Proceedings of 23rd International Scientific Conference. Transport Means 2019.

Reducing the Wheel-Rail System Wear Intensity with Thermomechanical Impact

M. Gorbunov[1], M. Kovtanets[2], G. Bureika[3], T. Kovtanets[4]

[1]*Volodymyr Dahl East Ukrainian National University, Tcentralny 59-a, 93400, Severodonetsk, Ukraine,*
E-mail: gorbunov0255@gmail.com
[2]*Volodymyr Dahl East Ukrainian National University, Tcentralny 59-a, 93400, Severodonetsk, Ukraine,*
E-mail: kovtanetsm@gmail.com
[3]*Vilnius Gediminas Technical University, Saulėtekio al.11, LT-10223 Vilnius, Lithuania,*
E-mail: gintautas.bureika@vgtu.lt
[4]*Volodymyr Dahl East Ukrainian National University, Tcentralny 59-a, 93400, Severodonetsk, Ukraine,*
E-mail: kovtanect@gmail.com

Abstract

The article discusses the method of controlling friction in the wheel-rail system, which suggests using compressed air that passes through the Ranque-Hilsch tube and is supplied to a wheel-rail contact area as a third body. This method allows to provide efficient energy and resource saving, stabilize the amount of locomotive traction and braking effort required for effective starting and braking of rolling stock, reduce wear intensity in the wheel-rail system and increase the level of environmental safety of the railway transportation process.

KEY WORDS: *rail transport, wheel-rail contact, friction coefficient, temperature, cooling, clutch control*

1. Introduction

The ability of railway transport to protect the lives of passengers, the safety of cargo and the environment in general determines its development and its achievement of a leading position in the transport market. One of the urgent tasks of energy and resource saving on the Ukrainian railways is significantly to reduce the material and energy costs associated with the contacting and wear of friction pairs in the “wheel-rail” system.

Wear of wheelsets of railway rolling stock is considered a change in their profile under the influence of forces arising between the wheel and the rail during movement. The amount of wear on the wheel is estimated by the size of the excavation in a circle of its skating, which is called rolling, as well as reducing the thickness of the ridge. Friction wear is divided into [1]:

1) molecular seizure, occurs when sliding friction with low speeds and at high specific pressures (the particles of one rubbing surface penetrate into the other and are separated when the surfaces move relative to each other);
2) oxidative, occurs due to the destruction of metal oxides with increased fragility (for example, corrosive wear);
3) heat generated during sliding friction with high speeds and high specific pressures due to the rapid temperature increase and the separation of metal particles;
4) abrasive, arising in the process of removing metal from the surface of parts due to the ingress of solid mineral particles (especially typical for rolling stock, since all friction units are saturated with abrasive particles of quartz sand fed to the contact zone of the wheel with the rails to increase their coefficient of adhesion and prevent boxing);
5) fretting, occurs when rolling friction and loads, exceeding the yield strength of the metal, resulting in fatigue micro cracks on the surface and the detachment of metal particles.

In recent years, the turning of wheel pairs of locomotives has significantly increased, due to the formation of thermoplastic defects on the wheel rolling surface, which leads to the removal of a metal layer and leads to an increased consumption of wheel material. One of the reasons for the emergence of defects is the formation of thermal micro cracks on the wheel rolling surface as a result of repeated heating and cooling in the process of wheel sliding (skidding) along the rail to a temperature at which structural transformations occur, and quickly dissipating the released heat to the cold metal of the wheel after sliding stops and cooling by counter-flow of air. As a result of this process, with further growth and unification of micro cracks under the action of contact loads, chipping of the metal on the rolling surface of the wheel occurs. The causes of this kind of damage are:

a) faulty locomotive brake equipment;
b) braking inefficiency – the actual parameters of the braking forces exceed the calculated ones due to the scatter of friction forces between the individual wheel pairs;
c) reduction of wheel adhesion to the rail during braking due to improper operation of sand systems and lubrication systems.

The world experience of locomotive operation demonstrates the solution of the problem of increasing the rolling stock wheel life, working under conditions of increased axial loads and speed, which requires a systematic approach and is a complex task for improving the stability of friction forces between the wheel and the rail during braking and braking.

