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THE ASSESSMENT OF TRIBOLOGICAL PROPERTIES IN ROLLING-SLIDING CONTACT IN RECIPROCATING MOTION ON A DEVICE FOR SURFACE WEAR TESTING

OCENA WŁAŚCIWOŚCI TRIBOLOGICZNYCH SKOJARZENIA TOCZNO--ŚLIZGOWEGO W RUCHU POSUWISTO-ZWROTNYM NA URZĄDZENIU DO BADAŃ ZUŻYCIA POWIERZCHNIOWEGO

Key words: wear, rolling-sliding contact, reciprocating motion, tribological properties.

Abstract The paper presents wear tests of a sample made of rail steel in a reciprocating motion on an experimental apparatus for surface wear testing. Professional machines for wear tests of rolling-sliding contact, whose main task is to simulate the multiple passage of rolling stock, are large in size and have a significant financial burden on the implementation of scientific projects. The mobile device used for surface wear testing in reciprocating motion has a number of advantages over existing research units with high mass and high financial costs. The proposed device makes it possible to significantly reflect the actual conditions of co-ordination of a rolling-sliding contact, for example, the wheel-rail assembly, while maintaining a reasonable financial outlay for the entire project. The results obtained are highly consistent with those obtained under real conditions, which allows us to put forward far-reaching assumptions about the durability of the contact in question and its wear resistance.

Słowa kluczowe: zużycie, skojarzenie toczno-ślizgowe, ruch posuwisto-zwrotny, właściwości tribologiczne.

Streszczenie W pracy przedstawiono badania zużycia próbki wykonanej ze stali szynowej w ruchu posuwisto-zwrotnym na eksperymentalnym urządzeniu do badań zużycia powierzchniowego. Profesjonalne maszyny do badania zużycia skojarzenia toczno-ślizgowego, których głównym zadaniem jest symulacja wielokrotnego przejazdu taboru kolejowego mają spore gabaryty i cechują się znacznym obciążeniem finansowym przy realizacji projektów naukowych. Wykonane mobilne urządzenie do badań zużycia powierzchniowego w ruchu posuwisto-zwrotnym ma wiele zalet w porównaniu z istniejącymi w jednostkach badawczych, charakteryzującymi się dużą masą oraz wysokimi nakładami finansowymi. Zaproponowane urządzenie umożliwia w znacznym stopniu odzwierciedlenie rzeczywistych warunków współpracy skojarzenia toczno-ślizgowego, np. zestawu koło-szyna, przy jednoczesnym zachowaniu rozsądnych nakładów finansowych na całe przedsięwzięcie. Otrzymane wyniki charakteryzują się dużą zgodnością z otrzymanymi w warunkach rzeczywistych, co pozwala wysuwać daleko idące przypuszczenia co do trwałości rozpatrywanego skojarzenia i jego odporności na zużycie.

INTRODUCTION

In order to reduce the cost of wear testing of rails, many research centres use stationary simulation devices. They allow reflecting the working conditions of the railroad – rail contact. Unfortunately, they are not free from defects. Simulations carried out with full-size rail wheels require that the device has large dimensions. Installing such a device requires special preparation of the room. When designing an experimental research station, the pattern was taken from a large-scale workstation used in the research laboratory of the German company Schienen GmbH and the EMS-60 machine in the Research Institute for Materials and Construction of the Railway Institute in Warsaw **(Fig. 1)**.

The main assumption was the miniaturization of the position, while maintaining the conditions occurring in a wheel-rail contact.

