Some Technical Problems of the Railway Transport and Proposed Ways of their Solution

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***Abstract*— Wheels and rails are the most critical and vulnerable elements of railway transport. The main technical problem of the East-West middle Transport Corridor is the coincidence of European and Russian standards railways that have quite different operational properties. The coincidence of railway tracks of different standards in the middle railway transport corridor with different technical characteristics, operating modes, safety requirements, preventive maintenance, and environmental standards, as well as outdated infrastructure and rolling stock, negatively impacts the efficiency of rail transport. Our research has shown the crucial importance of the tribological characteristics of wheels and rails, which depend on the properties and degree of destruction of the third body, on their operational properties.**

In order to improve the operational properties of wheels and rails, their operating conditions were analyzed, technological and design measures were outlined to reduce loads and sliding speeds, in particular, new, environmentally friendly friction modifiers for the directional and rolling surfaces of wheels and rails were developed and tested, wheel pairs for carriages and electric locomotives and a device for fastening rails with constant track gauge and rail inclination angle were also developed..

Keywords*— *wheel, rail, third body, rolling and steering surfaces, friction modifier

I. Introduction

A characteristic feature of the middle railway corridor is the coincidence of tracks with different track gauges: the track gauge between China and Eastern Europe is 1520 mm, while in China, Eastern Europe, and Turkey it is 1435 mm. This creates problems associated with delays due to the transfer of passengers or cargo from one train to another or the replacement of carriage bogies. Also of note are the varying operating modes and safety measures, preventative maintenance/repairs and environmental standards, as well as aging infrastructure and rolling stock, which negatively impact the efficiency of rail transport.

A characteristic problem for all railways is the control of tribological processes in the contact between wheels and rails. This work is devoted to identifying the causes of instability of friction forces, increased energy consumption for traction and the intensity of wear of wheels and rails, as well as other undesirable phenomena and methods for their prevention.

Our research has shown that separating the friction surfaces of wheels and rails with a third body with appropriate tribological properties is one of the necessary conditions for preventing the above-mentioned undesirable phenomena. The tribological properties of heavily loaded friction surfaces depend primarily on the actual contact area of the surfaces (the degree of third-body destruction) and the tendency of these surfaces to seize. The article shows the dependence of the tribological properties of wheels and rails on the tribological properties of the third body and the degree of its destruction, in particular, its influence on the magnitude and stability of friction forces and the intensity of damage to rubbing surfaces.

II. Features of the Middle Railway Corridor

A characteristic feature of medium-gauge railways is the convergence of tracks of different widths: the track gauge between China and Eastern Europe (the countries of Central Asia and the Caucasus) is 1520 mm, while in China, Eastern Europe, and Turkey it is 1435 mm. This creates problems associated with delays due to passenger transfers, the transfer of cargo from one train to another, or the replacement of carriage bogies. Devices for automatic adjustment of the distance between carriage wheels are known, but they have not yet become widespread, and the conversion from 1520 mm to 1435 mm wide rails is an expensive and labor-intensive process.

In recent years, the role of the Eurasian Railway Corridor (Middle Corridor) has significantly increased for well-known reasons. This corridor includes relatively developed European (Turkey, Eastern European countries, and China) and 1520-standard railways (Transcaucasia and Central Asia). Among these, the infrastructure and equipment of 1520-standard railways are often outdated and require repair or modernization, which negatively impacts their operational characteristics and efficiency. Outdated equipment is characterized by a high rate of damage during operation, which degrades its operational properties (reducing already low speeds, axle loads, traffic safety, etc.). The table 1 below presents the relevant technical specifications of these railways

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TABLE I. THE TECHNICAL SPECIFICATIONS OF THE EUROPEAN AND 1520-STANDARD RAILWAYS

№	Parameter	European standard	Standard in 1520 space
1	Speed of passenger trains	60–120 km/h, high-speed train – 200–350 km/h (in tests 560–580 km/h)	80-100 km/h, and high-speed (Lastochka) and high-speed (Sapsan) trains 140-250 km/h.
2	Maximum speed of freight trains	140 km/h	90 km/h
3	Permissible axle load of a freight car at a speed of 90 km/h	25-30 t.	23,5-25 t.

As can be seen from Table 1, the speed and axle load of European standard railways exceed those of class 1520.