2. Reducing the Wheel-Rail System Wear Intensity with Thermomechanical Impact

Carried out in the works [2, 3, 16] analysis of the reasons for the failure of the steel tires of locomotive wheelsets indicates (Fig. 1) that the main ones are: the maximum wear of the ridge (43.64%), the pointed ridge of the ridge (20.91%), the excess of the allowable difference of wheel diameters (15, 45%), various types of defects and shell wheel rim (9.09%), the occurrence of a slide on the rolling surface (5.45%), chips (3.64%) and other reasons (1.82%).

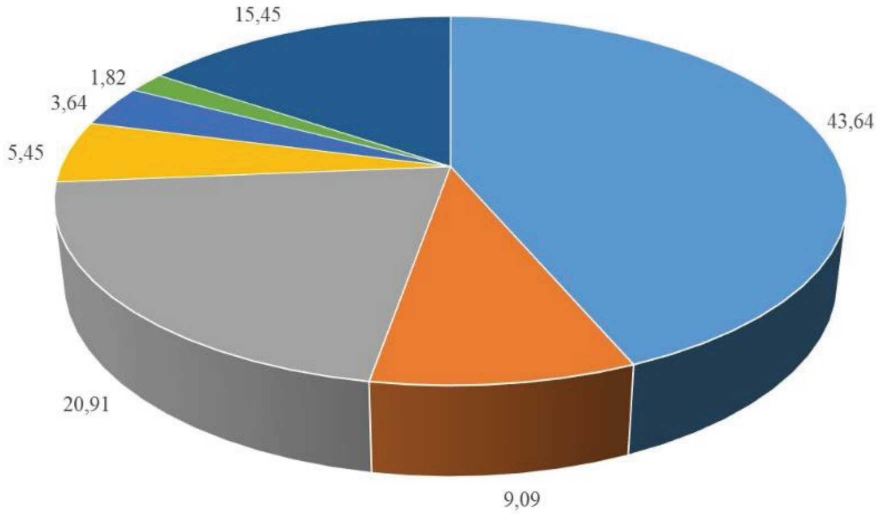

Fig. 1 The locomotives wheel pairs tire failure reasons

As can be seen from Fig.1, the most common reason for the failure of the wheelsets is the wear limit of the ridge. The intensity of wear of wheel flanges and rails on the side surface can be significantly reduced by using special systems for lubricating the surface of the wheel flange. To solve this problem, in 1995, a program was introduced to reduce the wear rate of a wheel-rail pair, increasing the reliability and durability of rails and wheelsets of rolling stock, which operated until 2005, but even now the wheel turning level on the ridge reaches 100 % This is due to the fact that track locomotive lubricators are practically not serviced, there is no lubricant and there is no unified approach to its composition and application. Proper use of lubricants is the most effective way to protect against increased wear of wheels and rails. Lubrication systems should be universal for various types of rolling stock and track sections, there should be no operational restrictions on the speed of rolling stock when applying a lubricant in a wide range of surface temperatures, and the lubricant should be resistant to various weather conditions and precipitation.

To a large extent, wear of the wheel flange and the side edge of the rail occurs when the wheelset runs onto the rail in curved sections of the track, and wear is particularly intense in dry and hot weather.

To reduce the wear of the friction pair “wheel-rail” on the railways of Ukraine, the following measures are used:

1) use of stationary lubricators before turnouts;
2) lubrication of rails with mobile rail lubricators;
3) plasma hardening of wheel flanges;
4) the use of wheel flanges surfacing;
5) grinding rails;
6) the elimination of rail joints with welding self-propelled machine;
7) the use of lubricators on the locomotive.
8) After analyzing these events, it has been established that they have several disadvantages, namely:
9) in winter, lubricant thickens, which leads to disruption of the normal functioning of the feeder and does not solve the problem of wear of the wheel and rail;
10) lack of specialists and inefficient work of rail-lubricating systems made in Germany due to the lack of proper maintenance, adjustment and diagnostics;
11) hit of grease on the rolling surface of the wheels and spacing on the rail head, which leads to the process of sliding or skidding;
12) deviation of the direction of the nozzles and graphite rods in the process of locomotive movement.

