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Study of the prospect of k-Li lubricant for axle boxes of the railway rolling stock

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Abstract. The use of various types of plastic lubricants (such as LZ-TsNII, ZhRO, etc.) in the axle boxes of locomotives, cars and track machines in the Ukrainian railway network causes technological inconveniences at the stage of procurement, supply and regulation of this process, moreover, their operational capabilities do not quite satisfy modern operating conditions of axle boxes of the railway rolling stock. The paper proposes to solve this problem by using a single brand of modern multi-purpose lubricant on lithium complex basis (k-Li) – MZT – in axle boxes of all types of railway rolling stock. The presented results of the comparative analysis of the physical and chemical properties of the mentioned lubricants demonstrate that the MZT lubricant completely meets the operating conditions of the axle bearings and can provide their high-quality lubrication under any conditions of operation. The tribological studies of lubricants on frictional testing machines, with simulation of their operation with rolling friction and sliding friction, demonstrated that anti-wear, antifriction and anti-cuffing properties of the MZT lubricant are much better than those of LZ-TsNII and ZhRO lubricants. It has been found out that the properties of the MZT lubricant are most effectively used under high load in friction pairs. The paper presents the results of testing the MZT lubricant in the actual conditions of operation of locomotives, railway cars and multiple unit rolling stock, which demonstrated its high efficiency and operation capacity.

1. Introduction

The reliable operation of the axle boxes of the railway rolling stock has a significant impact on its overall performance [1]. Trouble-free operation of the axle boxes can be achieved by using lubricants to grease the elements of the box to prevent their wear, significantly reduce the resistance during the operation of axle boxes and protect the surface of the friction pairs from corrosion [2].

Various types of rolling stock are operated in the Ukrainian railway, such as cars, locomotives, track vehicles of different manufacturers and years of production. Historically, different types of lubricants have been used to lubricate axle boxes of different types of rolling stock – predominantly, a Na-Ca based lubricant LZ-TsNII [3] and a Li-based lubricant ZhRO [4], and a few other brands of lubricant of limited use. This situation creates certain technological and economic problems in the operation of the railway rolling stock. Also, since these lubricants were developed 30-40 years ago, their functional properties do not always meet the modern requirements to box lubricants predetermined by the modern conditions of rolling stock operation with increasing speeds and train weight [5].

The above inconvenience can be solved by using of a single brand of modern multi-purpose lubricant on the lithium complex basis (k-Li) – MZT – in axle boxes of all types of railway rolling stock. As significant research shows, lubricants on k-Li basis have certain advantages over other lubricants, including those on an ordinary Li base, and even more so before Na-Ca lubrication [6, 7 and others].

2. Purpose and tasks of the paper

In order to substantiate the expediency of using a single brand of box lubricant in the rolling stock, a wide range of versatile studies was conducted with the task of comparing the properties and possibilities of common use of LZ-TsNII and ZhRO lubricants vs. the new lubricant MZT in different conditions.

For this purpose, comparative studies of the physicochemical and tribological properties of the named lubricants were conducted in the laboratory. Also, to check the performance of the studied lubricants in real operating conditions of the railway rolling stock, they were tested in the axle boxes of cars, locomotives and multiple unit rolling stock in the regular mode of operation of the latter.

3. Results of laboratory research

3.1. Analysis of physicochemical properties

The properties of MZT lubricant were studied using the standard methodologies (see table 1). The obtained results were compared with the requirements for the currently used LZ-TsNII and ZhRO lubricants, according to the normative documents and technical specification for their manufacture.

Table 1. Results of physicochemical study.

