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A STUDY OF THE EFFECT OF ELECTROSTATIC PROCESSING ON PERFORMANCE CHARACTERISTICS OF AXLE OIL

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Отримані результати зміни експлуатаційних характеристик осьової оливи на різних етапах напрацювання та при застосуванні методу електростатичної обробки. Дослідження проводились на парі тертя «ролик – колодка», яка змочувалася осьовою оливою на різних режимах навантаження та ступенях напрацювання. Отримані залежності зносу експериментальних зразків при різних режимах навантаження, напрацювання оливи та ступеня електрообробки

Ключові слова: осьова олива, електростатична обробка, моторно-осьовий підшипник, колісно-моторний блок, швидкість зношування

Получены результаты изменения эксплуатационных характеристик осевого масла на разных этапах наработки и при использовании метода электростатической обработки. Исследования проводились на паре трения «ролик – колодка», которая смачивалась осевым маслом на различных режимах нагрузки и степенях наработки. Получены зависимости износа экспериментальных образцов при различных режимах нагрузки, наработки масла и степени электрообработки

Ключевые слова: осевое масло, электростатическая обработка, моторно-осевой подшипник, колесно-моторный блок, скорость изнашивания

1. Introduction

Rail transport plays one of the key roles in maintaining sustainable economic development, ensuring stable operation of the entire transport system of any modern developed state. But the peculiarities of growth rates of the economies of the former CIS countries in recent years complicate the renewal of the existing rolling stock, which causes aging. Thus, at the beginning of 2008, the service life of mainline locomotives has reached 20–29 years, and physical wear – 83 %. For electric locomotives, these figures amounted to 22–45 years and 89 %, respectively [1–3]. Therefore, the issues of improving the design of railway rolling stock, increasing its efficiency and operational reliability are of paramount importance. An important place among the existing state programs of the former CIS countries is given to extended overhaul and modernization of the locomotive fleet. Freight and shunting locomotives are attributed in them to priority and promising tasks [1, 2, 4]. The plans for the modernization [1, 2] of the part of the locomotive fleet, as well as the fact that the supporting suspension of this type is supposed to be used on freight locomotives of the new series, make the problem particularly acute [5]. Thus, the research aimed at increasing the operational reliability and the service life of traction rolling stock units remains relevant today.

2. Literature review and problem statement

A wheel-motor unit is an important part of the locomotive underframe, which provides the interaction of the locomotive with the railway superstructure elements. Its technical condition characterizes not only the operational reliability of the locomotive, but is also directly related to the train traffic safety [6]. In the majority of locomotives, which provide freight transportation in Ukraine and in post-Soviet states, the axial suspension of traction electric motors is used. The scheme of such a power transmission according to the classification [6] corresponds to the first class of traction drives. In this case, one half of the mass of the traction electric motor (TEM) is firmly supported by the bogie frame, while the other one is rigidly supported by the wheelset axle by means of motor-axial bearings (MAB).

Traction rolling stock failures in 25 % of cases are caused by malfunctions of the wheel-motor unit, about half of which are due to MAB failures [7]. Per the length of the locomotive run of 1 million km, there are 3–5 unscheduled repairs to replace MAB liners [8]. The share of MAB failures in the total number of failed ED118A traction electric motors is 10 % [9].

Many special studies deal with the problem of improving the operational reliability of the WMU [10–12]. Proposals for solution concern three main directions. In particular, it was proposed to increase the wear resistance of friction surfaces by using modern tribotechnologies [13, 14], new materials or methods of surface preparation [15] and WMU design improvement [16, 17]. However, the application of modern technological and construction methods is associated with significant economic and financial costs and introduces a number of new requirements for the operation of lubrication systems and lubricant properties. Therefore, the optimum solution of the problem, in our opinion, is the search for new methods of influence on performance characteristics of lubricating oils.

