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Investigation of physical properties of magnetic liquids in alternating and constant magnetic fields

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Abstract. The physical properties of magnetic fluids (hereinafter - MF) of three types are investigated: on the basis of mineral oil; silicone (silicone) liquid PES-5 and organic-fluorine compounds. The influence of the change in the MF physical properties at the moment of friction in the "shaft-bushing" coupling is determined, depending on the magnetic field induction (alternating magnetic field) and the shaft rotation frequency. The values of the breakdown pressure of magnetic fluids in the gap "shaft-pole tip" are determined at a constant magnetic field (permanent magnet), depending on the shaft rotation frequency as well as the time factor. To assess the MF stability, a stability factor that is capable of taking into account the structural changes in MF over time has been proposed.

1. Introduction

Magnetic fluids refer to new technical materials, and their use in the design of structures and technologies provides further technical progress. MF is a suspension of fine magnetic particles in carrier fluids. Such MFs are macroscopically homogeneous, do not stratify in magnetic and gravitational fields for an unlimited time. In comparison with ordinary liquids, MFs have strong magnetic properties, which made them a promising material for technical applications [1]. The MFs physical properties depend on the magnetic field characteristics and can vary over a wide range. Virtually all MFs contain particles up to 0.01 μm in size as ferromagnetic microparticles.

Most MFs belong to non-conducting media. In this case, the mechanisms of the effect of the superimposed magnetic field on the MF are related only to its own magnetic moment, which appears in the external field. Quite often, the interaction of a field with a magnetized liquid can be attributed to a quasi-stationary one, when the time for the establishment of the equilibrium value of the magnetization is much less than any macroscopic time. MFs are used to lubricate friction pairs that function both under hydrodynamic and boundary lubrication [2], and in some nodes of technical devices, the MF can perform two functions simultaneously: sealing and lubricating working surfaces [3, 4]. The physical properties of MFs are essential in solving the problem of the appropriateness of using MF as a sealing and lubricating material in the design of various technical devices.

2. Materials, methods, research results

In most magnetic-fluid devices, the MFs are constantly exposed to a magnetic field. That is why the stability of magnetic fluids in permanent and alternating magnetic fields is one of the most important factors determining the possibility of their practical use and service life [5].

To study the physical properties, three MF types were chosen, differing in the composition of the carrier fluids:

MF-17 – based on mineral oil;

MF-20 – based on silicone liquid PES-5;

MF-31 – based on organofluorine compounds.

One of the most important parameters of the magnetic-fluid devices is friction torque M_f , which affects the values of the transmitted moments and power. At the time of friction $M_{f,}$ a magnetic-fluid device used affects the viscosity of the magnetic fluid, the magnetic field gradient of the shear rate in the working gap of the device; the size of the working gap includes the surface roughness values of components in contact with the magnetic liquid [6].

The research of the MF physical properties and their influence on the friction moment M_f in coupling "shaft - bushing", depending on the magnetic field B induction (alternating magnetic field) and the shaft speed, was conducted in a pilot plant [7] according to the test scheme shown in Fig. 1.

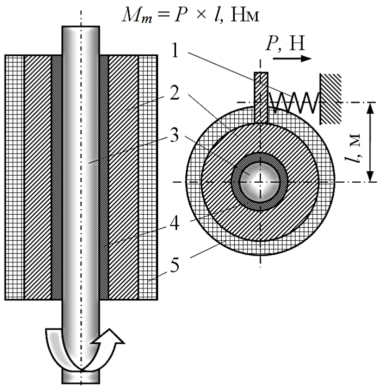

Figure1. Test scheme**:** 1 –catch mechanism; 2 – busing; 3 – shaft; 4 – examined MF; 5 – solenoid

Investigations of the MF (Figure 1, item 4) located in the "shaft-bushing" gap and held by the magnetic field produced by the solenoid (Figure 1, position 5) were carried out with the following geometric dimensions of the parts in the ranges of the values of the variable parameters:

– a shaft with a diameter $d_{shaft} = 16 \pm 0{,}05$ mm, made of 45 steel, GOST 1050-88;

– a bushing with an internal diameter d_{bush} = 18 0.05 mm, made of MZ copper, GOST 859-78;

– shaft rotational speed n_{shaft} = (0 ... 2800) min-^{1};

– magnetic field induction B = (0…1,0) T;

– a friction unit temperature T = (20…30) ^{0}C.

Studies on the determination of frictional moment M_f depending on shaft speed 3 in bushing 2 (see Figure 1) of the bearing assembly for the three types of magnetic liquids after mathematical processing are shown in Fig. 2.

Studies have shown a tendency to reduce the friction torque for the MF on average to (0.02 ... 0.04) Nm in the range of low rotational speeds of the bearing assembly shaft (of the order of 400 to 800 rpm^{-1}) with a constant magnetic field induction B = 0.6 T .