Quality indicator	LZ-TsNII [a]	ZhRO [a]	MZT [b]	Study method
Thickener	Ca-Na	Li	к-Li [a]	-
Temperature limits of application, °C	–60…+100	–50…+120 (for a short term +130)	–30…+130 (for a short term +150)[a]	-
Viscosity at an average shear rate gradient 10 s^{-1}, Pa·s	not more than 420 (at 0°C)	not more than 2000 (at –30°C)	1874 (at –30°C)	GOST 7163 [9]
Shear strength, Pa	not less than 220 (at 50°C)	not less than 350 (at 50°C)	600 (at 20°C) 410 (at 50°C) 180 (at 80°C)	GOST 7143 [10]
Melting point, °C	not lower than 135	not lower than 175	248	ISO 2176 [11]
Colloidal stability, % extracted grease	not more than 22	not more than 15	8.76	GOST 7142 [12]
Mass fraction of free alkali expressed as NaOH, %	not more than 0.2	not more than 0.25	0.16	DIN 51809-1 [13]
Evaporation at 100°C for 1 hour, %	not more than 7.0	not more than 2.5	0.53	ASTM D 2595 [14]
Penetration at 25°C, mm×10^{-1}	200 to 260	190 to 250	260	ISO 2137 [15]
Mass fraction of water, %	not more than 0.4	traces	traces	ASTM D95-13e1 [16]
Corrosive influence on metals	-	withstands	withstands (steel and bronze)	ISO 11007 [17]

[a] Information according to the normative documents for the material.
[b] The values actually determined during the study.

The analysis of the results of physicochemical study demonstrated that all the properties of lubricant MZT meet the requirements for currently used lubricants, and are better by most indicators.

The use of complex lithium soaps on a mixture of fatty acids as a thickener in MZT ensured its high flooding resistance, i.e., formation of stable emulsions with water. In case of heating to rather high temperatures, which occurs during the operation of bearing boxes of the rolling stock, flooding resistance, together with high adhesion properties and thermal stability, ensures the protection of the friction surfaces from corrosion wear.

The low temperature viscosity of MZT has a value that ensures the least possible resistance to the rotation of the bearing in the initial period of motion after a prolonged standstill of the rolling stock, especially in the cold season, when the temperature of the lubricant becomes low enough for transition to the softened state. This value of viscosity will also ensure that the lubricant reaches all pairs of friction of the axle box. This indicator is in some way related to the energy consumption of traction rolling stock for the train movement. The data obtained by studying the low-temperature viscosity are completely correlated with the results of other studies of lithium oils [8 and others]

The strength of the lubricant at the operating temperature of the box must not exceed (300 to 500) Pa, and its minimum value at the highest temperature in the working area should not be lower than (100 to 200) Pa. Since the axle box bearings operate in sealed conditions, and the box is filled with lubricant in sufficient quantity, the possibility of removing the lubricant from moving surfaces is out of the question, and insufficient lubrication of the surfaces is only possible with too high a limit of strength when the lubricant simply does not come to surfaces. The properties of the MZT fully meet these conditions, and it always reaches the lubricant of the friction areas of the axle bearings.

Due to the melting point, MZT has a sufficient margin of properties, which ensures its efficiency with substantial heating, which often happens in the axle boxes, especially during the initial period of operation of a new bearing.

Also, the data in table 1 suggest that MZT in comparison with other lubricants has:

- excellent resistance to separation of the lubricant base (breaking) during the storage and use;
- good anti-corrosion properties for non-ferrous and ferrous metals;
- low inclination to liquid fraction evaporation, i.e., not inclined to increase the concentration of thickener, dehomogenization and a decrease in plasticity;
- good ability to withstand the load and resist pulling out of the bearing.

Rather high physicochemical properties of MZT were the reason for further studies.

3.2. Results of tribological tests

Since the tribological characteristics for LZ-ZNII and ZhRO are not regulated with normative technical documentation, all three lubricants were tested to evaluate the performance of MZT. Anti-wear, anti-friction and anti-cuffing properties were studied on well-known friction and wear machines [18].

