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Study on the prospects for the use of lubricants produced by Fuchs Lubritech GmbH on the Ukrainian railways in “wheel of rolling stock-rail” tribocoupling

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Abstract. Controlling friction and wear of rolling stock wheels and rails is a very urgent task for railway workers and scientists in many countries of the world, including Ukraine. The use of lubrication of the wheel-rail friction pair is rather a promising way to solve this problem, and the success of the solution depends significantly on the choice of an effective lubricant.

The article considers the results of study of Locolub ECO and Tramlub F 234 MOD 2 greases, taking into account the prospects for their use in locomotive wheel flange lubricators that are operated in the Ukrainian railway. The results of laboratory and operational tests of these greases in comparison with the currently used Relsol lubricant are presented and analyzed. Quite high tribological characteristics of Locolub and Tramlub lubricants and their compliance with the operating conditions of rolling stock, wheel flange lubricators and track lubricators are noted. Based on the results of operational tests, recommendations are given on the prospects for the use of the studied lubricants in the Ukrainian railway transport.

1. Introduction

The problem of wear of the wheel flanges of rolling stock and the gauge face of rails is very relevant for railway transport in many countries [1, 2], since it affects the dynamics of rolling stock movement, its service life, noise characteristics of movement, and cargo safety [3, 4, 5]. In Ukraine, this problem has recently been becoming ever more urgent, primarily due to the increased severity of the operating conditions of rolling stock [18], and, accordingly, the track, as well as the fact that this problem has been neglected for a long time in the national railway.

This problem can be controlled in the traditional way – by applying grease in the “rolling stock wheel – rail” friction pair (lubrication) [4, 5, 6]. This method has demonstrated positive results on rail transport in many countries [1, 2, 7]. To ensure the best effectiveness of the use of lubricants on the Ukrainian railway, it should be taken into account that the factors that have the most significant impact include:

- rational choice of lubricant;



- rational organization of the lubrication process;
- correct operation of the lubricant feed system.

The second factor, which is purely organizational and technical, is the correct choice of the lubricant feed system (lubricator), taking into account the local operating conditions of the track and rolling stock. Currently, there is a certain parity between the use of locomotive wheel flange lubricators and stationary track rail lubricators at the Ukrainian railway. Although it should be noted that locomotive wheel flange lubricators are more commonly used on trunk routes, while rail lubricators are utilized on station tracks and in mountain areas, where there are many track curves of small radius.

Concerning the third factor, it is purely technological and depends primarily on the “culture of utilization” of the lubricants already in use.

It is due to the first factor that can be used to control the efficiency of the entire lubrication process without making changes to existing designs of lubricant feed systems and operating modes of rolling stock and track. For this purpose, an effective lubricant must be selected taking into account the following requirements [6]:

- good performance within a wide temperature range;
- high tribological (anti-wear) properties;
- high adhesive capacity;
- easy to pump through the lubrication system;
- no impact on the performance of components and parts of the lubrication system;
- good environmental properties (biodegradability).

Lubricants for the “rolling stock wheel-rail” friction pair are now manufactured by almost every well-known manufacturer of lubricant oils. There is a wide variety of lubricants, and the essence of the process of rational selection is a deep analysis of the local operating conditions of a specific friction pair; analysis of the design features of the lubrication systems that are already available; conducting necessary preliminary studies to justify the feasibility of using this particular lubricant.

2. The purpose and objectives of the study

Relsol greases, which are currently used on the Ukrainian railway in locomotive wheel flange lubricators, have much poorer performance than that achieved on other railways in the world where other more modern lubricants are used.

It is obvious that in order to reduce the operating costs of the locomotive facilities associated with the operation of the wheel-rail friction pair, it is now reasonable to consider applying other, more up-to-date lubricants to protect parts from wear. One of the world's recognized leaders in this industry is the manufacturer of lubricants Fuchs Lubritech GmbH. Confirmation of the effectiveness of utilization of this manufacturer's greases in the wheel-rail friction pair is their sustained use on the railway in Austria, Switzerland, Germany and other countries of the world.

The purpose of the study which will be discussed in this article was to justify the feasibility of using Locolub ECO and Tramlub F 234 MOD 2 greases by Fuchs Lubritech GmbH in locomotive wheel flange lubricators, which are installed in locomotives of the Ukrainian railway.