Attempts to develop and apply such methods have been proposed in a number of scientific studies. In particular, in [18] the results of experiments on ultrasound treatment of oil in the «bronze-steel» and «cast iron-steel» friction pairs have been presented. The result of the research is the friction coefficient reduction by 13–15 % for synthetic oil and 25–28 % for semi-synthetic oil. However, the tests did not concern the identified problem of the service life of MAB and related materials.

In [19–21], the authors have proposed the introduction of friction modifiers and magnetic filler as an additive to oil, but this idea is unacceptable in specific operating conditions of existing MAB lubrication systems. Also, it is necessary to note studies in the direction of adding structurally sensitive liquid-crystal materials [22] and clay minerals [23] to oil in order to achieve more manageable and predictable friction control of tribounits. But for the same reasons related to the specifics of the MAB capillary lubrication system, they cannot be used to solve the problems considered in the paper.

Another method of influence on performance properties of mineral oils is the introduction of fullerene soot as an additive [24, 25]. But the successful implementation of this proposal, in the context of solving the issue of insufficient service life of MAB, is also incompatible with the operating conditions of the capillary lubrication system.

The above methods have been successfully implemented to address a wide range of technical problems, but cannot be considered to enhance the operational reliability of MAB. The problem is primarily associated with the efficiency of the used lubrication systems and performance characteristics of axle oil. The existing capillary lubrication system eliminates the possibility of introducing additives or modifiers to oil. Therefore, it was decided to apply the method of electrostatic processing of mineral oils.

Oil processing by external electrostatic field [26, 27] contributes to the destruction of the micellar aggregates and formation of a solid layer of polar molecules on friction surfaces. This increases the adsorption activity of polar-active molecules, increases the lubricant film thickness, and, accordingly, decreases the wear rate of friction surfaces.

3. The aim and objectives of the study

The aim of the study is to determine changes in performance characteristics of the axle oil «L» at different operating times when using the electric processing method.

To achieve this aim, the following objectives were set:

– to determine the wear rate of the samples in the «roller – pad» friction pair when using the axle oil with different operating times;

– to determine changes in the wear rate of the samples when applying electrostatic processing of axle oil at different operating times.

4. Materials and methods of research on the effect of electrostatic processing of axle oil on performance properties

4. 1. Research materials and equipment used in the experiment

The research was conducted with the following test materials:

a) «L» summer axle oil (GOST 610-72), which is used in the MAB lubrication system of locomotives. Axle oil belongs to a group of mineral gear oils. Physicochemical parameters of axle oils are given in Table 1. In the tests, oil with different operating times in the MAB lubrication system: as-delivered oil, oil after the operating time of 75 thousand km, and 150 thousand km, respectively was used.

Oil operating time (number of operating hours in the MAB lubrication system) for tests is selected in accordance with the standards of time between repairs for mainline locomotives [28].

Table 1

Basic physicochemical parameters of axle oils

Parameter	Norm for the brand		
	L (summer)	W (winter)	S (Northern)
Viscosity: kinematic at 50 °C, cSt	42–60	≤22	12–14
dynamic (at a temperature, °C), Pa·s, at most	150(–10)	600(–30)	0.2(0); 2,500(–50)
Open flash-point, °C, at least	135	125	125
Pour point, at most	–	–40	–55
Content of water-soluble acids and alkalis	absence		
Content of mechanical impurities, %, at most	0.07	0.05	0.04
Water content, %, at most	traces	0.3	0.1
Content of additives	introduction of pour-point depressants into the L axle oil is allowed		

b) a pad and a roller, the materials of which are similar to the those used to produce the «axle journal – liner» friction pair of the MOP TED-118B unit, i. e. steel Os. L GOST 4728-72 and bronze Br. O4Ts4S17 (GOST 613-79). Roller diameter is 50 mm, width – 12 mm, the width of the pads – 10 mm. The surface roughness of the part is similar to the friction surface roughness of the MAB liner – $R_z = 7.5$ µm.

Electric processing of oil was carried out using a laboratory device with a coaxial arrangement of electrodes (Fig. 1).

