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Experimental Study of the Limit-Maximum Adhesion Coefficient

M. Gorbunov[1], M. Kovtanets[2], T. Kovtanets[3]

[1]*Volodymyr Dahl East Ukrainian National University, Central Avenue 59-a, 93400, Severodonetsk, Ukraine,*
E-mail: gorbunov0255@gmail.com; kovtanetsm@gmail.com; kovtanect@gmail.com
[2]*Volodymyr Dahl East Ukrainian National University, Central Avenue 59-a, 93400, Severodonetsk, Ukraine,*
E-mail: kovtanetsm@gmail.com
[3]*Volodymyr Dahl East Ukrainian National University, Central Avenue 59-a, 93400, Severodonetsk, Ukraine,*
E-mail: kovtanect@gmail.com

Abstract

The article discusses the modernization of the Wheel-Rail full-scale bench stand for studying wheel-rail grip. The test bench is designed in a way that allows testing to take into account the effect of each separately acting factor, its value and their combination, which are observed under real operating conditions. To obtain quantitative characteristics of the adhesion influence from various surface contaminants, the authors developed a methodology for conducting experimental studies to determine the limit-maximum adhesion coefficient. The results obtained make it possible to predict the control of the change in the adhesion coefficient of the wheel and rail under various frictional contact conditions.

KEY WORDS: *railway transport, wheel-rail, adhesion coefficient, load, sand, abrasive material*

1. Introduction

Analysis of the creation of railway transport showed that the most expensive and problematic is the development and technical implementation of the crew of the locomotive, which largely determines the technical and economic efficiency of the traction vehicle [1-4]. At the same time, the assessment of this efficiency is contradictory, caused by the complex and ambiguous dependencies of the towing and hitching, braking and dynamic qualities of the locomotive in various operating conditions.

2. Research Results

To determine the experimental dependences of the wheel and rail adhesion coefficient on the factors such as the vertical load in the contact, the kinematics of the position of the wheel on the rail and the wheel and rail surface condition, the authors modernized the Wheel-rail full-scale stand, created at the department of railway, automobile transport and hoisting-and-transport machines of the Volodymyr Dahl East Ukrainian National University [5-7]. The authors have made and installed on the stand the device for changing the position of the wheel on the rail with varying vertical and horizontal loads in single-point and two-point contacting, while creating the possibility of changing the frictional state of the contacting surfaces of the full-scale wheel and rail, as well as the possibility of using various methods of cleaning surfaces and varying the temperature in tribological contact. The scheme and general view of the Wheel-rail full-scale stand are shown in Fig. 1 and Fig. 2.

The stand is designed in a way that allows testing to take into account the effect of each separately acting factor, its value and their combination, which are observed under real operating conditions.

The main parts of the stand are: full-scale wheel, rail section, frame, drive, loading system, braking system. The scheme “electric motor-flywheel-multiplier-torque converter-reducer” allows for relatively short drive power to achieve short-term powers sufficient to simulate skidding even at high wheel loads on the rail.

The stand includes a base *1* mounted on a foundation, a drive comprising an accelerating motor *2*, a flywheel *3*, a multiplier *4*, a torque converter *5*, an auxiliary brake 6 connected by a cardan *7* to a gear *8*. The latter is rigidly connected, via a clutch *9*, to the wheel axle *10* A wheel *10* with a semi-axis is installed in the axle box *11*, which is connected with the frame *12* of the stand. On the base *13* of the stand, the main support rollers *14* are installed, as well as two horizontal thrust rollers. The rail *15* is mounted on the support rollers *14* with the possibility of movement relative to the wheel *10*. In the upper part of the stand frame *12,* a loading system is installed, which includes a set of elastic elements *16* and a hydraulic cylinder *17* connected in series with it. The vertical load from the wheel *10* on the rail *15* is created by the hydraulic cylinder *17*, which transfers the force through the elastic elements *16* and axle box *11* to the wheel *10* [5].

The braking system consists of a main magnet-rail brake *18*, designed to create reactive braking force during simulating a traction mode, and an auxiliary drum brake *6* mounted on the drive shaft of the torque converter *5*, designed to control the drive.

It is known that the adhesion coefficient is influenced by a number of factors, the main of which in the operating conditions of locomotives, is the presence of various contaminants on the contacting surfaces of the wheels and rails, the kinematics of the movement of the wheel along the rail, the presence of static and dynamic vertical and horizontal forces. To obtain quantitative characteristics of the adhesion from various surface contaminants, a methodology has been developed for experimental studies to determine the limit-maximum adhesion coefficient [8, 9].