To achieve this goal, comparative tests of these greases and Relsol lubricants were carried out both in laboratory and in real operating conditions of locomotive wheel flange lubricators.

3. The results of laboratory studies

Tests of lubricants in laboratory conditions consist in the study of their chemotological and tribological properties. In this case, the performance features of promising lubricants Locolub and Tramlub were compared with those of the currently used Relsol lubricant. During the study, the authors focused on the already established ideas about the quality indicators of lubricants for the wheel-rail friction pair [8] and took into account the experience of other researchers in this field [9]

As for the comparison of chemotological indicators, the complete results of which have been already published [10], it should be noted that the properties of Locolub and Tramlub greases quite suit the operating conditions of locomotive wheel flange lubricators and can provide good pumpability in

the system, even at quite low temperatures, as well as adhesion on working surfaces of tribocoupling, corrosion protection of friction surfaces and parts and components of the system wheel flange lubricator and other performance properties.

To evaluate the ability to protect the wheel–rail friction pair from wear and reduce the energy cost of overcoming the friction forces in it, tests using special friction machines are more remarkable. Such tests were carried out using quite well-known and widely used methods, namely, “four balls in a pyramid” and “block-roller” [11, 12, 13].

Tests on the four-ball friction machine were carried out according to the standardized methods of ASTM D2596-15 [14] and ASTM D2266-01 (2015) [15]. The scheme of the tribocoupling during testing, which is shown in figure 1, implements the contact of friction surfaces at a point and simulates the operation of higher kinematic pairs. Several tribological parameters were determined on the four-ball machine, among them: welding load and critical load, which determine the limits of the maximum performance of the lubricant; load wear index, which characterizes the properties of the lubricant to protect surfaces under boundary friction; the diameter of the wear scar on the surface of fixed balls, which determines the anti-wear properties of greases.

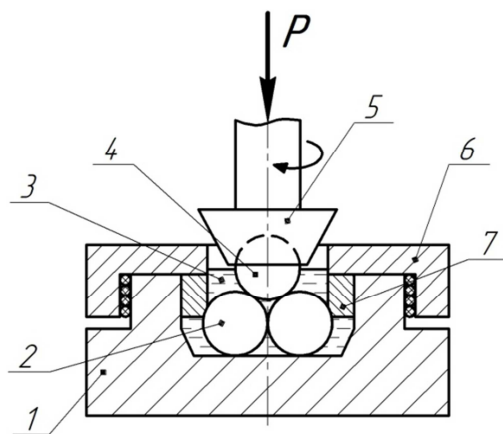


Figure 1. Test scheme on the four ball friction machine: 1 – cup; 2 – bottom fixed ball; 3 – tested lubricant; 4 – upper moving ball; 5 – collet clamp (cartridge); 6 – nut; 7 - clamping washer.

Based on the results of study on the 4 ball friction machine (table 1), the following was established:

- the diameter of the wear scar when loading on the upper ball was $P=196\text{ N}$ is almost the same for Tramlub and Relsol greases, but it is almost 1.6 times larger for Locolub grease;
- the diameter of the wear scar when loading on the upper ball is $P=392\text{ N}$ is 10% larger with greasing with Relsol than when greasing Locolub oil and almost 34% larger than with Tramlub
- the load wear index with Tramlub grease is almost 15% better than with Locolub, and 40% better than with Relsol;
- in terms of critical load, the lubricant exceeds Locolub by 1.33 times, and Relsol by almost 1.6 times;
- in terms of welding load, Tramlub has 1.58 times better performance than Locolub and 2.35 times better than Relsol;

Table 1. Test results on the four-ball friction machine.

Quality indicator	Locolub	Tramlub	Relsol
diameter of the wear scar at a load of 196 N, mm	0.76	0.47	0.48
diameter of the wear scar at a load of 392 N, mm	0.88	0.65	0.98
load wear index, N	429	502	306
critical load, N	980	1303	823
welding load, N	2323	3685	1568

In general, the analysis of the test results on the four-ball friction machine showed that Tramlub is superior in all respects to both Locolub oil and Relsol greases. In addition, Locolub was inferior to Relsol only in terms of diameter of the wear scar at a load of 196 N. The results also show that Tramlub and Locolub greases demonstrate their anti-wear and anti-friction properties better at higher loads, while Relsol practically does not work at high loads and, accordingly, hardly protects the tribocoupling from friction and wear.

