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Mykola Gorbunov, Rostislav Domin, Maxym Kovtanec, Kateryna Kravchenko

Volodymyr Dahl East Ukrainian National University

THE MULTIFUNCTIONAL ENERGY EFFICIENT METHOD OF COHESION CONTROL IN THE "WHEEL-BRAKING PAD-RAIL" SYSTEM

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Summary: The paper considers the question of decrease in probability of slipping and skidding occurrence by controlling the friction in the contact "wheel-braking pad-rail". The variants of technical solutions on multifunctional (temperature, abrasive) controlling tribocontacts by of energy air, air-abrasive stream or pellets of dry ice, electrified sand supply are proposed

Keywords: interactions in the "wheel-braking pad-rail" system, the temperature in tribocontact, the coefficient of cohesion

1. INTRODUCTION

The issue of safety in transport remains one of the urgent problems of the modern world. Moreover, its alertness is boosted with increasing population mobility and freight flows. There is a need in the progressive development of the transport sector, providing competitive and high quality transport services, improve environmental performance, energy efficiency of the transport processes in the unconditional security of transportation of passengers and cargo.

The safety of the transport process depends on many factors:

- state of the railway;
- rolling stock design (conditions of interaction of the wheelsets with the rail track, the presence of highly efficient braking system);
- the human factor;
- availability of modern diagnostic technologies;
- systems of control and regulation of movement of vehicles, etc.

One of the significant factors affecting the safety of rail vehicles is the process of interaction in "wheel-braking pad-rail "system which ensures the reliability of the implementation of traction and braking. Interactions in the system "wheel-brake shoe", "brake disc-pad", "wheel-rail" are complex tribological processes, which largely depend on the design features of the rolling stock and the rails, frictional contact state, etc.

The stability of the locomotive tractive and braking effort implementation is possible due to the process of cohesion control in the contacts, depending on their friction condition. The presence of contamination on the wheels rolling surface and rails is one of the main reasons for the decrease and instability of the coefficient of friction, and therefore traction and braking effort of the locomotive. Therefore, existing methods of the coefficient of friction increase are based on cleaning of these surfaces or on the supplying into the contact zone substances, partially destroying the flick of contaminations and promotes the cohesion conditions improvement.

Development of theoretical and experimental substantiation of various methods of multifunctional cohesion control in the "wheel-braking pad-rail" system for the coefficient of friction increase and stabilization, the safety and efficiency of the transportation process improvement.

2. RESEARCH ANALYSIS

To date, research schools and centers in many countries (Great Britain, USA, France, Japan, Germany, The Netherlands, etc.) tested such methods of increasing the cohesion in the wheel-rail system – arc, laser, plasma, chemical and blast cleaning, supply of abrasive materials of different properties in the contact and other. Many of the established methods yielded positive results, but had not received wide dissemination and implementation because of their inherent flaws. Therefore, the experts conducted a further search of the most effective methods to control the cohesion.

In the research works [7, 12, 16] it is indicated that contamination of the roll surfaces of wheel and rail, forming an intermediate layer, called the third body, adversely affects the cohesion quality of the locomotive. To improve traction in conditions of usage the most widespread are special feeder in the contact zone of abrasive material and cleaning of roll surfaces. In [12] proposed to regulate the quantity of supplied sand to the contact depending on the quantity of moisture or contamination of the rail surface and the speed of the locomotive. In the paper [4] the cleaning front wheel rails in pairs effect on the coefficient of friction is researched. According to research [13] the coefficient of friction depends on the nonequilibrium state of the surface nanolayers of wheel and rail in the contact area caused by the increase of temperature in them up to10^3 K. In research works [6, 15] showed that to ensure a high cohesion qualities of the locomotive to the wheel contact with the rail should be supplied a certain amount of sand. There are other ways of increasing the cohesion in the contact of wheel with rail, however, due to the difficulty and complexity of the research question improve gripping qualities of the locomotives remains open.

In the world practice of rail transport operation, the most common method of regulating the cohesion is the supply of sand to the rails. The study of different designs of sand systems allowed to identify their shortcomings, which are mainly related to:

– excess supply of sand, which causes contamination of the rail ballast and rail-sleeper grid, negatively affects the railway facilities;

– increasing resistance to the movement of the passing train due to the remaining sand on the rails, after the passage of the locomotive, sand under the wagons, about 10-12 %, which directly affects the consumption of fuel and energy resources [9];
– increased abrasive wear and damage of rails and wheels of rolling stock;
– clogging of the gap between the point and rail frame in railroad switch, thereby disrupting the functioning of the transfer mechanism, which affects the safety of train movement;
– contamination of the elastic strips between the bottom of the rails and the sleepers, which leads to their deterioration and change in the stiffness of rail-sleeper grid.