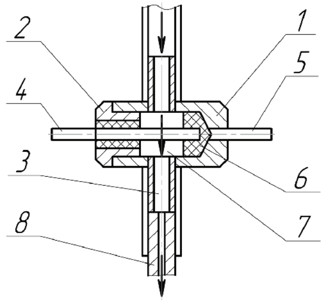

Fig. 1. Scheme of the axle oil processing device

The device consists of a cylindrical body 1, one end of which is dead, and the other is covered by a flange joint 2. To the inner chamber of the body 1, two tubes 3: one for oil supply to the chamber and the other for oil removal and subsequent feeding to friction pairs were connected from two sides.

Voltage is supplied to the device from the mains through a high-voltage power supply unit using the electrodes 4 and 5 insulated with a dielectric 6. Oil processing by an electrostatic field occurs in the inner chamber 7, the processed oil is further fed to the friction pair through a tube 3 and a capillary 8. The electric field strength is $E = 0.5 \cdot 106$ V/m.

For testing the samples, a laboratory installation consisting of the SMT-1 frictional machine, the oil electric processing device and the axle oil feeder was used (Fig. 2).

Oil is fed to the chamber 3 from the tank 1 by the pump 2. Then, it passes through the choke 4 and the ESP device 5 dropwise to the surface of the roller 6, against which the pad 7 is pushed with a force P. The excess oil returns to the tank 1 through the drain pipe 8.

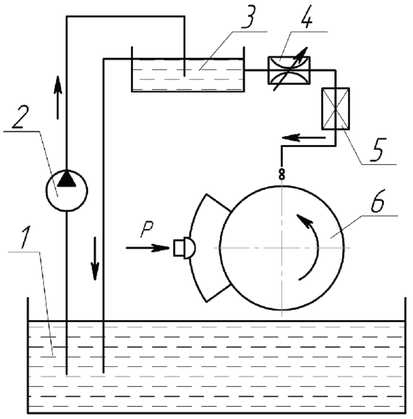

Fig. 2. Scheme of the laboratory installation for the model experiment:
1 – tank; 2 – pump; 3 – chamber; 4 – control choke;
5 – ESP device; 6 – roller; 7 – pad; 8 – drain pipe

Oil operating time (number of operating hours in the MAB lubrication system) for tests is selected in accordance with the standards of time between repairs for mainline locomotives [28]. The wear rate of the samples was determined by weighing on the VLA-200g-M analytical scales with an accuracy of 0.001 g.

4. 2. Method of determining the effect of electric processing of axle oil on performance properties

The minimum required frequency of experiments, the actual value and the standard deviation of the individual measurements of wear rate were determined by the following method. To determine the minimum required number of experiments, a predesign was carried out. The frequency of experiments was determined by tenfold measurement of the pad wear rate. Power of friction forces in the «roller-pad» contact (load conditions) is $P = 0.215$ W/mm^2. Oil operating time is equivalent to $Z = 150$ thousand km of the length of the locomotive run.

The results of the measurements are presented in Table 2.

As the calculated value of wear rate, the arithmetic sample mean $\bar{X}$ was taken.

$$\bar{X} = \frac{X_1 + X_2 + \ldots + X_n}{n}, \tag{1}$$

where X_1, X_2,... X_n are the results of individual measurements; n is the total number of individual measurements.

After substitution in (1), we determine: $\bar{X} = 1.07$ mg/h.

The standard deviation of the measurement results:

$$\sigma_X = \sqrt{\frac{\sum_{i=1}^{n} \left(X_i - \bar{X}\right)^2}{n-1}}. \tag{2}$$

The standard deviation of the individual measurements of the pad wear rate for (2): $\sigma_x = 0.014$ mg/h.

