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POSTĘP MODELOWANIA INTERDYSCYPLINARNEGO – TRIBO-TATIGUE

Streszczenie: Z inżynierskiego punktu widzenia tribologia bazuje się na studiowaniu współdziałania elementów systemów mechanicznych. Właśnie dla tego współdziałania w systemie, wyznacza się docelowo pewność jak węzłów, jak i maszyny jako całości. To oznacza, że odchodzimy, w mechanice, od tradycyjnych obliczeń oddzielnych detali i przechodzimy do obliczeń oraz konstruowania jednolitych mechanicznych systemów.

Słowa kluczowe: tribo-fatigue, opis interdyscyplinarny, zniekształcony stan, kontaktowe obciążenie, powtórnie-przemienne obciążenie

PROGRESS OF THE INTERDISCIPLINARY COOPERATION – TRIBO-FATIGUE

Summary: From the engineering point of view, tribo-fatigue is based on studying of interaction of elements of mechanical systems. It is for this interaction in the system that the reliability of both the nodes and the machine as a whole is ultimately determined. This means that we are leaving, in mechanics, from the traditional calculation of individual parts and proceed to the calculation and designing of holistic mechanical systems.

Keywords: tribo-fatigue, wear-fatigue damage, deformed condition, contact load, repeated and variable load

1. Introduction

A special feature of the modern scientific knowledge is the emphasis on the cooperation of various disciplines, involving specialists and organizations to scientific process that have a whole range of theoretical and practical competences. [1]
This feature manifests itself at all levels of the functioning of science:

1) As a system of rational knowledges;

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2) As a specially organized activity for their receipt, verification and operationalization;
3) As a social institution.

In the first case, it is motivated by the fact that the studies of complex of phenomena and of processes of nature, society, and the technical sphere requires a combination of differences, which sometimes are manifested in the inevitable theoretical bases and approaches.

In the second, it is conditioned by the character of the most "social order" for the science and, to a large extent, by the fact that the most important modern tools for financing of scientific researches, such as the European Union Framework Programs, not only allow but also explicitly provide for the formation of scientific consortia of interdisciplinary and international character.

In the third aspect new forms of the organization of scientific process are determined by need of optimum distribution of resources of scientific activity, and in some cases, by the need for consolidation of scientific-intellectual elites for representation and protection of their interests at the sphere of social management, business, in broad public consciousness.

Many research programs of modern science are in some respects a prerequisite, and in another - the result of the process of integrating scientific knowledge and the community of scientists. The cementing factor of these programs is different forms of communication between the subjects of the scientific process - from simple dialogue, mutual coordination of conceptual pictures to close cooperation and even to situations where one discipline practically assimilates another. Difficulties in the way of their formation are connected with the development of a "common language", the harmonization of traditional basic assumptions and broad interpretations characteristic of disciplinary "pictures of world", by the construction of subject areas and the choice of objects of joint research.

2. General problem of refusals of the loaded details

Comparatively "young" cross-disciplinary program of scientific research, which requires a strong theoretical-methodological basis where the significant component it is knowledge at the field of mechanics, engineering, the philosophical theory of systems, synergetic and logic. The scientific knowledge obtained in studies on tribo-fatigue is a complex theory of factors limiting operational reliability, functional efficiency and durability of technical systems, of modern machines and equipment - this is not only the applied importance, but also a wide worldview potential. Fatigue changes, accumulation and gradual development of private damages, dysfunctions, errors in system disorder happens not only in machines and mechanisms - quite often it characterizes the life activity of the human-dimensional social systems, of the whole societies, states and of historical eras.

Fatigue and wear are the eternal "enemies" of machines and equipment: according to various estimates, from 65 to 90% of operational refusals of loaded details, of systems and units are due to them. In process of growth of capacity and productivity of the modern technique the equipment failure also increased. And more and more often their analysis did not give desirable answers to a question: What are the main reasons for this or that failure? In such cases, scientists and engineers of various specialties began to come to the conclusion that, in reality, when a mechanical system perceives

and transmits the working repeated-variable loadings and simultaneously in it the friction process is realized in any manifestations (rolling, sliding, impact, etc.), the main cause of operational failures is a complex - the wear-fatigue damage and destruction. In fact at the junction of tribology and the mechanics of fatigue destruction, tribo-fatigue arose, and the objects of its studies began to call powerful or tribo-fatigue systems. The 32 years have passed since the birth of tribo-fatigue was declared.

It is necessary to consider all the most important achievements of a tribo-fatigue.