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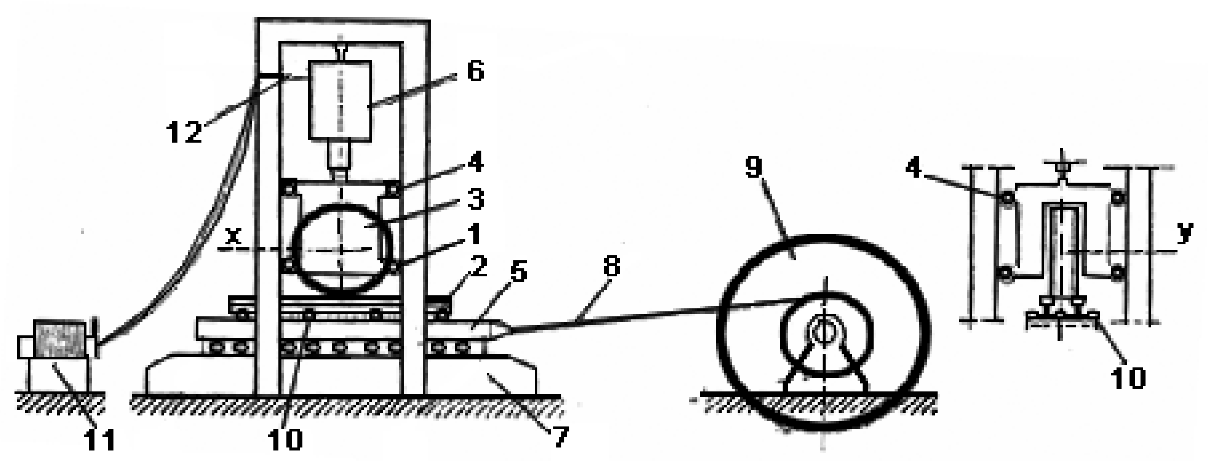


Fig. 1. EMS – 60 Working Diagram: 1 – wheel, 2 – rails, 3 – yoke, 4 – rollers, 5 – table, 6 – cylinder, 7 – cradle, 8 – rod, 9 – flywheel, 10 – props, 11 Pump, 12 – check valve [L. 1]

Rys. 1. Schemat działania maszyny EMS – 60: 1 – koło, 2 – szyny, 3 – jarzmo, 4 – rolki prowadzące, 5 – stół, 6 – cylinder, 7 – łoże, 8 – korbowód, 9 – koło zamachowe, 10 – podpory, 11 – pompa, 12 – zawór zwrotny **[L. 1]**

Fig. 2. Large-scale research station of the wheel-rail contact in the rolling-sliding contact [L. 2]

Rys. 2. Wielkogabarytowe stanowisko badawcze skojarzenia koło-szyna w styku toczno-ślizgowym **[L. 2]**

Tests at the aforementioned stations are carried out by placing a railway track sample on a trolley (platform) that performs reciprocating motion **(Fig. 2)**. The platform is driven by a connecting rod eccentrically with the motor. A railway wheel, which is mounted on a movable frame and pressed by a hydraulic cylinder, is affected by the rail section (anti-sample). The clamping force is dependent on the pressure generated by the feed pump and should reflect the actual wheel pressure on the rail **(Fig. 2)**.

In the works **[L. 3, 4]**, simulations were performed on a station reflecting the real-world conditions. Very similar processes of wear and the impact of operational factors on the mechanism of wear in both the real object or on a laboratory station have been found **[L. 5]**.

The purpose of the study was to design and construct a test station whose test elements cooperate in reciprocating motion on dry-friction, perform tribological wear tests, and determine and compare wear mechanisms in wheel-rail and test machine. The scope of the study included the preparation of a sample for wear testing at an experimental station, tribological research, and preparation for further metallographic research.

MATERIALS, DEVICES, AND CONDITIONS OF TESTS

A number of different materials, from plastics (acrylic glass), structural steel S275JR to bearing steel 100Cr6 have been used in the construction of the experimental test station.

Particular attention was paid to the materials from which the components are made, which directly affect the tests carried out, namely, the thrust bearing, the clamping mechanism, the trolley, and the test sample. Elements made of construction steel S275JR were used to produce a compact, relatively light weight, and low cost construction, while maintaining adequate strength and reliability.