Therefore, to solve this problem, it is necessary to conduct a scientific substantiation of the choice of methods and structures to reduce the cost of wear of the wheel-rail system, which will increase the profitability of rail transport by reducing the operating costs associated with the overhaul life of rolling stock, and reduce wear rolling surfaces of wheels and rails and the number of turning or wheelset replacements.

According to the research Luzhnov Y.M. when the surface temperature in the local contact exceeds 450 °C, there is a significant deterioration in the mechanical properties of the interacting surfaces, which leads to a decrease in the friction force and their intense wear [4]. Thus, theoretical and experimental studies have confirmed the fact that it is the temperature in contact that is the most important factor that influences the whole complex of contacting material properties [5-7]. This is confirmed in the works [1, 8, 9] where it is established that the number of turning points of wheel sets of locomotives grows in hot, dry weather in the period from May to September (Fig. 2). This is explained by the fact that on a snowy road and frost on the surface of the wheel (raceway and ridge) and rail (rolling surface and side of the head) an ice film is formed, which is a natural lubricant and protects the interacting surfaces of the friction wheel-rail system the growth of surface temperature, and, consequently, the yield strength and wear.

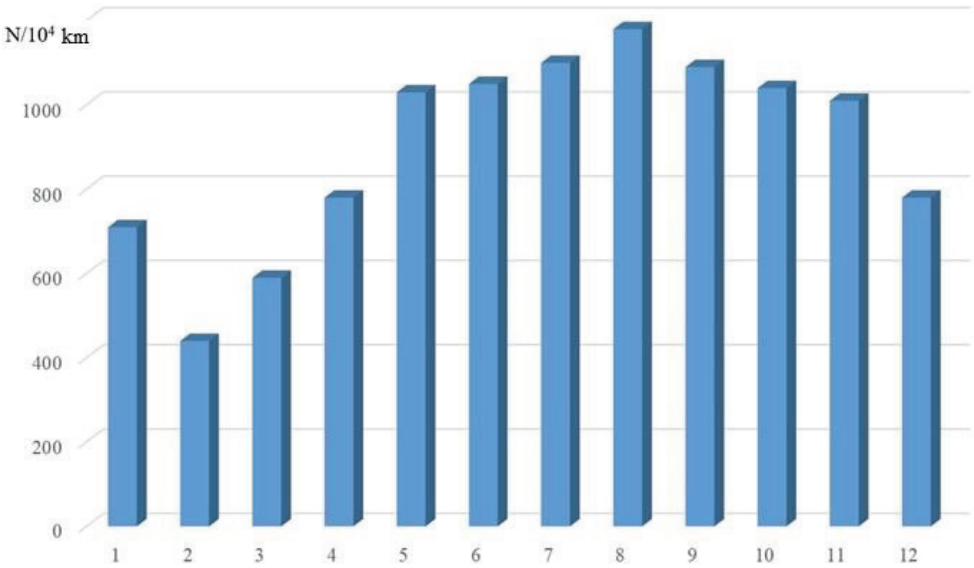

Fig. 2 The number of wheelset turnings

Authors of this work propose the control of the process of frictional interaction of the tribological contact by temperature control by forced cooling, which will allow stabilizing the friction coefficient. On the basis of numerical experiments and bench tests, it was established that controlling the temperature in the tribological contact zone creates conditions for controlling the wheel-rail adhesion process, and enforcing the constancy of the temperature at the contact stabilizes the coefficient of adhesion at the maximum-maximum level. [5, 10]. One of the way to achieve this goal is to develop a new method of controlling the wear rate of the tribological system “wheel-rail”, which involves passing a compressed air flow through a vortex tube that works on the Ranque-Hilsch effect, and separates the compressed air flow simultaneously into two components - cold and hot [11, 12].

The Ranque-Hilsch vortex tube consists of a cylindrical tube, an inlet, a swirl chamber, an outlet for hot and cold air, the general view and layout of which are shown in Figures 3 and 4. When high-pressure air flows into the vortex chamber of the Ranque-Hilsch tube the periphery of the chamber forms a swirling flow with a higher temperature, and in the center a swirling cooled flow, with rotation in the center of the chamber going the other way than at the periphery. Part of the air is cooled, expands and concentrates in the center of the tube, the other part of the air acquires great speed, heats up and remains at the periphery. The Ranque-Hilsch tube allows for the supply of incoming air with a pressure of $P = 0.4 \ldots 1$ MPa and a temperature of 20 °C to obtain at the outlet a cold air flow with a temperature of + 20 °C to –80 °C and simultaneously hot - with a temperature from + 40 °C to + 150 °C [13].