One of the machines used in the study was a four-ball extreme pressure tester (FBEPT), used to conduct testing in accordance with ASTM D2596-15 [19] and ASTM D2266-01(2015) [20] standard test methods. The tests were conducted according to the scheme pattern in figure 1, which implements the point contact of the friction surfaces and simulates the work of the higher kinematic pairs. This type of contact is characteristic for roller bearings, which are used in the axle boxes of some track vehicles.

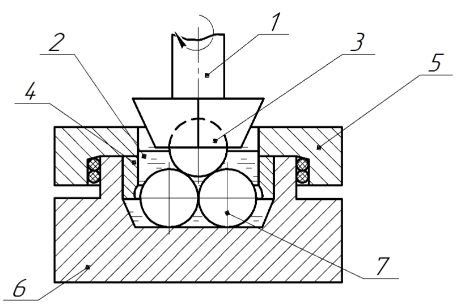

Figure 1. Testing pattern on FBEPT: 1 – collet clamp (cartridge); 2 – tested lubricant; 3 – the upper moving ball; 4 – clamping washer; 5 – nut; 6 – cup; 7 – the bottom fixed ball.

In FBEPT used for testing, standard Ø12.7 mm balls from ball bearings are used in the friction unit.

The results of the study on FBEPT (figure 2) demonstrated the following:

- by welding load (L_W), which determines the boundary capacity of the lubricant, MZT exceeds LZ-TsNII 1.4 times and exceeds ZhRO almost 1.5 times;
- by critical load (L_C), the characteristics of the lubricant are better than those of the other two lubricants by 12%;
- load wear index (I_W) that characterizes the properties of the lubricant at marginal friction, does not differ substantially (by 3.5%) in ZhRO and LZ-TsNII, but in MZT it is about ¼ higher than in other lubricants;
- The diameter of wear scar at loads of 196 N (D_{196}) and 392 N (D_{392}), which determines the anti-wear properties of lubricants, showed that in MZT it is by 27.3% and 30.5% better than in LZ-TsNII, depending on the load, and by 32.2% and by 33.3% better than in ZhRO, respectively.

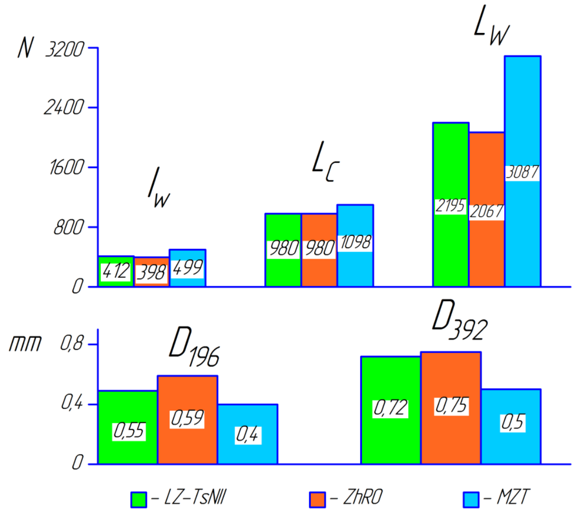

Figure 2. Results of tests on FBEPT.

The tribological properties of lubricants were also tested on a SMTs-2 friction and wear machine according to the generally accepted method [21] using two contact patterns of test specimens:

- the "roller-pad" pattern (figure 3 (a)), which implements the area contact of the tribocoupling and simulates the operation of the lower kinematic pairs. This pattern simulates the operation of tribocoupling with slipping friction. This type of contact is found in roller axle bearings between the end face of the rollers and the flange of the outer ring;
- the "roller-roller" pattern (figure 3 (b)), which implements the line contact of the tribocoupling and simulates the operation of higher kinematic pairs. This pattern simulates the operation of tribocoupling with rolling friction. This type of contact occurs between the working surfaces of rollers and bearing rings in roller axle bearings.