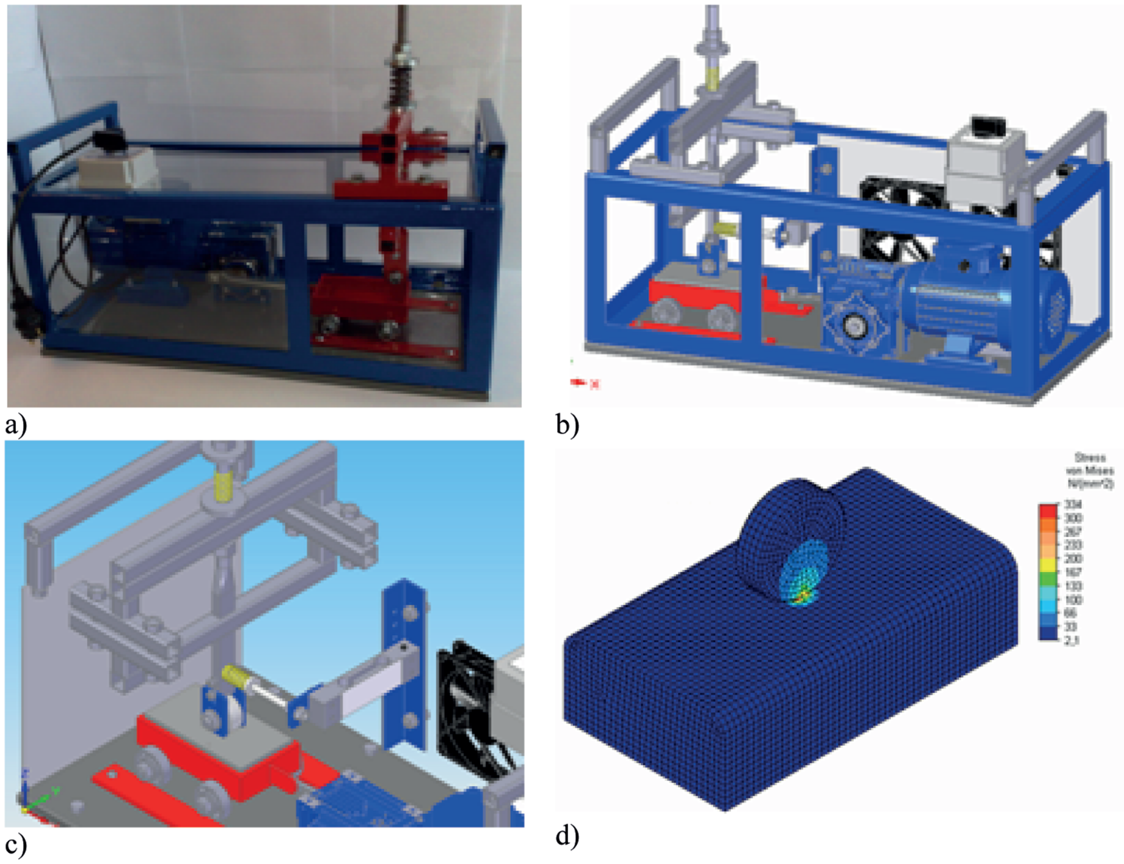


Fig. 3. Experimental station for wear surface testing: a) general view, b) 3D model, c) clamping mechanism with strain gauge beam, d) roller-block combination and MES stress distribution

Rys. 3. Eksperymentalne stanowisko do badań zużycia powierzchniowego: a) widok ogólny, b) model 3D, c) mechanizm dociskowy z belką tensometryczną, d) skojarzenie rolka-klocek i rozkład naprężeń za pomocą MES

Due to good weldability, this material has been used to build the machine frame, the clamping mechanism, the base of the device with the retaining tracks, and the trolley **(Fig. 3)**.

Due to the significant pressures and long load times, the clamping mechanism and wheels of the trolley are made of 100Cr6 bearing steel. The test station is equipped with an electric motor of 1.5 kW, coupled to worm gears to ensure a reliable and prolonged operation of the entire station. The worm gear, through a connecting rod, is connected with a trolley, on which was placed the test sample made of a rail steel. To the surface of the sample is pressed an anti-sample in the form of a ball bearing, using a spring with linear load characteristics. In addition, a strain gauge beam was attached to the measuring system to determine the friction coefficient. In this way, a system for rolling friction is shown, but it is possible to obtain friction rolling with sliding by decreasing the linear velocity of the anti-sample against the speed of a trolley on which a sample is mounted. It is also possible to obtain a sliding friction by replacing an anti-sample with a spindle or block.

Assessment of the use of the tested contact is performed on the basis of weight wear and measurements of the friction coefficient.

In order to carry out experimental laboratory tests on the wear of a wheel-rail contact, it was necessary first to become acquainted with the actual conditions of such a tribological node. **Table 1** shows the typical geometric and operational parameters of the wheel-rail system.

Table 1. Selected geometry and operating parameters of the wheel-rail system
Tabela 1. Wybrane parametry geometryczne i eksploatacyjne układu koło-szyna

PARAMETER	VALUES INTERVAL
weights of railway vehicles, m	20,000–120,000 kg
rail wheel pressure on the rail, P	25,000–100,000 N/wheel
rail wheel radius, R	400–725 mm
width of cooperation track, L	10–18 mm
average number of cycles of railroad wheels on the rail, f	4 million/year

From a number of different sources of information, we have obtained data that have allowed us to designate the pressure ranges, masses, and dimensions of rolling stock commonly used in our country **(Tab. 1)**.

