Investigation of the effect of a dent on the stress state of the wheel in the "wheel-rail" contact

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Abstract. The Purpose of this work is to determine the effect of a dent on the stress state of the wheel at different rim thicknesses. The article uses methods of numerical solution of partial differential equations (finite element method) to determine the stress state in the contact "wheel-rail" at different thickness of the rim with a chink and without a chink. Based on the research, proposals have been developed to change the norms of rejection of wheels with a thin rim in the presence of a dent on the surface of the ride. Changing the norms of rejection of wheels with a thin rim in the presence of a dent on the surface of the ride will increase the resource of the wheels and thereby reduce the need for new wheels.

1. Introduction
On the surface of rolling railway wheels, such defects as dents often appear (Fig. 1). A dent is a contact-fatigue defect [1]. Unlike wheel wear due to abrasion which occurs on the surface and is accompanied by the formation of fine dust particles of wear, chipped arises as a result of fatigue crack development occurring at a depth of 4-6 mm under the surface, which extends in the direction of the surface and leads to the breakaway of a significant part of the metal [2]. The formation of a fatigue crack begins at the point where the maximum equivalent stresses are applied, which are responsible for the accumulation of fatigue damage in the structure of the material. Maximum pressures are realized on the surface, but maximum equivalent stresses are applied below the surface. In addition to fatigue-related dents, there may be dents in light spots, sliders, and navars, as well as thermal cracks [3]. Fatigue dents can be distinguished by an extremely uneven (stepped surface).

2. Statement of the problem
When operating freight cars, dents up to 50 mm long and up to 10 mm deep are allowed, and passenger cars up to 25 mm long and up to 10 mm deep. Gouges up to 1 mm deep are not rejected at any length [4].

Figure 1. Dents on the surface of the rolling wheel
A dent can cause the wheel to reject when the rim is thin. The permissible operating thickness of the wheel rim is 22 mm. The rim thickness should be measured on a dent. Therefore, if the operation detected by the wheel rim thickness is 26 mm and the wheel is chipped, with a depth of more than 4 mm, the wheel can't continue to operate, the carriage is disengaged in repairs to replace the wheelset, and the wheelset is sent to overhaul for replacement wheels.

The presence of a dent leads to a change in the geometric parameters of the "wheel-rail" contact due to the appearance of a "P-shaped" work-out on the surface of the skating profiles. Therefore, it is urgent to study the effect of a dent on the stress state in the "wheel-rail" system at different thickness of the wheel rim.

3. The results of the experiments

To determine the stress state in the "wheel-rail" system, the Hertz theory is often used [5], which gives relatively simple analytical dependencies and makes it possible to simplify the calculation significantly. However, the application of this theory leads to significant errors in the calculation of the stress in the "wheel-rail" system for a wheel that has a dent. This is due to the fact that in the Hertz theory deformations are considered only in the contact zone of bodies and the actual shape and size of the contacting bodies are not taken into account. A numerical solution using the finite element method allows us to solve the problem of determining stresses taking into account not only local, but also General deformations of contacting bodies, taking into account their real shapes and sizes.

Due to the symmetry of the problem, we will consider only one-fourth of the wheel part, which will make it possible to simplify the solution of the problem by using fewer finite elements. A volumetric model of one quarter of the wheelset and a section of rail was created for the calculation (Fig. 2).

Four models were created:
1. Wheel Model with nominal rim thickness without chipping;
2. Wheel Model with a nominal rim thickness with a dent;
3. Wheel Model with 22 mm rim thickness rim without chipping;
4. A model of a wheel with a rim thickness of 22 mm with a chipped.

The model used a wheel with a flat conical disk. When creating the model, the wheel dimensions were taken in accordance with [6], the rail with [7]. The depth of the dent was assumed to be 6 mm. The wheel contact with the P65 rail was simulated (the radius of the rail head is 500 mm).

The wheelset was loaded with a vertical force applied to the centers of the necks. The value of the load per neck was assumed in accordance with [8] as 0.621P₀ (P₀ is the axial load taken when calculating 23.5 ts). Since the ¼ part of the wheelset is considered, half of the calculated load value was applied to the model. The rail was rigidly fixed on the sole, and symmetry conditions were set at the junction of
the wheelset with the cut-off parts. A contact interaction was described between the rolling surface of the wheel and the rail head; the axle was rigidly connected to the wheel hub.

The calculation used a linear-isotropic model of the material. The modulus of elasticity was assumed to be $2.1 \times 10^{11}$ PA, and the Poisson's ratio was 0.3.

