Tribological Aspects of Electrosensitive Lubricant Usage

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Received 27 December 2007; accepted 10 February 2008

The possibility of usage of electrosensitive lubricant in the transition processes at interaction of junctions with oxide-ceramic coatings is investigated. This lubricant allows changing the coefficient of sliding friction and provides effective governing of tribotechnical characteristics of rubbing junctions due to controlled change of rheological properties of a lubricant in elastic hydrodynamic contact. The contents of lubricants are developed and their viscoplastic properties at changing such factors as applied electric field, the type of composition components are investigated. The sliding friction coefficients are evaluated.
Keywords: electrosensitive lubricants, electric field, tribotechnical characteristics, viscoplastic properties, sliding friction.

INTRODUCTION

At interacting friction junctions in technological equipment, working nonstop at stationary regimes of loading in the conditions of liquid sliding friction, the most intensive wear of working surfaces of bearings and supports of sliding appears at stopping and launching the gear drive. In these periods the hydrodynamic component of the thickness of a lubricant layer decreases. Friction of the boundary lubrication and even in some cases dry friction appears in some parts that lead to a drastic increase of wear of friction junctions and to accelerated loss of efficiency of bearing sites and of the unit on the whole. This problem is of a great importance for expensive and unique equipment. One of the ways of solving it is to use lubricants with special antifriction reducers, and also lubricants possessing higher viscosity.

The using of wear-resisting oxide-ceramic coating is also possible. It allows to enlarge essentially friction junction longevity in comparison with chemical-thermal fastened alloyed steel coatings in the conditions of liquid sliding friction [1 – 4]. However, the friction coefficient shortly increases (up to 0.3 – 0.45 in dependence on specific contact phenomena) at the transition to friction of boundary lubrication and dry friction regimes. The significant overheating, oxide-ceramic coating destruction and capacity for work loss of bearings and supports of sliding may arise in this case.

The increase of viscosity of the lubricant materials allows shortening the duration of unfavorable for the bearing site period of interaction of friction junctions in the condition of friction of boundary lubrication but it also leads to big losses on friction and additional power inputs.

One of the ways to solve this problem is to use lubricant materials with governed, in particular, by the external electric [5] and magnetic [6] fields rheological properties, that allows to provide viscosity needed for liquid friction adaptive to the conditions of the loading interaction of the contacting interfaces of bearings and sliding supports.

The aim of our investigation is to develop compositions of viscoplastic electrorheological fluids (ERF), which could be used as adaptive lubricants. The most important parameter, which characterizes these lubricants, is the fluidity limit τ_0, the value, of which determines the thickness of a lubricant, divides the areas of elastic and plastic deformation and determines the conditions for launching a gear drive. The electric field heightens significantly τ_0 of such fluids. After switching the electric field off the medium completely returns to the initial stage.

THE FLUIDITY LIMIT OF LUBRICANTS

Compounds of plastic electrosensitive lubricants contain high dispersive silicon dioxide – aerosil – a pure nonporous SiO_2, which is characterized by high dispersion, homogeneity of the particle sizes and big specific surface – from 150 m^2/g up to 450 m^2/g. The particle sizes are from 5 nm up to 40 nm (generally 10 nm – 15 nm). Except SiO_2 (99.8 %), it consists of aluminum, titanium, boron, iron and other oxides. The activator was polyethylenepolyamine (PEPA), which has a much higher sensitivity than the compounds according to the well-known research. Besides, this amine has not a big volatility, which is important for practical application. As the dispersed medium motor oils, such as Mobil-1 SAE 5W-50, Castrol GTX3, PES-5, and transform oil were used.

The measuring method of the fluidity limit τ_0 is based on the determining minimum torque, which enough to fix plastic deformation [7]. The measuring of the fluidity limit of electrorheological lubricants lies in the formation of a sample deformation, linearly changing in time, in measuring the shear stress in the sample and its change in the conditions of electric field impact [7, 8]. The working site of the device represents a measuring system disk-disk,

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used for application of electric potential. Such geometry of a measuring site allows to create a homogeneous electric field and to set accurately a value of the measuring slot which corresponds to the conditions of further mechanical lubricant property tests, as the value of the measuring slot could be thousand fraction of a millimeter. In this very site a plastic flow develops at certain deformation values and a certain intensity of electric field.

