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USING A WHEEL PAIR WITH A COUNTER-FLANGE TO PREVENT DERAILMENT

Summary. The authors propose an engineering solution for a wheel pair with a counter-flange that satisfies the existing standards of vertical and horizontal dynamics and the movement stability index.

An improved profile of a rail wheel with a counter-flange is developed. It provides additional contact in the horizontal plane in the situation of transverse vibrations of the wheel pair against the rail track, adds to carriage stability and increases the wheel's resistance to derailment when passing a curved part of the tracks or when rails deflect due to force interaction. The wheel pair profile is stabilized with an additional running track and counter-flange that prevents derailment when base flange of the wheel rolls onto the working surface of the rail or when there is a way spacer due to rail spring deformation. The proposed design of the wheel pair is covered by an Ukrainian utility model patent.

Derailment avoidance is one of the main safety issues in the rail transportation of freight [14]. According to the literature [see, for example, 4 – 6, 8 – 10], finding ways to reduce the number of derailment events is the key task of wheel-rail interaction research.

Basic derailment scenarios include derailment due to wheeling onto the rail and track thrusting, when the railhead is pressed out by one wheel flange due to its spring decline and the other wheel falls off the other rail [1, 2, 11, 15].

Consequently, we need to create such elements of trucks (or a wheel-rail system) that provide movement stability, exclude the possibility of a wheel-flange rolling onto the railhead and counteract derailment in the situation of spring rail deflection [3 – 7, 12, 13].

The issue can be solved by introducing counter-flange wheels, which have been used successfully and with steady performance, such as in bridge cranes [16, 17]. Unlike bridge cranes, however, rail transportation presents its own unique challenges to using counter-flange wheels: that of passing track switches and other track devices, which constitute an obstacle for passing of the second wheel flange.

To mitigate this, we need to create a wheel where the top of the second flange is higher than its rolling surface [6]. In this case, track switches and other track devices will not be an obstacle to the second flange as its highest point will be above rail (Fig. 1). The article provides theoretical grounds for the solution proposed. The wheel-pair design for a special-purpose rolling-stock is covered by a utility model patent of Ukraine [5, 6].

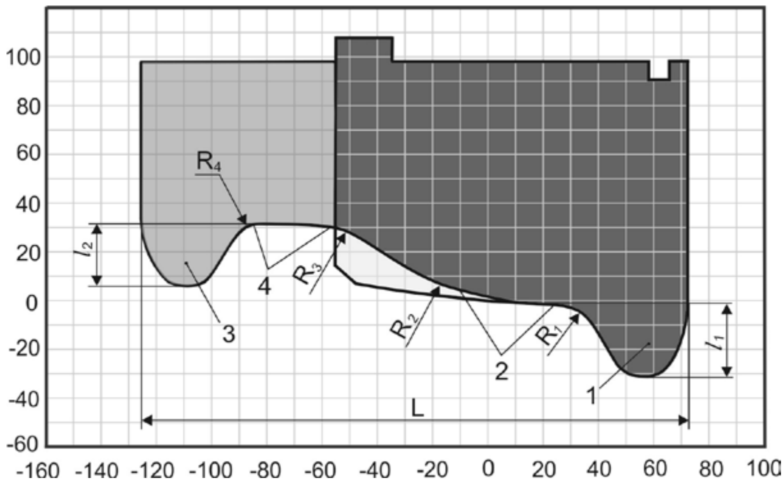

Fig. 1. Comparison of profiles of a standard solid-rolled wheel and the proposed wheel:

+ – solid-rolled wheel profile (National State Standard 9036-76);

+ – proposed wheel with counter-flange;

1 - inner solid-rolled flange of wheel; 2 - main rolling profile; 3 - counter-flange; R_1, R_2, R_3, R_4 - curve radius in transition sections of curved surface that connects counter-flange and wheel; 4 - extra rolling profile

The proposed wheel has two flanges: the main flange and the counter-flange. The tops of the flanges are positioned on different horizontal planes, and the space between them is equal (not shorter) than the height of the flange. The wheel profile has three conical parts corresponding to the main rolling profile (2), an extra rolling profile (4) and a transition profile, located between the R_2 and R_3 curving radii (interaction dynamics between the rail and the transition profile is beyond the scope of the present paper).

The counter-flange only contacts the external rail in case of derailment, when a flange of one of the wheels rolls onto the surface of the rail in a lateral direction and runs a distance equal to the width of the rail. In this case, the second flange will act as a force against derailment (fig. 2).

By design, the first contact point of the wheel is at the main rolling profile, with the flange-rail being the secondary contact point.