III. WHEEL-RAIL INTERACTION PROBLEMS

Ensuring the normal operational properties of wheels and rails is a fundamental problem in the railway sector. The tribological properties of rails and wheels involve a multitude of processes of varying scales, the essence of which is insufficiently understood, and factors, some of which are unknown or random. Currently, no physical or mathematical model, nor modern test rigs, can fully reproduce the tribological and other processes characteristic of the interaction of heavily loaded wheel and rail surfaces and their impact on the operation of rolling stock [1]. Therefore, an interdisciplinary, experimental and theoretical approach is necessary to solve these problems. Vague recommendations existing in the literature on predicting and monitoring tribological processes at the interfaces of wheels, rails, and friction brakes are often the source of various undesirable phenomena and erroneous decisions to prevent them (railway accidents, increased energy consumption, environmental pollution, etc.). This also applies to the selection of structural materials and lubricants, optimal operating modes depending on various conditions, and measures to improve the performance of wheels, rails, and friction brakes.

The main challenges relate to the interaction between wheels and rails. These issues also include difficulties in predicting and preventing derailments, reducing energy consumption during traction, wheel and rail wear rates, and frictional instability.

One of the conditions for improving the efficiency of wheels and rails is to provide their contact zone with a solid third body. Failure of the third body increases friction instability, wear intensity, and geometric mismatch between the wheel and rail profiles [2]. This can lead to increased friction, increased lateral movement frequency, and further increases in power and thermal load in the contact zone, which negatively impacts train performance, passenger comfort, the risk of wheel derailment, reduced wheel service life, and, consequently, reduced performance [3, 4].

IV. SOLUTIONS TO SOME TECHNICAL PROBLEMS OF WHEEL/RAIL INTERACTION

To address some technical issues related to wheel-rail interaction, we conducted experimental and theoretical studies on the formation of the third body, its loading, damageability, and proposed various technological and design measures. Relative slip at the wheel-rail interface leads to an increase in temperature causing thermal softening of the steel that can even lead to its metallurgical transformation. Furthermore, thermal stresses cause occurrence of residual stresses which contribute to the propagation of cracks in materials [5].

To address some technical issues related to wheel-rail interaction, we conducted experimental and theoretical studies of third-body formation, loading, and damage, and proposed various technological and design measures. Specifically, we investigated the influence of the thermophysical properties of a micro-rough medium on its thermal load [6].

The primary source of surface damage is arising in discrete parts of contact zone. The [7] deals with the solution of the one-dimensional problem of micro roughness temperature, but it does not provide for the influence of the environment of the micro roughness. In the certain contact zones, traces of seizure may be observed due to seizure or adhesion of the contacting surfaces, which occurs when the third body fails. Localized adhesion increases friction and causes even higher temperatures, after which the wear process can become catastrophic. As our experimental studies have shown, third-body failure begins at individual points in the actual contact zone, manifested by an immediate increase in frictional force (torque), accompanied by characteristic noise and signs of seizure at the points of third-body failure. Recovery of individual damaged points was often observed under unchanged operating conditions, but as operating conditions worsened, the number of surface damage increased, leading to multiple lesions. Our experimental researches have shown that in other equal conditions the variation of the friction coefficient mainly depends on degree of destruction of the third body. Therefore, preservation of the third body between interacting surfaces and avoidance the scuffing, has a crucial importance for decrease and stabilization of the friction coefficient, wear rate, etc. This issue became critical especially for wheels and rails in the last 50 years and many works appeared that are devoted to enhancing stability of the wheel flanges against the operational impacts. As operating conditions further deteriorate, a narrow band of damage forms, subsequently spreading across the entire surface, leading to deterioration of tribological parameters and catastrophic wear. The aforementioned stages of third-body failure are shown in Fig. 1.

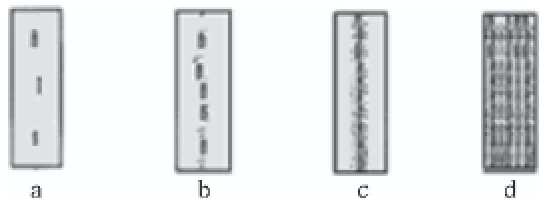

Fig. 1. The damage stages of the interacting surfaces. (a) Unit seizures; (b) multiple seizures; (c) seizures on the narrow strip; (d) seizures on the whole area.