The finite element model was created using elements of the 10-node tetrahedron type (the grid of finite elements is shown in Fig. 3).

These isoparametric finite elements have a quadratic form function, which makes it possible to describe well the high-gradient stress state that occurs in the "wheel-rail" contact. In the contact zone of the wheel and rail, in accordance with the recommendations [9], the size of the final elements was assumed to be 3 mm. The grid of finite elements in the contact zone is shown in Fig. 4. The Calculation was performed using the ANSYSWORKBENCH version 18.2 application software package.
As a result of the calculation, the stresses and contact pressures in the wheel-rail system were obtained for the four wheel models described above. To assess the strength in accordance with the recommendations [10], equivalent stresses determined by the Mises theory were used. For a wheel without a dent with a nominal rim thickness, the distribution of equivalent stresses is shown in Fig. 5, contact pressures in Fig. 6, for a wheel with a minimum rim thickness and a dent in Fig. 7-8. The values of stresses and pressures in Fig. 5-8 are given in MPa.

Figure 5. Distribution of equivalent stresses in the "wheel-rail" system (nominal rim thickness without chipping)

Figure 6. Distribution of contact pressures in the "wheel-rail" system (nominal rim thickness without chipping)
4. Discussion of results

From the calculations obtained, it can be seen that the wheels without a dent have the highest equivalent stresses at a depth of 4-5 mm below the surface of the ride, while the maximum equivalent stress is 0.71 of the maximum contact pressure. For wheels with a dent, the maximum equivalent stress occurs in the "P-shaped" recess formed by the dent at a depth of 4-5 mm from the surface of the ride, the value of the maximum equivalent stress is 1.71 of the maximum contact pressure.

When the rim thickness of a wheel with a chipped rim decreases, the maximum contact pressures increase from 1,346 MPa to 1,617 MPa, while the maximum equivalent stresses do not increase practically (at a nominal rim thickness of 1,754 MPa, at a rim thickness of 22 mm -1,762 MPa). The results of calculations are shown in table 1.

| Table 1. Maximum equivalent voltage and maximum contact pressure |
|---------------------------------------------------------------|
| Name of the value | Nominal thickness of the rim | Rim thickness 22 mm |
|-------------------|-----------------------------|---------------------|
| Without a dent    | With a dent                  | Without a dent      | With a dent         |
|                   |                             |                     |                     |
The maximum equivalent stress, MPa

|          | 719 | 1,754 | 726 | 1,762 |
|----------|-----|-------|-----|-------|

Maximum contact pressure, MPa

|          | 1,012 | 1,346 | 1,026 | 1,617 |
|----------|-------|-------|-------|-------|

Thus, the equivalent stresses of a wheel with a dent at the nominal and minimum thickness of the rim are almost the same, which leads to the idea of unjustified rejection of wheels with a thin rim with dents on the surface of the ride of up to 6 mm.

Rejection of such wheels leads to a significant reduction in the wheel resource. So, if a wheel has a rim thickness of 26 mm and a ridge thickness of 29 mm and there is a 5 mm deep chink on the surface of the ride, then according to existing requirements, such a wheel is rejected. Since the thickness of the rim, measured at the point of the dent, will be 21 mm. Despite the fact that the residual life of such wheels on the wear of the ridge based on the minimum flange thickness 24 mm (1 mm flange thickness 10-12 thousand kilometers) will amount to 50-60 thousand kilometers. Based on the total wheel resource of 400-500 thousand km of mileage, the total wheel resource is reduced by 10-12.5%.

Taking into account the current shortage of wheels, it seems appropriate to allow for wheels with a minimum rim thickness of up to 6 mm, even if the thickness of the rim together is reduced to less than 22 mm. The equivalent stress at the point of the dent here will be almost the same as that of a new wheel with a dent.

5. Conclusions and conclusion

- Stresses and contact pressures are Determined for wheels with nominal and minimum rim thickness in the presence and absence of a dent.
- As a result of the calculations, it was found that the wheel with a 6 mm depth chink with a decrease in the rim thickness, the value of equivalent stresses in the place of the chink practically does not change (1,754 MPa at the nominal thickness of the rim and 1,762 MPa at the minimum)
- Based on the results of the calculations, a proposal was formulated to increase the wheel resource, which is that wheels with a minimum rim thickness can allow dents on the surface of the ride up to 6 mm, while the minimum thickness of the rim and dents should be at least 16 mm.

6. References

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