DYNAMIC MONITORIZATION IN SLIP TRANSLATION CYCLIC MOVEMENT TRIBOSYSTEMS

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ABSTRACT

The paper approaches certain methodological aspects for the research of the tribomaterials in slip translation cyclic movement conditions. The variability of working parameters creates dynamic effects in the functioning tribosystem. The dynamic effect is manifested by the fluctuant oscillating evolutions of the tribosystem variables. The fluctuating nature of the friction forces and the contact processes impose the appropriate conditions when choosing the measurement systems. To record the friction forces, the signal fluctuation of a mechanical oscillator with an elastic element, forced by the tribosystem, is used. The result of the oscillator state analysis underlines the tribological properties of the material reaction on the dynamical influences in slip conditions.

Keywords: Tribosystem, tribomodel, dynamic, fluctuation, evolution

1. INTRODUCTION

The friction process includes mechanical, thermal, chemical, electrical and other phenomena. Having a dominant influence, the mechanical processes produce fluctuations causing the friction forces to lead to dynamic regimes in functioning of the tribosystems. The fluctuation of the friction force is due to a multitude of factors: the discrete structure of the real contact area, the elastic and plastic deformations in the contact area, the variation coefficient of friction due to the velocity relative difference of the physico-mechanical properties of the triboelements materials, the influence of different temperature and the temperature gradient on the material characteristics (including the lubricant) [4, 9]. The friction force impulses are generating noises in the triboelements as oscillations and elastic waves in a wide frequency range [2, 10]. The range of frequencies depends on the elastic characteristics of the materials, the form and the dimensions of the triboelements, the dissipation factors of the contact. The spectrum structure, the oscillation amplitude and the shape are influenced by the friction regime, the load parameters, the condition and the material properties of the triboelements and lubricant, the origin and the intensity of the

processes occurring in the contact [6]. The mechanical processes (elastic and plastic deformation) and the thermodynamic processes (phase transformations etc.) produce "stick-slip" oscillations accompanied by the vibration and noise in the acoustic range [5, 10].

The modern technical means and the new signal processing methodologies have created the conditions for the thorough research of the noise generated by the tribosystems. This research is aimed of several objectives including: the link between the oscillatory processes and the transformation processes in the tribolayer, the study the dynamic behavior and the rheological properties of the lubricants under boundary, determine the cause of the "stick-slip" movements and their scale under the boundary friction regime, determine the conditions for a dynamic stability and the critical values of the parameters for which the tribosystem loses its stability [1, 2, 6]. The dynamic nature of the friction process and the mechanical oscillations are the main causes of the structural and phase transformations of the materials tribolayer space, increased the plastic deformation and priming the reactions of mechanical-chemical origin, the temperature fluctuation in the contact area, the fragmentation and the surface layer wear, the contact surface seizure [3, 5, 8].

2. METHODOLOGICAL ASPECTS OF THE RESEARCH

The tribomaterial selection is a key issue in tribosystem designing. During the last decade we see and increase in both technology research and development of the tribomaterials and new generation additives. A new direction was established in the development of specific additives (friction geo-modificators) with coating effect on the friction surfaces. Contradictory results for a series of new generation materials and additives recently obtained on real operating tribosystems and on laboratory tribomodels, the raised problems of applied and fundamental interest. A number of issues are related to the research methodology and the diversity of the experimental models (used tribometers) and another part is related to the interpretation of the experimental data. Currently the experimental researches largely run on tribometers and classic research facilities, using traditional methodologies.

These tribometers have reduced sensitivity to the fluctuations in the contact process. In this situation it is necessary to raise the problem of the tribomodels modernization and the unification of the research methods, which must ensure: 1 – an adequate sensitivity to various fluctuations of the contact processes; 2 – a "step by step" monitoring of the contact state evolution; 3 - automated data acquisition and signal processing of the experimental dynamic variables, 4 – the identification of the evolution regime; 5 – the selection of the signal processing method for the system variables according to the evolution regime, established for each portion of the path, 6 – the presentation of the experimental data in an accessible format for its interpretation [7].

In order to improve the tribometer a mechanical oscillator with elastic element was used as a body sensitive to the fluctuations of friction forces.