The measuring was carried out on the Vibrorheometer VR-74 (SDO IPCS, Moscow), used for the investigation of anomalous viscous and viscoelastic fluids at nonstop deformation at constant speed and cyclic deformation with different frequencies and amplitudes. In the regime of nonstop deformation the measuring was done at constant speed of change of deformation (0.1 rad/min, in the range of turning angles φ 0 rad – 0.06 rad, that corresponds to the range of changing of relative deformation ε, equal to 0 % – 500 %) at temperature (25 ±1) °C. The slot between disks was 0.2 mm. The range of changing electric voltage was 0 V – 500 V, that corresponds to the intensity of electric field 0 kV/mm – 2.5 kV/mm in the measuring site.

13 samples of ERF were prepared and investigated, the dependencies of durability limit on the composition and the value of the voltage applied were determined. The compositions of ERF are submitted in Table 1.

Table 1. The composition of ER lubricants

Sample No.	Aerosil, %	PEPA, %	MOG, %	Oil
1	30	20	20	Transform oil
2	30	20	10	
3	35	20	10	
4	40	20	20	
5	45	20	30	
6	30	10	20	
7	30	10	10	
8	35	20	10	PES-5
9	30	20	10	
10	30	20	20	Castrol GTX3
11	30	20	10	
12	35	20	10	Mobil-1 SAE 5W-50
13	35	20	–	

In Fig. 1 a typical dependence of shear stress on the deformation applied for the one of samples is shown. It can be conditionally divided into three areas: rectilinear that describes elastic deformation, then nonlinear that characteri-zes the developing of plastic deformation, the third area characterizes viscoplastic flow. From Fig. 1 it is seen that with an increase of intensity the nonlinear area broadens. The value τ_0 corresponds to the maximum value of the shear stress on the dependence $\tau(\varepsilon)$. The higher intensity of the applied electric field is the bigger value of τ_0.

LUBRICANT CHARACTERISTICS

Two samples of ER suspensions have been chosen to determine exploitation characteristics of the lubricants. In Table 2 the results of ER lubricant tests are presented. The compositions developed by us absolutely correspond to the requirements, made to the industrious lubricants.

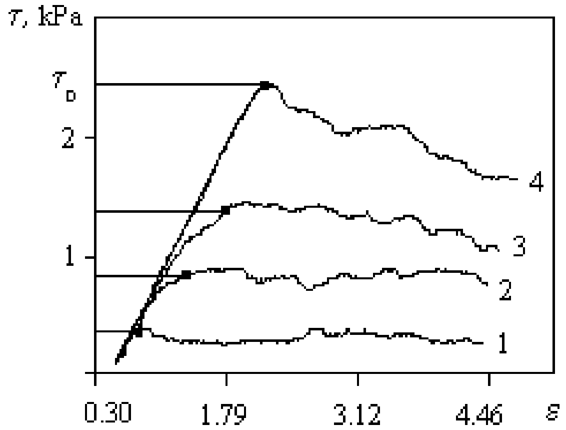

Fig. 1. The dependence of shear stress on the deformation applied for a sample No. 3: 1 – U = 0 V; 2 – 125 V; 3 – 250 V; 4 – 500 V

Table 2. The results of the electrorheological lubricant tests

Sample number	1	2
Colloidal stability, % of the oil released	2.8	3.5
Drop falling temperature, °C	120	118
Penetration at 25 °C with mixing, mm^{-1}	215	230
Viscosity, Pa·s at 20 °C and mean deformation speed gradient 10 s^{-1}	630	540
Mean diameter of a wearing spot, mm (determining critical loading (P_c) on the four ball friction machine), critical loading, H = 1235	0.65	0.65
Mean diameter of a wearing spot, mm (determining welding loading (P_w) on the four ball friction machine), welding loading, H = 1960	1.35	1.48
Fin index $I_f = \Sigma Q/n$ (determined on the four ball friction machine)	78.19	67.67

