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WEAR MECHANISMS ANALYSIS AND ELABORATION OF MEASURES ON IMPROVING THE INTERACTION OF WHEELSET WITH RAIL TRACK

There is provided the method and device for improving the condition of interaction of the wheelset with the rail. This method consists in that during the implementation of the tractive effort it is suggested to feed pressurized heated air with an abrasive material into the wheel-rail contact; during braking it is suggested to feed into the cold air with sand; for cleaning out the contact in the contaminated areas it is suggested to supply the compressed air with high temperature; for heating and cooling the air in a sand system it is suggested to use Ranque effect. This procedure will help to stabilize the adhesion in contact and reduce wearing.

У статті розглядається питання зношування робочих поверхонь колеса й рейки. Наведено аналіз видів зношування. Запропоновано пристрій та спосіб покращення взаємодії колісної пари тягового рухомого складу з рейковою колією за рахунок управління температурою в контакті при різних режимах руху.

В статье рассматривается вопрос износа рабочих поверхностей колеса и рельса. Приведен анализ видов изнашивания. Предложено устройство и способ улучшения взаимодействия колесной пары тягового подвижного состава с рельсовой колеёй за счет управления температурой в контакте при различных режимах движения.

Keywords: «wheel-rail» tribosystem, wearing, sand system, Ranque tube.

While the interaction of the wheelset with a rail track as a result of friction the irreversible process of both wheels and rails surfaces wearing appears. The condition of these surfaces largely influences safe running of the rolling stock operating efficiency as a whole. Wearing leads to uneven redistribution of loads from the wheelsets to the rails, respectively, to decrease of traction qualities and deterioration of the dynamic one.

Furthermore, surfaces wearing of the wheel and rail results in significant material costs for their reorientation or replacement when the limit sizes are reached. These costs account both for the owners of the rolling stock, and the track service.

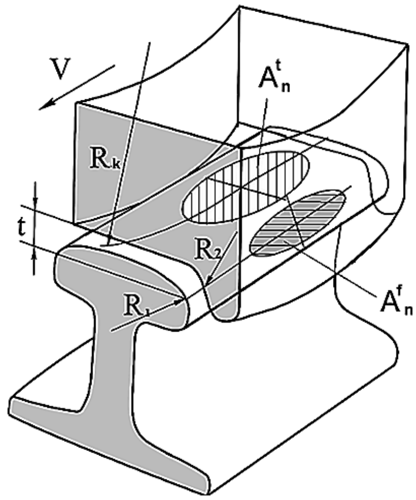
Wearing is a complex stochastic process. The analysis of technical solutions to reduce the wear rate proposed by different researchers [1, 2, 3 et al.] allows classifying them into four groups:

– constructional;
– technological;
– operational;
– track maintenance.

Each group offers a variety of ways to reduce wearing, but the problem of wearing in the «wheel-rail» system is still not resolved. The solution of this problem requires a comprehensive approach because from one side, the process of wheel-rail interaction has a considerable influenced by the number of factors, on the other side, while reducing friction, which directly affects wear, traction and braking characteristics of the rolling stock may get worse. Efficient operation in the «wheel-rail» system achieves by controlling the characteristics of the contact.

It is known that the wheel-rail interaction may occur in the contact point of (see Fig. 1) [4, 5, 6]:

- wheel and the work surface of the rail;
- wheel flange with the side surface of the rail head.



V *– linear speed;*

$\boldsymbol{R_k}$ *– wheel radius;*

$\boldsymbol{R_1}$, $\boldsymbol{R_2}$ *– the radii of curvature in cross section of the rail and the wheels;*

t *– the distance from the rail head level to the point of flange tightness to the wheel.;*

A_n^t, A_n^f *– nominal contact area of the wheels with the rail (Tread contact) and the wheel flange with the side surface of the rail (Flange contact)*

Fig. 1. **Double-point wheel-rail interaction**

For each contact patch there are typical conditions of interaction. In contact of the wheel flange with the side surface of the rail head it is necessary to reduce the friction, in contact of the wheel rim and the work surface of the rail it is necessary to increase adhesion, which leads to increased friction and wearing. Wheels which have lower hardness in comparison with hardness of the rail is more exposed to wearing.