The scheme of the tribometer test assembly is shown in Fig. 1, where the "fix triboelement" 1 together with the support 3 form the "m" mass of the oscillator. The mass "m", connected via the elastic system with the stiffness "c" is the oscillating part of the tribometer. The triboelement 2 is fixed on a mobile platform 4, which is
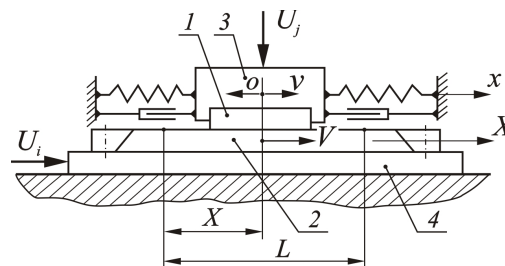

Fig. 1. The scheme of the test assembly

making a cyclic translation movement on the tangential direction *X,* according to the motion law (1):

$$X = X_0 \sin \omega t$$

$$V = -X_0 \omega \cos \omega t \tag{1}$$

where: X, V, - coordinates, the speed and cyclic frequency of the mobile triboelement 2 on the stroke L within the working cycle; $X_0 = L/2$.

Under the tribosystem friction forces, the oscillating part is making forced movements with small amplitude on the direction „*x*" with speed „*v*", to the equilibrium point. The oscillator motion is described by the dynamic equation (2),

$$m\frac{d^2x}{dt^2} + h\frac{dx}{dt} + cx = F(X, V, p, U)\operatorname{sign}(V - v) \tag{2}$$

where: m – the oscillator mass reduced to the gravity center "o"; x – coordinate and v=dx/dt – the speed of the gravity center of the oscillator (of the triboelement 1); h – the dissipation factor; F – the friction force in the tribosystem; p – the tribosystem parameters; U – the control parameters.

During tribomodel tests, the co-ordinates movements "x" to the equilibrium point of the oscillator and the speed "v" are subject to registration. The coordinate and the speed unequivocally establish the oscillator state in the given point of the trajectory of the tribosystem evolution of the. Thus, the studies of the oscillator evolution show the oscillator interactions evolution of the contact for each working cycle period of the triboelements material testing. The evolution of the oscillator movement depends on the impulse variation of the friction force caused by the friction regimes, the origin and the intensity of the contact processes, the particular characteristics of the tribosystem, etc. The oscillator parameters are chosen so that we can obtain a maximum sensitivity to the specific regimes of the contact evolution.

3. EXPERIMENTAL RESULTS

The following conditions were established for researches: the mass of the oscillator **m** = 0.2 kg; the stiffness of elastic element **c**=750 N/mm; the oscillator's natural frequency $_0$ = 62 s^{-1}; the cyclic frequency of the mobile triboelement = 300 min^{-1}; the contact loading – consecutive in steps; the lubrication – by continuous dripping; experimental temperature   in the contact area was measured with a **K** type mini thermocouple. The temperature in the contact area evolves at the expense of the heat released by the dissipation of mechanical energy. The contact form is plan/plan. The dimensions: along the direction of movement – 2 mm; along the direction perpendicular to the movement – 40 mm, the length of stroke **L**=100 mm.

The behavior of a series of tribomaterials was studied using this methodology, including lubricants and additives of different origins, coatings of metallic alloys and composites deposited on the steel surface, metal-polymer composite coatings, additives and friction modifiers with coating effect, mineral and synthetic origin engine oils of different brands.

The tests in sliding conditions of cyclic translation movement have highlighted a fluctuating evolution trend of the tribosystem's dynamic variables (mechanical and thermodynamic).

To achieve a tribosystem floating evolution, the following pair of materials is representative: for tribo-element 1 (Fig. 1.) – electrolytic chromium deposited on steel surface; for the triboelement 2 - steel 38 KH2MYUA (analogue of 41*CrAlMo7*) superficially plasticized on the friction surface with Cu. The contact lubrication was done

with oil for engines, type *VNIINP 50-1-4U* (*TU 38. 401-58-12-91*). In the course of the experiment, the state parameters of the oscillator (the coordinate and the speed) and temperature in contact area were step by step registered. The contact loading was executed until reaching the gripping state.

The fluctuating evolution was registered for specific loads of the contact. When reaching the given level of load dynamic and kinetic processes kick-off leading to structural transformations and degradation of the materials in the tribolayer space, thermo-dynamic phase transformations in the interposition environment, in the gap between the friction surfaces [5, 7, 8]. These processes result in fluctuations of the temperature and the mechanical condition of the oscillator. Each elementary fluctuation is "an irreversible step event" in the tribosystem's evolution and consists of two phases: the activation, followed by the relaxation phase.

