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INCREASING THE WEAR RESISTANCE OF THE LOCOMOTIVE WHEEL CREST BY INTRODUCING AN ANTIFRICTION ADDITIVE INTO THE LUBRICANT

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Abstract. Tests were carried out to determine the wear of the surface of the locomotive wheel rail using a Puma lubricant with a sulfonic additive, with an additive of a hydroquinone derivative and an organophosphorus compound and to determine the amount of diffusionally active hydrogen released in the system. The purpose of the work was to determine the wear of the rail material and analyze the lubricant with the selected additives. The principle of action of additives and the nature of their interaction with rubbing surfaces is analyzed. Additives have been identified that reduce surface wear, as well as an additive that best binds hydrogen. As a result of the work, it was revealed that the additives of the sulfo- and organophosphate compounds reduce the wear of the friction surface, and it is also shown that the organophosphate compound reduces the release of diffusionally active hydrogen into the system.
Keywords**:** friction, wear, lubricant, additives.

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1. Introduction.

To increase the service life and wear resistance of the machines, antiwear antifriction additives are used for lubricating oils. The flange of the wheel rim of a mainline locomotive is subjected to intense wear at the moment when the train enters the curved section of the railway track. The wheelsets are transferred to the ridge contacts for the left and right wheels simultaneously. This leads to increased wear of the traction part of the tire and the flanges of the wheels of the rolling stock [1]. The presence of lubricant between the flange and the rail helps to reduce wear and coefficient of friction. The viscosity of the lubricant must be sufficient to remain on the friction surface when the locomotive turns. The tribotechnical properties of the lubricant are set by the addition of additives, which must ensure high adhesion to the surface of the wheel flange of the main locomotive. Relevant is the question of researching existing analogues of lubricants using additives that meet the specified operating conditions, as well as the development and testing of new compounds. Therefore, the purpose of the work was to study the effect of existing lubricants on the wear of rubbing surfaces, as well as with the use of additives introduced into it.

Antifriction additives affect the surface layers, their composition and the thickness of the protective film. Understanding the mechanism of action of additives will allow the development of new types of compounds that will have a significant impact on the antifriction properties of lubricants. The correct choice of components determines the effectiveness of the lubricant in the given operating conditions, and the selection of additives will allow the lubricants to be used in the required conditions, depending on their functions.

In a lubricant, phosphorus compounds can be used either as base lubricants or as additives. The authors of [2, 3] carried out studies on the dependence of the friction coefficient on the structure and length of a chain of organic molecules. Studies have shown that the coefficient of friction decreases with increasing length of the hydrocarbon chain. It can be assumed that additives in the form of long-chain branched organic compounds based on phosphates can act as antifriction additives that reduce the coefficient of friction. Due to its long and branched chain, tricresyl phosphate ($OP(OC_6H_4CH_3)_3$) is used as an antiwear and extreme pressure additive in lubricants [4,5].

Organophosphate additives have better lubricating properties than pure organic substances. The most common mechanism for film formation with organic phosphates involves the initial adsorption of the phosphate ester on the iron oxide surface. One of the alkyl groups is replaced due to the breaking of the P – O bond with the formation of bound phosphate, which then reacts with the formation of an iron polyphosphate film [6]. There is another theory explaining the effectiveness of phosphorogenic compounds [7]. The higher the viscosity of the material, the greater the load the lubricant can withstand. The low wear rate of the material when using an organophosphorus additive is associated with the high viscosity of the phosphate compounds, which form a thick film to protect the surface. The tribological properties are related to the wetting properties, the spreading coefficient depends on the solid-liquid interaction, which actually determines the wetting properties. The lower the spreading coefficient, the less surface wear.

2. Methods and materials.

Experimental studies were carried out on the effect of additives on wear and release of diffusion-active hydrogen. The determination amount of released hydrogen was carried out on a friction machine with submitted method [8].