3. THE MAIN RESULTS OF THE RESEARCH

For many years at the Department of railway transport of Volodymyr Dahl East Ukrainian national University conducted theoretical and experimental researches on increase and stabilization of the coefficient of cohesion of wheel and rail. Developed laboratory and bench equipment as well as research software systems. Given the shortcomings inherent in existing systems of improving the cohesion of wheels and rails, based on the experience and research of predecessors created, tested and brought to the model samples of promising ways of controlling the cohesion of wheels and rails for different designs of prospective and existing rolling stock:

1. impact one - or two-phase air or air-abrasive stream (with different temperature) on the contact surfaces of wheel and rail [3];
2. supply of electrified abrasive material into contact, thus reducing its costs by 25 times [10];
3. jet-abrasive impact on the rolling surface of wheel and rail, regardless of their initial friction condition provides the value of the coefficient of friction of 0.25 above, reduces the abrasive material amount by 3-7 times, depending on the operating conditions of the locomotive [9];
4. cleaning contact surfaces with dry ice pellets – the most environmentally friendly and efficient method of combined control of tribological contact condition (temperature, roughness) (Patent UA №94498. A method of increasing the cohesion in the contact zone of wheel and rail).

3.1. IMPACT ONE - OR TWO-PHASE AIR OR AIR-ABRASIVE STREAM ON THE CONTACT SURFACES OF WHEEL AND RAIL

According to research [12] generated in the friction zone "wheel-brake-rail" the thermal energy becomes extremely energy-intensive, as is accumulated in metals and dispersed layers, which divides them. A substantial part of this energy upon reaching temperatures above 450 °C significantly degrades mechanical properties of metals, which further leads to their intensive deterioration.

To avoid this phenomenon it is required to perform a regulated limited energy released in the zone of friction. The temperature in the contact "wheel-braking pad-rail" allows to stabilize the whole system.

One of the methods of stabilization of the friction in the pairs is a temperature control system based on the use of constructive and technological elements for the absorption and removal of heat from the friction pairs to the environment.

To solve the problem of thermoregulation, the authors have developed a promising method of controlling the cohesion – the impact of air or two-phase air-abrasive stream (with different temperature) on the contact surface of the "wheel-block-rail".

When starting movement the locomotive in adverse conditions (dirty rails) to increase the coefficient of friction in contact of wheel and rail, serves abrasive material in the stream of compressed air of high temperature. The value of the coefficient of friction increases from point *A* on the chart (Fig. 1) to *B*. Heating the contamination of the contact of wheel and rail, facilitating their evaporation, cleaning and residue from the zone of contact with abrasive particles and compressed air. In the result of the thermal impact the coefficient of friction increases (point *C*, Fig. 1), ensuring high cohesion quality of the locomotive [1].

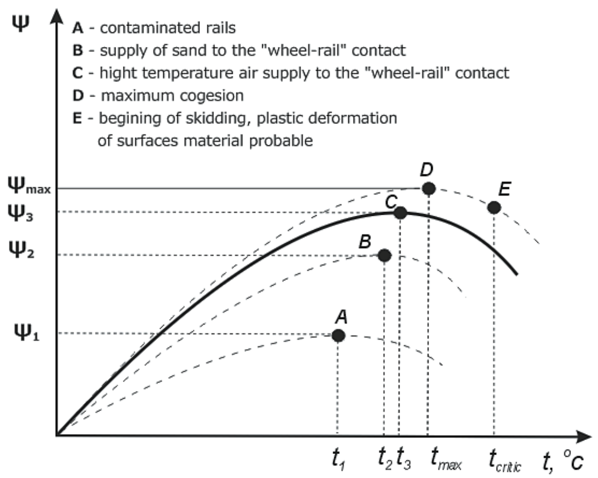


Fig. 1. Dependence of cohesion coefficient Ψ on temperature T

To prevent the occurrence of skidding of the wheel pair and reducing friction forces component (point *E*, Fig. 1), it is necessary to support the energy heat balance of the "wheel-rail" contact. For this purpose, the contact zone is supplied with cold air, providing local cooling of the friction surfaces. This allows to achieve higher value of the coefficient of friction between wheel and rail.

