach 5...6% of the national income. To overcome frictional resistance in machines and mechanisms, 20...25% of the energy generated per year is spent all over the world.

An increase in the economic and environmentally sound reliability of systems and assemblies of machines, technological equipment and tools is directly related to an increase in the wear resistance of resource-determining mates of parts. The solution to this urgent problem is possible only on the basis of deep scientifically grounded fundamental knowledge, the processes occurring in the surface layers of parts, and have a tribophysical nature and which can be substantiated at the levels: nano-, micro-, meso- and macrolevels.

Management of friction processes, the correct choice of materials for mating parts according to the criteria of friction and wear resistance, their rational design, as well as optimization of operating conditions can significantly provide a high level of operational reliability of machines and increase the efficiency of their use, reduce harmful environmental impacts with a slight increase in cost [1].

Academicians V.I. Kolesnikov, Yu.M. Luzhny, A.V. Chichinadze believed that the complex of studies in the field of macro-, meso-, micro- and nanotribology of triboconjugation of parts of systems and aggregates of transport machines in general refers to the main and topical areas of their operational reliability [2].

Literature review

I.V. Kragelsky, M.N. Dobychin, V.S. Kombalov [3], analyzing the critical points characterizing the conditions for the transition from one type of frictional interaction to another, argued that in some local areas of a thin surface layer of parts, significant stress and strain and high contact temperatures develop. In this case, the material of the contact zone of the parts passes into a special activating unstable state. This position of the material P.A. Thyssen is called magma-plasma or triboplasm [4]. Substances in the state of "triboplasma" are capable of reacting with materials of mating parts and the external environment. It is typical that a reaction is observed even with neutral substances, neutral gases.

A new interpretation of the mechanisms of thermoplastic deformation during the phase transformation of the materials of parts under nonequilibrium conditions and a significant temperature gradient is given in [5]. It is shown that in the friction zone the processes and states of materials self-organize. Positive self-organization in tribotechnical systems increases the efficiency of their functioning [6]. A physical approach to the mesomechanics of wear of the working surfaces of parts of tribocouplings [7,8] is considered and a scale-level approach to the analysis of the characteristics and properties of surface layers of parts and a lubricating medium is proposed [9]. It is noted that mesomechanics is a modern approach to the theory of wear [10]. The tribophysical material science approach is informative about the processes and states of materials, and the assessment of their resources [11]. From a physical point of view, the processes of friction and wear in the contact zone of the triboharness of parts of motor transport and agricultural machinery have been analyzed [12]. From the standpoint of fullerenes, their influence on the physical and mechanical properties of the friction surface of tribocouplings of parts has been clarified [13]. The physics of the formation of a stress-strain state makes it possible to clarify the formation of local areas of compression and tension deformations [14]. The electrochemical and mechanical loads on the tribocouplings of parts with the implementation of a whole range of phenomena and the improvement of tribocharacteristics are also of interest [15]. The essence of a new approach is to identify the physical nature of friction processes [16] with the construction of a physical model of tribological processes [17] and analysis of the processes of changing the states of materials in the tribosystem [18].

Analyzing the solution of general issues concerning nanotribology, Yu.I. Golovin [19] notes that the desire to identify and understand the nature of nanocontact processes of friction and wear of mating parts at a higher fundamental level is quite natural. The first step in this direction is the level approach of considering the characteristics and properties of individual micro- and nanocontacts of the friction zone, and then, by integrating or averaging over the surface, proceed to investigations at the meso- and macrolevels. This approach has become available only in recent years in connection with the development of nanoidentification and nanoscraping techniques.

Purpose

The aim of this work is to elucidate the physical nature of the processes occurring in the surface layers of the friction zone of mating parts of systems and aggregates of transport machines based on the data of their tribophysical essence and a set of chemical reactions occurring at the nano- and microlevel, representing the mechanisms of processes.

Results

An important step towards the creation of a physical theory of friction and wear of mating parts of systems and machine assemblies is the transition to research at the nanoscale. Such studies have become possible thanks to the improvement of scanning probe microscopes, in particular, atomic force microscopes operating in the lateral mode (friction for semicroscopy – FFM). On the basis of this information, various processes in the materials of dynamic tribocontacts have been modeled, new approaches to identifying regularities have been elucidated, and the mechanism of their development has been refined.

This indicates that the study of the processes of friction and wear in this direction goes to a higher quality level. At the same time, a whole series of new questions arise that need to be clarified, identified and resolved. The main ones are the issues of determining the characteristics and properties of the friction zone and the relationship between them on the macroscopic, mesoscopic, microscopic, nanoscopic. It needs an explanation and the result of their forecasting in the process of development and operation, as well as the identification of sets of processes that correspond to them. The state of triboconjugations in the surface layers of materials, which are formed in the process of self-organization, are also of interest and synergistic foundations of the "green" tribology of systems and machine assemblies are being created. When solving these issues, it is advisable to proceed from fundamental knowledge of the properties of interacting atoms and the topology of the working surfaces of mating parts.