Table 2

Results of preliminary tests to determine the minimum required number of experiments

Experiment No.	1	2	3	4	5	6	7	8	9	10
Results of mass loss measurements, mg for 240 min	1.06	1.08	1.07	1.05	1.06	1.09	1.07	1.05	1.08	1.09

Then, in accordance with [25], the minimum required frequency of experiments

$$n_{\min} \geq \frac{\sigma_X^2 \cdot t_{cr}^2}{\Delta^2 \cdot m_m^2}, \qquad (3)$$

where t_{cr} is the tabular value of Student's coefficient: with a given reliability of measurement results, $P = 0.95$; $n = 10$, $t_{cr} = 2.26$ [30]; Δ is the permissible relative error of measurements, $\Delta = 0.02$; m_m is the arithmetic mean of measurement results, $m_m = 1.07$.

Then the minimum (3) frequency of experiments is $N_{\min} = 3$.

Experimental investigations provided for two two-factor experiments, where the response function is the wear rate γ, which, in turn, depends on the oil operating time in the MAB lubrication system – Z, and the load P.

The first stage provided for a two-factor experiment to determine the wear rate of friction surfaces with the oil operating time Z as an independent factor:

a) oil with an operating time of $Z = 0$;

b) oil with an operating time of $Z = 75$ thousand km;

c) oil with an operating time of $Z = 150$ thousand km.

The coefficients of simulation [7] of the process (Table 3), which correspond to friction conditions in MAB, are determined by the universal equations of similarity [31] taking into account the scale factor C_i. The similarity coefficient is $C_i = 4.20$.

Table 3

Coefficients for the simulation of friction in a motor-axial bearing on an experimental sample

Similarity parameter	Model-prototype correlation factor	Model-prototype parameter ratio
1. Specific load	$C_p = 1$	$p_m = p_n$
2. Slip velocity	$C_v = 1/C_l$	$v_m = v_n \cdot C_l$
3. Temperature in the friction area	$C_\theta = 1$	$\theta_m = \theta_n$
4. Friction duration	$C_t = C_l$	$t_m = t_n \cdot 1/C_l$
5. Heat transfer coefficient	$C_\alpha = 1/C_l$	$\alpha_m = \alpha_n \cdot C_l$
6. Friction surface roughness	$C_h = C_l$	$R_{zm} = R_{zn} \cdot 1/C_l$

The largest loads on MAB [10], and accordingly the wear rates of their surfaces, are observed at the locomotive speed of 10–20, 30–40 and 50–60 km/h (Table 4). These conditions were chosen for simulation by means of the SMT-1 frictional machine.

At the locomotive speed of $V = 10–20$ km/h, the nominal pressure in the MAB working area is $p = 1.33$ mPa. These conditions correspond to the slip velocity of the model of $\nu = 4.79$ m/s. The frictional area of the pad is $S = 1.81 \cdot 10^{-4}$ m^2. The load applied to the pad is $N = 263$ N. The duration of each experiment is $t = 4$ hours. The specific power of friction forces – $P = 0.138$ W/mm^2.

At the speed of $V = 30–40$ km/h, the bearing liner is exposed to the nominal pressure of $p = 1.05$ mPa. The slip velocity of the model is $\nu = 9.78$ m/s. The load on the pad is $N = 208$ N. The specific power – $P = 0.215$ W/mm^2. The duration of each experiment is $t = 4$ h.

In the locomotive speed range of $V = 50–60$ km/h, the pressure in the working area of the bearing is $p = 0.86$ mPa. The slip velocity of the model is $\nu = 14.36$ m/s. The load on the pad is $N = 170$ N. The specific power – $P = 0.247$ W/mm^2. The duration of each experiment is $t = 4$ h.

Table 4

Prototype and model parameter correspondence table

Similarity parameter at the locomotive speed, km/h	Prototype parameter			Model parameter		
	10–20	30–40	50–60	10–20	30–40	50–60
1. Specific load, MPa	1.33	1.05	0.86	1.33	1.05	0.86
2. Rotation frequency, rev/s	1.68	3.36	5.04	1.68	3.36	5.04
3. Slip velocity, m/s	1.14	2.28	3.42	4.79	9.78	14.36
4. Friction coefficient	0.1196	0.1182	0.1106	0.1196	0.1182	0.1106
5. Temperature in the friction area, deg. °C	58	74	80	58	74	80
6. Friction surface rougeness R_z, μm	2.2/7.8			0.5/2.0		
7. Friction duration, h	4	8	8	4	8	8

Temperature and volume of the oil fed into the friction area per unit time are constant.