In particular, we investigated the influence of the thermophysical properties of the environment of micro asperities on its thermal loading [8]. Fig. 2 shows the results of solution of the problem for different ambient materials - for water and for oil lubricant: intensity of the temperature reduction toward the base of the micro-asperity is higher for water than for oil lubricant.

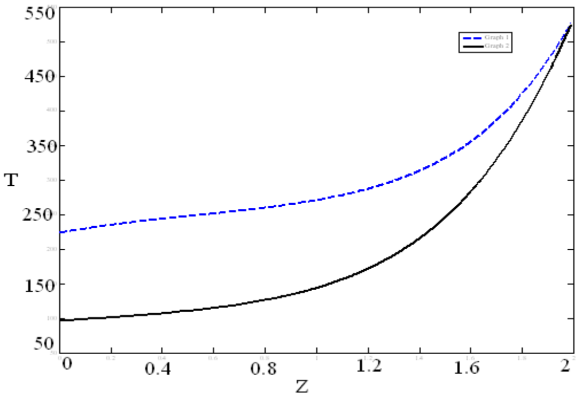

Fig. 2. Dependence of the temperature on the distance from the micro-asperity base for various ambient: ——— water - - - - oil lubricant.

As can be seen from the figure, the increased heat capacity and thermal conductivity of the surrounding micro asperity contribute to improved cooling conditions. As the distance from the heat source increases, the temperature of the micro asperity in water becomes lower than the temperature of the micro asperity in the oil.

We developed and tested environmentally friendly friction modifiers and a device for applying them to the track surface. We also developed wheelsets for railcars and locomotives that reduce the relative sliding velocity, unsprung mass, and radial deviation of the wheelset's axis of symmetry. Thus, the friction modifier enables the formation of a stable boundary layer and third body, while reducing the relative sliding velocity reduces the thermal load and stability of the third body. We also developed a device for unimpeded passage through the place of coincidence of tracks of different standards by a wheelset capable of automatically adjusting the distance between the wheels of an electric train. However, as noted above, a necessary condition for improving the conditions of interaction between the wheel and rail is to provide their contact zone with a continuous third body with specified tribological properties.

Heavily loaded interacting surfaces of wheels and rails are characterized by unpredictable changes in tribological properties, abrupt changes in the friction coefficient, and wear rate. The main cause of wear is considered to be seizure, leading to a sharp increase in tangential deformation of surfaces, friction forces, adhesive and fatigue wear, and seizure. However, various aspects of the complex physical, tribochemical, and mechanical processes occurring in the contact zone remain insufficiently studied [2], which, accordingly, affects the methods for the predisposition of a third body to failure and seizure of the rubbing surfaces.

To study the properties, prediction, and state of the third body in more detail, we performed experimental studies on a two-disc machine (Fig. 6) using existing lubricants and environmentally friendly friction modifiers developed by us. The tests were performed at single application of the friction modifier on the rolling surface of the roller.

The graphs of dependences of the friction coefficient and number of revolutions of rollers until appearance of the first signs of scuffing on the contact stress for initial linear contact of disks are shown in Fig. 3.

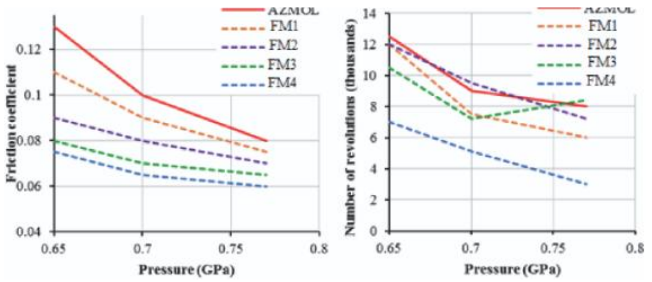

Fig. 3. Dependences of friction coefficients (a) and numbers of revolutions (b) until appearance of the first signs of scuffing on the contact stress for initial linear contact of disks and different anti-frictional friction modifiers.

It is seen from these graphs that for the initial linear contact, when the contact stress is in the range of 0.65-0.77 GPa increase of the contact stress leads to decrease of the friction coefficient. It can also be seen that increase of the contact stress leads to decrease of number of revolutions until the destruction of the third body and onset of scuffing.