It is also necessary to solve the issues of controlling external and internal friction in tribo-couplings of parts of systems and machine units on the basis of this knowledge. This will make it possible to create new and improved existing tribosystems (tribosystems of parts) with high friction and energy dissipation. For example, for tribo-couplings of parts of braking and friction systems, clutches or, conversely, for tribo couplings of parts with low friction (sliding bearings, for guide parts of systems and assemblies: valve bush, brake calipers, car suspensions, etc.).

In this case, it is desirable to identify conditions in which friction is practically zero, that is, the phenomenon of wear-free or positive selforganization is realized. There are no fundamental obstacles to this, and in a sense, such regimes have already been found.

Interaction in mobile interfaces of machine parts (fig. 1) is accompanied by a complex of different processes: mechanoemission, mechanochemical, gasdischarge, etc., as well as the course of tribochemical reactions, the synthesis of some compounds - the emergence of high-energy particle flows: excited molecules, atoms, ions, fast electrons, phonons (sound quanta), photons (quanta of electromagnetic radiation).

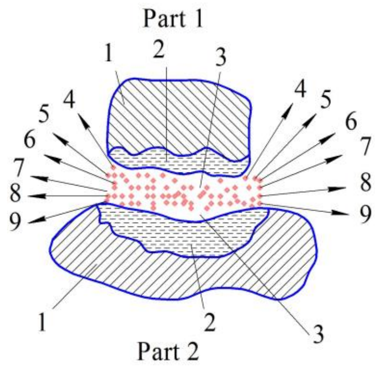

Fig. 1. Schematic representation of the triboplasma model in conjugation of details:
1 – the original structure of the material of the part; 2 – molten structure of the contact zone; 3 – plasma state of matter in the contact zone; 4 – triboemission electrons; 5 – flows of atoms, photons, phonons, ions, excited molecules, fast electrons; 6 - area of the reactor compartment of cold synthesis; 7 – heat flow; 8 – helium flow; 9 – fluxes of radiation of various types of energy; acoustic waves, triboluminescence, triboemission, exoelectron emission, photoelectron emission, photoelectric effect

The regularity of the additivity of the elastic aftereffect in the volumetric parts and surface layers of the parts of tribocouplings [20] has been revealed, which consists in the fact that in their elastic and plastic regions, in the zone of frictional contact, there is a summation (additivity) of elastic and plastic aftereffects caused by changes in frictional bonds, physical and mechanical characteristics of the material and the spatial position of the tribocouplings of parts. This is due to the directed movement of dislocations in the elastic and plastic regions of the surface layers of the material of the parts.

The regularity of the additivity of the magnetic aftereffect in the volumetric parts of the ferromagnetic material of the details of tribo-couplings and their surface layers has been also established [21]. The effect is that the summation (additivity) of magnetic aftereffects occurs in the elastic and plastic regions of the frictional contact zone. This aftereffect determines the behavior of hydrogen atoms in triboconjugation materials: intense diffusion is observed, a high degree of energy pumping in the surface layers, molization and interaction with atoms of other chemical elements dissolved in the main material of the parts. This is due to the directional movement of dislocations in the materials of parts, which capture hydrogen atoms and transport them to the zone of frictional contact with elastic and plastic local regions of the surface layers of materials of parts and affect their structure, as well as the mobility of the domain walls in them.

One of them is realized in tribocoupling of parts with helium wear [19]. The use of such tribosystems will make it possible to control friction due to superfluidity and the presence of helium parts in materials.

In this direction, a positive point is the established regularity of the additivity of the diffusion magnetic aftereffect in the volumetric parts and surface layers of tribocouplings of parts made of ferromagnetic materials and alloys [3]. Its essence lies in the fact that in the elastic and plastic regions of the material of the parts, in the zone of their frictional contact, the summation (additivity) of diffuse magnetic aftereffects occurs. In this case, the effect is accompanied by elastic and plastic aftereffects and determines the behavior, first of all, of the carbon and nitrogen atoms embedded in the material of parts. In the process of friction of the mates of parts, a directed movement of dislocations is observed, which transport the carbon and nitrogen atoms present in the materials of the parts into the zone of frictional contact with the elastic and plastic regions and their influence on the structure and mobility of the domain walls of the material.

It should be noted that the carbon C and nitrogen N atoms, which work by the interstitial mechanism, create the so-called carbon-nitrogen cycle, which is responsible for the synthesis of helium in the friction zone

[22]. The revealed conditions under which friction in the mating of parts is practically absent and the phenomenon of super-sliding is realized [7,23], similar to the phenomena of superconductivity or superfluidity.