During braking in the wheel contact with the block temperature rises (Fig. 2) that when the critical temperature T_{critic} reduces coefficient of friction and risk for the emergence of skidding. To stabilize the adhesion in the contact of the wheel with the pad it is proposed to supply the cold air that will maintain maximum value of the coefficient of friction.

For cooling air which is supplied to the "wheel-brake pad-rail" contact Ranque-Hilsch effect is used. Ranque-Hilsch effect (vortex effect) divides compressed air into two streams (Fig. 3) when moving through a cylindrical or conical chamber [5, 11, 14]. When the flow of compressed air through a nozzle formed intense circular flow, which markedly axial layers are cooled and discharged through the aperture in the form of cold flow, and peripheral layers are heated and flow through a throttle hot flow. As the cover of the reactor total pressure in the vortex tube increases, and the flow rate of cold flow through the aperture increases with a corresponding decrease of the flow rate of the hot stream. The temperature of the hot and cold flows are also modifying [5, 14].

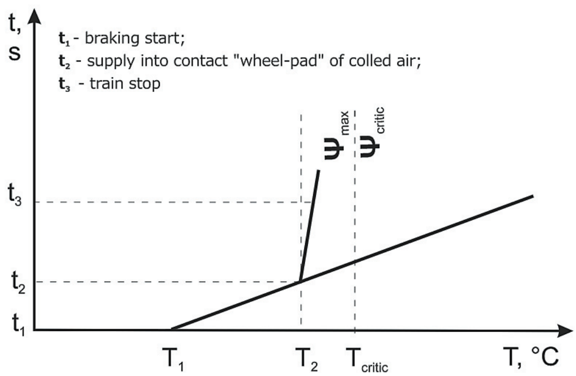


Fig. 2. Dependence of the “wheel-pad” contact temperature T on braking duration t

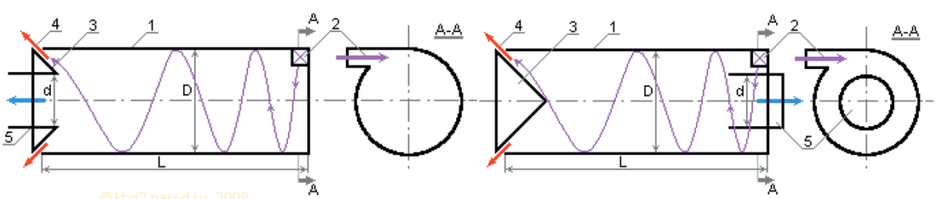


Fig. 3. Classic designs of ramjet (a) and counter flow (b) vortex tubes, based on the Ranque-Hilsch effect
1 - smooth cylindrical pipe, 2 - the entering of compressed air (swirl of tangential or snail type), 3 - throttle, 4 - exit of hot air through the annular gap, 5 - aperture for output of cold air

The advantages of using vortex tubes for cooling air supplied to tribocontact are [11]:

- significant cooling capacity;
- constructive simplicity, compactness, safety and reliability compared to the more effective but also significantly more complex and expensive generators of cold (expanders, pulsating gas coolers, etc.);
- automatic regulation performance in a wide range of air flow from 20 to 100 % with relatively small changes in temperature;

– ease of maintenance and the upkeep of the technological mode;
– low capital costs.

The Ranque-Hilsch tube allows at pressure of P = 0,4...1 MPa and the initial flow temperature of 20 °C to produce a cold air stream with a temperature of +20 °C to – 80 °C and hot at the same time – with a temperature from +40 °C to +15 0°C [14].