While wearing of the first wheelset in the direction of travel a significant difference in diameter between the wheels of the bogie wheelsets may appears, which often causes necessity of the wheelsets machining, because it affects the redistribution of loads and therefore the implementation of tractive effort and dynamics of the locomotive.

Surfaces wearing occur not only when the wheel moves on the rail (in this case depending on the type of friction processes of different factor occur), but also at rest (there is the crushing of irregularities under the action of vertical force) (Fig. 2) [7, 8].

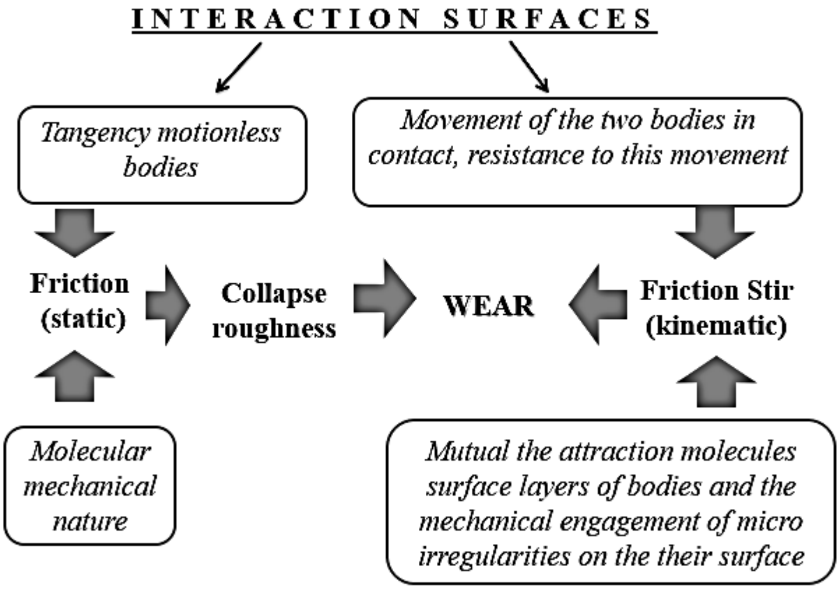
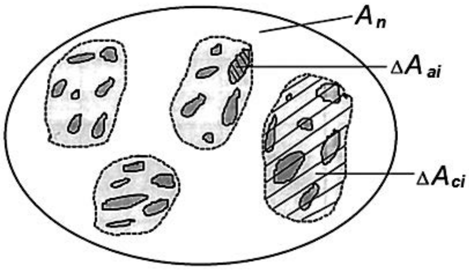


Fig. 2. **Types of surfaces interaction**

Crushing of the roughness leads to a change in the contact area. There is a distinction between nominal, contour and the actual contact areas [9, 10].



A_n *– nominal contact area;*
ΔA_{ai} *– the actual contact area;*
ΔA_{ci} *- contour area of contact*

Fig.3. **Contact area**

While moving of the wheel on the rail there is friction in the contact, which is classified according to [11]:

– the type of mutual motion of bodies – sliding friction, rolling and spinning;

– the presence or absence of the third body in contact – clean surface, greasy or covered with other types of pollutants;

– the place of localization of the friction process – external and internal types of friction.

Depending on the types of friction different types of wearing are distinguished. According to GOST 27764-88 «Friction, wearing and lubrication. Terms and definitions» all types of wearing are classified into 3 groups, which are listed in Table 1 [12].