A tribophysical model of such a selforganization phenomenon can be built on the basis of the carbon-nitrogen cycle of a number of the following chemical reactions:

$$^{12}C+^{1}H\rightarrow^{13}N+\gamma; \quad (1)$$
$$^{13}N\rightarrow^{13}C+\beta^{+}+\nu; \quad (2)$$
$$^{13}C+^{1}H\rightarrow^{14}N+\gamma; \quad (3)$$
$$^{14}N+^{1}H\rightarrow^{15}O\rightarrow+\gamma; \quad (4)$$
$$^{15}O\rightarrow^{15}N+\beta^{+}+\nu; \quad (5)$$
$$^{15}N+^{1}H\rightarrow^{12}C+^{4}He. \quad (6)$$

In these tribochemical reactions, the carbon atom plays the role of a catalyst for the process of proton fusion. A proton, colliding with a carbon nucleus ^{12}C (1), turns into a radioactive isotope ^{13}N, and a γ-quantum (photon) is also emitted. The ^{13}N isotope, undergoing β^{+} decay with the emission of a positron and neutrino (2), turns into an ordinary nitrogen nucleus ^{14}N (3). In this reaction, a γ-quantum is also emitted. Further, the ^{14}N nitrogen nucleus collides with the ^{1}H (4) proton, after which a radioactive oxygen isotope ^{15}O and a γ-quantum are formed. Then this isotope is converted by β^{+} decay into the nitrogen isotope ^{15}N (5). Finally, the last ^{15}N isotope, having attached a proton during the collision, decays into ordinary carbon ^{12}C and helium ^{4}He (6).

The entire chain of nuclear reactions observed are the sequential weighting of the carbon nucleus by the addition of protons, followed by β^{+} decay. The last link in this chain is the restoration of the original carbon nucleus and the formation of a new helium nucleus at the expense of four protons, which at different times, one after another, joined to ^{12}C and to the isotopes that were formed from it.

In recent years, numerous experimental realizations of details of local nuclear reactions at low energies, that is, realizations of local nuclear reactions in condensed media, have been obtained in tribological conjugation materials. This is the so-called cold nuclear fusion (CNF). On the basis of CNF, it is proposed to replace the nuclear processes induced by the crystal lattice of the material. These processes are anomalous in terms of vacuum nuclear collisions. First of all, this fusion of nuclei with the release of neutrons that exist in non-equilibrium solid materials of parts during friction is stimulated by the transformation of elastic energy in the crystal lattice during phase transitions, mechanical influences, sorption or desorption of hydrogen (deuterium). CNF has been reliably recorded in a number of physical and physicochemical processes involving deuterium. Many of them with the participation of natural hydrogen take place in natural processes. These include: the phenomenon of sorption-desorption of hydrogen in metals, redox effect on the compound of hydrogen, mechanical damage and crushing of hydrogen containing rocks.

Note that a satisfactory quantitative and even qualitative theory of CNF has not been created yet, which is of fundamental importance both for fundamental science and for practical use. At the same time, original theoretical and physical models of the CNF mechanism in the crystal structures of the surface layers of triboInterface parts made of ferromagnetic materials and alloys have been developed. An unknown regularity of the additivity of the hydrogen magnetic aftereffect in the bulk parts and surface layers of these materials has been established [22]. It consists in the fact that in elastic and plastic regions, in the zone of their frictional contact, there is a summation (additivity) of hydrogen magnetic aftereffects. Accompaniment by elastic and plastic aftereffects cause directional displacement of dislocations carrying hydrogen to the contact zone. As a result, a number of chemical reactions occur in the tribocontact zone:

$$^{1}H+^{1}H\rightarrow^{2}D+\beta^{+}+\nu; \quad (7)$$
$$^{2}D+^{1}H\rightarrow^{3}He+\gamma; \quad (8)$$
$$^{3}He+^{3}He\rightarrow^{4}He+2^{1}H. \quad (9)$$

On the basis of this, it is possible to formulate the CNF mechanism, which arises in the surface layers of triboconjugation parts, which determines the directional dislocation movement in the crystal structures of the surface layers of materials with the implementation of the proton cycle. As a result, hydrogen is converted to helium.

It should be noted that academician B.V. Deryagin and his co-workers in 1985 discovered the phenomenon of neutron mechanoemission in crystalline materials containing deuterium. In his publications, he interpreted this phenomenon as a manifestation of CNF reactions. It was hypothesized that in substances with hydrogen bonds, one of the bonds may contain two nuclei of hydrogen atoms with a distance between them less than one angstrom. It was found that tunneling of deuterons through a narrow barrier can occur with a high probability even at relatively low temperatures.

Note that according to modern concepts of nuclear physics, a proton and a neutron have two states of one particle – a nucleon. A proton becomes a neutron, attaching an electron, and a neutron - a proton, giving an electron to another proton, which, in turn, turns into a neutron.