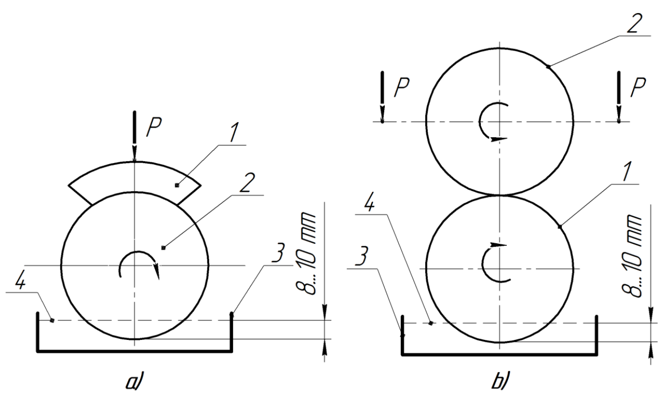

Figure 3. Test patterns on the friction and wear machine SMTs-2: (a) – "roller-pad"; (b) – "roller-roller"; 1 – pad; 2 – roller; 3 – lubricant tray; 4 – lubricant level; 5 – main roller; 6 – counterbody roller.

In these studies, the material of the pads and rollers was the same – steel with surface hardness of (55 to 58) HRC, which is close to the surfaces hardness of the parts of the axle bearings of the railway rolling stock. The maximum (working) load (P) in the friction pair of the SMTs-2 machine was selected based on the loads in the real friction units of the cars, locomotives, track vehicles, motor car rolling stock which were determined using the methods described in [22], taking into account the ratio of the dimension of the parts of the axle boxes of rolling stock and rollers and pads. All tests on SMTs-2 were repeated 4 times for each lubricant with each test pattern, and every time new parts of the friction pair and a fresh portion of lubricant were used, as recommended [21].

In the "roller-pad" tests, the loading mode in the friction pair shown in table 2 was selected. In this case, the rotation rate of the roller was set at 5 s^{-1} (300 min^{-1}). The result of the tests (the level of anti-wear properties of the lubricants) was determined by the weight loss of the friction pair parts during the test. In this case, the control of temperature of the roller surface was used to evaluate the antifriction properties of lubricants.

Table 2. "Roller-pad" test pattern.

Load, N	Time of testing, min.
0	10
50	20
100	30
500	30
800	240
	∑= 360 (6 hours)

Tests on the SMTs-2 friction and wear machine demonstrated that the total wear (W) of both samples (figure 4 (a)) lubricated with MZT was by 30% lower than that of the ones lubricated with LZ-TsNII and by 47% lower than that of the ones lubricated with ZhRO. Similar results are also shown in temperature control (figure 4 (b)) – the antifriction properties of MZT are better than those of the other two lubricants. In samples that were lubricated with MZT, the average surface temperature was approximately by 12°C lower than that in the ones lubricated with LZ-TsNII, and by 17.6°C lower than that in the ones lubricated with ZhRO.

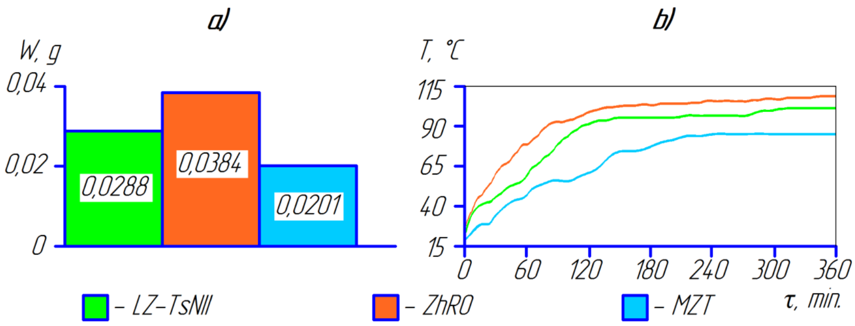

Figure 4. Results of tests on SMTs-2: (a) Total wear of pads and rollers; (b) Temperature of the roller surface during the tests.