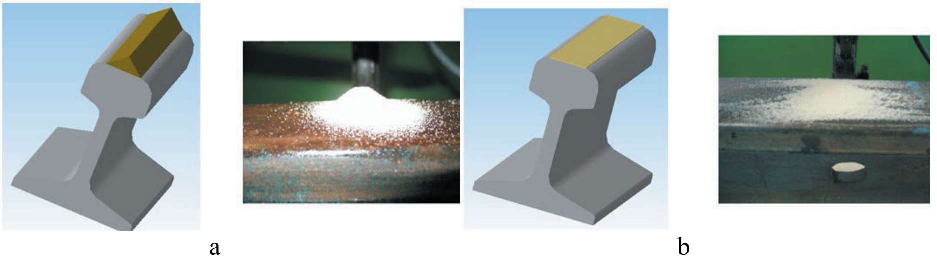
For the most rational and energy efficient use of air pneumatic system of the locomotive it is proposed to use the air brake cylinders, which in locomotives after the release of brakes are discharged to atmosphere. Discharging, accumulating and flowing the air through the Ranque-Hilsch vortex tube, it should be dispatched on different nodes, requiring exposure to cold (in the contact zone of the brake shoes and wheels) or hot air (for cleaning rails) [2].

This technical solution allows to reduce the wear of the locomotive wheels and rails to reduce the expense of outfitting materials (sand can be used in the most extreme cases) and to exclude the clogged ballast prism. Thus cohesive qualities of the surfaces of wheels and rails are increased due to of pre-heating and cleaning from "third body" adverse. The cold air in the "wheel-pad" contact allows to stabilize the temperature in the contact and improve the braking performance, reducing the risk of skidding.

3.2. SUPPLY OF ELECTRIFIED ABRASIVE MATERIAL INTO CONTACT

Achieving optimum amount of supplied sand in the wheel-rail tribocontact is proposed through the use of his electrostatic or tribostatic, electrostatic methods (Fig. 4). When electrostatic charging of the electrization the particles occurs under the influence of the field of high-voltage corona charge (Patent UA on useful model № 56033. Locomotive sand system).The main disadvantage of this method is the difficulty of obtaining high voltage and the associated increased requirements to safety. The advantage of this method of electrification is the high performance, due to the almost 100 % charge small particles.

Without sand *With electrified sand*



a b

Fig. 4. The distribution of sand along the rail: a – without electrization; b – with electrization

Tribostatic charging is based on the friction of abrasive particles on pipe wall with inserts of dielectric (e.g. Teflon) (Patent UA on useful model №48520. Method of improving the wheel and rail cohesion).Transfer charge to the particles of sand does not require additional equipment to produce a high voltage, for electrostatic charging. The complexity of the method lies in the selection and location of dielectric material. Both this methods are acceptable for use on the locomotive.

3.3. JET-ABRASIVE IMPACT ON THE ROLLING SURFACE OF WHEEL AND RAIL

A promising direction of improving the cohesion of the locomotive and reduce the running resistance of rolling stock is the method of two-phase jet-abrasive impact (JAI). The abrasive material under the stroke of compressed air cleans the surface and removes surface impurities creating favorable conditions for the contact of wheels with rails (Patent UA on useful model № 69853. System of increase the coefficient of friction in the contact zone of wheel and rail).

In the result of simulation, the expression for determining the coefficient of friction with concern to the formed modified rail surface (removal of surface contamination and the change of roughness parameters with JAI), can be written as:

$$f=\left(\frac{\sqrt{\pi}}{\sqrt[2\nu_K]{2}k_\nu}\right)^{\frac{2\nu_K}{2\nu_K+1}}\frac{\tau\left(2\frac{1-\mu_C^2}{E_C}\right)^{\frac{2\nu_K}{2\nu_K+1}}}{P_0^{\frac{1}{2\nu_K+1}}\Delta^{\frac{\nu_K}{2\nu_K+1}}}+\beta+0{,}19K_\nu\left(\frac{2\sqrt{\pi}}{k_\nu}\right)^{\frac{1}{2\nu_K+1}}\alpha_\Gamma\left(P_0 2\frac{1-\mu_C^2}{E_C}\right)^{\frac{1}{2\nu_K+1}}\Delta^{\frac{\nu_K}{2\nu_K+1}},\quad(1)$$

Where: Δ – complex roughness criteria [8]; k_ν, K_ν – gamma-function related to ν_K coefficients; E_c – elastic module, $E_c = 2\cdot10^5$; μ_c – Poisson coefficient, $\mu_c = 0{,}3$; α_Γ – coefficient of hysteresis losses during slipping, $\alpha_\Gamma = 1$; P_0 – actual contact pressure, P_0 = 120 kN; β – piezocoefficient of molecular component of the friction, $\beta = 0{,}08$.