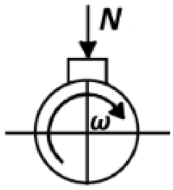

Figure 1. Friction scheme shaft – bushing

The experimental setup shown in Fig. 1 is located in a chamber equipped with a pipe and a hydrogen measurement sensor. The measurement of the amount of hydrogen is carried out in the room and in the chamber. Diffusion-active hydrogen is considered to be the difference between the hydrogen passed through the pipe and the hydrogen present in the environment. The wear was measured with an Omron ZX1 sensor - a laser distance measurement sensor - so that it shows the total wear of the sample-counterbody friction pair [8]. A cut of a P65 rail was used as an analyzed sample. Steel 45 was used as a counter-sample, which is used as a tire material for diesel locomotives. The roughness of the surface of the P65 rail in accordance with GOST 2789-73 was Rz = 25.0 microns, the roughness of the band - Rz = 12.5 microns. The lubricant was Puma grease. SM "Puma" is made on the basis of mineral oil thickened with stearic acid lithium soap, contains anti-corrosion and antioxidant additives and molybdenum disulfide. Compounds containing the sulfur group R – SO_2OH (where R is a hydrocarbon radical) and hydroquinone derivatives $C_6H_4(OH)$ were used as additional additives. The sulphide additive was used on the basis of the activity of sulfur compounds and its adhesion to the surface, with the formation of a protective film of sulfur compounds with iron. The hydroquinone derivative was used as a pure component of an organic compound in order to reveal the regularity of the influence of the structure and length of the hydrocarbon chain on the wear process of the wheel-rail flange friction pair. In the experiment, the lubricant-additive ratio was 25:1. A series of tests were carried out with a load of 60 newtons. The friction path of the rail surface against a point on the band was calculated using the expression given in [9].

Calculation of the length of the friction path of the wheel flange of the locomotive on the rail head is expressed through the geometric parameters of the wheel by the formula:

$$L_{расч} = \frac{\pi}{2}\left[3\times(a+b)-\sqrt{(3\times a+b)\times(a+3\times b)}\right], \quad (1)$$

where: a - the radius of the wheel, b - the length of the semi-axis of the ellipse,

$$b = (r + \Delta r) \times sin(cos^{-1}(r \div (r + \triangle r))) - r \times cos^{-1}(r \div (r + \triangle r)). \quad (2)$$

The authors of [9] calculated the initial data for the wheel diameter d = 1050 mm, wheel flange thickness - 25 mm, L_{calc} = 737.194mm.

The number of multiple contact cycles of the point on the band with the rail surface is 130. During tribotechnical studies, the hydrogen content was monitored during testing in the sealed chamber of the friction machine with simultaneous continuous recording of total wear. By diffusion-active hydrogen we mean hydrogen released from samples and lubricant [10]. Diffusion-active hydrogen ppmH2 is defined as the difference between the hydrogen passed through the pipe, ppm, and the hydrogen present in the environment, ppm.

$$\rho\rho m H_2 = \rho\rho m_m - \rho\rho m_{en} \quad (3)$$

Wear was determined by an Omron ZX1 sensor with an accuracy of 0.01 µm (Δ0.005 µm) as the total wear of the sample-counterbody friction pair. The wear rate was calculated using the formula:

$$I_h = \frac{h}{L}, \quad (4)$$

where: h - the total wear of the friction pair, L - the friction path.

The calculation of the wear rate was carried out according to the expression:

$$V = \frac{h}{t}. \quad (5)$$

where: t - time. Each material was tested for 30 minutes. The readings from the sensors were taken at intervals of 1 minute.

To analyze the wear products of the friction surfaces, an IR spectroscopic analysis of the original lubricant and the used one was carried out. The ATR spectrum (ATR spectrum) is very similar to the normal absorption spectrum in the IR range. As the wavelength increases, the observed absorption bands in the ATR spectrum become more intense than the corresponding absorption bands in the usual spectrum. For identification of lubricant samples by the method of multiple disturbed total internal reflection, the sample was applied to the surface of a zinc selenide prism; this method allows obtaining a good undistorted spectrum. ATR is a form of spectroscopy. The principle of operation of this method is that the radiation, having passed through the sample, is reflected from the mirror surface, again hits the sample, and only after that the signal goes to the detector. Part of the incident radiation hits the sample and is absorbed there by the wavelengths corresponding to the given vibration. As a result, this method is referred to as "disturbed total internal reflection".

