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APPROBATION OF TRIBOMETER WITH SEPARATED INPUT AND OUTPUT SIGNALS IN INVESTIGATION EXTERNAL FRICTION DYNAMICS STEEL AND BRASS MATERIALS

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Abstract: *This investigation suggests a method used to determine the evolution of metallic wear and friction by sliding. The problem of external dynamics friction is investigated through the definition of the dynamic characteristics such as damping factor and natural frequency. Some certain automatic control methods were applied for sliding friction contact, including parametric identification, ARX simulation and Newton's dynamic equation. The suggested approach allows using amplitude-frequency characteristics to assess the dynamic factors (coefficients) under friction interaction. The research findings indicate that the proposed method allows monitoring the evolution of metallic wear and friction. The friction of steel moving over brass was taken as example.*

Keywords: *dynamic characteristics, friction interaction, input-output model, damping coefficient, cyclic movement.*

1. INTRODUCTION

In most practical friction systems, metal, fiber, composite alloys in sliding contact with metal alloys were need to predict faticulare changes. This problem can be implement by other ways, only some of them: vibration and noise controle, oil fouling and near friction area temperature inspection [1, 2].

However, the creation an accurate forecast based on friction model in present time is not simple task, due to the complexity of the processes occurring during frictional interaction [3–7]. In this work aims to study internal dynamics processes of evolution and determination of adaptive model in sliding contact.

Research friction units based on input-output model has been widely discussed. An important aspect of this approach is to find the damping and vibration properties for tribology system. Model input-output is used for handling of applied problems in automatic control theory. Using the identification process, the applying of equations with different grades allows to simulate various motions of interactions and even intermediate layers for 4 orders and higher [8–11].

2. FUNDAMENTAL PRINCIPLES OF INPUT-OUTPUT MOTION

Introduce system is convenient to consider from the perspective of input-output. Where are input parameters of dynamic characteristics – sliding speed, rolling velocity, force and pressure. Output parameters tribological system vibration and heating power dissipation. When the system is influenced, it is possible to trace the response of the system to external influences. The main consequences of the process – friction resistance, wear, generation of temperature at the friction surface, grip.

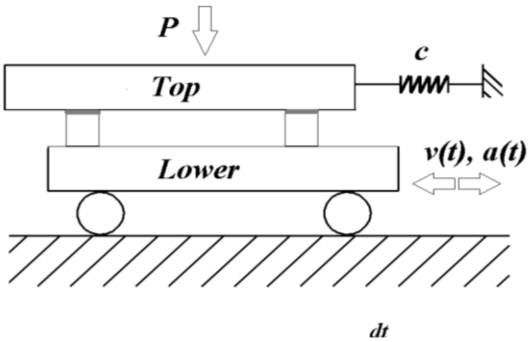

Figure. 1. Schematic diagram of the device operation and their components: *P* – loading, *c* – variable stiffness, *v*(*t*), *a*(*t*) – speed and acceleration of the given motion law

The result of the solution of the problem is the identification of the mathematical model presented in time or frequency domain. This model repeats adequate behaviour of the object.

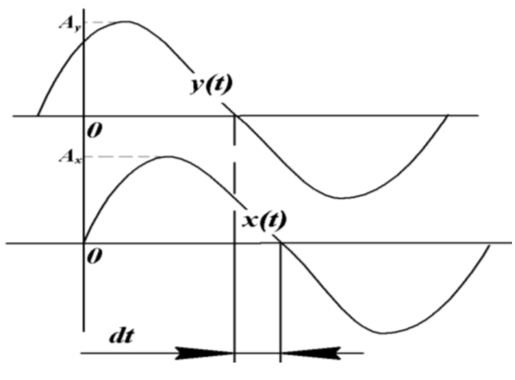

Figure. 2. The main mode of displacement curves, where *dt* is the phase shift, A_x, A_y are the oscillation amplitudes

Operating principle the "Tribal-T" device is shown in Fig. 1, realizing this concept, the device is intended for determining the friction coefficient, real-time process monitoring. The main difference from analogs of friction and wear consists from the free movement of the upper sample relative to lower.

On (Fig. 1, 2), the phase shift curve of the displacement curves is shown, the lower sample *x(t)* moves, the upper sample *y(t)* is delayed due to the spring elasticity and frictional forces affecting its movement. When the unit is operating in this mode, relative motion of the samples with characteristic sliding friction is observed [8].