The amplitude and the period of the temperature variation characterize the unfolding intensity of the processes and the energy dissipation in the contact. The oscillator state is an important source of information on the dynamic behavior of tribosystem.

The presentation modalities of the trajectory evolution oscillations in different coordinate allows for studying the characteristics of the dynamic contact processes both within the work cycle period (the default stroke L) and each sequence variation from cycle to cycle.
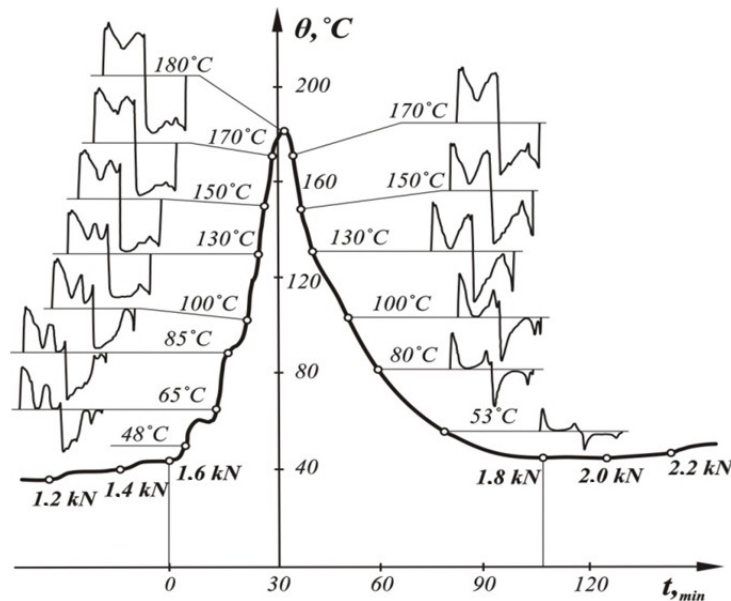
Fig. 2. The evolution of the temperature ^0C in the contact zone and the evolution of the oscillator within the cycle for the materials subject to load F_n=1.6 kN

The evolution in time of the experimental temperature signal fluctuation is presented in Fig. 2. The activation phase portions (left slope of the temperature fluctuation) contain processes accumulating the internal energy in the tribolayers spaces till reaching critical local values (the extreme point for =180°C) after which during the relaxation phase (the right slope) the material restructuring processes occur [1, 2]. As a result, the pair of tested materials at the end of the relaxation process acquires new stable tribological properties.

The energetic activation and the relaxation processes can be followed and specified using the evolution of the oscillator signal. The fluctuations of the oscillator signal are determined by the level, the duration, the intensity and the coordinate of the friction force

impulse occurring. Knowing the real values of the friction force characteristics allows the concretization of the internal dynamic processes tribosystem models.

The behavior of the oscillator in the cycle period shows the variable fluctuant and the ambiguous character of the interaction in the contact. In conditions of instability in the contact process, the fluctuations change their characteristics from cycle to cycle at the temperature variation in the contact zone. The variation of the oscillator signal is complicated and is different on the stages of activation and relaxation (Fig. 2).

Additional information can be obtained when presenting the oscillator signal (Figs. 3 and 4) in states' (phase) space, where: x – the coordinate of the mass center of the oscillator on the movement direction of the mobile triboelement 2 (Fig. 1); v – the speed of the mass center of the oscillator on the coordinate x; AB – the trajectory of the oscillator on the positive direction of the movement; CD – the oscillator trajectory on the negative direction (opposite) of the movement; DA - the return trajectory portion of the oscillator motion on the positive direction; BC – the return trajectory portion of the oscillator motion on the negative direction. The arrow indicates the movement direction on the trajectory.

The state phase space is investigating the following characteristics: the frequency, the state of motion and the energy of the oscillator on each point of the path of the evolution, the area included by the oscillator states for each cycle (the contact interaction states), the dynamic regimes during the tribosystem operation, the actuator form and the area in space during the tribosystem transition to the dynamic stability regime etc.

Figure 3 presents the oscillator evolutions in the states space within the working cycle, in the activation phase of the contact, with loading F_n=1.6 kN for the temperature points =(85^{0}C; 150^{0}C; 180^{0}C).

For all values of temperature, the states trajectories are situated asymmetrical in relation to the movement direction, which demonstrates the aperiodical character of the interactions in the contact. When the temperature rises in the contact zone, the space area of the trajectories is extended.