The main type of wear in the second contact pattern ("roller-roller") is fatigue flaking (pitting), although there are also other types of wear. Since during rolling friction, the load in a friction pair is much lower, then taking into account the above principles of force calculation and simulation of operation of the friction pair, two test modes were selected on the basis of the "roller-roller" mode (table 3). Two modes were chosen because the estimated values of loads between the roller and the bearing ring in the real operating conditions of the axle boxes of cars, locomotives and motor car rolling stock differ quite significantly. The rest of the test conditions remained as described above.

Table 3. “Roller-roller” test pattern.

Load, N		Time of testing, min.
mode I	mode II	
0	0	10
100	100	10
300	500	20
500	800	20
1,000	1,400	30
1,500	1,800	30
2,000	2,500	240
		∑= 360 (6 hours)

According to the results of the tests shown in figure 5, in the case of rolling friction, MZT provides better wear protection of the friction surfaces vs. LZ-TsNII by 26 to 36%, and vs. ZhRO by 34 to 41%. The same trend was observed in changing the temperature of the friction surfaces. Generally, the temperature of the friction surfaces during these tests was significantly lower than the one during the slipping friction, which is quite natural. The nature of the temperature change was similar to the one shown in the diagram (figure 4). During the tests, the rollers lubricated with MZT had a lower average temperature than those that were lubricated with LZ-TsNII by 9.3 to 11.9°C. In turn, the temperature of the samples lubricated with ZhRO was higher than that o f those lubricated with MZT by 16.9°C to 19.5°C.

The best tribological indicators of MZT lubricants can be explained not only by its k-Li base, but also by the content of certain active components such as sulfur [23].

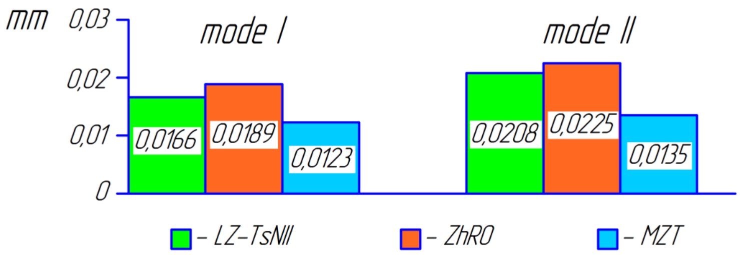

Figure 5. Total wear of rollers in testing on SMTs-2 in the “roller-roller” pattern.

4. Operational tests

Positive results of laboratory tests of MZT were followed by tests in the actual operational conditions of the axle boxes of railway rolling stock, namely, in freight cars, locomotives and electric trains.

Tests on a refrigerator car lasted until it had run 65706 km and were discontinued due to its major repair. During the periodic inspections of the axle boxes of the car, samples of the tested lubricants were taken and further analyzed in the laboratory using standard methods. The results of the study of the properties of all lubricant samples (table 4) showed that during the tests its quality slightly deteriorated, which is quite natural, but even at the end of the test, the values of the indicators are sufficient to ensure the normal operation of the axle box.

The following operational tests were carried out in the axle boxes of cars of the EP-9M No. 540 electric train until it had run 200000 km. During the tests, samples of the tested lubricant were taken from the axle boxes of the cars of the electric train, as in the previous case, to control their operational properties. The results of physicochemical studies (table 5) of these tests showed that MZT had stable properties throughout the test time. After the electric train ran for more than 200000 km, the chemotological parameters of the lubricant correspond to the operating conditions of the friction pairs of the axle boxes of the motor car rolling stock and have sufficient margin to achieve the boundary values.

Table 4. Quality indicators of MZT during the operational tests in the axle boxes of the freight car.