Tests according to the “block-roller” scheme (figure 2) were carried out on the SMC-2 friction machine according to the generally accepted method [16]. This scheme implements the contact of the tribocoupling in the plane and simulates the operation of lower kinematic pairs. It provides a simulation of the operation of the tribocoupling under sliding friction, which takes place between the wheel flange of the rolling stock and the gauge face of the rail.

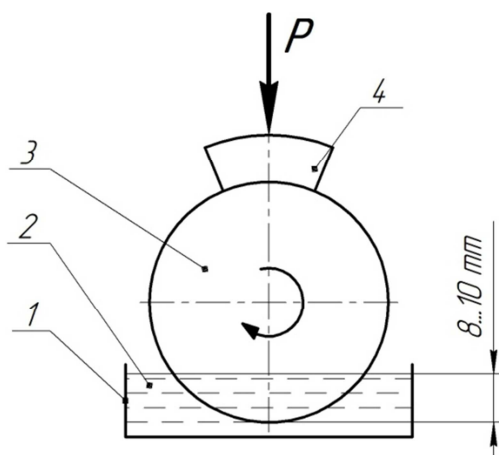


Figure 2. Schematic diagram of the “roller-pad” test on the SMC-2 friction machine: 1 – lubricant tray; 2 – lubricant level; 3 – roller; 4 – pad;

Since the force at the contact point of wheel and rail depends on many factors (such as curve radius, speed of movement, load of the rolling stock, the wheel profile, the degree of wear of both contacting elements [17, 18]), the simulation of power characteristics of work of this friction pair is a very complex process. Therefore, to study the behavior of the grease in different operating conditions of the tribocoupling, tests were conducted in four programs (table 2) with different load modes. In each load mode, tests were performed four times for each grease, each time with a fresh portion of grease using new friction pair components, as recommended [16]. The rotation speed of the roller was 5 s^{-1} (300 min^{-1}).

Table 2. Test program on the SMC-2 friction machine.

Test time, min.	Load, N			
	mode I	mode II	mode III	mode IV
5	0	0	0	0
10	50	100	100	200
10	200	300	400	500
15	400	500	800	1000
20	800	1000	1500	2000
360	1600	2000	2500	3000
$\Sigma=420$				

The block and roller were made of steel and processed to a hardness that is approximately similar to the hardness of the surfaces of the wheel flanges of the rolling stock and the gauge face of the rails, which are used on the Ukrainian railway (hardness of the block is 360 to 370 HB; hardness of the roller is 280 to 300 HB).

The anti-wear properties of the tested greases were determined by the mass loss of the friction pair parts during the tests (the block and the roller in total). The anti-friction properties were evaluated by periodical monitoring the surface temperature of the roller during the entire time of each test.

Studies on the SMC-2 friction machine showed that the total wear of both samples (blocks and roller) (figure 3) lubricated with Tramlub grease is less than of those lubricated with Locolub and Relsol. In addition, the performance of Locolub was worse than that of Relsol only in the first test mode - at fairly insignificant contact loads. However, at the lowest test loads, the difference between the anti-wear properties of all lubricants is only minor - 1.15-1.38%, which is not at all representative and is within the permissible error for such measurements. At the same time, it is remarkable that, as in the case of tests on the 4 ball friction machine, the anti-wear properties of Tramlub and Locolub greases are more intensively implemented at greater contact loads, which is clearly evidenced by the graphs in figure 4. In load mode IV, the wear of parts greased with Relsol is 28% greater than of those greased with Locolub and 37% greater than of those greased with Tramlub.