Having collected the necessary data of the real conditions **(Table 1)**, the calculations necessary for the design of the test device were commenced. The main assumption was to reflect actual operating conditions in the laboratory environment, keeping in mind the compact design of the station. For this purpose, the following relationship using the similarity criterion based on dimensional analysis was used **[L. 6]**:

$$\frac{P}{L \cdot R} = \frac{P'}{L' \cdot R'}$$

where
P – the actual object load,
L – the width of the contact of the real object,
R – substitute radius of the real object,
P'– the test object load,
L'– the width of the contact of the test object,
R' – substitute radius of the test object.

The data in **Table 2** are used to reproduce, in the experimental station, the maximum stress in the rail-wheel contact, a pressure of P' = 2200 N.

Table 2. Summary of actual values accepted for calculations and values used in the construction of the test station
Tabela 2. Zestawienie rzeczywistych wartości przyjętych do obliczeń oraz wartości zastosowanych przy konstruowaniu stanowiska badawczego

PARAMETER	CONDITIONS ADOPTED FOR CALCULATION	VALUES USED ON EXPERIMENTAL POSITION
rail wheel pressure on the rail	100 kN/wheel	2200 N
length of cooperation track	∞	70 mm
rail wheel radius	500 mm	20 mm
width of cooperation track	18 mm	10 mm
average number of cycles of railroad wheels on the rail	4 million/year	2 million (striving to minimize the duration of the study)

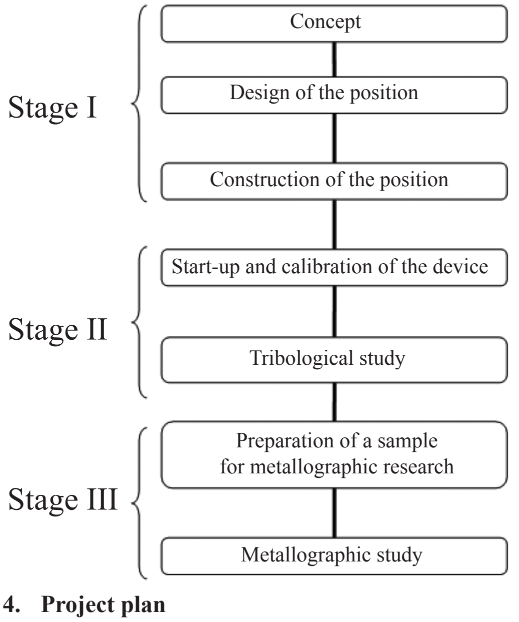


Fig. 4. Project plan
Rys. 4. Plan badań

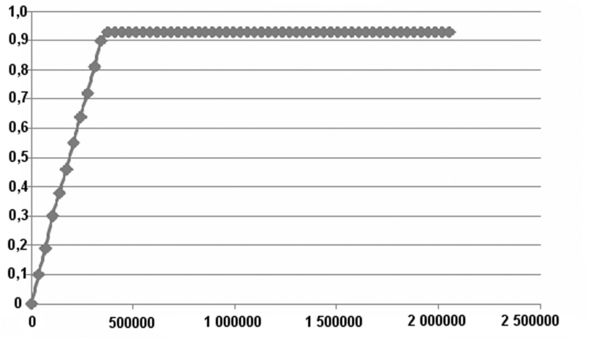
Having solved the structural and operational problems during the construction of the station, the test plan was presented, which is shown in **Figure 4**.

- Stage I includes activities related to the design and construction of the position.
- Stage II is the start-up and operation of the device, and
- Stage III is the study of the considered contact.

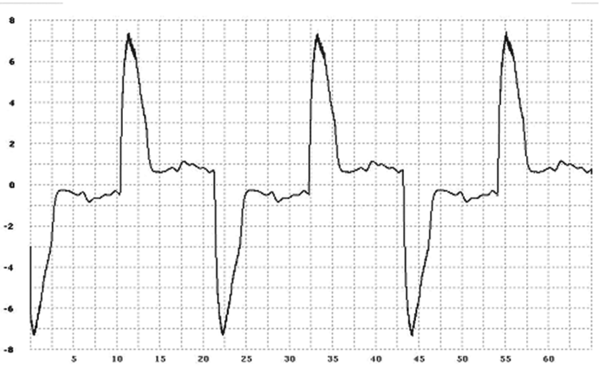
RESULTS

The study was conducted at the experimental station to study the use of the rolling-sliding contact.