To simulate the axle oil supply to the «roller-pad» friction pair, the calculation was made. The calculation is based on the data about the thickness and volume of the lubricant film, which separates the MAB surfaces at different speeds. The calculation of the required volume of oil was made for the maximum specific power of friction forces of $P = 0.247$ W/mm^2.

In the speed range specified in Table 4, boundary friction conditions prevail on the MAB friction surfaces. The total height of surface micro-rigidities of the friction pair of the model is 2.5 μm. Roller diameter is 50 mm, and the length of the surface generatrix – 157 mm. The roller wetting area with a width of 11.5 mm is 1805.5 mm^2.

With the lubricant film thickness on the model surface of 5.0 μm and shaft speed of 3.36 rps, the volume of oil to be fed to the friction area is 30 mm^3/s.

On this basis, the volume of the oil fed into the friction area is accepted as constant for all experiments – 30 mm^3/sec.

The variation levels of the factors [10] of the experiments of the first and second stages are presented in Table 5.

Table 5

Variation levels of the factors *Z, P*

Level	Code	X_1, (Z), thousand km	X_2, (P), W/mm^2
Lower level	–1	0	0.215
Zero level	0	75	0.247
Top level	+1	150	0.138

The second stage provided for a two-factor experiment with the same factors as in the first stage, but before being fed to the «axle-bearing» friction pair, the oil was processed by the superimposed electrostatic field with the strength of $E=0.5\cdot10^6$ V/m. Voltage at the electrodes – 1,000 V.

The orthogonal design of the experiment [10] of two applications of axle oil is presented in Table 6.

Table 6

Orthogonal design of experiments

Experiment No.	X_1	X_2	Z, thousand km	P, W/mm^2
1	–1	–1	0	0.215
2	+1	–1	150	0.215
3	–1	+1	0	0.247
4	+1	+1	150	0.247
5	–1	0	0	0.138
6	+1	0	150	0.138
7	0	–1	75	0.215
8	0	+1	75	0.247
9	0	0	75	0.138

In the first embodiment of the tests, the oil without ESP was fed to the friction pair. In the second embodiment, the olive subjected to ESP was used.

5. Results of the research on wear of the samples by means of the frictional machine

The results of experimental studies are given in Table 7.

According to the results of the research, the regression equations are constructed. They reflect changes in the wear rate of the samples with the same oil operating time, but the load conditions and the degree of electric processing are variable (Table 8, 9).

The dependence given in Table 7–9 is illustrated by the graphs in Fig. 3.

According to the results of the experimental tests (Table 7), the regression equations are derived (Table 10, 11). The equations describe changes in the wear rate of the samples under identical load conditions, but the operating time and ESP application vary. The corresponding graphs are shown in Fig. 4.

Table 7

Orthogonal design of the experiment and results of wear of the test samples

Series of experiments	X_1	X_2	Z, thousand km	P, W/mm^2	Average wear rate of the pad, mg/h	
					Oil without ESP	Oil after ESP
1	–1	–1	0	0.138	0.190±0.016	0.080±0.016
2	+1	–1	150	0.138	0.817±0.021	0.530±0.024
3	–1	+1	0	0.247	0.470±0.016	0.247±0.012
4	+1	+1	150	0.247	1.330±0.016	0.907±0.012
5	–1	0	0	0.215	0.310±0.016	0.177±0.012
6	+1	0	150	0.215	1.070±0.016	0.767±0.012
7	0	–1	75	0.138	0.400±0.016	0.220±0.016
8	0	+1	75	0.247	0.830±0.024	0.523±0.021
9	0	0	75	0.215	0.570±0.016	0.343±0.012

Table 8

Wear rate regression equation γ (mg/h). Oil with the same operating time. Different load conditions