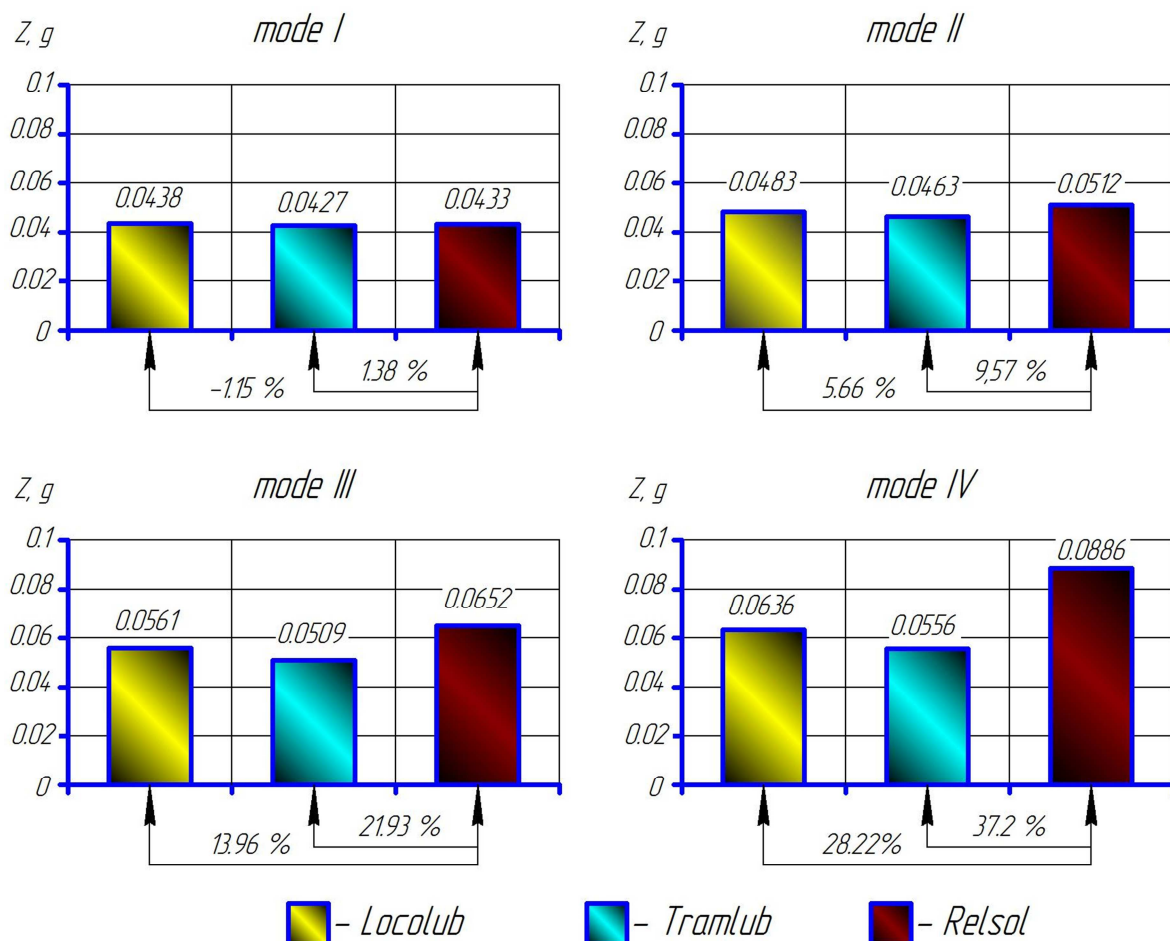


Figure 3. The average total wear Z of blocks and rollers on the SMC-2 friction machine at different load modes (Table 2.)

The best anti-wear properties of Tramlub oil are also proved by the appearance of the friction surfaces after testing (figure 5). A digital microscope photograph of the surface of a roller that was lubricated with Relsol (figure 5, b) shows numerous signs of adhesive wear, which are not observed at all on the surface of a roller that was lubricated with Tramlub (figure 5, a). The wear marks on Figure 5a are more uniform with fewer deep furrows, which indicates a more stable friction mode and, accordingly, better anti-friction and anti-wear properties of Tramlub grease.

