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Simulation of transient friction modes of fluoroplastic seals in hydraulic piston pumps

V.V. Alisin[1*]

[1] Mechanical Engineering Research Institute of the Russian Academy of Sciences, 101000 Moscow, Russia

Abstract. The article considers the issues associated with the friction of radiation-hardened fluoroplastic on steel in a hydraulic fluid environment during the transition period at the beginning of movement. The friction coefficients are studied when starting from a standstill, at the beginning and in steady motion. Changes in the value of the friction coefficient and changes in the amplitude of oscillation of the friction moment are analyzed. Particular attention is paid to the influence of the restart of motion in a friction coupling. Quantitative relationships of tribological properties are established depending on the time of relative sliding of the samples. It is noted that the friction coefficients in different modes are differ a lot, however, the running-in process proceeds quickly and in the practice of operating hydraulic devices, the running-in process of fluoroplastic seals can be ignored

1 Introduction

Hydraulic fluid leaks from a piston hydraulic pump depend on the proper operation of the O-ring on the piston. Wear of the friction surfaces of the cylinder rod seal is the main cause of leakage [1,2] in an aircraft hydraulic drive. Polymers are mainly used to seal hydraulic rods [3, 4]. PTFE is one of the promising sealing materials. The piston moves back and forth, so the seal operates with the sliding speed of the contacting surfaces varying in magnitude and direction. The most severe seal operating conditions occur in transient modes. The physical nature of friction in the seal-piston contact is very complex, because there is a transition from boundary friction to the hydrodynamic friction regime, when the direction of the velocity vector changes. Much attention is paid to studies of the performance of friction couplings in transient sliding regimes. It was noted in [5] that the reason for the difficulty of predicting the friction properties of friction couplings is the time-varying contact characteristics, which are analyzed on the basis of simulating transient processes, and the effectiveness of the model is verified by bench tests. It is shown that the indicators for assessing the non-uniform friction coefficient and contact stiffness obey a normal distribution. Transient friction characteristics under conditions of hydrodynamic effects during the operation of mechanical seals with chevron-shaped grooves at the start and stop stages were studied in [6]. It is proposed to determine the fluid throughput depending on the change in torque. The influence of groove

* Corresponding author: vva-imash@yandex.ru

shape on thermal effects during friction has been studied. In [7], the friction characteristics of a friction pair were studied by simulating the transient process and the dynamics of the friction unit, using the example of a free-running coupling operation. In [8], the influence of nanostructures of composite materials on the mechanical characteristics of materials and energy absorption in the surface layer during friction was studied. It has been established that taking into account surface effects allows one to increase the energy absorption capacity by 28%. In [9], under transient conditions, the sliding of surfaces in contact between a steel ball and the plane of a glass disk was studied. The difference in the friction coefficient under various experimental conditions is associated with different film thicknesses and shapes, as well as thermal effects. Analytical methods are used to analyze the operation of friction couplings in transient modes. In [10], using the finite element method, a two-dimensional nonlinear transient thermomechanical model of a friction material sliding on a steel disk was studied. The work took into account the influence of the coefficient of thermal expansion on the thermomechanical instability of friction linings. It is shown in [11] that during the process of heat release in the contact of rubbing surfaces, the temperatures on the surface can reach a critical value for a friction couple. Therefore, it is necessary to study the development of thermal parameters characterizing sliding surfaces. The proposed research methodology is based on the analysis of heat flow, heat flow distribution coefficient and thermal contact resistance. A simulation model was developed [12] based on the numerical solution of the generalized Reynolds equation and includes models of cavitation with mass conservation, non-Newtonian flow, mixed friction and microfluidics. The proposed model examines the friction coefficient and film thickness of point contacts in steady-state and transient conditions. In [13], a model of non-stationary thermomechanical contact of two sliding bodies with rough surfaces was developed. The influence of load on the stress distribution and temperature distribution for heat sources of arbitrary shape and time-dependent is studied. An effective strengthening technology for improving the mechanical properties of fluoroplastic is radiation treatment [14]. There are few experimental studies of the sliding friction of fluoroplastic on steel in the hydraulic fluids environment.

The purpose of the work is to determine the antifriction properties of fluoroplastic during friction against steel in a hydraulic fluid environment under transient conditions from static to a steady-state sliding mode.

2 Materials

The friction couple is made of radiation-modified fluoroplastic Ф-4PM, obtained by thermoradiation treatment of fluoroplastic with ionizing gamma radiation according to technology [15], and steel 40X. The stationary sample is made of fluoroplastic Ф-4PM in the shape of a disk. The sample-counterbody is made of steel in the shape of a ring (Fig. x); as a result of rotation, its end surface rubs along the plane of the stationary sample (Fig. 1). Hydraulic fluid AMг-10 (GOST 6794-2017) was chosen as the working fluid.

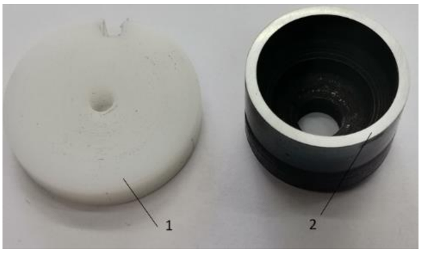

Fig. 1. Photos of samples: 1 - stationary sample made of Ф-4PM; 2 – rotating sample made of steel 40X

3 Equipment and technologies

Tribological tests were carried out on a MACT-1 friction machine, which was subjected to deep modernization, including a drive, a system for shaft speed regulating and monitoring, a loading device, and means for registration and recording the friction moment. The tests were carried out according to the adjustment method [16].