Fig. 3 General view of the Ranque-Hilsch vortex tube

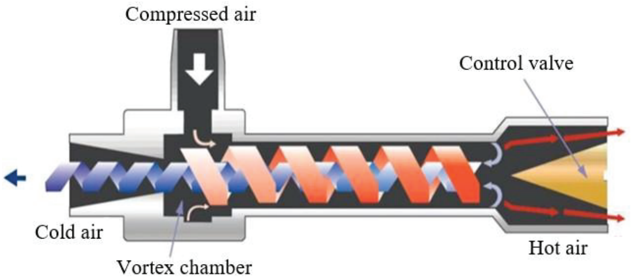

Fig. 4 The work scheme of the Ranque-Hilsch vortex tube

The study of the Ranque-Hilsch tube allows us to distinguish five basic parameters of the system (Fig. 5) at the inlet, at the outlet of the hot stream, and at the outlet of the cold stream [13]: pressure p_i, p_h, p_c, temperature T_i, T_h, T_c, density ρ_i, ρ_h, ρ_c, velocity V_i, V_h, V_c and enthalpy flow $\dot{H}_i$, $\dot{H}_h$, $\dot{H}_c$.

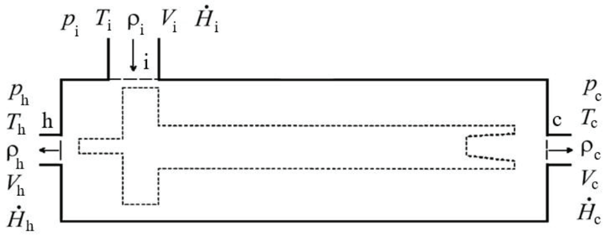

Fig. 5 The main parameters of the Ranque-Hilsch tube

As indicators of the effectiveness of vortex tubes, the following temperature differences are used: $\Delta T_h = T_h - T_i$ – the difference between the hot and inlet temperature, $\Delta T_c = T_c - T_i$ – the difference between the cold flow temperature and the inlet temperature, $\Delta T_{hc} = T_h - T_c$ – the difference between temperature cold and hot streams [14]. The application of the proposed method of controlling the wear rate of the tribological system «wheel-rail» will increase the coefficient of adhesion and reduce wear of the rails due to the supply of hot air to the contact «wheel-rail», which reduces the likelihood of the process of skidding (slipping), reduce wear of wheel flanges and lateral faces of the rails by creating a wet film (condensate), and reduce the operating costs of their lubrication, discard technologically complex existing devices.

Compressed air (hot or cold) after passing through the Ranque-Hilsch vortex tube is proposed to be used in three modes:

1. At the beginning of the locomotive pulling away, in order to avoid blocking and improving grip, a stream of compressed hot air is supplied to the wheel-rail contact area, which leads to preliminary contacting surface heating, drying them from moisture and cleaning the contact zone from the unfavorable third body. This mode will reduce the likelihood of boxing, reduce the wear of the wheels of the locomotive and rails, reduce the consumption of equipment materials and eliminate the blockage of the ballast prism with sand.

2. The cold component of compressed air flow is directed to the «wheel flange-side rail» contact zone, which, due to the temperature difference, will sometimes cause condensation to occur on the contacting surfaces, reducing surface wear and mimicking the winter environment.

3. At the time of starting, braking or braking, the temperature of the wheel and rail steels increases, the elastic modulus and tensile strength decrease, creating favorable conditions for plastic deformation and the process of setting the roughness of the roughness of the contacting surfaces. As a result, metal particles are pulled out from the wheel or rail surface and metal particles are transferred from one surface to another.

In order to avoid this phenomenon, it is proposed to feed the wheel-rail tribological system through supplying cold compressed air to the contact zone by controlling the local mechanical temperature component in the range from 250 to 450 °C, depending on the frictional contact conditions. Experimental studies were carried out on an upgraded SMC-2 friction testing machine, which allows tribological tests of samples according to the disc-friction scheme (Fig. 6).