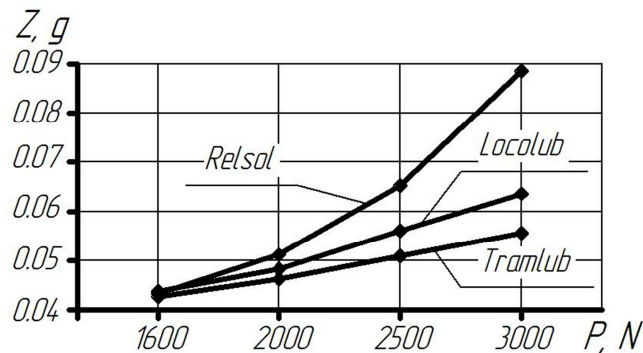


Figure 4. Change in the average wear of samples depending on the load mode

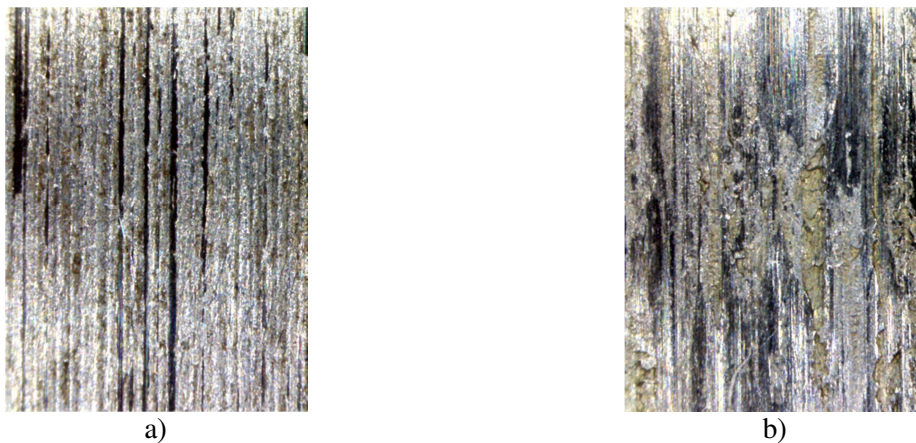


Figure 5. The surface of the rollers which were lubricated with Tramlub grease (a) and Relsol (b) when testing on SMC-2 in loading mode IV

Control of the surface temperature of the rollers showed that in all tests, the highest temperature was on the rollers that were lubricated with the Relsol lubricant. The graph of temperature changes in the roller surface in load mode IV (averaged results of four tests), shown in figure 6, demonstrates that when the temperature of the roller surfaces lubricated with Locolub grease was 10-13°C lower, and of those lubricated with Tramlub - 15.5-19°C than when lubricated with Relsol. A similar trend was observed in other tests, only that the temperature values were slightly lower (in mode III by 7-11%, in mode II by 18-24% , and in mode I by 29-37%), which is quite natural. At the same time, with an increase in the maximum load in the friction pair, the difference in surface temperatures became more significant, i.e., the anti-friction properties of Locolub and Tramlub greases, as well as their anti-wear properties, manifested themselves with greater intensity. This suggests that even better results can be expected when these lubricants are used in a real wheel-rail friction pair, where the contact forces can be significantly greater than those experienced on the SMC-2 friction machine.

In addition, it should be noted that during the tests on friction machines, the worn particles of the tribosurface are removed from the friction zone together with the lubricant. In real operating conditions, the worn particles in the “wheel-rail” friction pair will in fact stay on the surfaces together with the lubricant and be involved in the further work of this tribocoupling. In view of this, the best anti-friction and anti-wear properties of the lubricant (for example, Tramlub) will lead to the prevention of adhesive wear and reduce the destruction of surfaces during abrasive and other types of wear, i.e. the formation of finer wear particles. As it is known, when such fine particles fall into the clearance of the friction pair, they create a positive effect on its operation, separating the surfaces, taking on the load and reducing the wear rate [19].