3. Results and discussion

As a result of tests with an additive of a sulfonic compound and an organophosphorus compound at a load of 60 N, the wear is 180 µm (Fig. 2). Wear when using an additive with hydroquinone derivatives is 170 microns.

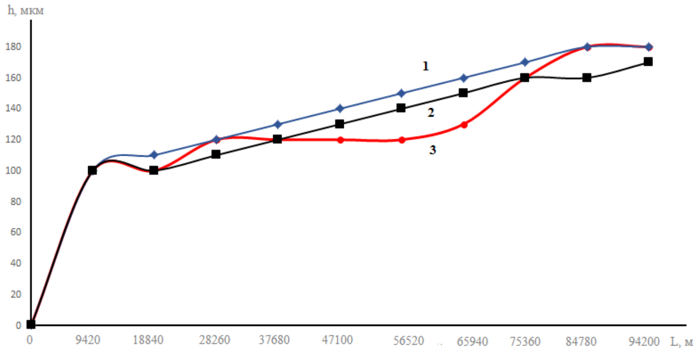

Figure 2. Dependence of the wear of the friction pair on the path: (1) an organophosphate additive; (2) an additive for hydroquinone derivatives; (3) sulfoorganic additive

The high adsorption capacity of the sulphate additive is explained by the breaking of S-S bonds in the lubricant. As a result of decomposition, active radicals interact with the juvenile metal surface with active centers. The presence of a unshared electron pair at the sulfur atom and the presence of free orbitals at the metal atom contribute to the formation of stable iron sulfide. The high adsorption capacity of organophosphorus additives is associated with the activity of alkyl groups and the rupture of the P-O bond in the molecule.

During the study, the amount of evolved diffusion-active hydrogen was measured (Fig. 3).

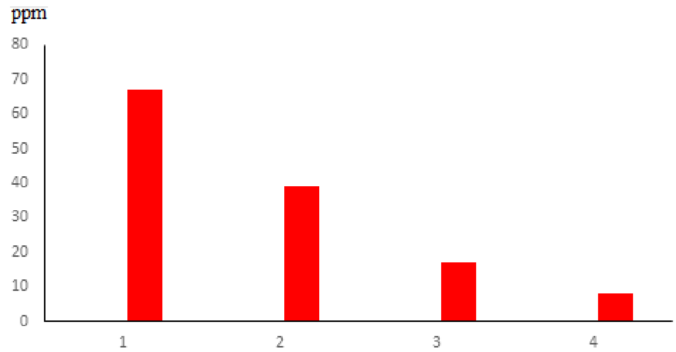

Figure 3. Discharge of diffusion-active hydrogen in the analyzed system: 1- Puma; 2-Puma + sulfo compound; 3-Puma + hydroquinone; 4-Puma + organophosphorus compound

As can be seen from Fig. 3, the largest amount of hydrogen is released when using pure Puma lubricant and is 67 ppm. With the addition of additives, the amount of hydrogen is significantly reduced, 40, 18 and 8 ppm with the use of a sulphate additive, a hydroquinone derivative and an organophosphorus compound, respectively.

As can be seen from Fig. 4, in the spectra of the samples, the intensity of the band at a frequency of 633 cm^{-1}, which belongs to the absorption band of Fe-OH, increases in comparison with the original sample, which is directly related to an increase in the concentration of iron in the used lubricant.