Table 1. **Types of wearing according to GOST 27764-88**

1	***Mechanical wearing***	*In contact*	**Adhesive**	*Seizure wear*
			Abrasive	
			Fatigue	
			Fretting wear	
		external influence on the friction surface	**Erosion**	*Hydroabrasive*
				Gasoabrasive
				Hydroerosive
				Gasoerosive
				Cavitation
2	***Mechano-corrosive wearing***		**Oxidative**	
			Fretting corrosion wear	
3	***Wearing under the influence of an electric current***		**Electroerosion**	

In tribocoupling there are four most prevalent types of wearing [13, 14]: abrasive, adhesive, fatigue, corrosion. According to the researches [15] during the interacting of steel surfaces the frequency of occurrences of the abrasive wear is the highest (Fig. 4).

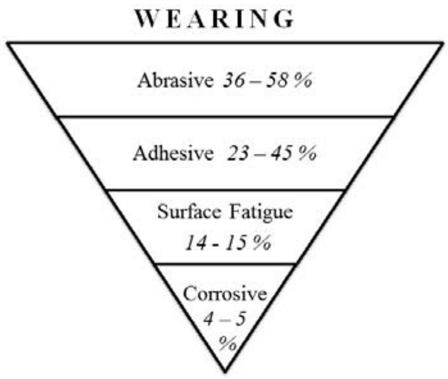


Fig. 4. **The frequency of occurrence of the different types of wearing during the interaction of steel surfaces Wearing mechanism**

Abrasive wearing occurs as a result of cutting or scratching action of abrasive particles formed as a result of friction or interaction surface contamination [12]. These particles have a greater hardness than the friction surface and they plastically deform the friction surface forming the risks and scratches on them.

Abrasive wearing can be divided into two types [16]:

first type – two clean surfaces are interacted, thus there is a cutting of roughness of the softer metal (see Fig. 5a);

second type – with the presence of abrasive particles, thus there is the cutting either of both surfaces or one of them (see Fig. 5b).

The speed of wearing in an abrasive environment depends on concentration, size, shape and properties of abrasives, properties of metal surfaces, sliding speed, and the specific pressure and reaches 0.5-5.0 μm/h [17].

a)
in the absence of abrasive particles

b)
in the presence of abrasive particles

Fig. 5. **Abrasive wearing**

Adhesive wearing. Real metal surface always has some undulation and many microtips, therefore the contacting of two surfaces occurs only in certain exposed points. The friction of two metal surfaces under a certain load occurs under conditions of plastic deformation of the metal at the points of actual contact, the development of which is accompanied by convergence of surfaces up to activation of the adhesion forces between the atoms of metal of the mating surfaces and the occurrence of adhesion in limited areas (see Fig. 6) [16, 18].

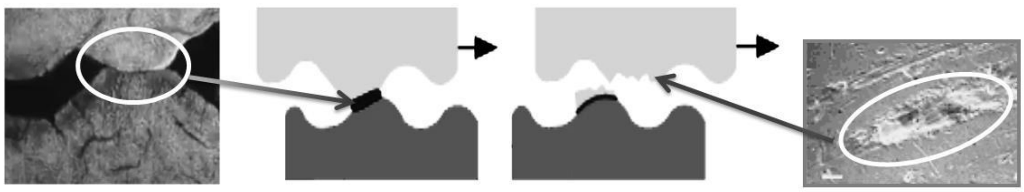


Fig. 6. **Adhesive wearing**

As a result, plastic deformation of the two metal surfaces there is their coupling, however, under the action of shear stress this coupling is inevitably destroyed (see Fig. 6). The destruction begins in the areas of presence of the smallest cohesive forces – at the interface between the two surfaces, and in case of sufficiently strong adhesion – gripping, shear fracture occurs within one of the materials with less durable section (Fig. 6).

Multiple repetitions of the described process of the adhesion occurrence and the subsequent destruction of gripping assemblies accompanied by tearing-up and abrasion of less solid metal cause the ***adhesive wearing*** [19]. Part of the metal with low hardness remaining after the cutting off on the mating surface of the metal of high hardness, and then turning into a powder, is separated from it. Mechanical strengthening of this powder becomes the reason for abrasive wearing.

