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Process features and parametric assessment of the emergence of the excessive wear for the brake pads of freight car bogies

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Abstract. The article presents a new scientific approach to the problem related to the specific nature of the adverse biplanar critical friction wear profile of brake pads which is quite common in cars of Ukrzaliznytsya JSC, as well as in many countries where the so-called three-element bogies are used. In order to study the dual wear of brake pads during the operation, the statistical material was collected and processed in the specialized software STATISTIKA to obtain graphical dependences that confirm the results of theoretical research. In the conducted studies, the concept of dual friction wear of brake pads was first discovered as a phenomenon and introduced. The stages of formation of especially harmful wear on the working surfaces of brake pads causing the complex formation of adverse specific dual wear are shown. A new concept of the duality coefficient of frictional wear of brake pads has been introduced, and a formula for its calculations has been proposed, which has been tested in the calculations of the values of brake pressures of pads with dual wear to support the analytical studies.

1. Introduction

Reducing the cost of transportation is very important for the competitiveness of the railway infrastructure, and the technical condition and reliability of the rolling stock play a special role here. The brake equipment impacts significantly both traffic safety and energy-saving. However, the situation with the abnormal loss-making wear of brake pads in freight cars is critical. In freight trains driving without braking, adverse friction of the upper edges of the brake pads which are inclined and pressed to the surface of the wheels occurs commonly. Such friction causes considerable losses to both freight traffic and the railway industry in general. Therefore, in Ukrzaliznytsya JSC and countries where three-element bogies are used, work is conducted to improve the reliability of brakes and the element of the mechanical parts of the brake and its maintenance and repair using the design methods.

2. Analysis of recent studies and publications

The problem of uneven wear of brake pads has existed for a long time and is associated with a decreased braking effectiveness of the rolling stock. Numerous articles deal with studies of the causes and consequences of this phenomenon. Among them, in [1], it was determined that the configuration of the brake rigging (BR), which is currently used in two-axis bogies of freight cars by installing brake pads of maximum thickness does not ensure their wear to the minimum allowable value during the operation. However, the authors of the article do not focus on the effect of abnormal wear of brake pads. In [2], the coordination of the dimensional chains of the BR of the freight car is substantiated in order to determine the nature and extent of wear of the brake pads. The method of calculation of dimensional chains of BR is proposed, which allows determining the limiting deviations of links for brake pads, which wear out evenly.

In view of the special relevance of the problem of wedge-shaped wear of brake pads in three-element bogies, specialists and researchers from different countries perform multiple studies, on the basis of which various BR devices and mechanisms are developed to eliminate or decelerate the intensive wear of pads. In [3], a pad retraction device was proposed for the bogies of freight cars with automatic adjustment of the position of the brake pads relative to the rolling surfaces of the wheels. However, such a device complicates the BR and requires periodic labor-intensive adjustments during the operation, therefore its use became inappropriate.

In the analyzed foreign studies [4], the stresses and temperatures occurring in the brake pad were analyzed using SolidWorks software and an alternative solution is proposed to improve the brake pad material and increase the service life.

The information of [5] on the innovative Chinese bogie design (mod. ZK1) demonstrates that a substantial change in fastening of the triangles – supported by the guide brackets specially cast in the side frames of the bogie instead of the pendulum suspension – have significant drawbacks. This involves a significant interference in the design of the most important bearing parts of the bogie – cast side frames.

Foreign researchers prefer experimental approaches based on the study on wear and temperature performance indicators of brake system components of rolling stock [6, 7], while some focus on the use of special cast-iron brake pads [8]. At the same time, no sources were found which study abnormal wear of brake pads characterized by biplanar wear, which is now common in the brake systems of three-element bogies and causes significant losses in the railway industry.

3. The purpose of the article

Studying the phenomenon of frictional dual wear of brake pads during operation of freight cars, the nature of formation and the complete process of dual wear of pads and introducing in braking calculations new mathematical dependencies that will enable to take into account the dual wear of brake pads.

