tribosystem, lubrication, functional additives

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FUNCTIONAL ADDITIVES FOR LUBRICANTS OF MOTOR-AXIAL BEARINGS OF LOCOMOTIVES

Summary. In article possibility of increase in a resource of work of motor-axial bearings of locomotives is considered by quality improvement of lubricants at introduction in their structure of functional additives

ФУНКЦИОНАЛЬНЫЕ ПРИСАДКИ ДЛЯ СМАЗОЧНЫХ МАТЕРИАЛОВ МОТОРНО-ОСЕВЫХ ПОДШИПНИКОВ ЛОКОМОТИВОВ

Аннотация. В статье рассматривается возможность увеличения ресурса работы моторно-осевых подшипников локомотивов путем повышением качества смазочных материалов при введении в их состав функциональных присадок

1. INTRODUCTION

Share of refusals of friction units of rolling stock reaches 85%, therefore a problem of increasing of trib coupling reliability including motor-axial bearings (MAB), is paramount value. Practically design of MAB had no changes during many years. Their fragility caused by rapid deterioration of the suspension babbit layer of liners and weak removal of heat from the friction, due to low antifriction properties of lubricating materials (LM). Substantially prolongation of a resource of these bearings can be provided by improvement of quality of LM through introducing functional additives in their structure. Alongside with high lubricant quality, the developed LM have such qualities as simplicity, low cost, availability of synthesis of additives, ease of introduction in an oil basis, and also ecological safety.

2. ADSORPTION OF GETEROPOLIPHOSPHATES OF ALKALINE METALS ON IRON SURFACE

It is known, that steady downturn of factor of friction under influence of greasing basically is determined by adsorption or chemisorption interaction of a lubricant layer with surfaces of friction, therefore lubricant compositions should contain the components actively participating in adsorption processes at the tribocoupling. Thus, at lubrication it is necessary to create steady layers between the friction surfaces which prevent the convergence of the friction surfaces and can significantly reduce the friction force and wear. It is obvious that such processes can be directly connected with adsorption or chemical interaction of LM molecules with friction surfaces.

It is advisable to search additives for LM among the inorganic materials, for example, phosphorus-containing polymers, capable to be both in crystal and in the amorphous state, differing thermal and chemical resistance, high complexion ability, the extraordinary diversity of structure and properties. We carried out researches on the application of geteropoliphosphates - inorganic polymer additives, functioning at high temperatures and well compatible with oil the basis of [1].

Molecules of these compounds, obtained by the crystallization of the melt, have a cyclic form of alternating blocks, including phosphorus and molybdenum. By using IR spectroscopy and chromatographic methods [2] it was confirmed that compounds $LiPMoO_6$ and $NaPMoO_6$ are cyclical phosphoromolibdates, anionic structure of which is formed from phosphate and molibdate fragments of bridges P-O-Mo. A characteristic feature of the phosphoromolibdates and most of polyphosphates [3, 4] is belonging to the lowest crystalline structures and the ability, depending on the conditions, to be in crystalline or amorphous (glassy) state, or form nanoparticles [5, 6]. The characteristic properties allows one to change properties of compounds which can be used as additives to LM.

Phosphoromolibdates of Li and Na are thermo and moisture stable in a wide range of temperatures. They are inert to action of oxidants and other aggressive substances and also have the ability to make reversible transition from plastics into the linear structure [7]. This property allows polymeric phosphates to be adapted structurally to the relief of the surface of frictional contact on a nanosized level.

Changes in the structure of molecules of geteropoliphosphates, occuring on the surface of metal, were studied by us by means of the software package ADF [8], based on the density functional theory. It is set by the method of IR spectroscopy, and it is confirmed by the quantum-chemical calculations that in a friction process there is a transformation of cyclic structure into linear and fastening of last on a metal surface by the groups containing both atoms of phosphorus, and molybdenum with equal probability [9, 10]. It means that the geteropoliphosphate cycles on a metal surface are opened and transformed into linear chains. As shown by the experimental data, such a process is accompanied by smoothing of ledges of micro roughness, increase of the area of actual contact and the formation of a smooth surface.