Erosive wearing it is the wearing caused by the influence of the flow of liquid or gas containing the abrasive particles on the surface (Fig. 7) [18, 20].

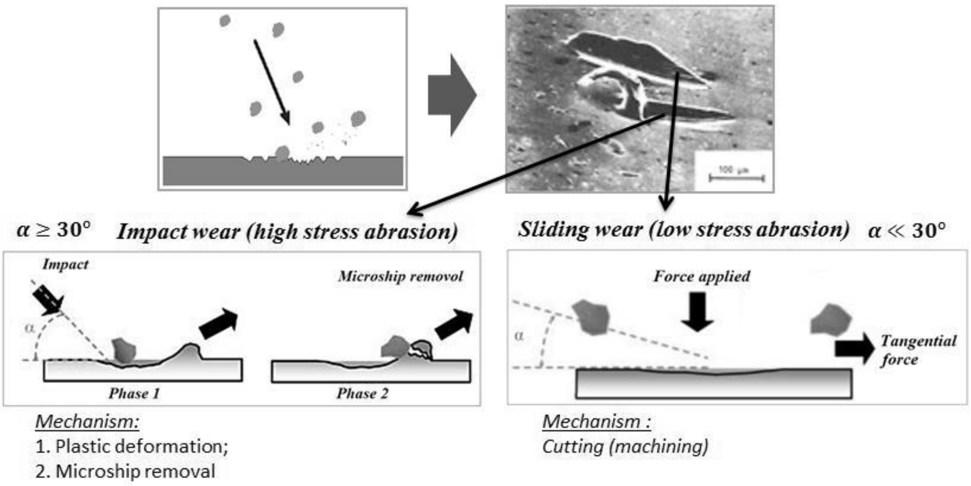


Fig. 7. **Erosive wearing**

Factors influencing the erosive wearing:

1. Abrasive: particles shape, particles size, particles hardness, particles speed, particles mass.

2. The material of the interaction surface: hardness, strength, microstructure, thermostability, corrosion resistance.

3. The external environment: temperature, humidity.

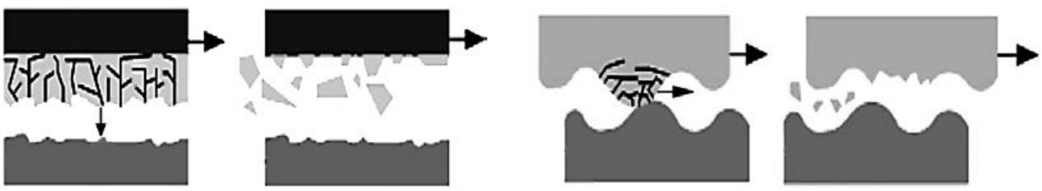
Fatigue wearing is the result of the cyclic effect on the microtips of the rubbing surfaces. Cyclically changing contact stresses cause surface damages such as cracks, chipping and peeling. Slight cracks are generated in the area of maximum shear stresses at some depth below the surface and then spread to the surface. Cracks can also arise at the surface and to spread deep into the material.

Chipping is characterized by the formation of pits on the friction surface resulting from the separation of the material particles during the fatigue wearing.

Fatigue wear arises from the action of:

– normal cyclic loading (Fig. 8a) [16];

– tangential cyclic loading (Fig. 8b).



a) *the impact of the normal cyclic loading*   *b)* *the impact of tangential cyclic loading*

Fig. 8. **Fatigue wearing**

Oxidative-corrosion wearing (Tribochemical) is a consequence of high temperature resulting from friction. Thermal processes of wearing are directly connected with increase in temperature caused by frictional heating in contact. With the temperature increase the interaction of the metal with oxygen increases. This phenomenon promotes the increase of oxide film which in some cases reduces wearing, but in some other cases it increases the wearing. If the films are strong, dense and well linked with the metal they protect the metal from further destruction, for example, like in such chemical elements as Zn, Al, Cr, Ni, Sn, Pb and others. If the film is loose, like in Fe, it does not protect the metal from further destruction. The wear resistance of the oxides is significantly lower than the wear resistance of the base metal. With the destruction of the oxide film the surface roughness and abrasive wearing increase. After the destruction of the oxide films metals are laid bare and again oxidized (Fig. 9) [21]. As a result, the overall wearing of components is intensified. The thermal stresses may cause the thermal fatigue and cracking which leads to wearing of the surfaces.