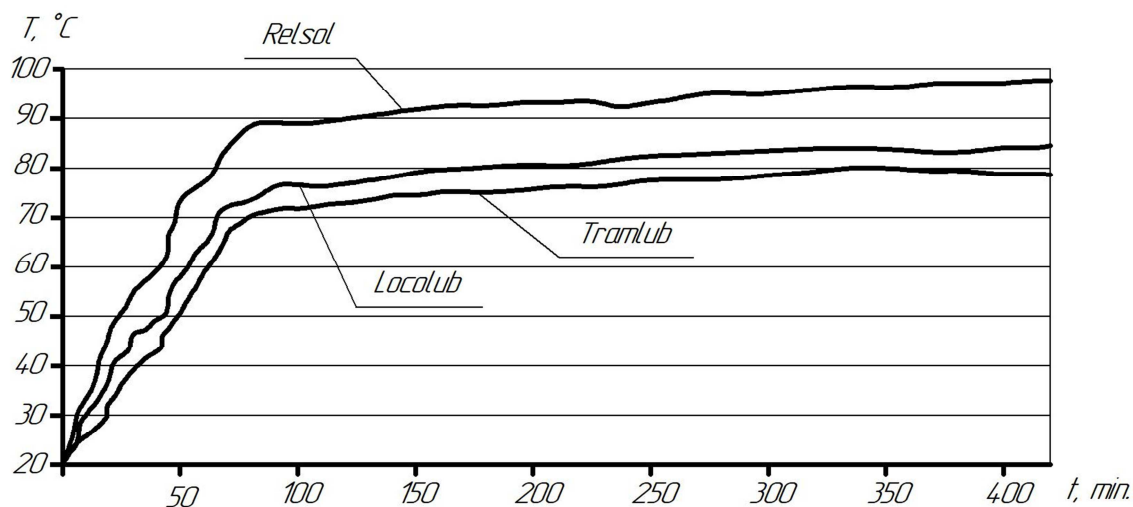


Figure 6. Change in the roller surface temperature during testing on SMC-2 in load mode IV

4. Operational tests

To confirm the results of laboratory tests and justify the feasibility of using Tramlub and Locolub greases in locomotive lubricators on the Ukrainian railway, these greases were tested in real operating conditions of wheel flange lubricators and rolling stock.

Operational tests were carried out on six two-unit locomotives (4 VL-11 locomotives and 2 VL-10 locomotives). The required number of study objects was determined using well-known methods [20]. Also, the number of locomotive wheels that are exposed to the studied lubricants, and, accordingly, their wear control, as well as the number of wheel flange lubricator systems on each locomotive were taken into account. On three locomotives, the wheel flange lubrication systems were filled with Tramlub grease and on another three – with Locolub. The mileage of the locomotives during the tests was about 150,000 km. The test lasted for 16-20 months, so that all seasons were covered and the influence of various natural factors on the performance of the tested oils were studied. During the entire time of testing, there were no issues with the operation of wheel flange lubricators with the studied lubricants.

During operational tests, the geometric parameters of the locomotive wheel flanges were controlled, such as the height, thickness and dangerous shape of the flange, the thickness of the tyre, and the total amount of grease consumed was recorded. Based on the results of measurements of locomotive wheel pairs, the specific change in the average thickness of the flange (wear rate) and the specific consumption of lubricant (in relation to the mileage of the locomotive) were determined. In general, processing of the data complex obtained allowed us to determine a number of parameters related to the effectiveness of the studied lubricants in the wheel-rail friction pair and the operation of the locomotive wheel flange lubricators (table 3). For comparison, the results of the application of Relsol grease were taken from publicly available information about the use of locomotive wheel flange lubricators at the Ukrainian railway transport.

The wear rate of the tyre flanges lubricated with Tramlub oil vs. Relsol decreases by 27.12% on VL-10 electric locomotives, and by 20.65% on VL-11 electric locomotives. However, Locolub ECO grease showed poorer results and the wear of the flanges with it was greater than with Relsol grease, by 7.6% for VL11m electric locomotives and by 28.81% for VL10 electric locomotives. The trend in the ratio of average thickness loss rates of tyres is preserved, but in somewhat other proportions.