Appearance of linear forms of the geteropoliphosphates of alkaline metals on the surface of iron is fundamentally important for the applicability of these compounds as additives to lubricants. The length of the link **P-O-Mo** (half-chain) in the molecules of geteropoliphosphates is equal to 3,53 Å or 3.47 Å, it differs significantly from the typical distances in the unit cell of the crystal α-iron (the cell parameter is 2,87 Å) [9]. This fact suggests that the linear chain cannot be pulled out on the surface of iron and form with it strong chemical bond along the entire axis. The chain is chemically attached to the surface by one end, containing the **P-O** bond. There is energy of about 6 eV is allocated, that testifies to high durability of connection of a chain with a surface. The rest of the chain interacts with the surface by Coulomb or Van der Waals forces. In the case of high concentrations of geteropoliphosphates the chain position becomes perpendicular to the surface that allows a durable coating of the surface to be formed (Fig. 1). Interaction of terminal fragment of linear chain with a model cluster consisting of 13 iron atoms minimizes the total energy of the system, provided that the molecular axis is normal to the surface.

The external ends of chains interacting with grease provide ultimately smooth sliding of a rider along the iron surface with small factor of friction. Under "heavy" conditions of friction, when energy of mechanical or thermal influence exceeds energy of chemical connections, the whole molecules dissociate into separate fragments and there is a chemical adsorption of these fragments on a surface of iron.

On the basis of quantum-chemical analysis it is possible to assume, that geteropoliphosphates of alkaline metals possess the properties of surface-active additives (through an arrangement of linear chains with respect to a surface of metal and the low factor of friction), and properties of chemically active additives (in the extent of binding with a metal surface and the resulting high wear resistance of metal).

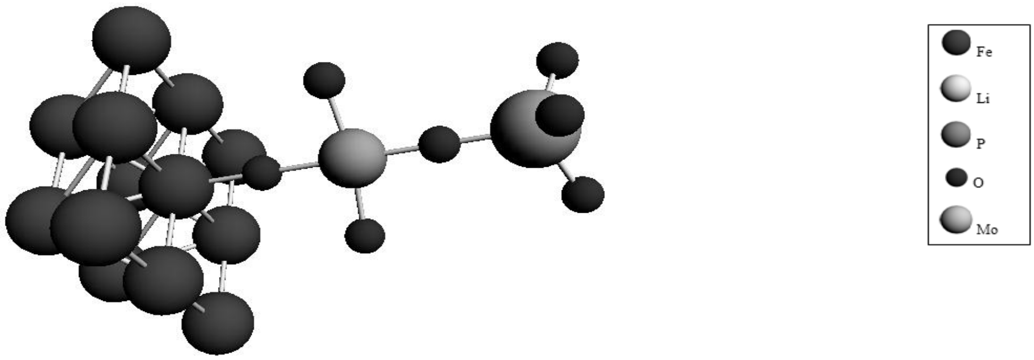


Fig. 1. Adsorption of geteropoliphosphates of alkaline metals on iron surface
Рис. 1. Адсорбция гетерополифосфатов щелочных металлов на поверхности железа

3. COMPARATIVE LABORATORY TRIBOLOGICAL TESTING OF THE FRICTION PAIR BABBIT STEEL WITH THE USE OF VARIOUS ADDITIVES TO LM

There were tribological tests and investigations of the bodies surfaces of friction pair MAB babbit-steel (B-16-Ст6СП) after tribocoupling of the friction pair in the presence of various LM. It was chosen as the base oil "Agrinol" As a basis of lubricating compositions, which is used in the MAB during the operation. The time of stopping the roller tested was 10 seconds, and the rotation time was 60 seconds. Various additives including developed additives on the basis of geteropolyphosphates were introduced in this base oil. Tribological tests on the tribometer SMT-1 using the scheme of a shaft -partial shell under the 200 newton load during 10800 sec were carried out. In the connection with the fact that the main wear of the pair occurs in the unsteady mode of friction (i.e. during starts and stops), the tests were carried out in continuous reproduction of cycles, consisting of starts and stops of the revolving sample, to achieve a pre-determined by preliminary experiments the total time of the test.