Operating time Z, thousand km	Specific power P, W/mm^2	Regression equation
0	0.138; 0.215; 0.247	$\gamma=1.038-11.312\cdot P+36.667\cdot P^2$
75	0.138; 0.215; 0.247	$\gamma=1.932-20.022\cdot P+63.333\cdot P^2$
150	0.138; 0.215; 0.247	$\gamma=1.853-14.732\cdot P+51.333\cdot P^2$

Table 9

Wear rate regression equation γ (mg/h). Oil with the same operating time. Different load conditions, after ESP

Operating time Z, thousand km	Specific power P, W/mm^2	Regression equation
0	0.138; 0.215; 0.247	$\gamma=0.124-1.365\cdot P+7.500\cdot P^2$
75	0.138; 0.215; 0.247	$\gamma=0.935-9.691\cdot P+32.250\cdot P^2$
150	0.138; 0.215; 0.247	$\gamma=0.410-0.597\cdot P+10.500\cdot P^2$

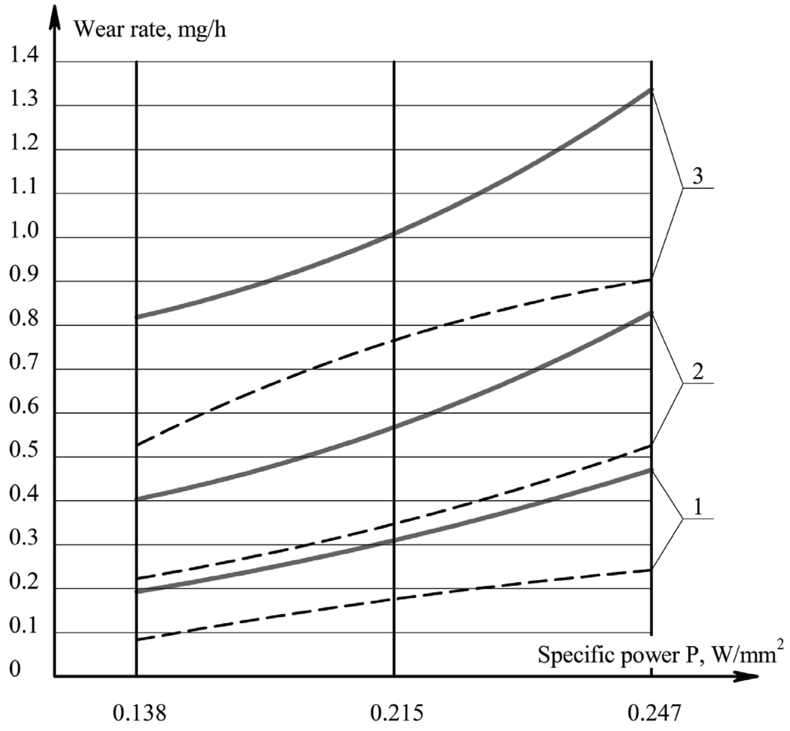

Fig. 3. Graph of the dependence of wear of the samples when using the axle oil, which has the same operating time, but works in different load conditions (specific power) ((«—» — oil without electrostatic processing; «- - -» — oil after electrostatic processing): 1 — as-delivered oil; 2 — oil with an operating time of 75 thousand km; 3 — oil with an operating time of 150 thousand km

Table 10

Wear rate regression equation γ (mg/h).
Oil without ESP, the same load conditions, different operating times

Specific power P, W/mm^2	Operating time Z, thousand km	Regression equation
0.138	0; 75; 150	$\gamma = 0.190 + 1.420 \cdot 10^{-3} \cdot Z + 1.840 \cdot 10^{-5} \cdot Z^2$
0.215	0; 75; 150	$\gamma = 0.310 + 1.867 \cdot 10^{-3} \cdot Z + 2.133 \cdot 10^{-5} \cdot Z^2$
0.247	0; 75; 150	$\gamma = 0.470 + 3.867 \cdot 10^{-3} \cdot Z + 1.244 \cdot 10^{-5} \cdot Z^2$