2.1 Experimental apparatus

The experimental tribological complex "Tribal-T" (Fig. 3) for determining the tribological and mechanical properties of materials the idea of mutual measurement of displacements was realized. As an analogy was used device for rub testing, which was described in the inventor's certificate [12, 13].

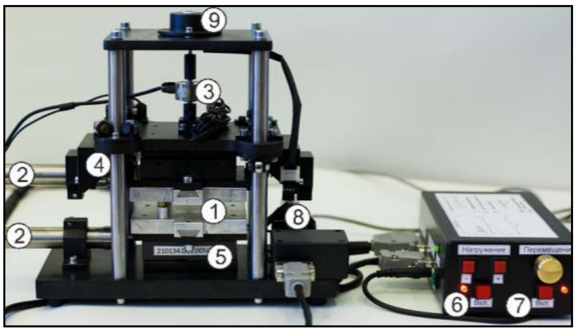

Figure 3. Appearance the "Tribal-T" tribometer and its main components

Lower specimens are in the cyclic reciprocating motion, driven by the external actuator. Upper specimens are in motion due to impact of frictional force. The tribometer is equipped by the displacement and pressure sensors, which allow tracking the absolute movement of specimens in the digital signals.

On Figure 3 shows main parts is *1* – specimens; *2* – displacement sensors; *3*, *4* – load sensors in normal and radial directions; *5* – precision roller slide tables; *6*, *7* – equipment control board of load and velocity; *8* – cyclic linear actuator; *9* – load actuator.

These measured signals are the inputs and outputs of the investigated system. The suggested approach provides by "Tribal-T" tribometer, which have a sliding contact and holders for investigated specimens (Fig. 4).

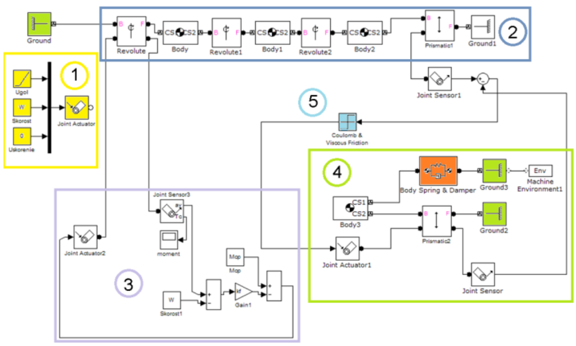

Figure 4. Simulink Dynamic model of Tribometer with block of variable viscous: *1* – angles, speeds and accelerate sensors; *2* – crank-slider mechanism used the upper linear slider; *3* – input force and speed impact for motion's law; *4* – crank-slider mechanism used of the lower linear slider; *5* – block of dry or viscous friction

2.2 Mathematical description of identification system

In the general case, the input and output signals of system "Tribal-T" can be described by differential equation [8, 14]. The n is equation order, parameters a_0, a_1 … a_n are selected based on the "input" (so-termed parametric identification), b_0, b_1 … b_n described "output", $x^{(n)} = d^n x/dt^n$ conditional upon $n > m$ are given:

$$a_0 x^{(n)} + a_1 x^{(n-1)} + \dots a_n x = \\ = b_0 y^{(m)} + b_1 y^{(m-1)} + \dots b_m y \qquad (1)$$

However, solution the equation starts with the account the order of differentiation, providing a physical interpretation. When $n = 2$ we get a differential equation of second order of motion:

$$\frac{d^2x}{dt^2} + 2n\frac{dx}{dt} + w_0^2 x = f(t) \qquad (2)$$

Where: x – the input value, $f(t)$ – the output value, n – damping coefficient, which characterize a environmental resistance, w_0 – free-running frequency. Stress forces are located in the right side of the equation, a system behavior to the external stress on the side of the measuring system – on the left.

Numerical solution of system (1) find in the state space model for the second order dynamic characteristics will be obtained. The solution to this loss is based on the nonlinear autoregressive exogenous model (ARX). The basis of a mathematical model of a multi-dimensional system in the time domain is a vector-matrix form of a first-order system of differential equations, which is called the equation of state. The equation of state and structure completely describe the control object, the state vector contains object variables that uniquely describe its state.