The following tasks should be addressed to achieve the set purpose:

- studying the process of formation of dual wear from the initial to the maximum permissible in accordance with the traffic safety requirements using the collected statistical material on dual wear of brake pads during operation of freight cars of Ukrzaliznytsya JSC;
- performing theoretical studies of the stages of formation of dual wear of pads on the pendulum suspension;
- determining mathematically the duality of wear of brake pads and testing it in the calculations of brake pressures.

4. Presentation of the main material of the article

Brake pads in the biaxial bogies of freight cars are known to wear out unevenly in the transverse sections of its length, with the thickness decreasing wedge-shaped during the operation [9, 10]. The appearance of worn-out pads removed from the bogies of the freight cars of the fleet of JSC Ukrzaliznytsia is shown in Figure 1.

Naturally, when a car is moving, friction and frictional wear occur during braking between the rolling surface of the wheel and the working surface of the brake pad. However, the inspection of brake pads removed during repairs of cars in the depot found that most pads have a partial upper wear, which does not coincide with the total braking wear area. At the same time, inspections of the pads in the car of the service fleet at the car maintenance points (CMPs) established that in the retracted state most pads are inclined with their upper ends touching the rolling surface of the wheels and rubbing during the movement. Therefore, two wear surfaces are formed on the pads: the upper one where the pad is worn out skew symmetrically during the movement of cars without braking, rather intensively when the movement speed is high; and the lower one which is used for braking, but is reduced by the value of the upper wear.

Figure 1. Appearance of brake pads which became unsuitable for further use due to the dual wear, but still with large remaining intact part of the working body: 1 – upper adverse wear; 2 – division line of wear areas; 3 – intact brake friction area of the pad reduced to the value of the upper wear

In fact, the working body of the pads wears out dually with the division line of two friction areas, therefore, this condition of the pads was first defined as dual friction wear.

It can occur in friction braking mechanisms of various vehicles with pad, disk, drum or other brakes in case of failure of mounting or retraction devices of pads or brake linings from the mobile surface to be braked.

All freight cars are now equipped with even wear devices for pads, but they have very low reliability. This is why they become unsuitable for use even in those cars that have just been put into operation from car-building or repair enterprises. Therefore, more than 90% of freight cars of Ukrzaliznytsya JSC operate with the dual wear of brake pads, which impairs the effectiveness of braking in freight trains. The car maintaining workers have to replace a lot of such pads with a significant part of the intact working body with new ones (Figure 1).

A large number of dual-worn rubber-asbestos pads are disposed from the car repair enterprises to the landfill. Processing, restoration or recycling technologies for them are unavailable.

Table 1 shows averaged statistical research data on the process of dual wear of brake pads, which were obtained with control measurements for different distances run by freight cars.

The optimal amount of statistical data was determined by the formula [11]

$$n = \frac{t^2 \cdot \sigma^2}{\delta^2}, \tag{1}$$

where t –Student criteria for the preset selection; σ – mean-square deviation of the studied random value; δ – absolute error of the measurement result.

For calculations, we accept the standard width of the brake pad, b = 80 mm.

The obtained statistical material allows analyzing the process of formation of dual wear and evaluating the effectiveness of braking of rolling stock. Therefore, the collected statistical data from the database of the automated workplace of the car maintenance point (AWP CMP) on the wear of new brake pads of the freight train was processed in the specialized software STATISTIKA.

When the distance run by freight cars increases from 17 to 20 thousand km, the intensive wear of brake pads begins, which quickly becomes dual. However, as the distance run by cars increases from 35 to 40 thousand km, the wear on the upper part of the pads will slightly decelerate.

Thus, results were obtained in which the increase in the distance run by cars is associated with a dual wear initially appearing on the working surfaces of brake pads – in most cases without braking, which, according to the results of the studies and measurements of the pad wear, was 95.6% dual; 3.2% wedge-shaped (monistic) and 1.2% even from the total number of surveyed pads.