Table 11

Wear rate regression equation γ (mg/h).
The same load conditions, different operating times. Oil after ESP

Specific power P, W/mm^2	Operating time Z, thousand km	Regression equation
0.138	0; 75; 150	$\gamma = 0.080 + 0.734 \cdot 10^{-3} \cdot Z + 1.511 \cdot 10^{-5} \cdot Z^2$
0.215	0; 75; 150	$\gamma = 0.177 + 0.493 \cdot 10^{-3} \cdot Z + 2.293 \cdot 10^{-5} \cdot Z^2$
0.247	0; 75; 150	$\gamma = 0.247 + 2.960 \cdot 10^{-3} \cdot Z + 0.960 \cdot 10^{-5} \cdot Z^2$

From the graphs in Fig. 4, it can be concluded that the oil operating time in MAB under the same load conditions increases along with the wear rate of the samples. After ESP, the wear rate decreases, while for the as-delivered oil, this indicator reaches 1.92 times. Accordingly, for the oil with an operating time of 75 thousand km, this indicator is 1.61 times, and for the oil with an operating time of 150 thousand km – 1.47 times.

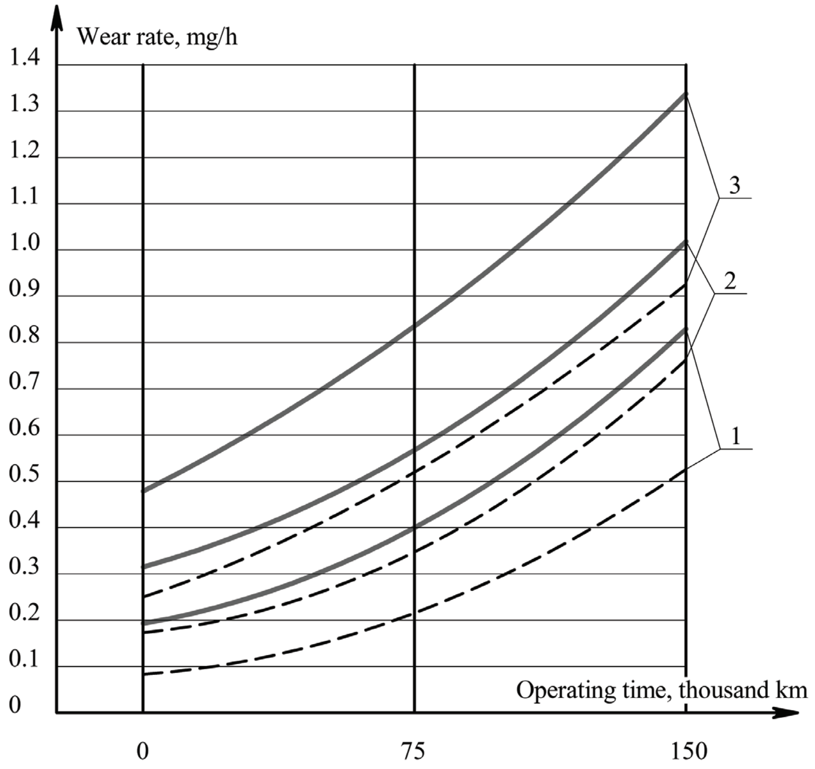

Fig. 4. Graph of the dependence of wear of the samples with the same load and application of the axle oil with different operating times («—» – oil without electrostatic processing; «- - -» – oil after electrostatic processing): 1 – load (specific power) 0.138 W/mm^2; 2 – the same, 0.215 W/mm^2; 3 – the same, 0.247 W/mm^2

6. Discussion of the results of the research on the effect of electrostatic processing on performance characteristics of axle oil

The experimental tests are the continuation of a series of studies aimed at investigating the effect of electric fields on performance characteristics of working fluids. To improve the axle oil performance properties affecting the MAB service life, we have chosen the known method of ESP, which wasn't used earlier to solve the problem. Oil processing by external electrostatic field [26, 27] leads to the destruction of a considerable amount of micellar aggregates in its volume. Consequently, in the volume, including superficial layers, a stable high concentration of polar molecules that exist in the monomer state is established. This increases the adsorption activity of polar-active molecules, increases the lubricant film thickness, and, accordingly, decreases the wear rate of friction surfaces. In the context of the existing problem of the MAB service life, for the first time it was proposed to use the method of ESP of axle oil to solve it. The results confirm the conclusions of previous scientific studies [21, 26, 27] concerning the positive effect of ESP on performance properties of mineral oils.