Analysis of the dependence (1) shows that the friction coefficient of wheel and rail eventually depends on the surface microgeometry, load of the wheel on the rail and physico-mechanical properties of material surfaces. Based on the formula (1) and the results of multilevel modeling [9] rational parameters of the JAI system are found, determining the formation of the surface layer of the wheel and rail. Found that adjusting the cohesion coefficient of wheel and rail in the range of 0,3 – 0,41 possible when the parameters of the JAI system within:

- abrasive jet attack angle $\alpha = 15 - 20^\circ$;
- abrasive material speed $V_1 = 50 - 60$ *m/s;*
- nozzle diameter $d_c = 0{,}02 - 0{,}025$ *m;*
- jet dispense angle $\beta = 4 - 6^0$;
- abrasive grain $d = 0{,}0003 - 0{,}0006$ *m*;
- the distance from the nozzle to the surface (the length of the abrasive jets) $L = 0{,}2 - 0{,}3$ *m*;
- abrasive material consumption $Q = 0{,}3 - 0{,}4$ *kg/min*.

3.4. CLEANING CONTACT SURFACES WITH DRY ICE PELLETS

After analyzing the methods of increasing and stabilizing the wheel cohesion with the rail, the authors have developed an innovative method (Fig. 5), consisting in the purification of the interacting surfaces with dry ice pellets (Patent UA №94498. A method of increasing the cohesion in the contact zone of wheel and rail**Błąd! Nie zdefiniowano zakładki.**). As known, dry ice is solid carbon dioxide (CO_2), low temperature product.

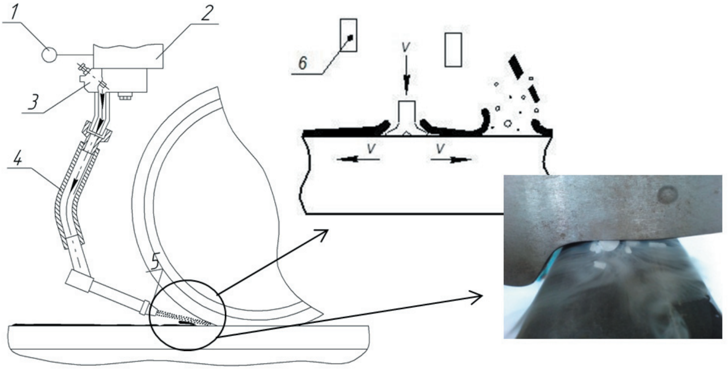


Fig. 5. The dry ice supply system to the contact of wheel and rail:
1 – control system; 2 - the device of the formation of dry ice pellets;
3 – injector; 4 – pipeline; 5 – nozzle; 6 dry ice pellets

Intensive cleansing action of this method is provided by three effects:

1. The mechanical cleaning effect of the dry ice pellets hitting the surface to be cleaned with a high speed (Fig. 5).
2. Cleaning due to the thermal energy the abrupt cooling of the surface of dry ice having a temperature of – 79 °C, leads to the formation of small cracks of the layer of pollution due to the large temperature difference.
3. Purification through sublimation – emerging through the cracked contamination of the dry ice pellets penetrate their layers and are sublimated in them with more than 400-fold expansion in volume, causing the explosion effect and pollution detach from the surface.

The main advantages of this method are:

– dry ice sublimates to form carbon dioxide returning to the atmosphere and taken from it to create dry ice;
– materials not subject to corrosion, no wear and erosion;
– dry ice pellets do not have an abrasive action, without damage to the surface being cleaned;
– usage of this technology does not require the use of additional chemicals or abrasives and is environmentally friendly.

4. EXPERIMENTAL STUDY ON THE FRICTION MACHINE

To check the effectiveness of the proposed methods values of the coefficient of friction for different friction conditions of contact of the roller with the rail and how to control the cohesion are experimentally defined. The tests were conducted on a specially designed stand setting "Machine of friction" (Fig. 6), which allows to investigate the frictional properties of the contact "wheel-rail" as rolling with sliding or without it (Patent UA on useful model № 40536. Friction machine determining the "wheel-rail" frictional contact properties).