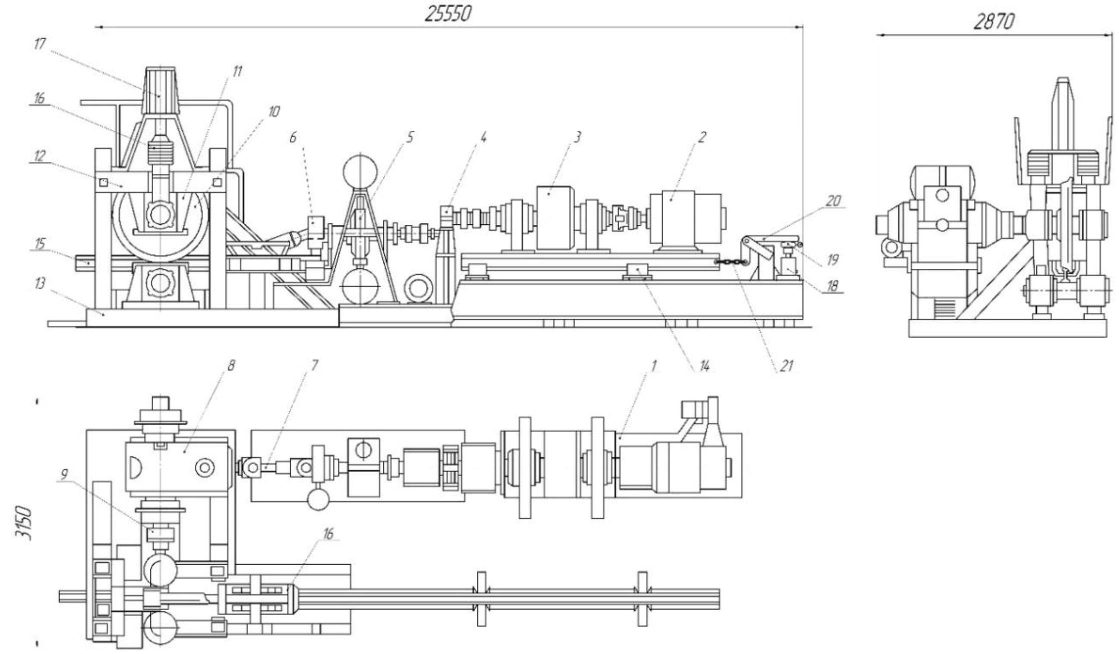

Fig. 1 The scheme of the Wheel-rail full-scale stand

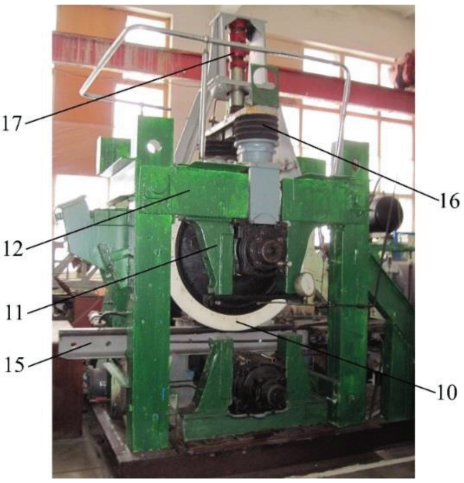

Fig. 2 General view of the Wheel-Rail full-scale stand: *17* – hydraulic cylinder; *12* – frame; *11* – axle box; *15* – rail; *16* – set of elastic elements; *10* – wheel

The studies were carried out at the stand according to the method developed by the authors. The rail *15* on the support rollers *14* rolled up under a previously raised wheel *10*, which then fell on the head of the rail *15*. The wheel *10* was braked by jamming the axle shaft and loaded with a hydraulic cylinder *17*, creating a vertical load $P_{st} = 115$ kN.

The normal wheel effort on the rail was counted on the gauge scale *4* (maximum measured pressure of 25 MPa, accuracy class 2.0), which shows the oil pressure in the cylinder of the hydraulic jack. Recalculation of pressure gauge readings into load value P_{st} was completed according to the formula:

$$P_{st} = P_w + \frac{P_m \cdot \pi \cdot d^2}{4}, \tag{1}$$

where – $P_w = 1\cdot 10^4\ N$ own weight of the wheel; P_m – pressure gauge readings, Pa; $d = 92\cdot 10^3$ m – the inner diameter of the cylinder of the hydraulic jack.

After the vertical loading of the wheel *10* and its jamming, tangential loading was carried out using a specially designed tangential loading mechanism.

Tangential load F_T transferred from the jack *18*, installed on the base *1*, to the rail *15* through the dynamometer *19*, the bracket *20* and the chain *21*. The value of this load was determined by the deviation of the dial indicator (GOST

577-68, division value 0.01-10^{-3} m) with the following listing according to the calibration characteristic of the exemplary dynamometer 19 (DOSM-3-5 according to GOST 9500-84), which takes into account the gear ratio of the bracket *20*, which equals $i = 2{,}445$.

Since the wheel *10* is jammed and frictionally connected with the rail *15*, the force F_T tends to create a slip of the wheel *10* relative to the rail *15*. As a reaction to this force, an external, relative to the rail, adhesion force $F_{ad} = F_T$ occurs that prevents the wheel *10* from slipping relative to the surface of the rail *15*. When the tangential load F_T exceeds the adhesion limit, the wheel *10* is slipping in the contact. At the moment of slipping on the indicator scale installed on the dynamometer *19*, the force value F_T is fixed, which corresponds to the maximum adhesion force F_{ad}.