The friction state-space model of the "Tribal-T" [4]:

$$x(t+Ts) = A \cdot x(t) + B \cdot u(t) + K \cdot e(t), \\ y(t) = C \cdot x(t) + D \cdot u(t) + e(t) \qquad (3)$$

$$A = [2\times 2], B = [2\times 1], C = [1\times 2], \\ K = [2\times 1], x(0) = [2\times 1] \qquad (4)$$

Where: A – coefficient matrixs in state space; B – control coefficient matrix; C – coefficients matrix of the observer; K – noise matrix; $x(0)$ – initial condition; $Ke(t)$ and $e(t)$ – correlated stochastic processes. In the presence of stationarity, the matrix K selects an effective recursive Kalman filter [14].

3. EXPERIMENTAL APPROBATION AND DISCUSSION

This section presents the experimental approbation of mathematical primitive integral decision where input data it upper specimen's displacements and output lower specimen's displacements (Fig. 1). In sliding contact were studied specimen's from steel ShH15 (analogs: 1.3505, 100Cr6) and brass L90 (analogs: C22000, CuZn10). 10 samples with the same roughness (Ra 0.25) were prepared for the experiment.

Five tests were conducted at various time intervals: 30 min, 60 min, 90 min. Experiments were conducted in such a way that after each periodic interval of time, surface samples profiles were measured (Fig. 5). In each test series were recorded input $u(t)$ and output $y(t)$ data for the subsequent identification of the dynamical system [12].

In accordance with objectives of external dynamic, the following parameters have been found: *n* – damping factor, *w* – natural frequency. Figure 6 to display how changes in time periods damping factor and natural frequency. It may be noted, that under the experimental conditions of damping factors and frequencies of the natural vibrations are couple of competing parameters.

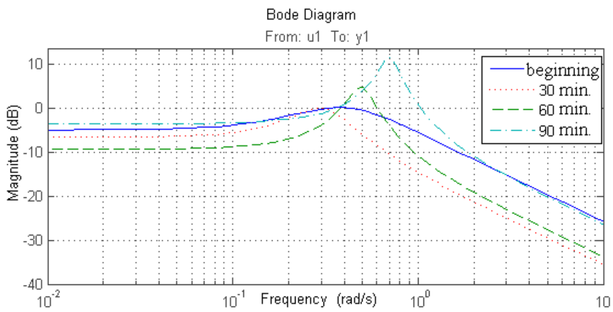

Figure 5. Bode diagram (amplitude characteristics) transfer functions at various time intervals as function of frequency: *1* – beginning, *2* – 30, *3* – 60, *4* – 90

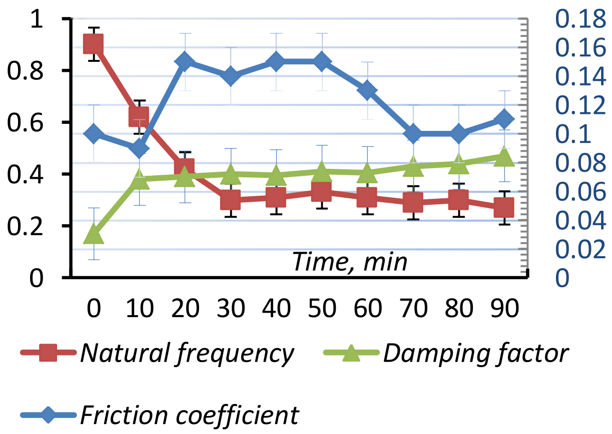

Figure 6. The diagrams show the variation in damping coefficient and natural vibration frequency (duration of the experiment 90 min)

This approach to the study of friction is useful in instrument making. In devices and mechanisms with moving parts made of brass and copper in contact with steel and metals. Reducing production costs for additional processing of rubbing surfaces can be eliminated knowing about the possibilities of self-working (self breaking-in) surfaces. The surface roughness at the level of Ra 0.25 corresponds to the finishing and semi-finishing milling or turning.

4. CONCLUSION

From the experiment, it is clear that the required breaking-in can occur in dry friction without additional effects. Over a period of time, the friction coefficient is aligned to a level of 0.12–0.1 and remains constant until the end of the experiment (Fig. 6).

The damping coefficient and the frequency of natural oscillations, respectively, tend to decrease in energy bursts in the contact. The system's damping increases and possible surges from surface geometry are reduced. The duration of the operation of such a friction pair in normal conditions can reach more than 5 000 Hours.

Further degradation of the contact will be associated with natural wear of the surfaces and a sharp violation of the geometry. The task of wear was not included in the scope of this work and will be considered further. Such a technique is not applicable for wear study, a variant of the experiment can be pin on disc of the installations in future experiment [10, 11].

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