Modern methods of modifying the frictional state of the wheel-rail system

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Abstract. The paper analyzes and provides a systematization of possible methods for increasing the coefficient of adhesion of locomotive wheels to rails. Ensuring a rational value of the friction coefficient at the point of contact between the wheel and the rail makes it possible to reduce the energy consumption for traction, significantly reduce the wear of the wheel and rail rolling surface when passing the curved sections of the railway track, and increase the smoothness of the carriage and its safety during braking. Two fundamentally different methods of improving the locomotive traction qualities have been established - by means of structural improvements of the carriage and a direct effect on the physicochemical properties of the wheel and rail contacting surfaces. Practical methods of increasing the value of the friction coefficient in the contact between the wheel and the rail which include the use of sand, materials of natural origin, abrasive magnetic powder, braking of moving wheels, mechanical cleaning of rails, chemical cleaning of rails, electric spark cleaning of rails, plasma cleaning of rails, cleaning with high-energy sources, cleaning with high-energy sources, transmission of electric current and magnetic flux in the contact zone, the use of various modifiers of friction surfaces, are considered in detail. Their main advantages and disadvantages are noted. It is established that when wheels friction is on rails, mechanical, electrical, vibration, thermal, chemical, and magnetic processes occur simultaneously. In view of this, the practical implementation of a multivariate analysis of the entire complex of these phenomena is in most cases impossible. In this connection, it is suggested to be limited to a small set of factors that could most fully characterize the tribological system under study and determine the basic requirements for the experimental and theoretical studies.

1. Introduction
The instability of the values of the coefficient of adhesion of the locomotive wheels to the rails leads to increased energy consumption and, as a consequence, to a decrease in the locomotive functional efficiency. In practice, two fundamentally different methods to improve the traction properties of a locomotive are used. The first one is to increase the efficiency of using the adhesion coefficient by means of structural improvements of the carriage, traction drive and anti-skid systems. The second method is influencing the physicochemical properties of the tire and rail contacting surfaces. I.V. Kragelsky [1], proceeding from the concept of a discrete contact structure, proposed to calculate the friction forces \( F \) by summing up the resistances arising from molecular and mechanical interaction at individual contact areas:

\[
F = \tau_{mol} \cdot A_{mol} + \tau_{mech} \cdot A_{mech},
\]  

(1)
where $\tau_{mol}$, $\tau_{mech}$ are specific molecular and mechanical interactions or friction forces; $A_{mol}, A_{mech}$ - actual molecular and mechanical contact area.

Therefore, the overall coefficient of friction $f$ is the sum of the molecular and mechanical components:

$$f = f_{mech} + f_{mol}. \quad (2)$$

The necessary measures to increase and stabilize the adhesion coefficient of wheels to rails can be conditionally divided into two groups. Belonging to a certain group is determined by the method of affecting the molecular $f_{mol}$ and mechanical $f_{mech}$ components of the adhesion coefficient (Fig. 1).

Let us consider in more detail the given methods.

2. Methods of solution

2.1. The use of sand

Stable adhesion of the wheels of traction rolling stock is not always realized, which requires a large consumption of sand, as the most effective and widespread method of increasing adhesion at present [2–9]. Due to the use of sand, the coefficient of adhesion of the wheels to the rails sometimes increases up to 70%. But the use of sand leads to intensive wear of wheels and rails, contaminates the upper structure of the track. Wheels "squeal" appears and wavy rail wear with short vertical irregularities develops. The low accuracy of sand feeding into the friction contact zone leads to the ingress of sand on the side surface of the rail and, consequently, to an increase in the wear rate of the wheel rails.

![Figure 1. Methods of influencing the frictional properties of contact surfaces.](image)
The results of experiments in which sand was spread on the tire surface using special prepared briquettes, consisting of sand and some binders are presented. However, there were difficulties in obtaining a uniform layer on the rolling surface, low reliability at high speeds.

2.2. Use of natural origin materials
In [10] it is noted that when using marble chips, potassium carbonate, blast-furnace slag, carborundum, etc. as an abrasive, no difference was found in the use of materials. Professor I.P. Isaev pointed out that the value of the adhesion coefficient depends on the hardness of the powder grains, but there is no single point of view on friction processes in the presence of solid particles in this zone. In [8], experiments on the supply of a jet of non-freezing suspension, consisting of sand, ethylene glycol, water and a binder, to the contact. The positive effect was seen on wet and oily rails. However, this abrasive delivery system proved to be complex and unreliable.

2.3. Abrasive magnetic powder use
Testing of the system [11, 12] that feeds, doses, distributes and retains abrasive magnetic powder on the rolling surface (grinding waste was carried out on a full-scale stand manufactured at the Lugansk Machine-Building Institute and on the test ring of the Lyudinovo diesel locomotive plant (diesel locomotive TGM - 4A)). Tests have shown the effectiveness and efficiency of this system. The use of abrasive magnetic powder increases the adhesion coefficient by 20 ... 30%. However, this system was not put into operation.