The mechanics of the last century was dominated by factor analysis. Thus, it turned out that fatigue failures depend on a large number of constructional, technological, metallurgical and operational factors. And the actual task was to study their effect on the change in the characteristics of fatigue resistance. The birth of tribo-fatigue marked the transition from the analysis of factors to the phenomenological analysis in mechanics, since it was found that fatigue and friction (including wear) are not factors, but phenomena that interact dialectically. As a result of the complex wear-fatigue damage the durability of systems as confirmed experimentally, not only decreases, but can also increase depending on the interaction conditions; so, a theory of the Interaction of Irreversible Damages was constructed. Thereby in a tribo-fatigue two main effects were formulated: direct (the effect of processes of friction and wear influences on change of fatigue resistance characteristics) and the reverse effect (the effect of processes fatigue damage influences on change in friction and wear characteristics).

Synergetic basis of tribo-fatigue.

During the first 10 years, the experimental studies dominated in the tribo-fatigue. Essentially new methods of wear-fatigue tests were developed and the new class of testing equipment was created-special machines for wear-fatigue tests of the SI series. They are manufactured in accordance with the requirements of the interstate standard [2]. It allowed to study experimentally the main regularities of direct and inverse effects (including tribo-fatigue surprises known now) and to create the first data bank - the characteristics of wear-fatigue damage and of destruction of the metals and power system models; the last are necessary for calculating the tribo-fatigue criteria.

Experimental bases of tribo-fatigue.

For the last decade there was an intensification of theoretical researches. The fundamental and applied problems have been set and solved, these include: the development of mechanical-mathematical models of the stress-deformed condition of the tribo-fatigue systems; the creation of a generalized theory of their various limiting states; analytical description of the states of volume damage of materials and elements of the powerful systems; formulations and solutions of some dynamic problems (for example, the phenomenon of Tropp), etc. These and other research results constitute the theoretical basis of tribo-fatigue.

3. Models of tribo-fatigue systems and their research chain

When determining a problem of combining of two large competitors: thermodynamics which was born 150 years ago and has great achievements in the description of evolution of systems (on the basis of researches of irreversibility of various processes), but predicts thermal death of the Universe, according to modern data of science, will not occur, and the most ancient science - mechanics, whose the main

laws allowed to describe the movement of any material objects, which however were unsuitable in the theory of evolution because does not pay attention to the past and the future. Due to their association in mechanic-thermodynamics becomes possible to construct a consistent and holistic theory of development of the irreversible damages which is based on ideas about tribo-fatigue entropy. These are those complex changes of structure, properties of solid deformable bodies in the thermodynamic environment that determine the so-called evolution of the system on damage. In the simplest tribo-fatigue systems, there is a complex wear-fatigue damage; it is due to the kinetic interaction of fatigue phenomena, friction, wear and (or) erosion. Classification of the main types of damage and types of the wear-fatigue damage on the typical examples of real tribological systems is given in Table 1.

Table 1. Complex damage of tribo-fatigue systems

Tribo-fatigue system	Complex damage and destruction	Definition
Crankshaft / crank head with sliding bearing	Friction-mechanical fatigue	The wear-fatigue damage caused by the kinetic interaction of the phenomena of mechanical fatigue and sliding friction
Wheel / rail	Contact-mechanical fatigue	The wear-fatigue damage caused by the kinetic interaction of the phenomena of mechanical fatigue and rolling friction (rolling friction with slippage)
Splined shaft / bushing	Fretting-fatigue	The wear-fatigue damage caused by the kinetic interaction of the phenomena of mechanical fatigue and fretting
Propeller shaft / seawater	Corrosive mechanical fatigue	Fatigue of the material with simultaneous action of repeatedly variable stresses and corrosive environment
Turbine blades / flow of liquid or gas, carries solid particles	Erosion mechanical fatigue	The wear-fatigue damage caused by the kinetic interaction of the phenomena of mechanical fatigue and erosion
Pipe / flow of liquid or gas under pressure	Corrosion erosion fatigue	The wear-fatigue damage caused by the kinetic interaction of the phenomena of mechanical fatigue, corrosion and erosion

It should be noted that these are the most responsible and massive units of modern machinery and equipment. Follows from contents of the table № 1 that complex wear-fatigue damage of the tribo-fatigue systems is caused due to the characteristic actions:

1) contact load (FN) - in the first approximation it can be characterized by the contact pressure of p_a and frictional tension $\tau_w = f\, p_a$, where f - a friction coefficient;
2) repeated-variable (not-contact) load (M) - in the first approximation it can be characterized by cyclic stresses σ;
3) thermodynamic load - integrally it can be characterized by temperature $T\Sigma$, caused by all heat sources;
4) electrochemical load - indirectly it can be characterized by corrosion parameters (D), at the same time it is necessary to distinguish a stress corrosion ($D\sigma$), friction corrosion ($D\tau$) and thermal corrosion (DT). [2]

In the analyzed tribo-fatigue systems, the whole complex of real damages is found.