Indicator	Lubricant sample		
	after 20000 km run	after 40000 km run	final
Penetration at 25°C, m×10^{-4}	265	270	280
Melting point, °C	238	231	234
Colloidal stability, %	11.2	11.3	11.6
Mass fraction of free alkali expressed as NaOH, %	0.36	0.37	0.35
Fe content, %	0.018	0.028	0.04
S content, %	1.405	1.365	1.305
P content, %	0.245	0.235	0.230
Tribology on FBEPT at t= (20±5)°C:			
- load wear index	480	480	486
- wear scar at load 196 N, mm	0.4	0.37	0.38
- critical load, N	1.039	980	980

Table 5. Quality indicators of MZT in the operational tests in axle boxes of the electric train.

Parameter	Estimated run of the electric trains at sampling, km			
	more than 20000	more than 45000	about 100000	more than 200000
Colloidal stability, %	2.79	2.77	2.9	2.87
Melting point, °C	247	232	232	232
Penetration, mm^{-1}	266	264	267	271
Mass fraction of water, %	none	none	none	none
Mass fraction of mechanical impurities, %	none	none	none	none

Similar tests of MZT were carried out in the axle boxes of ten freight cars (gondola cars) that had been in operation for more than two years. At the end of the test period, the inspection of the axle boxes of the cars showed that the friction surfaces of the axle bearings were in a satisfactory condition, without apparent significant damage, and the lubricant in them appeared as homogeneous grease, was neither contaminated, nor contained any metal inclusions, traces of rust or flooding. Analysis of the physicochemical properties of lubricant samples, like in the previous case, showed that all the tested quality indicators were rather high, and the change in most of them in comparison to the initial values was negligible, which allows for prediction of the effective operation of lubricants and longer time of operation and runs.

Operational tests of MZT in the axle boxes of locomotives were carried out on locomotive 2TE116 and electric locomotive VL-80. The tests lasted until the locomotive had run 111428 km, and the electric locomotive – 100705 km. During the tests, the axle boxes of one section of the locomotive ran with MZT, and the second section – with the reference lubricant ZhRO (for comparison). During the testing period, there were no problems with the operation of the locomotive axle boxes. During the tests, samples of the tested and reference lubricant were taken to control their operational properties. The results of these tests showed that MZT had stable properties throughout the test time. After the locomotives had run for over 100000 km, the physicochemical and tribological indicators of the MZT corresponded to the operating conditions of the friction pairs of the axle box of locomotives, had sufficient margin to achieve the boundary values and wear at a much higher level than those of ZhRO.

5. Conclusion

In general, all conducted studies show rather high operation capacity of the MZT lubricant, which corresponds to the operation conditions of a pair of rolling bearings of axle boxes of cars, locomotives, motor cars and other railway rolling stock.

The results of separate studies (figures 2 and 5) show that the anti-wear properties of lubricant MZT manifest themselves more explicitly when the load in the friction pair increases. This data comply with the results obtained by other researchers [24], which noted the effect of friction conditions on tribological indicators of oils which have a complex lithium base.

High stability of MZT lubricant recorded during the operational tests provides basis for proposing to extend both operating periods of axle boxes between repairs and lubricant change intervals.

Testing of MZT in the laboratory for possible mixing with ZhRO gave positive results. The mixture of two lubricants has a homogeneous structure; its physicochemical properties are not much inferior to MZT and exceed those of the ZhRO. Partial mixing is allowed during the lubricant change in the friction unit. However, this cannot be the case for LZ-TsNII – it has a fundamentally different base and may not be mixed in operation with MZT, which should be taken into consideration.

For the Ukrainian railway it is especially favorable that MZT is manufactured by a domestic producer “Research and Production Enterprise Agrinol” Limited Liability Company (NVP Agrinol LLC). This significantly simplifies the procurement procedures and increases the stability of the supply of the lubricant.

The results presented in the paper allow for recommending the transfer of all rolling stock of the Ukrainian railways to the use of the single modern universal lubricant on the complex lithium base – Agrinol MZT – in the axle boxes.

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