Table 1. Averaged statistical research data of parameters of brake pads with the formation of dual wear within the operational run of freight cars obtained from the AWP CMP database

Distances run by cars, *N*, [thous. km]	Averaged length of the adverse wear, l_{wc}, [m]	Length of the brake part of the pad, [mm]	Area of the brake part of the pad, $Q_c - Q_{wc}$, [mm^2]	Duality coefficient, ξ
0	0	340	27.200	1
0-3	5	335	26.800	0.985
3-7	10	330	26.400	0.971
7-9	15	325	26.000	0.956
9-13	20	320	25.600	0.941
13-17	25	315	25.200	0.926
17-20	30	310	24.800	0.912
20-24	35	305	24.400	0.897
24-27	40	300	24.000	0.882
27-30	45	295	23.600	0.868
30-35	50	290	23.200	0.853
35-40	55	285	22.800	0.838
40-60	60	280	22.400	0.824
60-85	65	275	22.000	0.809
85-110	70	270	21.600	0.794
110-135	75	265	21.200	0.779
135-160	80	260	20.800	0.765

The analysis of the phenomena of dual wear of brake pads shows that a new pad starts to wear out in the upper part (Figure 2, a) due to the low reliability of the uniform pad retraction device. After the car ran 3 thousand km, the wear has dual appearance as an edge wear with the reproduction of significant friction wear on the upper edge of the pad (Figure 2, b). In this case, the lower brake part of the pad is worn out wedge-shaped, more intensively under the upper wear, with a gradual decrease downwards.

Thus, the upper parts of the pad wear out significantly more intensively than the lower ones (Figure 2, c). On the upper, shortened part of the pad, the concentration of specific pressure q_u is much higher than on the lower one q_l. As a result, wear in the top of the pad occurs earlier than expected for the distance run by the car, requiring replacement of the pad with a quite significant unused remaining intact mass on the bottom of the pad (Figure 2, d). During braking, heat radiation t_u significantly increases below the division line (point A) with a gradual decrease down to the bottom of the pad t_l (Figure 2, c).

After analyzing the collected statistical material, the specific wear of brake pads was focused on for the first time, which causes a local friction wear to begin and grow intensively faster than in other parts, not during braking, but when cars move in traction and run modes. Such wear is proposed to be called dual.

To evaluate the adverse phenomena of brake force reduction in case of dual wear of pads, the concept of duality coefficient was introduced; and the formula was proposed to calculate it depending on the value of the dual wear of the pad to obtain the calculated parameters and conduct further research.

The proposed dual wear coefficient for brake pads is determined depending on the value of adverse wear relative to the total length of the pad, or as the ratio of these areas:

$$\xi = \frac{l_c - l_{wc}}{l_c} = \frac{Q_c - Q_{wc}}{Q_c}, \tag{2}$$

where l_c and Q_c are the total length and friction area of a new brake pad, respectively; l_{wc} and Q_{wc} are, respectively, the length and area of adverse wear, which decrease the friction area of the pad.