Fig. 2 shows the values of mass wear of babbit liner when various additives of LM are used in tribocoupling (no.2-5 – polyphosphates $NaPMoO_6$, and $LiPMoO_6$; no.6 – (A-22) zinc dialkilditiophosphate modified by boron; no.7 – (A-23) zinc dialkilditiophosphate with the content of the basic the substance is not less than 85%; no.8 – Lubrizol). Additives $NaPMoO_6$ and $LiPMoO_6$ are the fine-dispersed powder, and additives A-22, A-23 and Lubrizol - liquid.

It is visible from Fig. 2, that the introduction of all tested additives into the base oil "Agrinol" leads to a reduced wear of the babbit B-16. The lubricant 3 (the base oil with the 5% $NaPMoO_6$ additive) and the lubricant 5 (the base oil with the 3% $LiPMoO_6$ additive) provide a threefold decrease of wear of the babbit B-16 as compared with the deterioration of the same sample with the base oil only. The base oil with additives A-22, A-23 and Lubrizol leads to one and a half reduction of wear of the babbit B-16.

The above-stated LM has been tested by the four-ball machine of friction (definition of wear spots) and in the front machine of friction (studies the existence and stability of oil film on the surface of friction).

The measuring results of spot wear diameter after tribocoupling during 60-minute at loading 200 newton and a temperature of 25°C by the stereoscopic microscope MBS-10 with 8-fold increase of the eyepiece by a standard technique are given in Table 1.

There is significant reduction of wear in the case of using the lubrication with geteropolyphosphate additives from the test results.

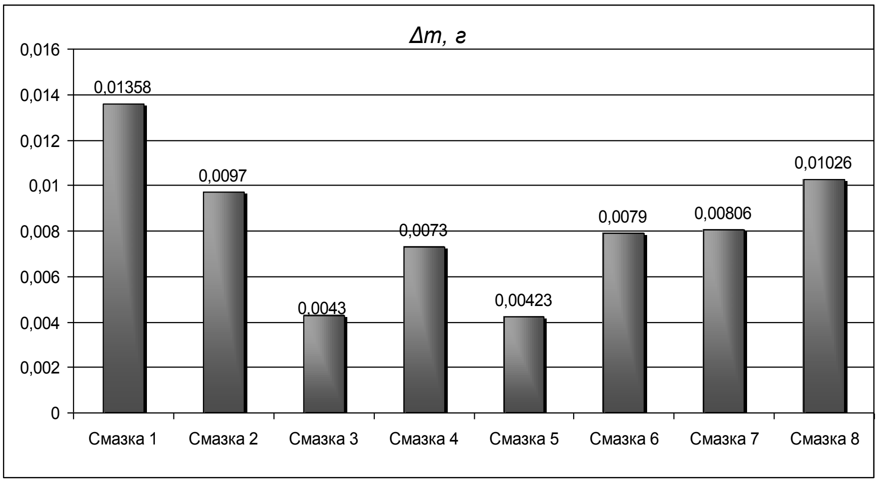


Fig. 2. The wear of babbit liner in the presence of various lubricating compositions.
Рис. 2. Износ баббитового вкладыша в присутствии различных смазочных композиций

The presence and stability of the oil film on the surface of the metal one determined on the IR Fourier spectra photometer Nicolet 380 prefix NPVO and software EZ OMNIC in the frequency range of 600 – 4000 $см^{-1}$. The tribocoupling was carried out by the face machine of friction with pair screw rollers at loading 1,2GPa and at introduction in a zone of contact various lubrication composition (LC) by a technique [1]. Working flat disks were made of steel 65G.

