Friction of fluoroplastic with steel in a hydraulic fluid medium when transient mode

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Abstract. The article considers the issues of experimental research of the antifriction properties of fluoroplastic seals of piston pump hydraulic systems in a transient friction mode. The statement about the influence of frictional heating on the tribological properties of the seal is substantiated. Model experiments are used to study the friction coefficients at the moment of changing the direction of the contacting surfaces movement and the transient period from the moment of starting from a standstill to the steady-state friction mode. The experiments were carried out under conditions of heating the hydraulic fluid to the maximum temperature. Particular attention is paid to the change in the friction coefficient with increasing load-speed characteristics. The limiting contact pressures that ensure trouble-free operation of a seal made of radiation-modified fluoroplastic have been determined.

1 Introduction

Leaks from pumps mainly determine the service life and reliability of hydraulic systems. Leaks are affected by seals, which are made of elastomers and thermoplastics. The reason for the pressure drop in the hydraulic system is wear and deterioration of the mechanical properties of the seal material affected by temperature. The most intensive wear of seals occurs in the transient mode due to the hydrodynamic friction abnormality. A lot of attention is paid to issues of seal performance. In [1], the reasons for a seal failure made of thermosetting polyurethane material were investigated. It was found that the temperature at the friction surface, resulting from heating from the frictional forces in the seal zone, was responsible for the seal failure. In [2], a study of failure modes and various parameters affecting the performance of seals was carried out, noted the need to improve the design of elastomeric seals, especially for applications under high pressure and at high temperatures. In [3], the seal of a pump in a reactor cooling system at a nuclear power plant was studied. It was established that the cause of seal failure was severe swelling caused by exposure to a hydrocarbon-organic medium during operation. In [4], the influence of friction modes on the formation of an oil film in contact was analyzed. Discrepancies between the theory of hydrodynamic lubrication and empirically measured film thickness are discussed. In [5], a model of mixed lubrication and wear of a seal operating under conditions of reciprocating

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motion and heat sources from the friction force of the seal is considered. It was shown that there is a significant change in the friction coefficient depending on the temperature. In [6], the efficiency of elastomeric seals of hydraulic rods during reciprocating motion is assessed theoretically from the point of view of mass leakage per cycle and friction work. A method is proposed for constructing maps of sealing characteristics based on a certain operating parameter to select optimal values of seal pressure and travel speed. The work [7] numerically analyzes the influence of the axial position of the contact zone on the sealing properties of seals with various forms of texture. In [8], a numerical model of elastohydrodynamics in contact (polymer or elastomer) seals, most often found in reciprocating hydraulic drives, is considered. A complete solution for analyzing the performance of a hydraulic machine is obtained. Life testing of seals is a very lengthy and expensive process. To carry out accelerated tests, the effect of solid abrasive particles on wear was studied in [9]. The use of abrasive particles has been shown to effectively speed up long-term testing of hydraulic pumps. In [10], the process a hydraulic seal failure under conditions of reciprocating motion was experimentally studied. The experimental data is monitored by a fiber pressure sensor and a friction sensor. A method for determining the parameters of deterioration of seal performance characteristics is proposed. A reliability prediction model has been created that can describe the process of performance degradation. [11] investigated a synthetic rubber seal with good heat resistance. Fatigue experiments were performed on samples at a temperature of 120°C, which is the average operating temperature, the promise of this sealing material has been demonstrated. The work [12] describes a processing technique of noise signals arising from friction to predict the tribological properties of polymers over a wide temperature range. It is shown that the method satisfactorily predicts the friction coefficients of various polymer-metal couplings in a wide temperature range according to tribological tests and can be used to monitor tribological properties. The work [13] notes that understanding the mechanisms of seal failure can increase the operational reliability and service life of the seal, the wear of which leads to the loss of mechanical and chemical seal properties. In [14], the efficiency of plasma treatment of filler fibers in a tetrafluoroethylene medium on the structure, mechanical and tribological properties of the fiber composite was studied. It has been established that fiber processing increases the density of the composite, heat resistance, mechanical strength and improves its tribological characteristics. Promising sealing materials include fluoroplastic. Interest in fluoroplastic-based materials is explained by their unique anti-friction properties. The mechanical characteristics of fluoroplastic can be improved by radiation treatment [15, 16]. PTFE seals are used in pumps operating in hydraulic fluids and their performance depends on temperature and load. However, there are few studies of the antifriction properties of the strengthened fluoroplastic seal during friction against steel, especially in transient conditions.

The purpose of the work is to study the friction coefficients of fluoroplastic in the transient mode of friction on steel in the AMГ-10 hydraulic fluid medium in the starting mode under conditions of maximum operating temperature and to study the effect on the friction coefficient of additional frictional heating at sliding speeds in the range of 1 - 3 m/s.

### 2 Materials

The sample is made of fluoroplastic Φ-4PM, strengthened by thermoradiation treatment of fluoroplastic with gamma radiation according to technology [15], the counterbody sample is made of 40X steel. Hydraulic fluid AMg-10 (GOST 6794-2017) is a working medium.
3 Equipment and technologies

The modernized tribometer MACT-1 (Figure 1), which implements friction of the end of a rotating steel sample along the plane of a stationary fluoroplastic sample.