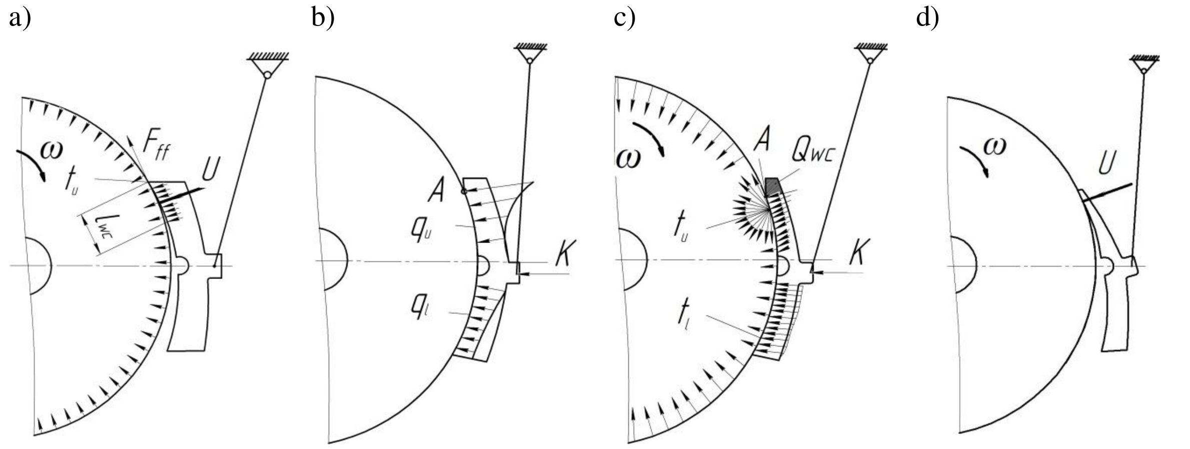

Figure2. Fragments of 2D presentation of the reproduction stages of dual wear of brake pads of the freight car: a) the top of a new pad touches the moving wheel, friction occurs without braking; b) uneven distribution of brake contact pressures q_u and q_l from the pad on the wheel when there is the upper wear; c) braking accompanied by increased heat release t_u and t_l due to the increased heat radiation through the upper wear of the pad; d) wedge-like wear of the pad which should be replaced together with a large part of the intact working body

From the standpoint of the elasticity theory, the brake pad can be represented as a flat rod model (Figure 2), which corresponds to a simplified crushing, shear or bending pattern of a curvilinear rod, where the stresses in the presence of marginal wear can easily be estimated, if the data on the dual wear coefficient ξ; the contact area of the new pad with the wheel Q_c and the corresponding pressing force K acting on the brake pad [12] are available according to the known values of adverse pad wear. With such a problem statement, it is natural to assume that the specific contact pressing forces q_u on the upper part of the working surface of the pad contacting with the rolling surface of the wheel will be greater than or equal to the permissible value of the specific pressure of the pad material

$$q_u = K_{cal} / \xi Q_c \geq [q], \tag{3}$$

where K_{cal} is calculated pressure force affecting the pad; $[q]$ is the permissible value of the specific pressure, which in particular is related to the crushing compressive stress, shear or bend stress, which determine the performance of the pad.

In accordance with Figure 2, we get:

$$K_{cal} \leq \xi Q_c [\sigma_{cc}], \tag{4}$$

where $[\sigma_{cc}]$ is permissible stresses, in this case, crushing compressive stress, which depends on the pad material.

That is, by the time when the pressure force acting on the pad reaches its nominal value, the edge begins to wear out intensively with the transfer and loss of the mass of its composite material and a significant increase in the friction temperature.

5. Models of formation of dual wear

Adverse phenomena of dual wear of brake pads occur due to imperfect triangle design and low reliability of the uniform pad retraction device, where gravity force $\bar{G}$ appears due to the own weight of the parts of the brake system of the bogie (Figure 3, a). Under its action, the pad inclines rotating around the hinge d pressing with slight effort $\bar{U}$ of 150-200 N to the rotating wheel. As the wear increases, a plane denoted by Q_{wc} is formed (Figure 4, c) on which the indicated force is distributed with specific press q_{ff}. As a result, frictional force $\overline{F}_{ff}$ occurs. In the contact of a wheel with the rail, resistance to wheel rolling B_{res} appears and acts with the creep effect, which is not considered here.

Figure 3, a and b show schematically (in the form of a curvilinear rod) a 2D view of the model with the interpretation of the wear of the new pad occurring due to its suspension with ahead angle α (Figure 3, b). Here, according to the static equations, the sum of the torque moments for the brake lever is zero $\sum M(e)=0$ relative to the fixed point of hinge *e*. Under this condition, the calculated braking force acting from the vertical lever of BR in the three-element bogie is determined.