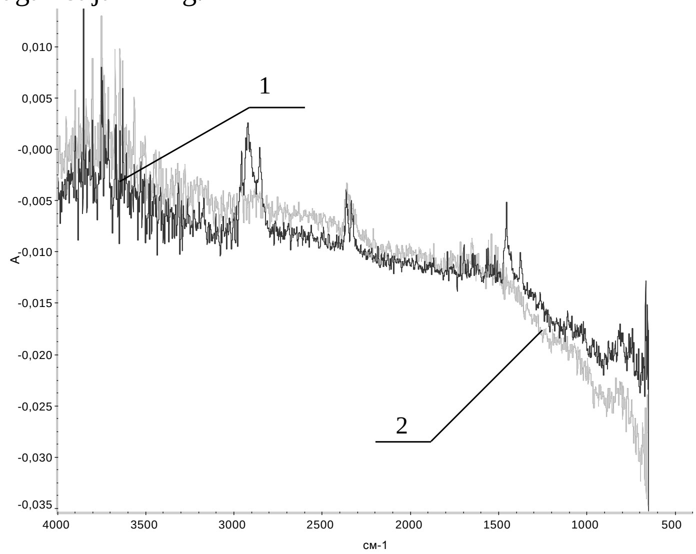
Table 1

Results of the LM tribological tests with various additives

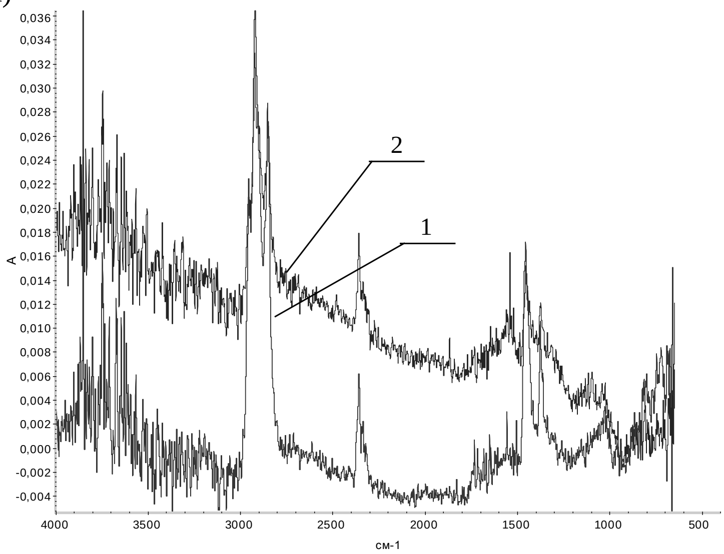
Lubrication No.	Additives, mass %	Spot wear diameter, mm
1	–	0,605
2	$NaPMoO_6$, 3%	0,492
3	$NaPMoO_6$, 5%	0,457
4	$LiPMoO_6$, 1%	0,520
5	$LiPMoO_6$, 3%	0,480
6	A-22, 1%	0,528
7	A-23, 1%	0,504
8	Lubrizol, 1%	0,498

Study of stability of oil film on the metal surface of friction showed that the introduction of pure base oils "Agrinol" in the zone of tribocontact the lubricant film to be stored for a short period of time - 1 hour. Already in tribocontact duration of about three hours the lubricant film disappears in the friction zone (Fig. 3a). Some improvement of the situation takes place by addition additives Lubrizol to the engine oil, because the signal after one hour of friction pair is slightly higher than with pure oil, but after three hours of the signal is very weak. Even more stable lubricant film is observed with additives $LiPMoO_6$, 3%. Intense signal is distinct after three hours of tribocontact, and is practically disappears after five hours. Film in the friction zone is kept up to five hours, although the signal is very weak in the conduct in the friction zone 1% zinc dialkillitiumphosphate - A23 and the A22 (additives, modified boron). The best results of the stability of lubricating film is received through introducing additives $NaPMoO_6$, 5% into the base oil "Agrinol". On the surface of the metal one is stable lubricant film, continuing up to five hours of tribocontact (Fig. 3b). These datas are in full accordance with the results of the tribological tests.

It should be noted that at the tribological tests with LM, which do not contain additives lithium and sodium, there is the heating of friction unit up to 80-100˚C. Therefore, only with inorganic polymer additives a thermal-oxidative destruction of the oil bases slows down, reduced evaporation, there is no over-lubrication and rheological properties of the LC long-term support at the legislative level. Delay of oxidation of an oil basis allows reducing friction factor, wearing of friction parts and protecting the surface of friction pair against jamming.



a)



b)

Fig. 3. IR Fourier spectrum of a surface of a counterbody at introduction in the friction zone a) the base oil "Agrinol" after 1 hour (1) and 3 hours (2) of tribocontact and b) the base oil "Agrinol" with a filler 5% $NaPMoO_6$ after 1 hour (1) and 5 hours (2) of tribocontact

Рис. 3. ИК Фурье спектр поверхности контртела при введении в зону трения a) базового масла «Агринол» после 1-го часа (1) и 3-х часов (2) трибоконтакта и b) базового масла «Агринол» с присадкой 5% $NaPMoO_6$ после 1-го часа (1) и 5-ти часов (2) трибоконтакта

4. CONCLUSION

1. The study of the adsorption of geteropolyphosphates of alkaline metals on a surface of iron has shown that chains of geteropolyphosphates form a strong coating of the surface. The external ends of chains, cooperating with greasing, provide, finally, smooth sliding of a counterbody along the surface of iron with a small friction. Geteropolyphosphates of alkaline metals possess properties of both surface-active and chemically active additives that leads to the high wear resistance of metal.