The loss of mass of the test sample during the tests was carried out every 50000 cycles, stopping the machine and measuring the weight consumption. Significant weight loss was observed only in the initial phase of wear, which is consistent with surface cooperation of the track area and wear. A weight loss of 0.93 g was recorded, which is 0.63% of the initial mass.



a)



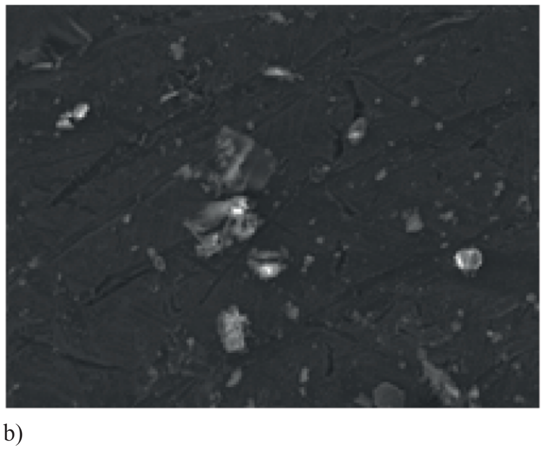
b)

Fig. 5. Changes in mass loss as a function of number of cycles (a), sinusoidal graph obtained with oscilloscope (b)
Rys. 5. Zmiany ubytku masy w funkcji liczby cykli (a), graf sinusoidalny otrzymany podczas badań za pomocą oscyloskopu (b)

The initial stage of the wear process of the test sample proceeded very rapidly. Numerous wear products have been observed in the form of fine dust and material scales. This was related to the stage of lapping the surfaces of the cooperating elements **(Fig. 6b)**. **Figure 5b** shows a graph obtained from the measurement system coupled to the beam strain gauge. As a result of the reciprocating movement, element pressing the anti-sample to the sample surface was bent on both sides. In this way, we are able to determine the coefficient of friction between the cooperating elements.

After the tribological studies, metallographic studies were conducted using a light microscope, which was used to evaluate the mechanism of wear on the studied association. For this purpose, fragments were removed from the rail and tested **(Fig. 6)**.

a)



b)

Fig. 6. Samples prepared for metallographic studies (a) and wear products obtained during tribological studies (b)
Rys. 6. Próbka przygotowana do badań metalograficznych (a) oraz produkty zużycia otrzymane podczas badań tribologicznych (b)

Prepared samples (slices) were subjected to grinding, polishing, and etching. **Fig. 7b** shows the cross-sectional view of the top layer, and the arrow indicates the location of the fracture caused by the variable impact of the operating factors. The abstracted flake exposed the clean material, which is visible in the picture as a bright area below the cracks below the present cracks **(Fig. 7a)**. This also shows the delamination wear process. **Figs. 7a** and **c** show the places of shear, which are characteristic of the adhesive wear process.

Comparing the wear mechanism in the wheel-rail system and the experimental station, there was a significant similarity not only in the wear mechanism but also in the depth of the subsurface cracks that are formed and propagated during the cooperation of the tested contacts.