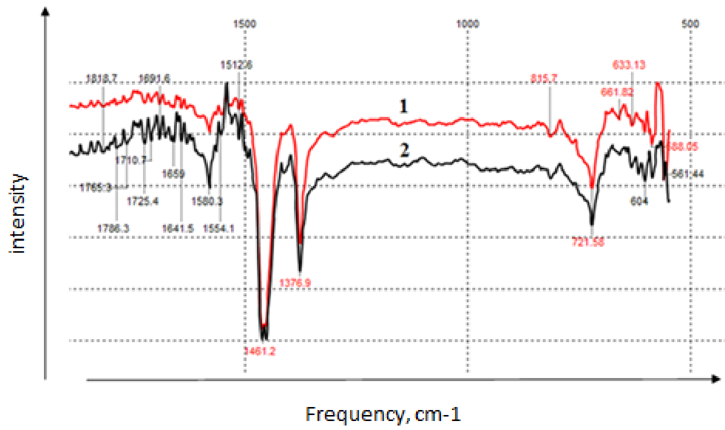

Figure 4. IR spectrum of the lubricant: 1-pure Puma lubricant; 2-lubricant after testing.

The calculated vibrations of the $Fe^{3+}O_4$ and $Fe^{2+}O_4$ groups are in the frequency range from 585 to 500 cm^{-1}. The spectrum also shows a change in the intensity of spectral lines in this region, which indicates a change in the concentration of iron in the material. A free tetrahedral ion has four types of vibrations - ν1 (A1), ν2 (E), ν3 (F2), ν4 (F2), the values of which are 981, 451, 1104 and 613 cm^{-1}, respectively. Only ν3 (F2), ν4 (F2) are active in the IR spectra. SO_4^{2-} groups in crystals occupy general positions, which leads to the removal of degeneracy and splitting of vibrations into individual components. In the region of bending vibrations of the group, lines appear, which are recorded with different intensities for all directions of excitation (Fig. 4). Three lines are observed for bending vibrations - 604, 633.15, and 661.82 cm^{-1}. The half-width of the lines in the spectra for the group is 3÷5 cm^{-1} and changes insignificantly when considering the spectra of the used lubricant and with the use of sulfo-additives. Bands of variable intensity in the region of 1580.3 cm^{-1} and 1659 cm^{-1} refer to vibrations of the carbon skeleton of conjugated polyenes and aromatic groups. IR analysis of the spectral lines of the characteristic frequencies of the test sample determines the presence of functional groups in the lubricant before and after the tests, the intensity of the spectral lines will make it possible to calculate the concentration of the system components. The frequency shift of spectral lines also reflects the forms of functional groups that can form after friction tests. It can be seen that the intensity and width of the bands changes in the used lubricant, which indicates the destruction of the structure of the basic components. In the region of 1376.9 and 1461.2 cm^{-1}, there are vibrations of CH_2 groups of solid fatty acids, the number of bands in this region increases by one with an increase in the number of C atoms by one in the C16 –C21 chains. The change in the intensity of the spectral lines in the region of 1376.9 cm^{-1} indicates a change in the concentration of the base oil in the spent sample.

Analysis of IR spectra showed an increase in the concentration of metal in the lubricant after testing. The intensity and width of some characteristic lines in the IR spectrum indicates a change in the qualitative composition of the oil, which may be the reason for the appearance of new compounds on the surfaces.

4. Conclusions

The activity of the additives is explained by the formation of absorbed layers on the surface due to the polar nature of the molecules. Organic components are attracted to the metal surface due to strong absorbing forces, the polar part of the molecule is fixed on the metal surface. The organosulfuric additive reduces the wear of the friction pair, which is explained by the breaking of the S-S bonds in the lubricant. As a result of decomposition, active radicals interact with the juvenile metal surface with active centers. It can also be noted that the presence of an unshared electron pair at the sulfur atom and the presence of free orbitals at the metal atom promotes the formation of complexes, resulting in the formation of stable iron sulfide. The organophosphorus additive in the process of friction and at high temperatures forms a eutectic system of metal phosphides, which have the ability to polish the surface.

Equal wear rate of organophosphate and sulfoorganic additives with significantly less hydrogen evolution in the organophosphorus additive indicates its lesser effect on diffusion-active hydrogen. Probably, the blockage of hydrogen is caused by the higher wettability of this additive, however, this statement requires further research.

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