Diagnostics – Experimental Analysis of Friction Pairs at Stick – Slip Sliding

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Abstract. The movement of parts of friction pairs with small quantities and displacements is the cause of the so-called stick-slip movement. This is due to the instability of the process of formation and destruction of adhesive contact between the surfaces. In this case, the lubricant has a decisive influence on the processes of friction in the contact. In this work, based on the diagnostic and experimental complex, the dependences of the magnitude of the friction force on displacements for various lubricants were obtained. Statistical characteristics of the scattering parameters of friction force are obtained to estimate the vibrations of a moving body. It is received that the dispersion of the friction force relative to the average value decreases with increasing load and with dry and lubricated contact. On the basis of the obtained experimental results, it is possible to establish some quantitative characteristics of such a movement: the number of oscillations (jumps) per unit of time; the average movement in a contact before a shift in a contact; the average resistance force in a contact before a shift. The correct selection of lubricant and loads ensures minimum values of vibrations of the friction units of machines. This consequently improves the positioning accuracy of the machines.

1 Introduction

With small movements in speed (10 ... 100 mm/min), movement with jumps is observed in translational friction pairs (stick-slip movement). This is typical for sliding friction in machine tools and instruments, sliders, presses and other machines. On the type of movement in this case, the magnitude of the friction force and its changes have a decisive influence. At low speeds, there is a transition from the forces of friction of a fixed body to the forces of friction of motion and vice versa. This is due to the instability of the process of formation and destruction of adhesive contact between the surfaces. As a result, the positioning accuracy of the machine components decreases, additional dynamic loads are created, failures occur and the wear rate of the machine parts increases. In this regard, the study of the processes of uniformity of movement and accuracy of the installation movements is given great importance. In this paper, we studied the characteristics of the frictional interaction of translational friction pairs with various types of lubrication of the contacting surfaces.

2 Literature review

The influence of friction mode on the nature of the motion of mechanical objects is studied in a number of articles. The paper [1] presents a demonstration of an oscillator with sliding friction that exhibits very good agreement with a linear fall off in amplitude. The demonstration also confirms that sliding friction is proportional to the magnitude of the normal force. The paper [2] introduces a more detailed friction model, one that explicitly

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considers deformation of and adhesion between surface asperities. Using probabilistic surface models for two nominally flat surfaces, the stick-slip model sums adhesive and deforming forces over all asperities. However, these studies do not take into account the damping properties of the lubricant. The lubricant has a decisive influence on the processes of friction and oscillations. In studies [3-4], methods for determining the parameters of sliding friction under damped oscillations are considered. Mathematical models and methods for identifying their parameters on the basis of experiments are proposed. The method of laboratory testing for friction has a great influence on the accuracy of the results of studying vibrations under friction. Works [5-6] propose various hardware (acoustic, electrical) to control the characteristics of sliding friction. These studies have a positive contribution to the study of the processes of friction, but they do not always determine the sufficient accuracy of the friction parameters. The result of friction on the law of motion is the accuracy of moving and positioning machine parts. In [7] the numerical simulations, the displacement of the moving part and the driving force of the controller are considered in cases of no friction, friction without stiction effect (sliding friction), and stick-slip friction. From these conditions, the influence of the friction on the sliding stability of the controller and the motion accuracy of the machine tool are analyzed and predicted. The study [8] gives an analysis of the basic friction models with tests and compares friction models in the literature: Coulomb friction model, Stribeck friction model, Dahl model, LuGre model, and the elastoplastic friction model on the same testbed. The experiments and models were done and the reasons for the difference in the basic of these models were investigated. Friction cannot be considered separately from modern surface engineering methods. The processes of friction depend on the properties of materials and coatings of the contacting bodies. In work [9] the influence of ionic nitriding on the processes of friction and wear under conditions of translational and swinging movement is considered. Resistance to wear of materials is also largely determined by friction processes. In work [10-12], the parameters of the friction process in the complex are presented in the model of wear proposed by the authors. The importance of laboratory and theoretical studies of friction parameters for practical applications follows from the literature review. For modern machines, friction is a necessary element that determines the accuracy of their operation. Thus, the study of friction processes requires more careful and detailed study.

3 Experimental equipment

For an experimental study of the friction force during the movement of a loaded plate on a lubricated and dry surface, the “LRX-E” model “Lloyd instruments” universal machine was used. The main characteristics of the testing machine are as follows:

Fig. 1. Testing machine LRX-E.

1. Maximum force: 2.5 kN.
2. Error measuring force: 0.005% of maximum value.
3. The limits of change of the speed of movement: 0.1 ... 1020 mm / min.
4. The amount of movement: 1 ... 1500 mm.
5. Error of measurement of movement <5.

The testing machine (fig. 1.) Is a laboratory computerized complex allowing to carry out various tests in the "force-displacement" format. In our case, it was configured to test for sliding friction in accordance with the international standard ASTM D1894. When testing, a steel, ground ($R_a = 1 \mu\text{m}$) plate 1 (Fig. 1.) measuring $63.5 \times 63.5 \text{ mm}^2$ and weighing 2N slid along the burnished surface of the table 2. The horizontal position of the table was controlled by level 6. The plate movement was carried out by means of tensile flexible filament 3 through block 4. The upper end of the thread was fixed in the grip 5. The grip 5 was fastened in the traverse and with the help of a screw was moved along the guide column. To measure the forces and displacements, a special strain gauge type LASERSCAN LR 01/2932 was used. The control of the testing process was carried out using the control panel 7 on the basis of a liquid crystal display. The software "Nexygen V4.5" and "Ondio V 4.5" was used to automate the test process with the specified parameters, automatically display the test results and statistical data processing. To study the friction force during the movement of a loaded plate on a flat surface, the following conditions were taken:

1. The speed of movement of the movable plate, mm/ min.
2. Distance of movement, mm.
3. Types of lubrication: 1-dry; 2- motor oil Formula Q8 (API- SJ/CD, SAE - 15W/40); 3-consistent oil Agip F1 CR MU3 (Castrol).
4. Loading mode: 1 – 2N; 2 - 7.5 N; 3 - 13.5 N.