From the rail P50 according to GOST R 51685-2000 and bandage according to GOST 398-96 samples of the investigated disks were made Ø35 mm (Fig. 7), the rolling surface of which was previously ground to a roughness of $Ra = 2.2$, which corresponds to the roughness of the rail head and the rolling surface of the tire in operation [15]. The studies used two frictional states of a friction pair: clean and dry, covered with water, and three proposed modes of using compressed air. The friction modes for both experiments were the same:

a) compressed air was supplied to the zone of contact of a friction pair "disk-disk" at a speed of 150 m/s and a temperature of 80 °C (errors in measuring the speed are ± 3 m/s, temperatures – ± 5 °C);

b) disk rotational speed $n = 500 \pm 10$ min^{-1};

c) specific pressure in the zone of contact of disks 0.9 ± 0.2 MPa.

Fig. 6 Machine test model SMC-2

Fig. 7 Friction pair "Disc-Disk"

The results of experimental studies (Fig. 8) show that with a clean and dry state of the contacting surfaces, the value of the friction coefficient of a «disk-disk» pair increases when compressed hot air is supplied to the zone of their contact by 6,67%. With a further increase in the surface temperature of the contacting surfaces of the «disk-disk» pair, the flow of compressed cold air is supplied, which makes it possible to obtain a stable friction coefficient higher by 9,4% than during preliminary heating and by 16,67% of the initial value (Fig. 8).

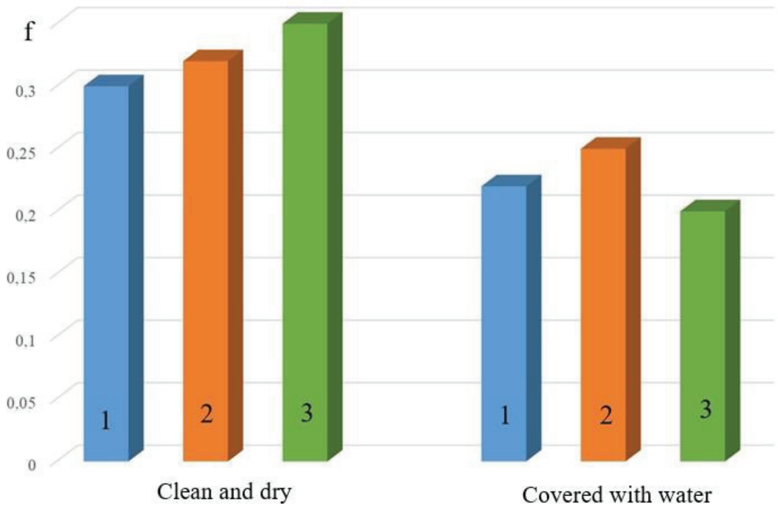

Fig. 8 Histogram of changes in the maximum coefficient of friction

When contacting surfaces covered with water, the supply of compressed hot air to the zone of their contact causes an increase in the friction coefficient by 13,6% of the initial value (without the supply of compressed air). But the flow of compressed cold air on the surface covered with water causes the formation of a thin ice film over the surfaces of the friction pair, thereby reducing the friction coefficient by 9,1% below the initial level (Fig. 8).

3. Conclusions

According to the results of theoretical and experimental studies, it was established that the temperature at “wheel-rail” contact of interacting surfaces is the most important factor that influences the whole complex of contacting material properties, as well as the intensity the wear of elements.

Based on the obtained results, an algorithm to control the thermomechanical loading of local tribological at “wheel-rail” contact is proposed. It consists in cleaning and forcibly cooling the contacting surfaces with hot or cold compressed air obtained using the Ranque-Hilsch vortex tube to achieve a stable temperature in the contact and stabilize the adhesion coefficient at the maximum-maximum level.

Acknowledgement

This research was funded by a grant (No. S-LU-18-12) from the Research Council of Lithuania and Ministry of Education and Science of Ukraine. This research was performed in cooperation between Volodymyr Dahl East Ukrainian National University, Ukraine and Vilnius Gediminas Technical University, Lithuania.

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