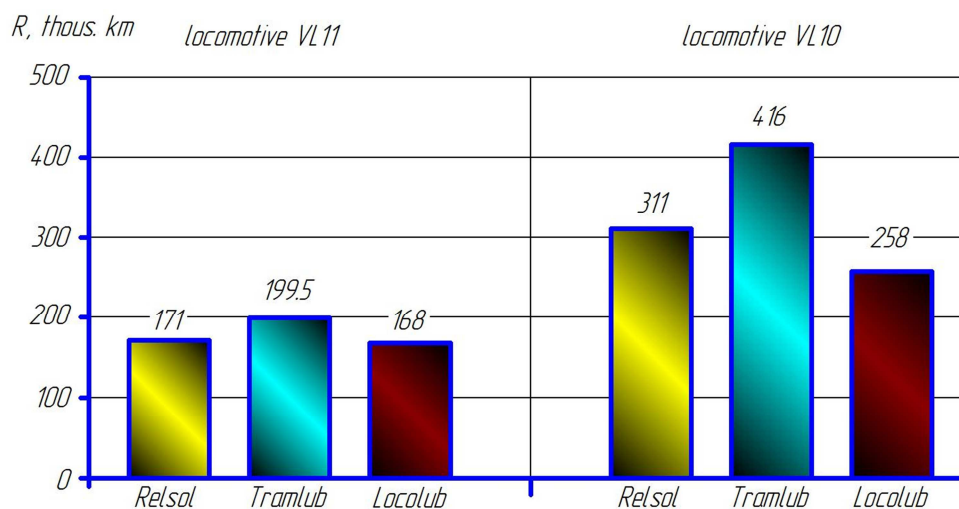
Knowing the average wear rate, the average predicted life of locomotive tyres was estimated, provided that the average thickness of the new tyre is 95 mm (figure 7). Estimations show that when Tramlub grease is used, an increase of the service life of tyres of VL-11 electric locomotives by approximately 16.37%, and VL10 - by 33.76% can be expected; at the same time, the use of Locolub oil can lead to a decrease in the service life of tyres of VL11m by 1.75 %, and VL10 – by 17.04 %.

Table 3. Comparison of the results of using various lubricants in the wheel flange lubrication systems of locomotives

Operational indicator	Relsol		Tramlub			Locolub		
	VL11m	VL10	VL11m	VL11m	VL10	VL11m	VL11m	VL10
1. Mileage of the locomotive during the test, km	-	-	153,878	150,224	50,235	159,895	158,863	97,996
2. Average mileage between tyre returnings, km	15,608	20,130	17,097.6	18,778	36,391	15,989	14,442.1	19,852.8
3. Wear rate of wheel flange, mm/10 thousand km	1.84	1.18	1.414	1.506	0.86	1.923	2.037	1.52
4. Thickness loss rate of the tyre, mm/thousand km	0.319	0.174	0.267	0.285	0.132	0.318	0.338	0.213
5. Service life of the tyre, thousand km	171	311	206 ^a	193 ^a	416 ^a	173 ^a	163 ^a	258 ^a
6. Specific lubricant consumption rate, l/thousand km	0.343 ^b		0.377	0.346	0.338	0.294	0.264	0.245

^a - estimated value, with an average thickness of a full tyre of 95 mm;

^b - estimated indicator for the average locomotive speed of 35 km/h and the grease feed rate of the wheel flange lubrication system twice a minute.

**Figure 7.** The estimated service life of wheel tyres of locomotives

5 Conclusion

The conducted study allows us to state the following:

1) In general, when the Relsol grease is used in locomotive wheel flange lubricators, it performs the functions of protecting the wheel-rail tribocoupling from friction and wear, but its effectiveness is insufficient, especially in view of the current operating conditions of rolling stock and track;

2) Locolub ECO and Tramlub F 234 MOD 2 greases manufactured by Fuchs Lubritech GmbH are proposed for use and have chemotological characteristics that match the operating conditions of the wheel-rail friction pair and locomotive wheel flange lubricators, and meet the requirements for this type of grease.

3) The tribological properties of Locolub and Tramlub lubricants defined on friction machines are better than those of Relsol lubricants. In addition, these advantages are more vivid at higher loads on the friction pair.

4) Performance testing showed definite advantages of Tramlub grease vs. Relsol. However, the Locolub lubricant performed somewhat worse and lost to Relsol in the ability to protect the wheel-rail friction pair from wear in real operating conditions.

5) Quite an important factor in modern conditions is 70-90% biodegradability of Locolub and Tramlub greases declared by the manufacturer, which positively affects the environmental aspects of the use of such greases and is consistent with the modern global trends [12, 13].

6) In general, the obtained results allow us to recommend and state the prospects of using Tramlub F 234 MOD 2 oil in locomotive wheel flange lubricators in existing railway transport in Ukraine in the conditions of track and rolling stock operation.

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