The shortcomings of the work include a limited range of temperature conditions, in which the research was conducted, and the use of only one brand of axle oil «L». Expansion of temperature conditions, in accordance with the standard requirements for the «L» and «Z» oils, would give a much broader idea of the effectiveness of the proposed method. In the future, it is planned to conduct researches taking into account the above-mentioned shortcomings.

The results of the research can be further used for the complex of measures for the improvement of existing MAB lubrication systems and the expected increase in the reliability of the MAB of locomotives.

7. Conclusions

1. The wear rate of the samples in the «roller-pad» friction pair when using the axle oil with different operating times was determined. To do this, experimental studies were carried out by means of the frictional machine with determining the weight loss of the test samples. It is found that the operating time of axle oil in the MAB lubrication system negatively affects its anti-wear properties. As the frictional forces increase, the wear rate of the samples increases monotonously. Deterioration of lubricating properties of the oil increases the wear rate of the MAB surfaces 3–4 times. Under the same frictional forces, the wear rate of the samples increases along with the oil operating time, and the nature of this dependence is close to linear.

2. The wear rate of the samples in a series of experiments, similar to those in the first stage, was determined, but the oil was subjected to ESP. The hypothesis regarding the improvement of lubricating properties of axle oil after ESP was confirmed in the tests of the physical model of the MAB by means of the frictional machine. It is found that when using the axle oil subjected to ESP, the wear rate of the experimental samples is reduced. Wear rate reduction depends on the oil operating time in the lubrication system. The greatest wear rate reduction of 1.92 times is noted for fresh oil. For the oil state after the locomotive run of 75 thousand km, the reduction is about 1.68 times and for the oil at the end of its service life, wear rate reduction is approximately 1.47 times.

Reduction of the wear rate of the friction pair when using the external electric field is caused by an increase in the thickness and bearing capacity of the boundary lubricant film due to the growth of the adsorption activity of polar active molecules of axle oil in relation to the friction pair materials.

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ESTABLISHING RATIONAL STRUCTURAL-TECHNOLOGICAL PARAMETERS OF THE MILKING MACHINE COLLECTOR

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Досліджено взаємозв'язок між конструкційно-технологічними параметрами колектора та режимами транспортування молока до молокопроводу. Запропонована конструкція двосекційного колектора. Отримана математична модель, яка пов'язує інтенсивність молоковіддачі з технологічними параметрами розробленого колектора, залежно від режимів доїння. Встановлено раціональні співвідношення між конструкційним об'ємом молочної камери колектора та діаметром молочного шланга

Ключові слова: градієнт тиску, дросельний отвір, швидкість доїння, подача повітря, якість молока

Исследована взаимосвязь между конструкционно-технологическими параметрами коллектора и режимами транспортировки молока к молокопроводу. Предложена конструкция двухсекционного коллектора. Получена математическая модель, которая связывает интенсивность молокоотдачи с технологическими параметрами разработанного коллектора, в зависимости от режимов доения. Предложены рациональные соотношения между конструкционным объемом молочной камеры коллектора и диаметром молочного шланга

Ключевые слова: градиент давления, дроссельное отверстие, скорость доения, подача воздуха, качество молока

1. Introduction

The milking machine is designed to perform a very important biotechnological function in the system of machine milking of cows – removal of the created milk from the udder. In this case, main operations are executed by the milking cups. Direct contact with the body of an animal requires taking into consideration anatomic structure of quarters of the udder. The implementation of cycles of milk removal and pressing is the only assignment of milking cups in a general