Fig. 1. Tribometer diagram: 1, 2 – samples; 3 – holder; 4 – shaft; 5 – cup with hydraulic fluid; 6 – platform; 7 – thrust ball bearing; 8 – base; 9 – heater; 10 – lever; 11 – force sensor.

In accordance with the test methodology, samples installed in a cup with hydraulic fluid were loaded with normal force, the cup with fluid was heated to 90 °C - the maximum temperature of the AMr-10 fluid (flash point 93 °C), the shaft was rotated and the friction moment was recorded. For this purpose, a lever is installed on the holder of the lower steel disk, which bumps into the strain sensor. When the upper sample holder rotates, the moment of resistance to rotation using a lever is transferred to the strain sensor. The frictional moment and temperature are recorded using strain sensors ZET 7111 Tensometer CAN. Data is transmitted digitally via the CAN 2.0 interface using the Modbus protocol.

The hardness of fluoroplastic was determined using a kinetic microhardness tester MNT_Z_AE_000 from CSM Instruments in accordance with the ISO/DIS 14577_1:2002 standard.

4 Results and discussion

The physical and mechanical properties of polymers depend on temperature. Figure 2 shows a diagram of the indentation of a Vickers indenter into a radiation-modified fluoroplastic at the test temperature (90 °C).
It has been experimentally established that the hardness of radiation-modified fluoroplastic (480 MPa) is approximately 2 times greater than before hardening treatment.

Tribological tests were carried out in the tribometer start-up mode with recording of the frictional moment before reaching steady conditions. In the process of friction of the fluoroplastic seal of a hydraulic pump cylinder cavity with the reciprocating motion of the piston, the most intense wear occurs at the moment the velocity vector changes, when the speed decreases to zero and a transition from the hydrodynamic friction mode to boundary friction occurs. When starting from rest the coefficient of friction is greater than when moving. The friction coefficient in hydrodynamic mode is much less than in boundary friction. The work of friction forces is directly proportional to the speed of relative sliding in contact between the seal and the cylinder; the higher the speed, the stronger the heating. The limiting operating conditions for the temperature of the friction unit become very sensitive for the seal material to additional heating of the contacting surfaces, which affects the antifriction properties. Figure 3 shows the dependence of the friction coefficient when starting from rest on the speed when sliding under load in a hydraulic fluid medium.

At sliding speeds less than 1.5 m/s, the sliding speed has virtually no effect on the friction coefficient, the absolute value of which is determined by the rate of the applied load. This
behavior of the friction coefficient indicates that the amount of heat from frictional heating is small to significantly affect the physicochemical processes occurring in the actual contact zones during surface friction. In the speed range of 1.5 – 2 m/s, the friction coefficient increases due to thermal destruction of the fluid film. In the speed range of 2 – 2.5 m/s, the process of destruction of the separating friction surface film has ended and stabilization of the friction coefficient is observed. After increasing the speed to more than 2.5 m/s, a significant reduction in the friction coefficient begins due to a decrease of the fluoroplastic hardness. After the transition to steady motion, the friction process stabilizes. Figure 4 shows the effect of normal contact pressure on the coefficient of friction during steady motion at minimum (1 m/s) and maximum (3 m/s) sliding speeds in the friction couple test speed range.

![Figure 4](https://example.com/figure4.png)

**Fig. 4.** Effect of contact pressure on the friction coefficient of fluoroplastic on steel under steady motion conditions.

It can be noted that the graph lines for different speeds are located very close to equidistance. Therefore, in practical terms, we can assume that in the tested speed range, a change in the sliding speed of fluoroplastic on steel has very little effect on the friction coefficient in a steady friction condition. No visible (at a magnification of $\times 10^5$) structural changes were detected in the material. The surface of fluoroplastic consists of randomly located colonies of crystallites. During the friction of fluoroplastic samples under different loads, no changes in the structure were found. Figure 5 shows the dependence of fluoroplastic friction coefficient on contact pressure when sliding on 40X steel in a hydraulic fluid medium.
Fig. 5. Effect of contact pressure on fluoroplastic friction coefficient at a speed of 3 m/s.

Taking into account that there are no noticeable changes in the structure of fluoroplastic, the steady decrease in the friction coefficient with increasing contact pressure can be explained by the stability of the shear strength of molecular bonds in the area of the friction pair actual contact, therefore, with increasing load, the friction coefficient decreases.

5 Conclusion

A study of the antifriction properties of reactionally modified fluoroplastic during friction in the transient mode on steel in a hydraulic fluid medium showed that under conditions of extreme temperature of the hydraulic fluid, a significant (up to 10 times) increasing of the friction coefficient is possible due to frictional heating of the friction surface.

To prevent emergency failures due to the trend of increasing the speed of axial piston pumps in hydraulic systems, at the design stage it is advisable to introduce control over the increase in heat generation from frictional heating of the seals.

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