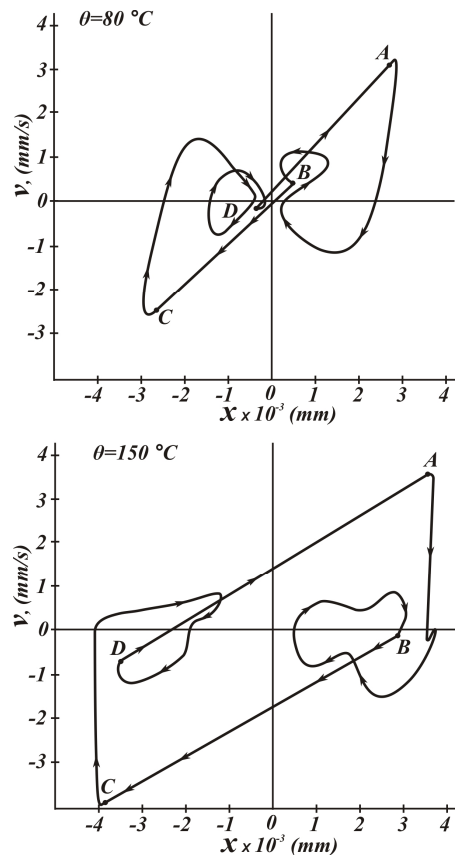The temperature growth and the extending of the trajectory are two processes
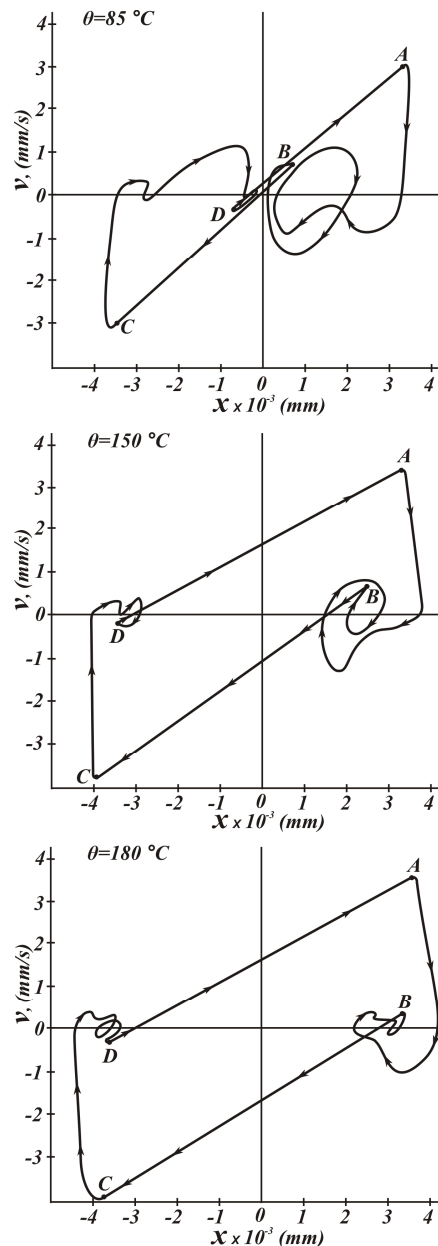
Fig. 3. The trajectories of the oscillator cycle in the states space during the temperature rise in the contact in the activation phase, for the values, = (85^{0}C; 150^{0}C, 180^{0}C) at loading level F_n=1.6 kN

that are influencing each other and characterize the energy dissipation intensity. The extension occurs till reaching a limit domain (point $= 18^0C$, Figs. 2 and 3), with maximal energy dissipation, where conditions are created for dynamic instability and restructuring, fragmentation and intensive degradation of the materials [2, 3, 5, 7, 8, 10]. On the relaxation phase (Fig. 2.), the energy dissipation intensity is reducing, the temperature in the contact zone is decreasing, and the area of the state trajectory (Fig. 4.) is converging to a symmetry limit. At the end of the relaxation period for temperature values $< 80^0C$, the trajectory is practically symmetrical (quasi-symmetrical). The following evolution of the tribosystem is characterized by periodical (quasi-periodical) processes with a stable dynamic regime.