On the basis of what has been considered, the idea of the known mechanocaloric effect [7, 8] is changing and it is possible to substantiate a number of effects and processes that arise in materials in the friction zone from a purely physical position of nanotribology. This can be used to create competitive technologies in the field of hydrogen energy, cryogenic and space technology. By taking into account an additional trend in the output parameters due to the additivity of the elastic magnetic and hydrogen-magnetic aftereffect in the volumetric parts and surface layers of the materials of the parts of tribocouplings of systems and machine units, it is possible to control the processes of friction and wear in them.

Conclusions

1. Considering that the contact zones of the materials of parts interacting in microelectromechanical and nanoelectromechanical systems, such as miniature telework, microsatellites, microdevices, nanocomputers, microsensor devices, chemical and biochemical microreactors, and others, are very small, and the specific loads on nanocontacts are large, then tribological processes are largely determined by the atomic-molecular interaction of contacting surfaces and are manifested primarily at the nano- and micro-level of the hierarchy of the totality of tribological processes.
2. It is urgent to create materials for mating parts with helium wear with the possibility of quenching it based on the implementation of a carbon-nitrogen cycle (effect) in the friction zone, as well as ensuring friction control due to the superfluidity of helium in micro- and nanotribosystems.
3. Creation of nanotechnologies and a new class of devices for microelectromechanical and nanoelectromechanical systems will give new competitive results, in particular, through the creation and use of tribosystems with helium wear, which will provide updated diagnostic information about the local states of materials and the identification of new processes in the friction zone.
4. The study of nuclear processes induced by the crystal lattice in micro- and nanotribology is of interest both from the point of view of fundamental research on the creation of a generalized theory of friction and wear, the creation of effective tribotechnologies of running-in and recovery, and for applied purposes.
5. The use of hydrogen as a fuel in a car engine, as well as the development of hydrogen energy can actualize the creation of materials for triboconjugation of parts with helium wear with the possibility of its extinguishing based on the implementation of a carbon-nitrogen cycle (effect) in the friction zone, as a result of which hydrogen is converted into helium.
6. The essence of the acoustic wave, tribological effects, triboelectronic, photoelectronic and triboemissions arising from the interaction of nanocontacts in tribosystems can be purposefully used not only in the study of cold nuclear fusion, but also for obtaining in the future an inexhaustible source of ecologically clean energy based on the synthesis of helium from more light hydrogen.

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Аулін В.В., Лисенко С.В., Гриньків А.В., А.Є. Чернай, І.В. Жилова Новий підхід до з'ясування фізичної природи процесів, що відбуваються в зоні тертя спряжень деталей машин

З'ясовано, що при фрикційному контакті в окремих локальних ділянках тонкого поверхневого шару деталей при значних напруженнях і деформаціях та високих контактних температур матеріал зони трибоконтакту деталей переходить в особливий активізуючий нестійкий стан магми-плазми або трибоплазми. Загальні питання, в яких з'ясовується природа процесів тертя та зношування спряжень деталей, розглянуто на більш високому фундаментальному рівні із залученням нанотрибології.

Проаналізовано ряд процесів, якими супроводжуються взаємодії трибоспряжень деталей.: механоемісійні, механохімічні, газорозрядні та ін., трибохімічні реакції, потоки частинок з великою енергією: збуджених молекул, атомів, іонів, швидких електронів, фононів (звукових квантів та квантів електромагнітного випромінювання).

Виявлено закономірності адитивності пружної та магнітної післядій в об'ємних частинах і поверхневих шарах деталей трибоспряжень з феромагнітних матеріалів і сплавів. Також встановлена закономірність адитивності дифузійної післядії в їх поверхневих шарах. Побудовано трибофізичну модель самоорганізації на основі вуглецево-азотного циклу реалізацій трибохімічних реакцій, які мають зміст термоядерних реакцій синтезу і які можливо розглядати на нанорівні. В цих реакціях атом вуглецю відіграє роль каталізатора процесу злиття протонів з подальшим перетворенням в радіоактивний ізотоп, який розпадається на звичайний вуглець і гелій. З'ясовано, що механізм реакцій ядерного синтезу в поверхневих шарах деталей трибоспряжень, обумовлений спрямованим переміщенням дислокацій в кристалічних структурах матеріалів з реалізацією протонного циклу та перетворенням водню в гелій.

Показано, що зазначене дає можливість змінити уявлення про механокалоричний ефект, процес тертя і зношування та обґрунтувати ряд ефектів і процесів з фізичних позицій нанотрибології. Це дасть можливість створити конкурентоспроможні триботехнології в різних галузях.

Ключові слова: спряження деталей, критерії тертя, зносостійкість, надійність систем і агрегатів.