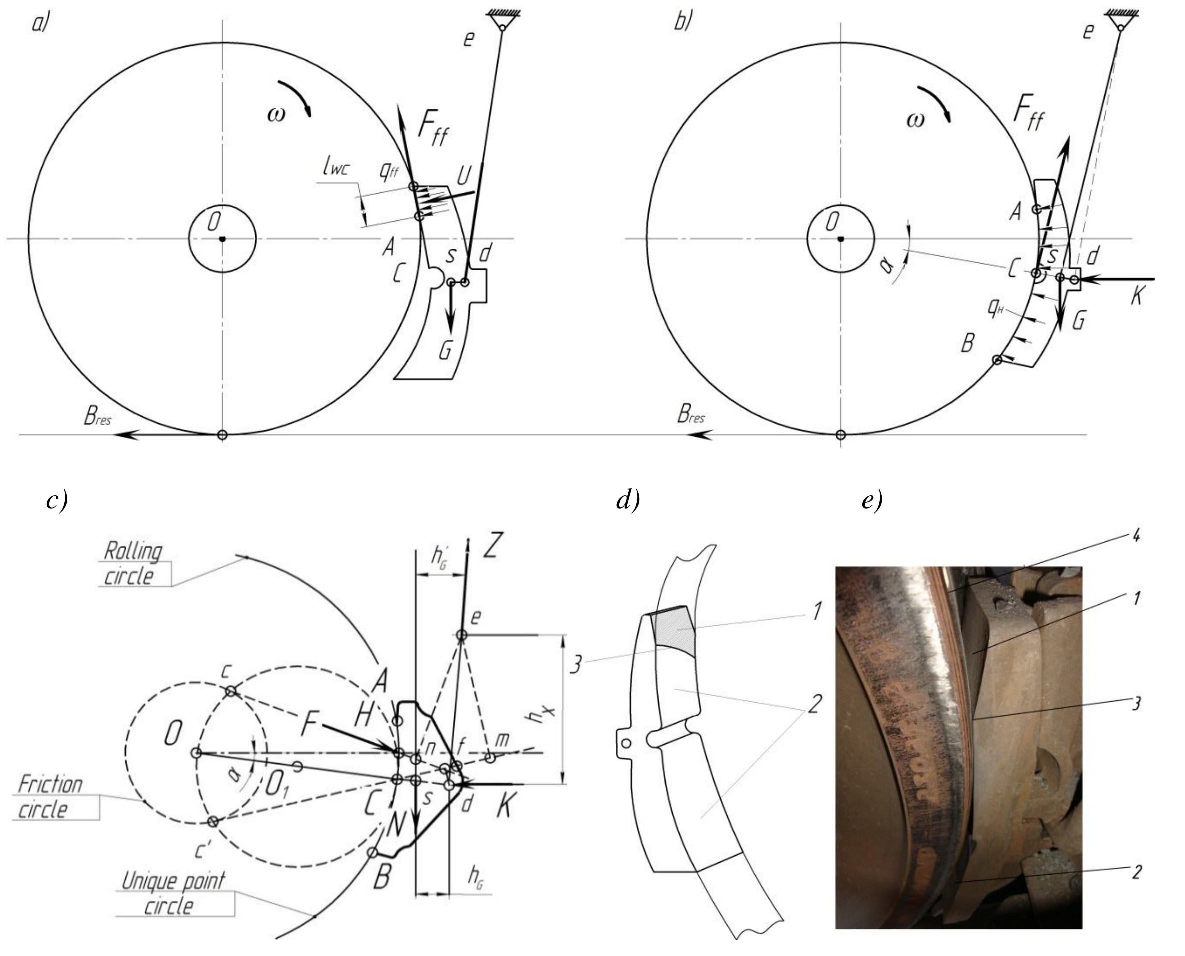

Figure3. Diagrams of formation of dual frictional wear: a) reproduction of the original wear area of the upper edge of the pad during motion without braking; b) braking with a pad brake and development of dual frictional wear of the pad; c) vector distribution of forces acting on the pad in the pendulum suspension *ed*; d) spatial diagram of the brake pad with dual wear; e) view of the position of the brake pad with dual wear relative to the rolling surface of the wheel; 1 – area of adverse wear; 2 – area of working brake wear; 3 – division line of areas; 4 – rolling surface of the wheel