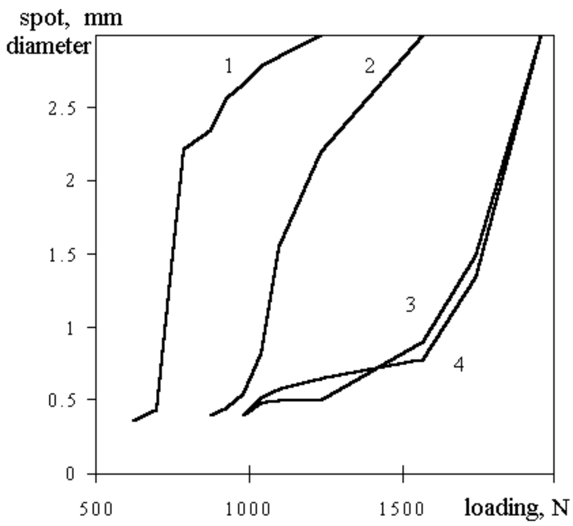

Fig. 2. Loading curves for the samples of lubricants: 1 – litol-24; 2 – Mobil-1 SAE 5W-50; 3, 4 – ER-lubricants

A loading curve (Fig. 2) has been received on the four ball friction machine. At the identical loading the mean diameter of the wearing spot of the developed electrorheological lubricants is smaller, than for a lithol and pure oil Mobil-1.

The main problem of the investigation was the experimental attempt to evaluate the possibilities of governing tribotechnological characteristics of friction junctions with oxide-ceramics coatings using electrically manageable rheological fluid for their lubrication [9]. Cylindrical samples with a plain periphery working surface and a counter body in the form of a plate, made of deformed aluminum alloy D16 were used as for friction pair under investigation (Fig. 3). Oxide-ceramics coatings with the thickness of 90 μm – 120 μm, that have hardness changing in depth over the range of 12 GPa – 16 GPa were formed on the interacting surfaces of the samples and counter body in the electrolyte of the alkaline type by the anode-cathode way.

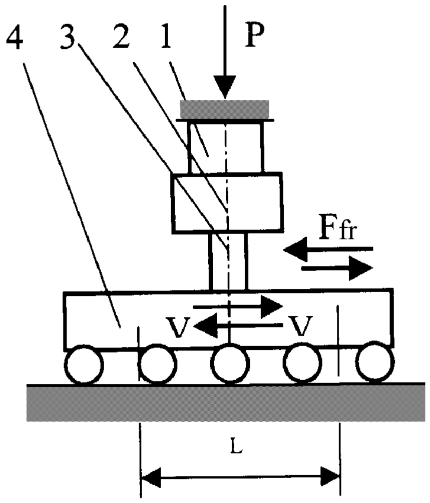

Fig. 3. The investigation scheme for a research of tribotechnical characteristics of sample interaction in the regime of sliding friction: 1 – friction force sensor; 2 – the hold for samples investigated; 3 – samples investigated; 4 – the counterbody; F_{fr} – a friction force; L – the length of the sliding path at reciprocal motion of a counterbody; V – sliding speed

Estimating friction coefficients was carried out in the modified friction machine with the plain parallel scheme of realization of interaction between the samples in the regime of sliding friction, staffed with microprocessed system of reading and preliminary processing of diagnostic information. As periphery sensor of friction forces, high sensitive tensormeter element was used, that allows fixing momentary values of a friction force.

During investigation the sample and the counter body were electrically isolated from the friction machine and measurement equipment by means of special rigging. The investigation was carried out at room temperature and ambient humidity. Reading of information about momentary values of the friction coefficients was made in automotive regime

In the scheme used the sliding speed of the object relative to the counter body increased smoothly according to the sinusoidal law from zero up to maximal value. Then it decreased smoothly to the full stop and the movement reversed; contact pressures after working out the given number of cycles increased stepwise from 0.5 MPa to 3.2 MPa.

In the lubrication layer voltages changing from zero up to 1200 V were created. As early as 1180 V – 1220 V substantial leaked current appeared which increased extensively at the following increase of the voltage. On the whole, at doing research leaked current was not higher than some milliamperes and power losses bounded with it were small, not more then some watts. Estimations of the results received had comparative nature – the ratio of friction coefficient in the lubricant layer with and without intensity was found experimentally out.

The change of the coefficients of the sliding friction and k_{fE} at the increase of the voltage of the electric field applied to the lubrication layer is shown in the Fig. 4, a, b.