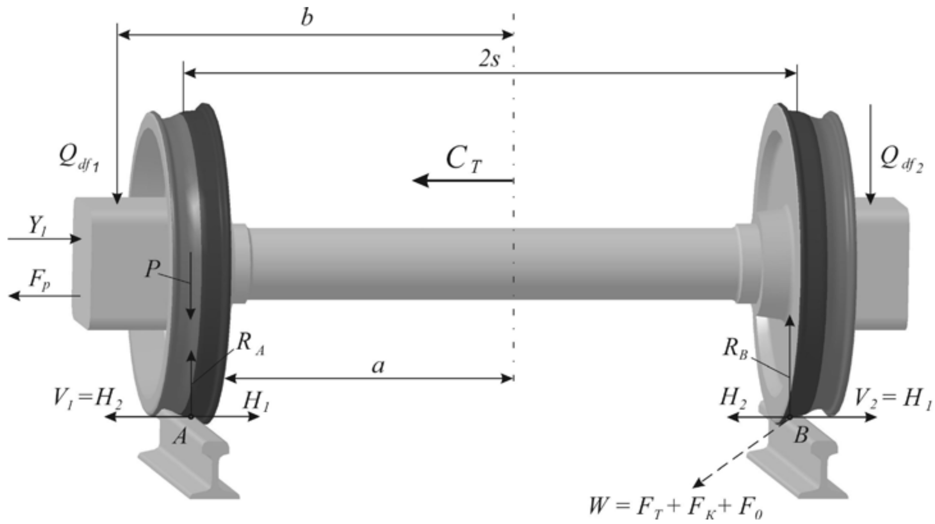

Fig. 2. Analytical model of wheel pair that has the wheels with counter-flange loaded with static and dynamic components of forces:

– main profile of the wheel; – extra profile of the wheel;

H_1 – side pressure on the wheel that guides (overruns);
H_2 – component of frictional force;
V_1, V_2 –forces generated when counter-flange contacts the rail;
$2s$ – distance between wheel pair rolling circles;
C_T – centrifugal force of inertia;
Y_1 – forcing on the side of outside rail;
R_A, R_B – reactions of outside rail to wheels;
Q_{df1} and Q_{df2} – dynamic vertical force acting on the neck of axle;
F_p – force acting from the frame;
b – half the distance between the axles of spring groupings of the car;
a – distance between wheel flanges of the wheel pair.

Having an additional counter-flange at the conical part of the wheel provides an extra contact point between the wheel pair and the rail, which is modeled as a spring contact with a spring element, the latter being used because of the fact that this contact is transitory and happens to be for a short while.

The ingoing wheel will have one contact point with the rail, whereas the non-ingoing wheel will have two contact points: at the rolling surface and on the outside at the external flange. The first contact point will be at the rolling surface of the wheel and the wheel-rail interaction force at this point (P_1) will show no specific features. Moreover, due to a small taper of the rolling surface of the wheel, we may consider that the force P_1 (fig. 3) acts true-vertical. In the second contact point, that is, at the cam surface of the external flange, there is a force generated, which prevents further movement of the wheel pair to the right (P_2). This force includes two components: lateral (P_{2y}) and vertical (P_{2z}).

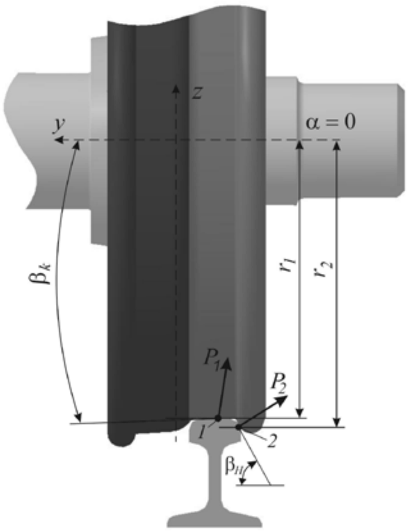

Fig. 3. Contact forces acting on the wheel at two contact points: P_1 - wheel-rail interaction force; P_2 - counter-force to wheel movement

Forces P_1 and P_2 and loading Q acting on the wheel are in quasi-static equilibrium.

$$P_1 = \frac{Q - P_2\left(\mu\ f_{y2}\ sin\,\beta_h + cos\,\beta_h\right)}{\mu\ f_{y2}\ sin\,\beta_k + cos\,\beta_k} =$$

$$= \left(Q - sin\beta_h + \mu\ f_{y2}\cdot\alpha\right) \Bigg/ \begin{pmatrix} \mu\ f_{y2}\ sin\,\beta_k + cos\,\beta_k + \\ + \left(\mu\ f_{x1}\ cos\,\beta_k - sin\,\beta_k\right)\cdot\ f_{y2}\ sin\,\beta_h + \\ + \left(\mu\ f_{x1}\alpha + \mu\ f_{y1}\ cos\,\beta_k - sin\,\beta_k\right) cos\,\beta_h \end{pmatrix} \tag{1}$$

$$P_2 = \frac{\mu P_1 f_{x1}\cdot\alpha + \mu P_1 f_{y1}\ cos\,\beta_k - P_1\ sin\,\beta_k}{sin\beta_h + \mu\ f_{y2}\cdot\alpha} \tag{2}$$

where f_{xi} and f_{yi} – normalized sliding forces; β_k – angle of the conical part of extra profile; β_h – slope angle of the additional flange to horizontal plane; Q – vertical loading of the wheel

Fig. 4 presents mutual positions of the wheel and rail in the normal state – in one-point contact at the tread circle of the wheel. The contact point of the wheel and rail at the tread circle is indicated by a spot.