The problem of assuring stability is a fundamental one for the tribosystems' functioning. Phenomena [4] that appear in contact during the relative movement of surfaces create the conditions for the realization of a complex of nonlinear processes, some of them being dominant, others - collateral. The reciprocal influence among the tribosystem's contact processes is accomplished via two groups of reverse internal links: positive and negative. The stability of the dynamic regime depends on the relation between these two types of links. In the case when the negative links predominate, evolution trajectories of the tribosystem converge into the domain of an attractor, in which stable regimes of functioning with periodic movements are realized. The destabilization occurs in the case when, under the influence of the external command parameters, the conditions of predominance for the reverse positive links are created in the contact area. In this situation, the evolution trajectories in the space of states (phases) abandon attractor's domain and expand non-linearly. At the transition through characteristic points (called bifurcation points) the direction of evolution trajectory becomes alternative and instable, whilst the tribosystem (implicitly, the contact processes) pass into a chaotic regime of movement [11].

Fig. 4. The trajectories of the oscillator cycle in the states space during the temperature fall in the contact zone in the relaxation phase, for the values $= (80^0C; 150^0C)$ at loading level $F_n=1.6$ kN

The functioning in this regime can be either temporary or catastrophic (intensive wear, gripping).

For the pair of specified above materials, as a results of the previous evolution at load $F_n=1.6$ kN, the tribosystem acquired a high level of stability, afterwards supporting high loads. At the load $F_n=3.0$ kN for a contact area temperature of $= 100^0C$, a new destabilization occurred (Fig. 5), the latest being characterized by spontaneous evolution with auto-oscillating movements [2, 10]. The fluctuations along the temperature evolution trajectory

contain a wide spectrum of frequencies and amplitudes with a positive trend. The tribosystem's functioning in such an instable regime during a long period of time can invoke the catastrophic phenomenon of contact surfaces' gripping. The study of gripping process conditions is of interest for force tribosystems under circumstances of boundary lubrication or in dry friction. In all cases of functioning in pregripping, the tribosystem's auto-oscillating processes become chaotic.

The gripping occurs spontaneously and non-deterministically. The analysis of oscillator's signals using informational methods of the processing constitutes a way to prognosticate the conditions of achieving the gripping phenomenon. The usage of methods of dynamic behavior study opens new possibilities for the research of grinding process, which represents an essential period in tribosystem's life.
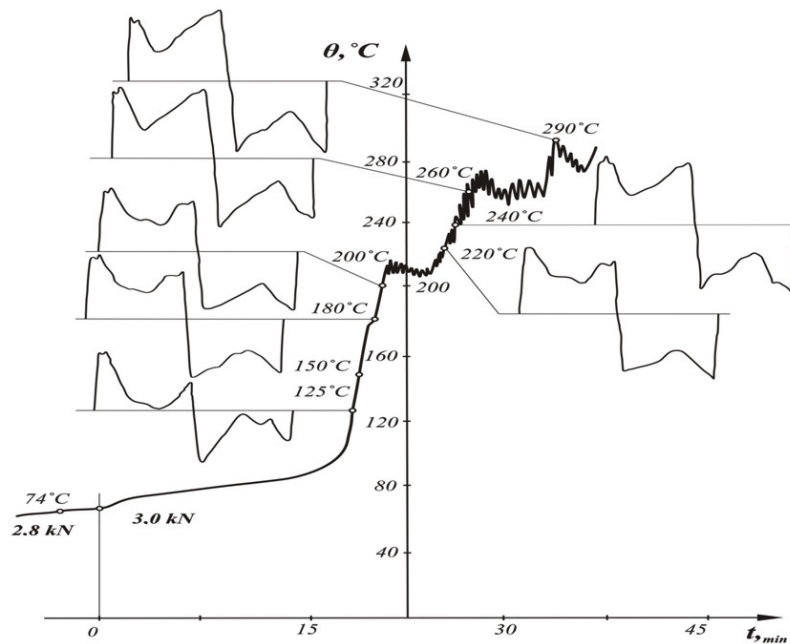
Fig. 5. The evolution of the temperature fluctuation ^{0}C in the contact zone and the evolution of the oscillator signal within the cycle, for the materials loaded with F_n=3.0 kN

4. CONCLUSION

The experimental data obtained on the basis of the tribomodel in sliding conditions at cyclic movement of translation have emphasized a dynamic floating behavior in the evolution of both friction force and contact processes for a series of tribomaterial couples.

For the analysis of the friction forces' fluctuations a tribometer with the sensing unit representing a mechanical oscillator with an elastic element is used, the latest being forced by the tribosystem.

It was determined that the interactions in contact have a variable nature, which influences the frictional properties of triboelements' materials under conditions of instability.

This research method can be extended for the study of the friction surfaces' gripping and the grinding processes.

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