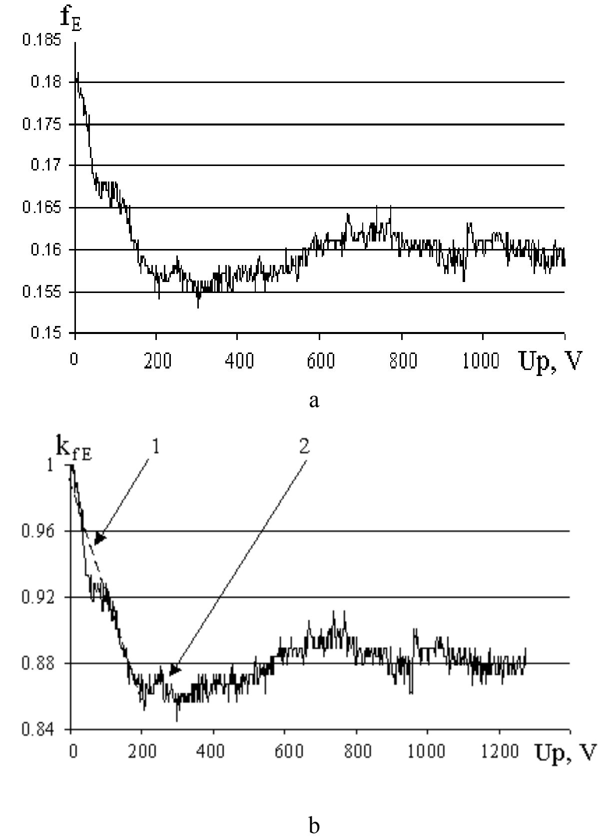

Fig. 4. The change of experimentally received mean maximal values of the friction coefficients at the increase of the intensity of electric field (a) and the coefficient k_{fE} – ratio of the coefficient of the sliding friction with electric field in the lubrication layer to the coefficient of the sliding friction without electric field (b), calculated (1) and experimental (2)

The analysis of the results received has shown the following. With an increase of the intensity of electric field mean values of the coefficients of friction decrease to a certain level after and smaller increase stabilize in a certain range of values (Fig. 4). This can be explained be the fact that with an increase of the viscosity the thickness of the lubrication layer increases and the friction of boundary lubrication converts into liquid friction, that leads to a change of the interaction nature of the friction junction and the decrease of friction coefficient.

Simultaneously with this the growth of the tractive resistance takes place, which is linked with the change of viscosity of ERF that should lead to the increase of the friction coefficient; and the forces of disjoining pressure appear, typical to the electrorheological interaction of the contacting surfaces with oxide-ceramics coatings [9]. More over the increase of the thickness of the lubrication layer leads to a decrease of intensity of electric field applied to ERF. Thus, the influence of the increase of electric tension between contacting surfaces with oxide-ceramics coatings affects nonlinearly on the changes of the friction coefficients and the thicknesses of the lubrication layer. In this connection at its certain values the values of friction coefficients and thicknesses of lubrication layers establish on a certain level and further do not increase.

CONCLUSIONS

The use of ERF on the basis of mineral oil as the lubricant material for friction junction with oxide-ceramics coatings on the contacting surfaces leads to the reversible change of the coefficient of the sliding friction, that allows to provide effective governing of the tribotechnological characteristics of friction junctions due to controlled change of rheological properties of the lubricant in the elastic-hydrodynamic contact. At this the most rational range of electric voltages applied to the contacting surfaces exists. The smaller values of voltage do not provide the accelerated transition from the friction of boundary lubrication to the liquid friction in initial moment of motion, and the biggest values lead to the increase of viscosity of ERF and, consequently, friction coefficient growth. This range is determined by the properties of ERF and the roughness of the contacting surfaces. For the sample discussed it is equal to 120V – 150 V.

The results obtained have shown, that the realization of the suggested way allows creating the rubbing junctions of expensive and unique objects with manageable tribological characteristics. Also it results in heightening their longevity.

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Presented at the 3rd International Conference "Mechatronic Systems and Materials'2007" (Kaunas, Lithuania, 27 – 29 September, 2007)