As we can see from the considered figure, the wheel without the additional flange is moved about 16 mm in the lateral direction when moving in a curved line, assuming the position relatively to the rail presented in fig. 5.

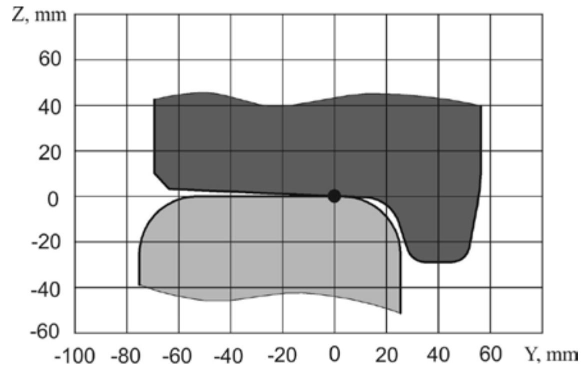

Fig. 4. Mutual positions of wheel and rail in normal state at the tread circle

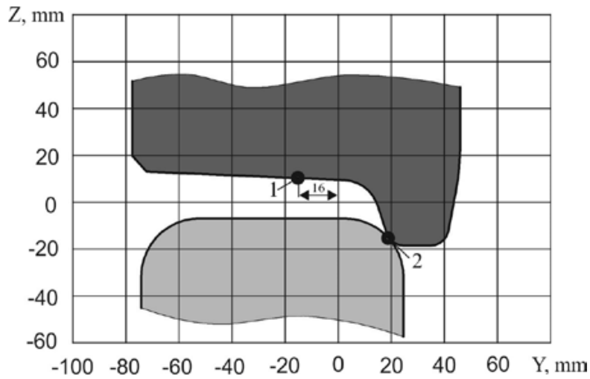

Fig. 5. Position of the wheel without the additional flange relatively to the rail when maximal side assignment

The contact point in a standard rolling circle is shown in figure 1 and the new point of contact between the wheel flange and the side surface of the rail in figure 2. Referring to the figure, we can see how the left wheel is in critical state and derailment is almost unavoidable.

In a similar situation, when the maximum value of the lateral motion is appr. 10 mm, wheels with additional flanges will take the position relative to the rail as presented in figure 6.

At a glance, the difference between lateral motions in these situations is not that great. Yet, when the wheel is equipped with an additional flange, the wheel pair is in a less hazardous situation. The contact is at the point (spot 2 at Fig. 6) that is located on the side surface of the rail, which is a safeguard against complete derailment.

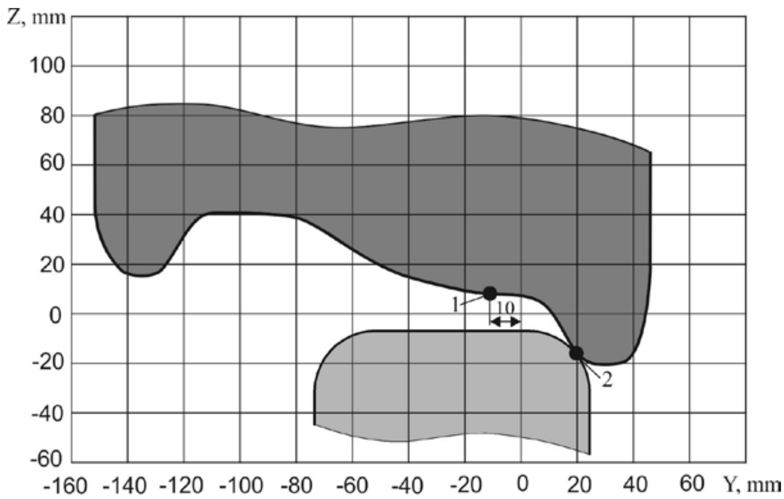

Fig. 6. Position of the wheel equipped with the additional flange relative to the rail at maximum lateral motion

The effects of force interaction can be powered down due to structural measures that make it possible to create alterations to the wheel pair design. Such alterations of traditional wheel pairs create a special-profile rolling surface and reach the lateral forces of interaction allowing tracks to increase stability and prevent derailment.

CONCLUSIONS

The authors have proposed a wheel pair that has the additional running track and counter-flange to provide an additional contact point in the horizontal plane in a situation of lateral vibrations of the wheel pair relative to the track, to ensure stability and increase the resistance against derailment when passing a curved part of the rail or in case of spring deflection of the rail as a result of force interaction. The design of the wheel pair with an additional counter-flange is covered by the Ukrainian utility model patent.

Providing stable wheel movement on the rail requires taking into account interdependence of geometrical, frictional and dynamic parameters of the wheel-rail interaction at the stage of design. It is necessary to take into consideration redistribution of the forces due to the presence of wheels with a counter-flange in addition to the classic distribution of forces in the wheel-rail contact zone.

Implementation of the proposed wheel pair that has a counter-flange to the special-purpose rolling stock will improve safety of movement and carriage integrity, and provide positive social and economic effects by decreasing the number of transportation incidents and emergencies.

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