4 Results and Discussion

The test results are presented in the graphs on fig. 2-4. Depending on the type of disturbing forces, the fluctuations of the friction force can be either deterministic (often periodic) or random. In our case, the reasons for the fluctuation of the friction force are the following: the random type of interaction of the roughness of the contacting surfaces (as a result, there is a random process of formation and destruction of frictional bonds between the surfaces); time dependence and different intensity of molecular adhesion forces (adhesion) between dry and lubricated surfaces; adhesive properties of lubricants; non-uniform distribution of the lubricant layer over the sample surface thickness. As a result, there is a stick-slip movement of a moving specimen (at relatively low sliding speeds) with random transitions from static friction to movement friction.

Fig. 2. Dependence of the friction force T on the displacement S during dry contact.

Fig. 3. Dependence of the friction force T on the displacement S with motor oil Formula Q8.

Fig. 4. Dependence of the friction force T on the displacement S with grease.

The friction force can take any value in a certain range. Therefore, the random process of friction force change should be characterized not by amplitude, frequency and phase, but by the mean value $\bar{T}$, standard deviation σ_T , coefficient of variation υ_T , minimum T_{min} and maximum values T_{max} and the range of change of the friction force ΔT .

To determine these characteristics, a statistical processing of the test results obtained on a testing machine was carried out. The results of statistical processing are shown in table 1.

Table 1. Statistical parameters of friction force changes.

Lubricant	Q, N	T_{min}, N	T_{max}, N	$\Delta T, N$	$\bar{T}, N$	σ_T, N	υ_T
Dry	2	0,08	0,4	0,32	0,24	0,078	0,325
	7,5	0,59	1,3	0,71	0,88	0,117	0,132
	13,5	1,63	2,27	0,64	1,9	0,14	0,073
Motor oil Formula Q8 (API- SJ/CD, SAE - 15W/40)	2	0,04	0,89	0,85	0,295	0,179	0,607
	7,5	0,26	2,25	1,98	0,9	0,508	0,564
	13,5	0,41	3,81	3,4	1,9	0,72	0,378
Agip F1 CR MU3 (Castrol)	2	0,6	2,4	1,8	1,28	0,293	0,229
	7,5	3,64	5,13	1,49	4,22	0,297	0,070
	13,5	4,42	5,49	1,07	4,92	0,27	0,055

An analysis of the results obtained by studying the friction force indicates the following. With a dry contact of the ground plate with the surface of the table, relatively low friction forces take place compared to even the lubricated contact. This can be explained by the low adhesion of the surface of the steel plate to the surface of the table, covered with a layer of protective oxide film.

When the plate moves along the motor oil layer, the friction force in comparison with the dry contact should decrease, but the results suggest that it is approximately at the same level as in the case of dry friction. Obviously, this is due to the additional resistance to movement due to the high adhesion of the lubricant to the surfaces at low sliding speeds. This effect is even more pronounced with the grease.

The dispersion of the friction force relative to the average value decreases with increasing load and with dry and lubricated contact. This is due to the increase hardness in contact with increasing load.

Stick-slip change in friction force is associated with the transition from friction of non-mobility to friction of motion. On the basis of the obtained experimental results, it is possible to establish some quantitative characteristics of such a movement: the number of oscillations (jumps) per unit of time ν_c ; the average movement in a contact before a shift in a contact s_c ; the average resistance force in a contact before a shift T_c . As a result of the graph analysis of fig 2 - 4, the following numerical values of these characteristics are established (Table 2).

The analysis of the obtained results shows that the greatest frequency of friction force oscillations occurs during dry contact. In this case, weak adhesion forces act and changes in the friction force are repeated more often than for contact with a lubricant. When using a lubricant, a large force is required to shift the contact layer and a correspondingly longer time for shear is required. Plastic lubricants at the same time have the best damping properties, since jumps of friction during their use are performed with the least frequency. However, the coefficient of friction is quite large (up to 0.5) due to the high adhesive properties of greases.

Table 2. Characteristics of the hardness of the contact layer for moving loaded plate.

Lubricant	Q, N	ν_c, sec^{-1}	$s_c, \mu m$	T_c, N
Dry	2	5,3	156	0,15
	7,5	7,7	109	0,26
	13,5	7,4	114	0,29
Motor oil Formula Q8 (API- SJ/CD, SAE - 15W/40)	2	2,9	286	0,28
	7,5	4,1	204	0,84
	13,5	4	208	0,97
Agip F1 CR MU3 (Castrol)	2	2,9	285	0,36
	7,5	2	417	0,57
	13,5	2,1	400	0,45

The obtained results of the quantitative analysis of the stick-slip movement with various lubricants are recommended for practical use in industry. The correct selection of lubricant and loads ensures minimum values of vibrations of the friction units of machines. This consequently improves the positioning accuracy of the machines.

5 Conclusions

On the basis of the laboratory diagnostic complex “LRX-E”, studies of the characteristics of friction during movement with a low speed of the loaded plate on the working surface in the presence of lubrication were carried out. As a result of processing the experimental

data, statistical characteristics of the friction parameters were obtained, which characterize the effect on them of the load and lubrication mode. The quantitative characteristics of the plate motion, which characterize the deformation properties of the contact layer, are established.

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