Let us consider the equilibrium conditions of the pad with its hinged suspension under the action of such forces and moments: force $\overline{F}$ - reaction of the interaction of the wheel and the pad; weight force of the pad $\overline{G}$ attached in the center of its weight *s*; pressing force $\overline{K}$ from the brake shoe on the brake block, the vector of action of which should be directed horizontally; force $\overline{V}$ - reaction of the suspension (acts upwards along the Z axis), which can (approximately) be considered to be directed vertically along line *ed* of the element of the brake pad suspension; M_{fr} - friction moment in hinge *d*. Thus, the system of equilibrium equations of all elements of the block brake relative to suspension point *e* will be written in a vector scalar form.

$$\overline{F}+\overline{G}+\overline{K}+\overline{V}=0; \tag{5}$$

$$F(ne)+G(h')+K(h_x)+V(0)=0, \tag{6}$$

where h' and h_x are moment arms of corresponding forces. For convenience of recording, arm*ne*, is denoted by a.

In addition, from the condition of equilibrium of the system relative to point d for the moments of the forces acting on the pad itself, as a separate link, we obtain:

$$F(fd)+Gh_G \pm M_{fr}=0, \tag{7}$$

where fd is the distance from point f to the hinge at point d (hereinafter, denoted b for the sake of convenience) and h_G - two arms for the moments of force $\overline{F}$ and $\overline{G}$ relative to hinge d; M_{fr} is the moment of friction forces that in hinge d will be positive when the wheel rotates clockwise and negative when the wheel rotates in the reverse direction.

After F is eliminated from equations (6) and (7), we obtain the relation:

$$\frac{(Gh_G \pm M_{fr})}{b}=\frac{(Kh_x - Gh'_G)}{a}. \tag{8}$$

The latter formula (7), after transformations, is reduced to equation:

$$\frac{Kh_x - Gh'_G}{Gh_G \pm M_{fr}}=\frac{a}{b}=q=const. \tag{9}$$

Marking the relationship between the numerical parameters taken from Figure 4, c, let us write:

$$l_1/l_2=a/b=q; l_1+l_2=l, \tag{10}$$

where $l=ed$ – length of the suspension; $l_1=ef$ – distance from point f to point e; $l_2=fd$.

In view of (10), the location of point f is determined from the ratio:

$$l_1=ql/(1+q); \quad l_2=l/(1+q). \tag{11}$$

I.e., both points c and f were found, through which during active braking the reaction line $\overline{F}$ passes, thus the direction of its action was found. Thus, we have everything necessary to close the polygon of forces.

Figure 3d and 3e show the spatial scheme and the appearance of a dually worn pad, taking into account the impact of technological conical shape of the rolling surface of the wheel on this process.

The occurrence of dual wear of brake pads is explained by the fact that the more the run of freight cars is, the wear of the entire working surface of the pad is so that the area of site Q_{wc} increases naturally. However, in braking modes under the action of the force of pressing the brake pad $\overline{K}$, the thickness and bending stiffness of the pad decrease and it easier takes a more stable balanced position (Figure 3, b and c). At the same time, any increase in the area of site Q_{wc} leads during braking to growth and the approximation of the specific pressure to the nominal value ($q_{t\rightarrow} q_0$). When the car runs more than 5 thousand km, the wear becomes dual with sagging (Figure 3, d), i.e., it looks like an edge wear with a reproduction of frictional abrasion of the upper edge of the pad.

6. Conclusions

The following conclusions can be drawn on the basis of the conducted studies:

1. The statistical material on measurements of the values of brake pad wear was collected, and the friction of the working body of the pads was virtually simulated in the real conditions of maintenance and repair of freight cars, the results of which revealed a special abnormal biplanar wear of the pads.
2. For the first time, the special character of the biplanar critical actuation profile of brake pads was recognized, and the concept of dual frictional wear of brake pads was introduced due to uniqueness of this phenomenon.

3. It was established that the dual wear of brake pads in the trains causes adverse consequences, such as increasing resistance to motion, therefore the energy consumption of train traction increases, the life of brake pads and wheels shortens significantly, and the braking performance deteriorates which threatens the traffic safety.

4. To calculate the parameters of reduction of the friction force of brake pads in the presence of dual wear of different intensity, the concept of dual wear coefficient has been introduced and a formula for its calculations has been proposed.

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