With an increase in the shaft rotation frequency, the friction torque increases, which is associated with a change in the MF structural components. However, the value of the frictional moment for a magnetic fluid based on mineral oil MF-17 is slightly lower than that of MF-20 and MF-31. This characterizes the fact that when operating friction units with MF-17 power losses will be less than with MF-20 and MF-31.

The effect of magnetic field induction at the moment of friction in the pilot plant bearing assembly filled with the MF under a constant shaft rotation frequency is shown in Fig. 3.

With an increase in the magnetic field induction from 0.2 to 1.0 T at a constant shaft rotation frequency of 800 min-^{1}, a smooth increase in the frictional torque on average from 0.03 to 0.09 Nm is observed for all three types of magnetic fluids. Such an increase in the frictional moment is explained by a change in the viscosity of the MF with an increase in the magnetic field induction.

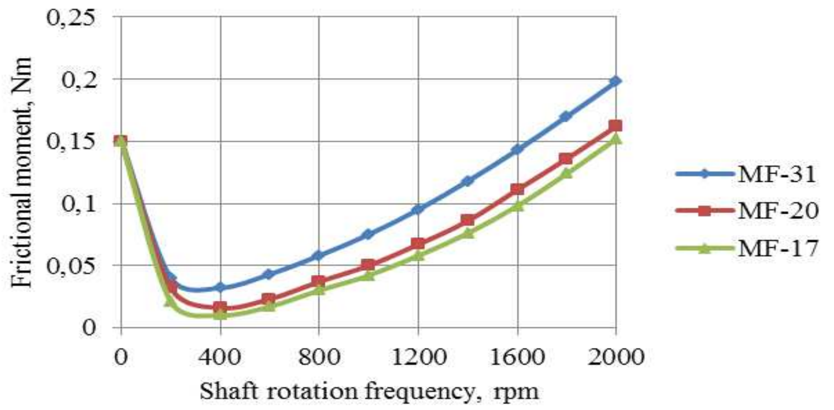

Figure 2. The frictional moment at a constant magnetic field induction B = 0,6 T

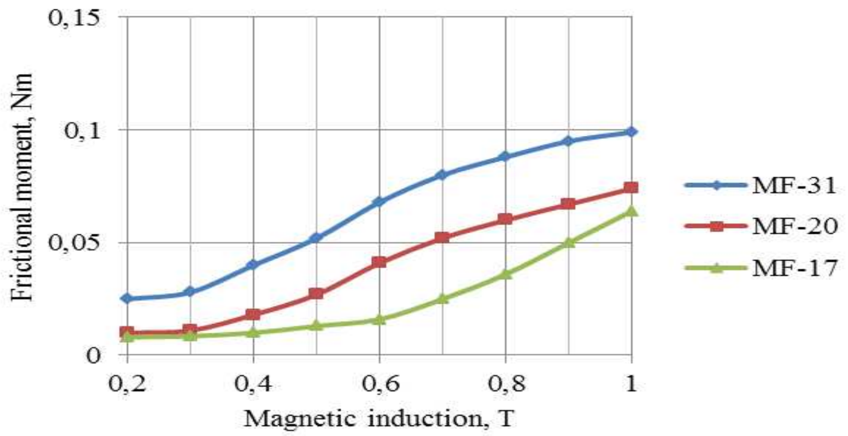

Figure.3. The frictional moment at a constant shaft rotation speed, n = 800 min^{-1}

Studies have shown that MF-17 based on mineral oil has better lubricity, as well as lower dynamic viscosity, than MF-20 and MF-31. Therefore, MF-17, unlike MF-20 and MF-31, can be used in technical devices at higher shaft speeds since it has lower viscosity under the same conditions and will have less frictional losses.

Investigation of the sealing properties of MF (breakdown pressure) in the "shaft-pole tip" gap with a constant magnetic field (permanent magnet), depending on the shaft rotation frequency and the breakdown pressure was carried out using the bench [7] according to the test scheme shown in Fig. 4.

To check the tightness of the magnetic-fluid seals of a single-pole version, studies of MF prototypes were carried out using a test bench.

The MF sealing capacity, depending on the sealing time, was determined as follows:

– MF was applied to the gap of the upper single-shank and lower five-shank poles;

– the breakdown pressure magnitude was determined in static and dynamic (with a stationary and rotating shaft) mode by crimping with liquid nitrogen at intervals of 38 times for 366 hours.

The stability coefficient was taken as the criterion for estimating the MF stability, which was calculated by the formula:

$$K^{t}_{stab} = \frac{P_{max} - P_t}{P_t}100, \tag{1}$$

where P_{max} – maximum breakdown pressure (breakdown pressure fixed after 30 minutes of testing), MPa; P_t – breakdown pressure (pressure after test time *t*), MPa.