We see that it simplifies the situation: in the first approximation, we consider not the three-dimensional system of contact and repeated stresses, but only their one-dimensional equivalents. Naturally, if necessary, we can refuse simplification and solve problems on the basis of general representations of the mechanics of a deformed rigid body, the theory of elasticity, the mechanics of contact interaction, the mechanics of destruction, etc. But the formulation, solution and analysis of specific tasks about an intense strained state of the tribo-systems is the fundamental basis of tribo-fatigue. In the mechanics of the tribo-fatigue systems, the volumetric stress analysis is not the final result of the calculation. But it serves as a starting point for the solution of a practical task - the determination of the mechanical condition of the material of the elements of the system during exploitation. The mechanical condition is characterized not only by the initial stress condition, but also by the state of damage during exploitation and by the limiting condition.

Features of the research of mechanical conditions of the tribo-fatigue system.

In a tribo-fatigue system, purely contact stresses arise in elements which do not give to the volume deformation. In the working zone of the main element of the tribo-fatigue system, which simultaneously undergoes contact and volume deformation, a connected condition of stress arises, caused by load of both types - by the surface and volume. It does coincide neither with purely contact-stressed condition, nor with a volume-stressed condition. Therefore, in practical calculations, specific problems should be posed and solved about the features of the condition of damage and the limiting state of the tribo-fatigue system: they turn out to be multi-criteria. If, for example, the criterion of the limiting condition of a structural element (shaft) that undergoes a repeated-variable (cyclic) load - can serve fatigue breakdown, i.e., its separation into parts if the criterion of the limiting condition of a friction couple can be the critical size of wear (sliding) or the critical density (depth) of the dying holes (during rolling), then the loss of working capacity by the tribo-fatigue system can occur according to all the specified criteria of the limiting state - depending on an external environment or tests.

Moreover under the conditions of exploitation or testing, there are two effects:

1) The influence of processes of a friction and wear on the change in the characteristics of damage and resistance of a fatigue (in tribo-fatigue it is called the direct effect)
2) The influence of processes of a fatigue damage on the change in the characteristics of friction and wear (in tribo-fatigue it is called the inverse effect).

In both cases, there is a complex wear-fatigue damage, the development of which leads to the achievement of a complex multi-criteria limit condition.

Main features.

Under certain conditions, the development of wear-fatigue damage can be greatly accelerated - this means that involuntary softening is realized in the system. In other conditions, on the contrary, the development of wear-fatigue damage is significantly slowed down - this means that involuntary strengthening is realized in the system. It is possible that the interaction of damage caused by different loads, that is, the damage events are incompatible, i.e., they are excited in different zones of the loaded system. When the various and innumerable acts and effects of the interaction of damages of many types cannot be accurately described and envisaged, a concept of the interaction of dangerous volumes is introduced, which contains a real complex of irreversible

damages, generated by the action of the corresponding stress fields. A dangerous volume can serve as an equivalent to a complex of damages, since its value is proportional to the level of tension and, consequently, the number of defects.
So, wear-fatigue damage is a complex damage in the sense that it is the result of the interaction of any damages caused by the contact and the non-contact loads (stresses, deformations) and develops at any scale levels (nano-, submicro-, micro- and macro damage) [2].
Tribo-fatigue teaches methods for calculating the damage state of tribo-fatigue systems, and gives the analysis of their evolution in various external environments.
If the intense strained state characterizes the beginning of the life of the tribo-fatigue system, and the limiting state is the end, then its evolution describes the state of the damage, which changes during the movement of the loaded elements of the system relative to each other.
The research chain in tribo-fatigue (TF) has the form [2]:

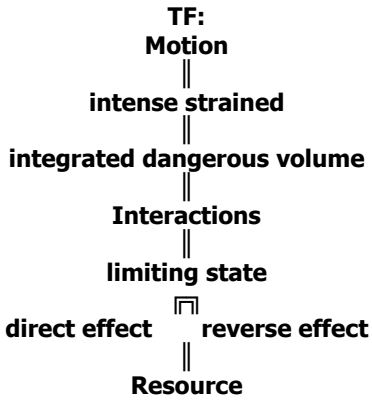

Figure 1. The chain of research in the tribo-fatigue

Apparently, the idea of the work is connected with the recognition of the multi-vector nature of the "conceptual transfer" in interdisciplinary projects - of the evolution of ideas and methods of cognition from the processing of "eternal enemies of machines" of fatigue and the embodiment in research practice and their backward ascension to a new stage of understanding tribo-fatigue. This active interdisciplinary partnership can provide modern mechanics with an active "anti-crisis" and even "rehabilitating" role. A concrete positive experience, a unique portfolio of mutually beneficial interdisciplinary cooperation will help mechanics convincingly demonstrate its heuristic activity.
It should be noted that its important role in interdisciplinary interaction of tribo-fatigue is able to play only if its disciplinary specifics are preserved, which requires not only talking about tribo-fatigue in the system of sciences, but also about the system of relations "tribo-fatigue-science". Organizing cross-disciplinary dialogue, tribo-fatigue should not dissolve in it; in a positivist manner it becomes a history of science.

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