4 Results

To carry out tests using the plane-ring end friction scheme, the friction unit of the MACT -1 machine was modernized. Figure 2 shows a diagram of the testing machine friction unit.

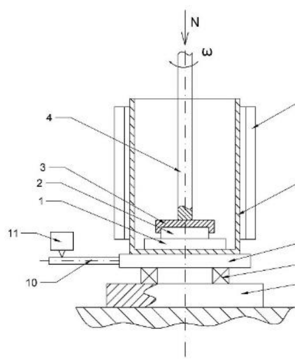

Fig. 2. Friction unit diagram

A friction couple consisting of a stationary sample 1 and a rotating sample 2, which is installed in a holder 3 mounted on a shaft 4. The assembly of samples 1 and 2 is placed inside a cup 5, which is installed on a platform 6, mounted with the possibility of rotation on balls 7 and resting on a base 8. The cup is filled with the testing liquid. Heater 9 provides the required liquid temperature under the experimental conditions.

The normal load on the friction couple is carried out by a lever loading device, the shaft rotation is carried out by an adjustable electric drive (not shown in the diagram). The friction moment is measured using a lever 10 mounted on the platform 6, which exerts force pressure on the meter 11 under the influence of friction forces. The experiments were carried out at normal temperature under conditions of contact pressure and sliding speed specific for the operation of the plunger seal of an axial piston pump.

The start of pump operation is the most difficult mode, during which the friction surface runs in and the tribological characteristics of the friction couple are stabilized. In accordance with the accepted testing methodology, only the starting moment of the friction machine was studied. The duration of each test is about 1 minute. The tests were carried out under a normal load on the friction couple of 350 H and a sliding speed of 2.5 m/s. The experiments were carried out in the following sequence. The samples are loaded with normal force before the drive is turned on. Fig. 3. shows the friction moment recording oscillograms for the fluoroplastic-steel couple in the initial state.

To assess the vibration background in experiment No. 6, the friction machine was started before loading the samples with normal force, which made it possible to record the vibration effects on the recorded characteristics of tribological properties. Figure 4 shows an oscillogram of the friction moment recording after the 6th repetition of the friction machine starting.

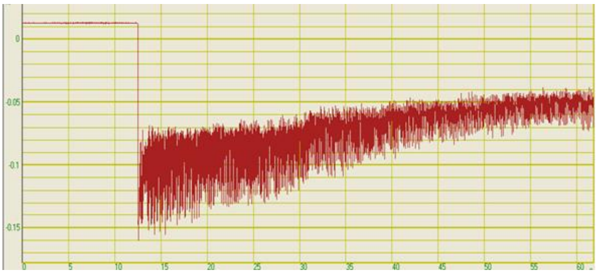

Fig. 3. Friction moment oscillogram of the first experiment

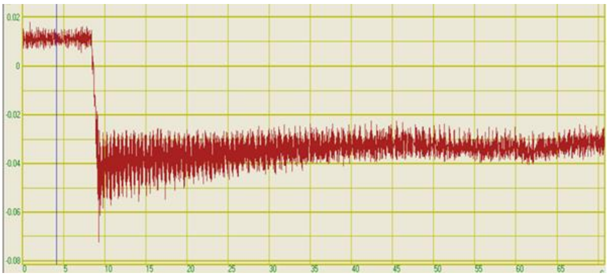

Fig.4. Friction moment oscillogram of the 6th experiment

As a result of the experiments performed, a steady decrease in the friction coefficient is observed as the surfaces are run in. Due to the heterogeneity of the contact because of its discreteness, external factors and vibrations, a leveling of the friction moment is observed. The initial and final friction moments were determined from the oscillograms (Table 1).

Table 1. Friction coefficients in the transient mode of steel sliding over fluoroplastic in the hydraulic fluid environment AMr 10 at p = 2 MPa, V = 2.5 m/s.

Start no.	f, static friction	f_0	f_k
1	0.062	0.042	0.023
2	0.057	0.031	0.022
6	0.031	0.020	0.016

Considering the morphology of the running-in process, we note a smooth decrease in the amplitude of oscillations in the friction moment recording readings (Fig. 5).

The quantitative tribological properties of the fluoroplastic-steel friction couple in the transient mode in a hydraulic fluid environment are very different. The starting friction coefficient decreases with running-in when motion starts, namely by 2 times, in comparison with the first start from 0.062 to 0.31 in the sixth start; the friction coefficient at the beginning of motion is 0.042, then decreases to 0.021; in steady state, the friction coefficients are very close and tend to 0.02. The oscillation amplitude of the friction moment decreases to the value of the vibration background.

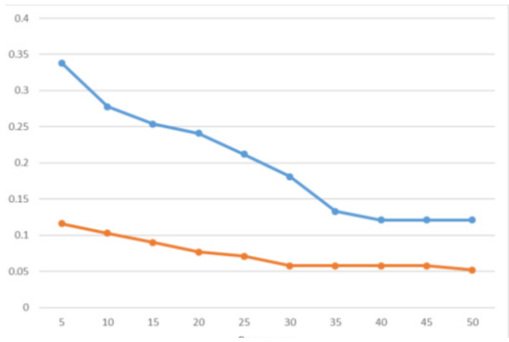

Fig. 5. The influence of sliding time on the friction force oscillations amplitude.

5 Conclusion

In relation to the fluoroplastic-steel friction couple, the process of running-in and approaching the equilibrium state according to the antifriction criterion (friction coefficient) is characterized by a significant decrease in the friction coefficient, however, it is fast process, therefore, in the practice of operating hydraulic devices containing fluoroplastic seals, the running-in period can be ignored.

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