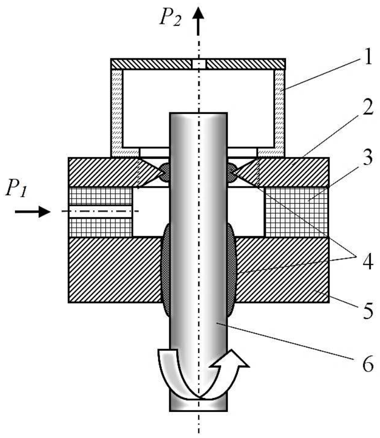

Figure 4. Test scheme**:** 1 – glass case; 2 – one-shank polar tip; 3 – magnet; 4 –MF; 5 –five-shank polar tip; 6 – shaft

The stability coefficient was determined after 366 hours of operation of the examined MF.
The results of the MF tests are presented in Table. 1.

Table 1. Test results

Sealing and lubricating material	Index		
	Maximum breakdown pressure я P_{max}, (after 0.5 hours of operation), MPa), MPa	Breakdown pressure $P_{t=366h}$, (after 366 hours of operation), MPa	The stability coefficient (after 366 hours of operation) $K^{366}_{stab} = \frac{P_{max} - P_{t=366}}{P_{t=366}} 100$
MF-17	0.0570	0.0566	0.7
MF-20	0.0631	0.0578	9.1
MF-31	0.0442	0.0398	11.1

MF can be recommended for use if its stability factor does not exceed 5% at the end of the test. Histograms of the change in the MF stability factor in comparison with the standard index are shown in Fig. 5.

3. Discussion of results

Since all MFs consist of three main components: surfactant (molecule), dispersed medium (liquid-carrier) and dispersed phase (solid particles) [8], the impact mechanism of the superimposed magnetic field on the MF is due to its structure. The magnetic field produced by the solenoid affects the dispersed phase solid particles, making them rotate, or vice versa, slowing down their rotation. The particles transmit this effect to the adjacent layers of the carrier fluid. Further, due to viscous friction it spreads along the liquid phase. Obviously, the forced fluid flow, in turn, can also affect the interaction of the field and particles [9].

MF, in contrast to traditional lubricants, contains highly magnetic dispersed particles. The energy of these particles in the magnetic field is comparable to thermal energy. Therefore, in an alternating magnetic field, particle redistribution over the volume of a substance is possible [10].

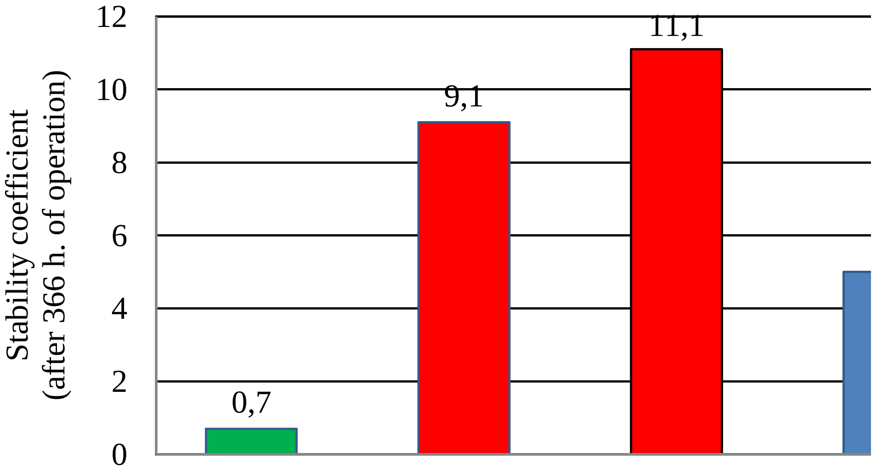

Figure 5. Histograms of the MF stability coefficient change in comparison with the standard index

The ability of MF to ensure the integrity of technical devices is determined not only by its properties, but also by its aggregate composition. The sealing capacity of a magnetic lubricant, which is under the action of a magnetic field, can be estimated with the help of stability factor value, comparing it with standard values.

4. Conclusions

1. The frictional moment for all types of magnetic fluids under investigation is optimal in the range of changes in shaft rotation frequencies from 400 to 1200 min^{-1} and magnetic field induction from 0.2 to 0.6 T. Under such conditions, the friction torque varies from 0.02 to 0.15 Nm and does not cause significant changes in the structure of magnetic fluids, as well as power losses with increasing MF dynamic viscosity.

2. The stability coefficient of the examined MF does not correspond to the standard value, except for MF-17. This means that in the course of operation these lubricants can lose stability (do not ensure the friction unit integrity and even coagulate) when operating, below the set values.

3. Magnetic liquid MF-17, consisting of a magnet (18%), iron carbonyl (16%) and mineral oil, has a high resistance to time factor and can be used in technical devices as a lubricating-sealing material.

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