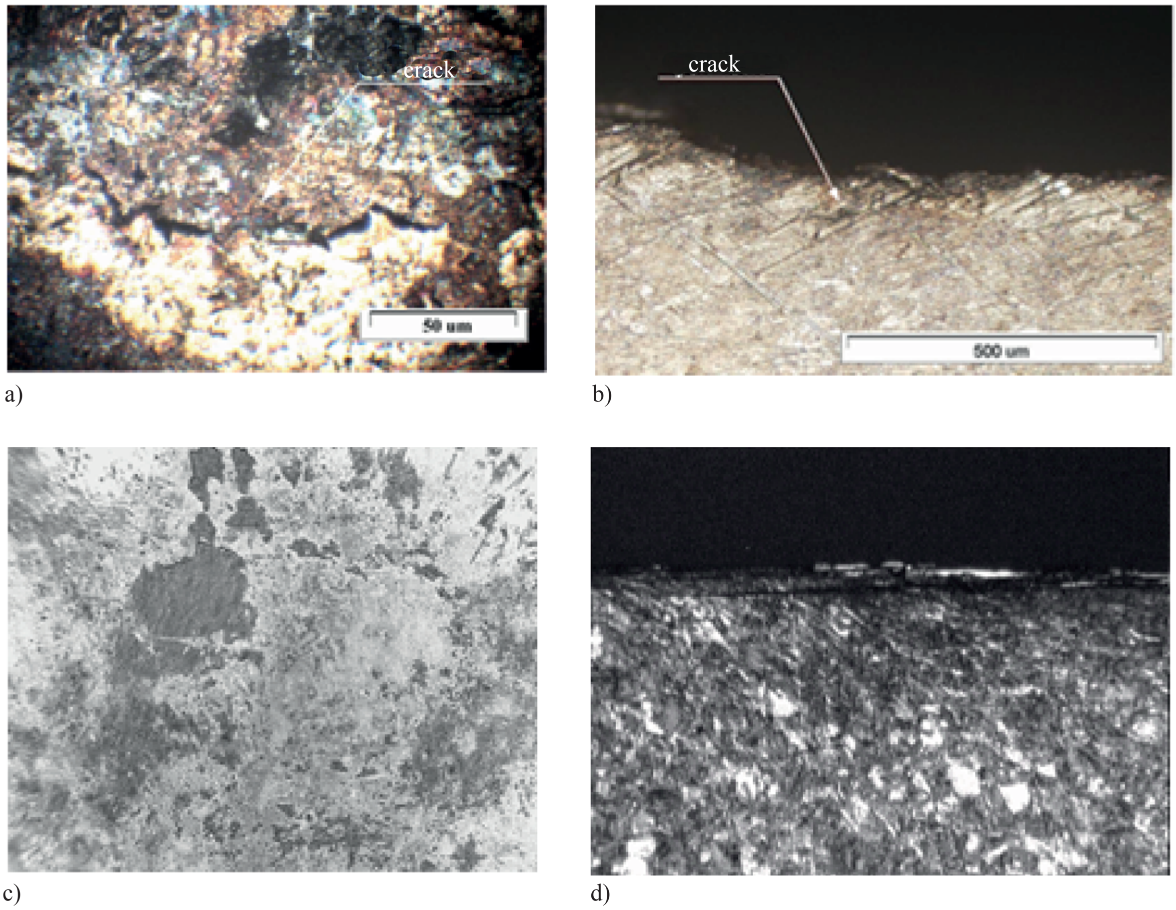


Fig. 7. Rolling surface and top layer: a) and b) sample after cooperation at the experimental station, c) and d) rail operated in real conditions

Rys. 7. Powierzchnia toczna oraz warstwa wierzchnia: a), b) próbki po współpracy na stanowisku eksperymentalnym, c), d) szyny kolejowej eksploatowanej w warunkach rzeczywistych

CONLUSIONS

Surface wear testing machines that reflect the actual conditions of cooperation are large and heavy, making them expensive in operation. The main assumption was to construct a test machine that would reflect the operating conditions of the real object and also meet economic constraints. Metallographic studies revealed a high similarity in the wear process itself, comparing actual, and laboratory objects.

Based on the results of experimental studies, the following conclusions can be formulated:

- Assumptions adopted in the design and construction of the test station have been realized, i.e. compact construction, simplicity of construction, availability and low cost of the components, reciprocating motion of the sample being tested, and a functional reflection of the conditions of the actual wheel-rail contact.
- 2 million cycles achieved during the study are not sufficient to reach the sample wear as a result of annual operation, but they provide a very good starting point for further operation testing.
- The research station provides the opportunity to conduct long-term studies at a low financial cost, and also allows for a number of further modifications (in the presence of test medium).
- Additional systems (lubrication or impurities) should be used to obtain more accurate results of the tests, which provide an even better reflection of the actual conditions of the rail-wheel system.
- Tribological studies can be used to determine the impact of one selected operation factor, which is unlike the case in real conditions (a multiselectional experimental design that can be applied to many operating parameters).
- Comparing the wear mechanisms at the laboratory station and in the real object, a similarity was observed in the process of the formation and propagation of subsurface cracks, which proves that the parameters of construction and operation are properly selected in the construction of the test machine.

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