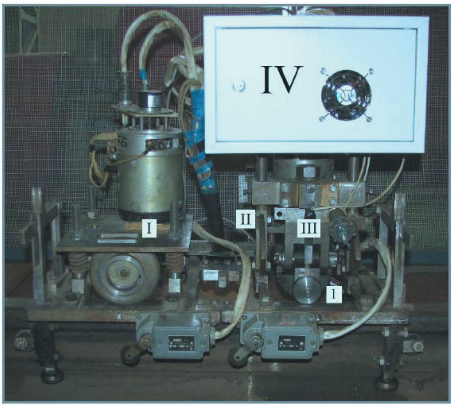


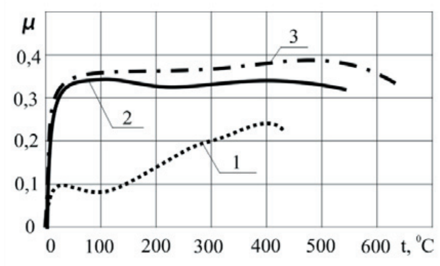
Fig. 6. Stand setting "Machine of friction"

"Friction machine" consists of a truck (Fig. 6) placed on it accelerating device (I) directing (II) and measurement site (III), and microprocessor-based measuring and control unit (IV) moving along the rail.

According to the results of experimental researches it is established that the filing of electrified sand on greasy rails enables to increase the friction coefficient to 0.4 (Fig. 7), and on the rails poured with water – up to 0.5 [10**Błąd! Nie zdefiniowano zakładki.**] (Fig. 8).

The obtained experimental dependence of the coefficient of friction with JAI used show its effectiveness (Fig. 9, 10):

- regardless of the initial frictional state of an object is the magnitude of the friction coefficient above 0.25;
- in comparison with the feed of sand to the rail surface resistance of movement of the train is reduced by 19-30% of under different frictional condition of the rail.



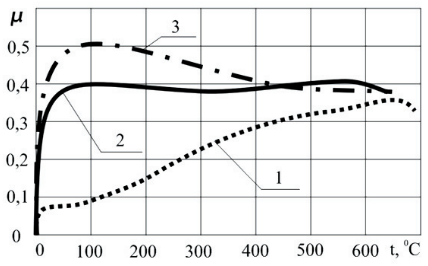
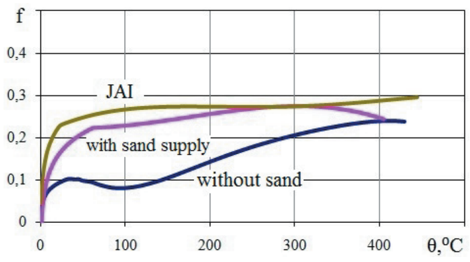


Fig. 7. The dependence of friction coefficient on temperature with the supply of electrified sand on greasy rails

Fig. 8. The dependence of friction coefficient with temperature at the supply of electrified sand on the rails covered with water

1 – without sand; 2 – with sand supply; 3 – with electrified sand supply



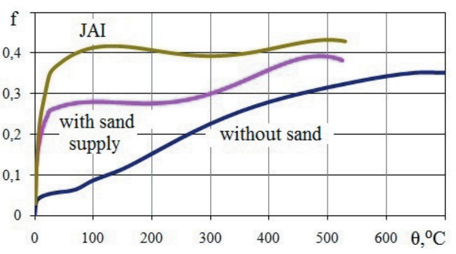


Fig. 9. The dependence of the friction coefficient while rolling with slipping on the temperature in the contact (the rail is covered with waste oil)

Fig. 10. The dependence of the friction coefficient while rolling with slipping on the temperature in the contact (the rail is covered with water)

5. CONCLUSIONS

To reduce the risk of occurrence of catastrophic situations in railway transport it is necessary to control the process of cohesion in tribocontact "wheel-brake pad", "wheel-rail", thereby reducing the probability of skidding and slipping. Proposed methods for the control of cohesion, due to the cleaning surface contamination.

According to the results of theoretical and experimental researches it is established: the use of the electrification of sand will increase the coefficient of friction as a result of more efficient allocation of it for the woin the contact area. The flow of sand is reduced by 25 times. Supply of electrified sand on greasy rails allows to increase the coefficient of friction to 0.4, and on the rails poured water to 0.5.

The use of combinedsupplying abrasive material in an environment of hot compressed air will remove surface contamination that can have a significant effect on the increase of the coefficient of friction. Further increase in temperature above 450°C will prevent the abrasive environment of cold compressed air, it will not decrease the mechanical properties of the metal of wheels and rails, and to decrease component friction forces that will help implement higher coefficient of friction between the wheel and the rail.