Tribochemical wear depends on:

– the speed of relative displacement;
– loading, dynamic of its applications;
– temperature generated in the contact;
– ambient humidity.

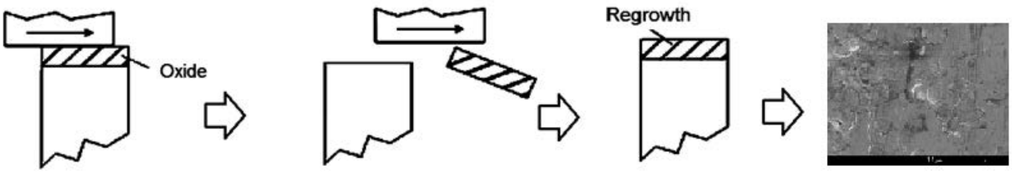


Fig. 9. **Tribochemical wear**

From the analysis of types of wearing follows that the temperature in the wheel-rail contact has a significant effect on the wearing of the working surfaces. In different operating conditions the corresponding temperature is desirable in order to achieve effective «wheel-rail» interaction. Therefore, it is possible to achieve stable operation of the «wheel-rail» system by controlling the temperature in the «wheel-rail» contact.

The method and device for improving the efficiency of the «wheel-rail» interaction. (application for invention «*Method of improving the interaction of the wheel-set with the rail*» and «*Sand system locomotive*»).

There is provided the method and device for improving the interaction of the wheel-set of the traction rolling stock with the rail. When the locomotive is pulling off the abrasive is supplied to the «wheel-rail» contact (point A in Fig. 10) for improving the adhesion (point B in Fig. 10) if necessary. Further, the pressurized air of high temperature is supplied to the «wheel-rail» contact (point C in Fig. 10). The heating of the «wheel-rail» contact helps to clean out the surface from contaminations and remove them from the contact area with help of abrasive particles. As a result of temperature rise in the contact friction coefficient increases (point D, Fig. 10), which provides high adhesion quality of the locomotive and prevents the wheelset slipping (point E, Fig. 10).

During the braking the temperature in the «wheel-shoe» contact area increases (Fig. 11), that on reaching the critical temperature T_{lim} leads to the decrease of the coefficient of adhesion and possibility of skidding. Pressurized cold air supplied into the «wheel-shoe» contact area, thereby achieving the support of the maximum value of the coefficient of adhesion to prevent skidding.

On the contaminated area of the track pressurized air of high temperature supplied to the «wheel-rail» contact, which is provided the evaporation of surface contamination and implementation of the maximum values of the coefficient of adhesion. The air supply process control is made from the driver’s cab. In the air supply system it is used the Ranque effect [22].

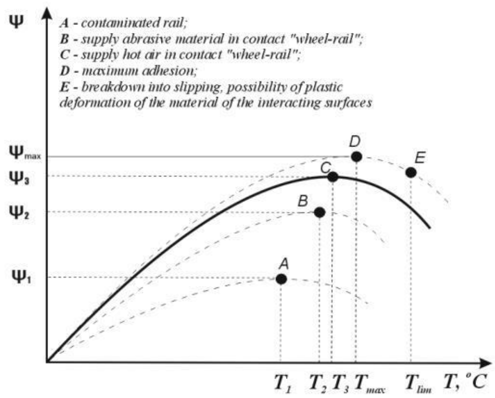


Fig. 10. **The dependence of the coefficient of adhesion** ψ **on the temperature** ***T***