In this case, the limit-maximum coefficient of adhesion is determined according to the formula:

$$\psi = {F_{ad}}/{P_{st}}\ . \qquad (2)$$

As the initial frictional states of the rail surface, the following states were used: the rail is clean and dry, covered with water, coated with diesel fuel and coated with waste oil [8, 9].

The experimental technique provided for three series of trips with the following sequence of actions:

1. The rail was brought into one of the listed friction kinematic and loading states, after that a series of measuring rolls of the friction machine were carried out;
2. Next, quartz sand was applied to the rail in an amount (≈ 0.1-0.2 kg/m^2), which corresponds to the standard sand supply of 1 kg/min with a standard sand system at a locomotive speed of 5 km/h and the characteristics of this modified frictional state were obtained [10];
3. After that, the rail was subjected to jet-abrasive impact (Fig. 3) using the most effective cleaning mode, and the frictional characteristics for various types of contaminants were determined again.

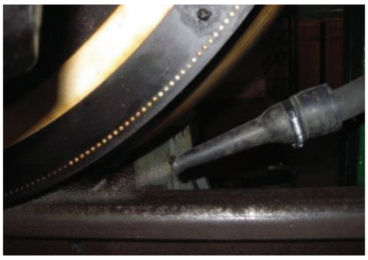

Fig. 3 Jet-abrasive impact on the rail surface

For studying the influence of the frictional state of the contact on the limit-maximum adhesion coefficient, the rail was divided into zones, on each of which a certain frictional state was studied. After each test, the surfaces of the wheels and the rail shifted relative to each other. To obtain reliable and objective data, each test was carried out repeatedly.

As a result of mathematical processing of the experimental data, the values of the limit-maximum coefficient of adhesion (Fig. 4) were obtained for each investigated frictional state of the rail, as well as when sand supply and the jet-abrasive impact on the rail surface (JAI).

For a rail covered with surface contaminants, it is representative that the contact conditions of the rail and wheel will deteriorate. Moreover, this deterioration depends on the type of pollution.

As can be seen from the diagram presented in Fig. 4, with JAI, the adhesion coefficient increases, which can be explained by improvement in the frictional state of the wheel-rail contact due to its cleaning, absorption, and removing of contaminants.

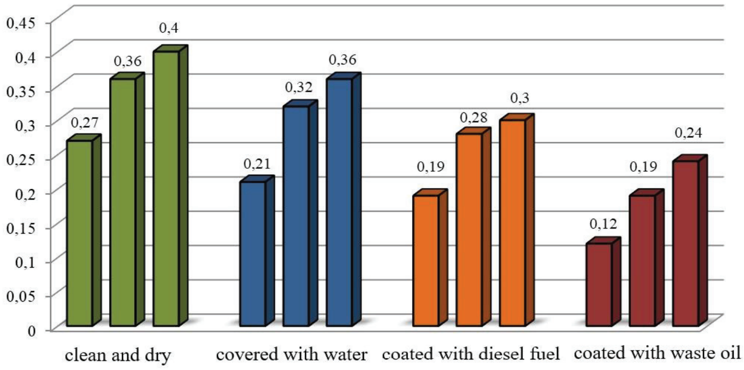

Fig. 4 The dependence of the limit-maximum adhesion coefficient on the frictional state of the rail: *1* – without sand; *2* – with sand supply; *3* – with JAI

Comparing the experimental results obtained for a rail covered with water, fuel and oil, we can see that the effect of cleaning a contaminated rail using a two-phase jet-abrasive stream is more effective than sand supply provided to a rail covered with contaminants.

According to the results of mathematical processing of the obtained experimental data, it was found that the difference in the adhesion coefficient between the sand supply and JAI on the fuel-covered rail is 6.6%. On a clean and dry rail, their difference is 10%, on a water-covered rail – 11.1%, on a oiled rail – 20.8%.

These results allow us to predict the change in the wheel to the rail adhesion coefficient under their various frictional contact conditions.

3. Conclusions

The Wheel-rail full-scale bench stand was modernized and methodology for conducting experimental studies to determine the limit-maximum adhesion coefficient from a different frictional state of the rail was developed.

In accordance with the purpose of the work, theoretical and experimental studies determined the limit-maximum adhesion coefficient, which indicates that on a clean and dry rail the difference between sand supply and jet-abrasive impact is 10%, on water-covered – 11.1%, on fuel-coated- 6.6%, on oiled rail – 20.8%.

Based on the results obtained, it can be concluded the effectiveness and practicability of using jet-abrasive impact on the contacting surfaces of the wheel and rail under different frictional conditions, as well as the opportunity to investigate a number of developed technical solutions in further studies.

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