Dependence of tribological properties of the interacting surfaces on the properties of the third body and degree of its destruction were ascertained on the base of results of the experimental researches. Research has shown a significant influence of the degree of third-body failure on the tribological properties of rubbing surfaces. In the presence of a continuous third body between the interacting surfaces, the tribological properties of the contact zone are primarily determined by the properties of the third body. In the presence of an intermittent third body, the tribological properties of the contact zone are primarily determined by the degree of its failure, defined using the damage stages of the interacting surfaces (Fig. 1).

To determine the parameters influencing third-body failure, a third-body failure criterion was developed using a system of equations from the elastohydrodynamic theory of lubrication, taking into account thermal processes occurring within the lubricant film and at the interface with the contacting bodies, the dependence of lubricant viscosity on pressure and temperature, and experimental results. The third-body failure criterion is as follows:

$$K \bullet V_{\Sigma k}^{a} \bullet V_{sl}^{\,b} \bullet P_{ll}^{c} \bullet \mu_0^{d} \bullet R^{l} \bullet \left(\sqrt{R_{a1}^2 + R_{a2}^2}\right)^{f} \bullet \beta^{g} \bullet \lambda^{h} \bullet \alpha^{i} \bullet a^{j} \bullet E^{n} \leq 1;$$

where VΣk is a total rolling velocity; Vsl – sliding velocity; Pll – linear load; μ - dynamic viscosity of the lubricant; R – reduced radius of curvature of the surfaces; Ra1 and Ra2 - average standard deviation of the interacting surfaces; β – piezo coefficient of the lubricant viscosity; λ – the lubricant thermal conductivity; α – thermal coefficient of the lubricant viscosity; a – thermal diffusivity; The exponents a, b, c, ... , n and coefficient K are specified on the base of the experimental data obtained by T.I. Fowle, Y.N. Drozdov, Vellawer, G. Niemann, A.I. Petrusevich, I.I. Sokolov, K. Shawerhammer, G. Tumanishvili and are given in the Table IV.

TABLE II. EXPONENTS OF FORMULA (58) PARAMETERS

a	b	c	d	l	f	g	h	i	j	n
0.37-0.7	(-0.36)-(-1.32)	(-0.15)-(-0.265)	0.04-0.52	0.25-0.36	-1	0.6	0.18–0.66	(-.18)–(-0.66)	0.09-0.33	0.045-0.165

As it is seen from the Table 4, destruction of the third body is especially sensitive to the degree b of sliding velocity. It follows from formulas (58), (59) that with increase of the rolling velocity, viscosity, radius of curvature, piezocoefficient of viscosity, heat conductivity factor, thermal diffusivity and coefficient of elasticity the stability of the third body increases and with increase of the sliding velocity, linear loading, roughness of surfaces and thermal coefficient of viscosity it decreases.

Taking some of the parameters as constant, the destruction criteria of the third body can be written as:

$$K_1 \cdot V_{\Sigma k}^{a} \cdot V_{ck}^{b} \cdot P_{п}^{c} \cdot \mu_0^{d} \cdot R_{пр}^{e} \cdot \left(\sqrt{Ra_1^2 + Ra_2^2}\right)^{t} \le 1 .$$

The properties and stability of boundary lubricating layers are manifested in the values of experimentally determined quantities K and e. The diagnostic method and criteria for the destruction of the third body can be used to predict the conditions for the destruction of the third body under laboratory conditions and to determine the conditions for its prevention.

V. CONCLUSION

Wheel-rail interaction is considered one of the key technical challenges in rail transport. The solution to this problem is primarily associated with providing a continuous third body in the contact zone between their rubbing surfaces. Technological and design measures have been applied to improve the stability of this third body. Specifically, environmentally friendly friction modifiers have been developed for the steering and rolling surfaces of wheels and rails. Experimental studies have shown the tribological advantages of our friction modifiers compared to those currently used for wheels and rails. The power and thermal loads in the contact zone between the rubbing surfaces of wheels and rails are reduced by decreasing the relative sliding velocity and unsprung masses. A railcar wheelset with independently rotating wheels and an electric locomotive wheelset with controlled rotation of the wheelset wheels have been developed, along with a device for securing rails with a constant gauge and rail inclination.

ACKNOWLEDGMENT

This work was supported by Shota Rustaveli National Science Foundation of Georgia (SRNSFG) [AR-25-3639, “Improvement of tribological and ecological properties of the railway wheels and rails”].

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