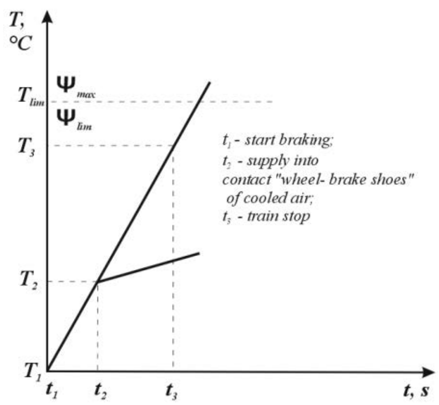
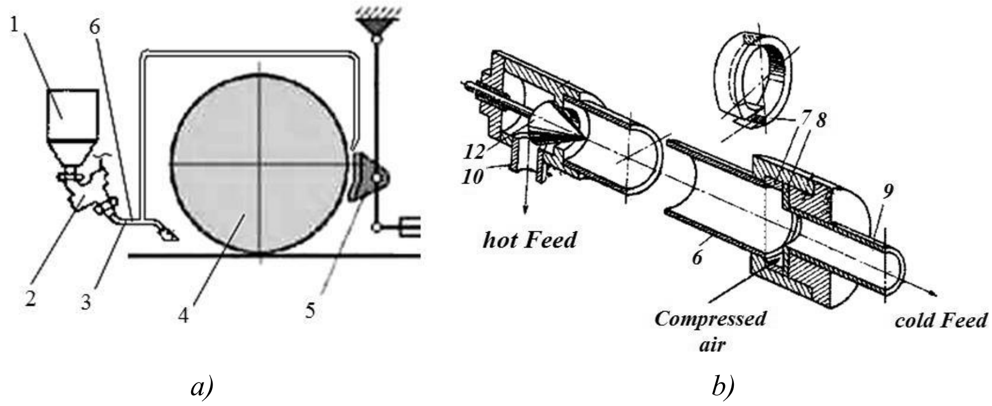


Fig. 11. **The dependence of the temperature T in the «wheel-shoe» contact area from the braking time**

The operation concept of the improved sand system. During the locomotive pulling off the sand from the sandbox 1 hopper is fed into the nozzle 2 (Fig. 12), and then under the pressure in a stream of air gets in the wheel-rail contact area. Simultaneously the pressurized air stream is supplied to the nozzle 7 of the vortex tube 6 (Fig. 12) of the pipeline 3. The construction of the vortex tube 6 is based on the Ranque effect.



a) *b)*

Fig. 12. **Sand system of the locomotive:** *a* **-** *General view; b - Vortex tube*

In the nozzle inlet and then in the vortex tube 6 the gas expands and splits into two streams such as cold and hot one. Cold stream is discharged through the diaphragm 8 through the tube 9 into the atmosphere. Hot stream is discharged from the opposite end through the valve 11 through the hot stream tube 10 into the wheel-rail contact.

As a result there is the distribution of air into two streams – hot and cold. Hot air is directed into the wheel-rail contact and the cooled air is directed to the atmosphere. During the braking the hot air is directed into the atmosphere and the cold air is directed into the wheel-shoe contact area, thereby providing temperature regulation in contact area of the interacting friction surfaces: the wheels and the rail and the wheel and the shoe.

According to the operating conditions (traction, braking) the controlling device 13 regulated the position of the cone 12 (Fig. 12) with the help of which air consumption and temperature of the hot and cold streams are vary. To reduce the temperature of the cold stream it is necessary to decrease the consumption of the cold stream (valve 11 is opened). To increase the temperature of the hot stream the valve 11 is closed down.

The application of the method and device for improving the conditions of interaction of the wheelset with rails will stabilize the value of the coefficient of adhesion at various modes of motion of the locomotive under different operating conditions and facilitate the work of the locomotive at maximum adhesion characteristics without break-down in slipping.

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