2.4. Partial braking of the driving wheels
In practice, light braking of locomotive wheels has become widespread [13, 14]. The tires are cleaned before long lifts. Partial braking can be used to reduce excess torque from a skidding wheelset. But this cleaning method cannot be considered effective, since additional wear of the brake pads and wheelset tires occurs. It should be noted that anti-slip braking can only be effective if locomotives have highly sensitive slip detection systems.

2.5. Mechanical cleaning of rails
Mechanical removal of dirt from the rolling surface is carried out using scrapers, brushes, elastic rollers located in front of a moving locomotive [15]. This method does not allow one to properly clean the contacting surfaces, the range of application is limited (no more than 15-20 km / h), low reliability in relation to the safety of train traffic.

The examples of cleaning rails using a strong jet of dried air [15], water or steam [16] are known. However, this method can only be used during summer. It is possible to clean the railheads [16] with a flame, it was supposed to heat up the rails in the most difficult sections, where there is a limitation of the weight norm of trains by adhesion. But this method is not profitable economically, as it requires huge energy costs.

2.6. Chemical cleaning of rails
Chemical cleaning of rails is based on the interaction of lubricant films, fatty acids with some chemical solvents. Various methods of chemical cleaning of rails were tested on a number of railways [17]. Experiments in which rails were treated with weak solutions of ether-caprylic acid showed that the adhesion coefficient increased to 30%. The rail surfaces were treated with an aqueous solution of polyamide resin and an alkali solution [18]. Effective chemical treatment of rails requires considerable time; it must be repeated after the passage of several trains. This limits the practical use of this method.

2.7. Electric spark cleaning of rails
The experiments related to electric spark treatment of rolling surfaces with high frequency current [19, 20] are known. With this method, a high-temperature effect on the treated surfaces occurs, while a
high degree of cleaning is achieved. But there is a process of seizure of surfaces with pulling out of metal. The wear of the contacting bodies increases, which is explained by a change in the structure of the surface layers themselves, which is expressed in the formation of a thin layer of martensite with inclusions of pearlite and austenite. Since this method of cleaning is effective only on dry and clean rails, it did not go beyond the scope of experiments and did not find application in operation.

2.8. Plasma cleaning of rails
Much work has been carried out to increase the adhesion of the wheels to the rails by destroying the surface of the pollution films using plasma [21, 22]. The efficiency of using a plasma-cooled argon-hydrogen torch corresponded to an increase in the adhesion coefficient by about 0.1-0.2. However, this method, due to its complexity, has not found application on locomotives.

2.9. Cleaning with high energy sources
In [23], it is supposed to influence the substances of surface contaminants (especially oily or ice-covered rails) with an energy flow of microwave electromagnetic oscillations of the millimeter range (MW). In addition, it is proposed to use microwave heating with other cleaning methods (hot air, ultraviolet or infrared radiation). The positive qualities of this method include smooth regulation of heat flow, high speed, preservation of the material structure of the wheel and rails. The disadvantage is the need to create radiation only in the nearest radiation field.

2.10. Electric current in the contact zone
Currently, work aimed at studying the effect of an electric current passing through the wheel-rail contact on the adhesion coefficient is underway. The article [24] presents the results of testing electric locomotives VL22M and VL23, which showed that when the motors were operated with a current of 250A, the adhesion coefficient was 0.25, and with current of 500A, it was 0.49.

2.11. Magnetic flux in the contact zone
The introduction of a magnetic field into the contact zone [25, 26] made it possible to increase the adhesion coefficient by 22%. However, the physical nature of the magnetic field effect currently has no general explanation. This is how the magnetoplastic effect is known [26]. The essence of this effect is to weaken the interaction of dislocations with obstacles. This effect is manifested in the change: the speed of the macroscopic flow in the surface layer; creep; yield point; internal friction. The study of the magnetic field influence on the tribological characteristics of the friction pairs of wheels with rails has not been studied properly and requires further research.

2.12. Friction surface modifiers
In a number of countries (USA, Canada, France), the friction modifiers Centrac VHPF, HPF, LCE are used to improve the parameters of frictional contact [27–29]. The new generation of friction modifiers is usually used in the form of a rod and is applied to the wheel using lubricators installed on locomotives in liquid form or using hand-held applicators. Modifiers like HPF improve friction conditions. However, each modifier cannot meet a wide range of environmental and track management requirements. When modifiers with a friction coefficient greater than 0.2 are used, problems associated with negative friction, wheel seizure, and dynamic braking arise [28, 29].

3. Conclusion
Many issues regarding the increase in adhesion are still unresolved. This is due to the fact that when wheels friction is on rails, mechanical, electrical, vibration, thermal, chemical, and magnetic processes occur simultaneously. A multivariate analysis of all these phenomena is practically impossible and, therefore, it is advisable to be limited to a small set of factors that could characterize the tribological system under study.
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