2. Based on the results of the tribological tests it is possible to draw a conclusion, that the introduction into the base oil "Agrinol" all tested additive leads to reduced wear of babbit B-16. Lubrication 3 (base oil with the entered additive 5% $NaPMoO_6$), lubrication 5 (base oil with the entered additive 3% $LiPMoO_6$, provide three-fold decrease in wear of babbit B-16, compared with the deterioration in the tests of the same sample with the base oil. The use of the base oil with additives A-22, A-23, Lubrizol leads to one and a half reducing of wear of babbit B-16.
3. Studying of stability of a lubricant film on a metal surface in the friction process confirms, that the best stability of a lubricant film is received by means of the introduction of additives $NaPMoO_6$, 5 % in the base oil “Agrinol”.
4. Lubricants with polymer additives of geteropolyphosphates reduce the wear of a metal surface, extending the life of the friction unit, and can be widely applied in friction pairs metal-metal, metal-ceramic and metal-polymer.
5. The bench tests of MAB by a reversion method (the rotation during 30 minutes in one direction and 30 minutes in another) with the developed lubricating compositions have shown that all the operating parameters of bearings are normal. The bench tests were carried out in the locomotive depot in running of the wheel-motor block. Operational trials are ongoing at the moment. Intermediate measurements shows a decrease of heating bearings and wearing the babbit layer in the MAB.

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References

1. Kolesnikov V., Myasnikova N., Savenkova M., Myasnikov P., Daniel P.: *Polymeric composite and lubricants for the wearresistant friction units of railway mechanics.* Transport Problems, 2009, vol. 4, no. 3, part 1, pp. 65-70.
2. Kroup K.: *Use of paper chromatograpfy for differential analysis of phosphate mixtures.* Anal. Chem. 1976, vol. 38, no 7, pp. 1091-1095.
3. *ASNV Diffraction Date Cardsand Alphabetical and Grouped Numerical Index of X-Ray Diffraction Date.* . Изд. Американского общества по испытанию материалов. Филадельфия. 1991. vol.27.
4. Констант А.З., Дидуне А.П.: *Фосфаты двухвалентных метал*лов. Рига.: Зинанте. 1990, с. 371.
5. Van Wazer I.R.: *Structure and Properties of the Condensed Phosphates.* J. Amer. Chem. Soc. 1986, vol. 97, pp. 287-297.
6. Колесников В.И., Ермаков С.Ф., Даниэль Ф., Савенкова М.А., Мясникова Н.А., Лунева Е.И.: *Синтез и исследование триботехнических характеристик новой наноразмерной керамической присадки фосформолибдата никеля к пластичным смазкам*. Трение и износ. 2010, т. 31, №6, с. 560-568.
7. Parks I.R., Van Wazer I.R.: *Principles of phosphorus chemistry*. J. Amer. Chem. Soc., 1977, vol. 88, pp. 4890-4898.
8. Velde G., Bickelhaupt F.M., Gisbergen S.J.A., Fonseca Guerra C., Baerends E.J., Snijders J.G., Ziegler T.: *Chemistry with ADF.* J. Comput. Chem., 2001, vol. 22, pp. 931-967.
9. Kolesnikov V.I., Migal Yu.F., Savenkova M.A., Mizhiritskaya S.N.: *Adsorption of Heteropolyphosphates of Alkaline Metals on Iron Surface.* Journal of Friction and Wear, 2009, vol.30, no. 6, pp. 404-410.
10. Kolesnikov V.I., Kozakov A.T., Migal Yu.F.: *Study of Friction and the Weel-Rail System by X-Ray Electron and Auger-Electron Spectroscopy and Quantum Chemistry*. Journal of Friction and Wear, 2010, vol. 31, no. 1, pp. 11-22.

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