Supply of dry ice pellets in the "wheel-rail" contact allows you to destroy contamination on tribromophenate, to reduce abrasive wear and to increase the coefficient of friction. It is advisable to apply this method to reduce the temperature in tribocontact during emergency brake.

References

1. Domin R., Gorbunov M., Domin Yu., Kravchenko K., Chernyak A., Kovtanets M., Nozhenko V., Mostovych A., Kravchenko K.: Locomotive sand system, Useful model patent № 104552, cl. B61C 15/08, publ. 10.02.2016, bull. № 3.
2. Domin R., Gorbunov N., Chernyak A., Kravchenko K., Kravchenko C.: Wear mechanisms analysis is and elaboration of measures on improving the interaction of wheelset with rail track, State Economy and Technology University of Transport, V 24, 2014.
3. Gorbunov N., Kravchenko K., Nozhenko O., Prosvirova O.: Technical solutions for temperature stabilization of the friction elements of the brakes, Vestnik of East-Ukrainian national University named after Volodymyr Dahl, Lugansk, 2013, № 4(193).
4. Gorbunov N., Slashchev V., Tkachenko V.: Investigation of the phenomenon of rail cleaning locomotive wheels, Republican interdepartmental scientific-technical collection "Design and manufacture of transport vehicles", Kharkov, 1989, Vol. 21.
5. Gutsol A.: Ranque effect, Advances of Physical Sciences, Vol. 167, № 6. 1997.
6. Kamenev N.N.: Effective use of sand for traction of trains, Moscow, Transport, 1968.
7. Kazarinov A.V.: Improving the efficiency of the brake means freight trains with optimal utilization of adhesion of wheels and rails, author. diss. PhD of technical Sciences: 05.22.07, All-Union scientific research Institute of railway transport, M, 2007.
8. Kombalov V.: The impact of rough rigid bodies in friction and wear, Moscow, Science, 1974.
9. Kovtanets M.: Improvement of the cohesion characteristics of the locomotive jet-abrasive effect on the contact zone of the driving wheel and rail, authoref. dis. Ph. D. of technical Sciences: 05.22.07, Severodonetsk, 2015.
10. Kravchenko K.: Substantiation of reserves of increasing the traction qualities of the locomotive and their implementation for control of slipping in the wheel-rail system, authoref. dis. Ph. D. of technical Sciences: 05.22.07, Luhansk, 2010.
11. Krupenenkov N.: The question concerning the application of the Ranque-Hilsch effect (Vortex tube) at the enterprises on manufacture of sausage products ,"Scientific journal NRU ITMO. Series: Processes and devices of food manufactures", Issue No. 1, March, 2013, electronic resource - http://processes.open-mechanics.com/articles/689.pdf
12. Luzhnov Yu.: Coupling of wheels with rails (nature and patterns), Moscow, 2003.
13. Lapushkin N.: The theoretical basis for the interaction of locomotive wheels with the rails at the nanoscale, authoref. dis. ... doctor of technical Sciences: 05.22.07, 05.16.01, Moscow state University of railway engineering, 2008.
14. Merkulov A.: The vortex effect and its application in engineering, Moscow, "Engineering" Publishing House, 1969.
15. Osenin Yu.: Forecasting and control of frictional properties of tribological system "wheel-rail", author. dis. ... doctor of technical Sciences: 05.22.07, East Ukrainian state University, Lugansk, 1994.
16. Verbeke G.: A modern concept of the cohesion and its use, Railways of the world № 4, 1974.

WIELOFUNKCYJNY ENERGOOSZCZĘDNY SPOSÓB STEROWANIA SPRZĘGŁA W SYSTEMIE "KOŁO - SZCZĘKA HAMULCOWA - SZYNA"

Streszczenie: W artykule kwestia zmniejszenia prawdopodobieństwa wystąpienia poślizgu i lokomotywy poślizgu wskutek tarcia w zarządzania kontaktami "koło - szczęka hamulcowa - szyna". Warianty rozwiązań technicznych dla urządzeń wielofunkcyjnych (temperatura, ściernych) tribocontact, zarządzanie powietrza energia, powietrze-ściernego lub strumienia suchego lodu granulki, zelektryfikowana piasku.
Słowa kluczowe: interakcja w systemie "koło - szczęka hamulcowa - szyna", temperatura w tribologicznym kontaktu, współczynnik przyczepności