Reduced Wheel-Rail Pair Wear Due to Differential Rotation of Wagon Wheel Pairs

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Abstract. Applied lubrication tools come to the brink of their normal effectiveness. A method for reducing the wear of wheels and rails and a design for its implementation, consisting in the application of the proposed differential axis. The predicted comparison criteria depending on the change in the value of the elastic-friction coupling between the wheels, as well as the calculated effect, in comparison with a rigid pair of wheels, indicates the possibility of selecting the optimal coupling between the wheels during operational tests.

A numerical assessment of the movement of the model 18-100 trolley in a curve with a radius of 200 m was carried out. Based on the results of a comparative assessment, it was determined that when the trolley with wheelsets moves in differential mode, compared with typical, depending on the amount of coupling between the wheels, the average decreases: lateral force by 20.5–40.2%, and the specific work of the displacement friction forces at the contact points by 26.6%. The criteria for reducing wheel wear along the surface of the ridge and the ridge, as well as the specific wear of the vertical and lateral rail, when the connection between the wheels (to critical to slip) increases, practically do not change and, accordingly, make up 36.8%, 13.2% and 33.5% and 25.5%.

1. Introduction
One of the main and most resource-intensive problems that have been acute for railway transport for more than three decades is the problem of ensuring stable interaction of the wheel-rail system [1, 2]. Currently used methods and means aimed at reducing wear are mainly concentrated in two directions: increasing the hardness of the wheels and rails and the direct application of various lubricants (lubrication) on the rolling surface to the wheel-rail interaction unit.

According to the results of the analysis, it was found that the tools used are approaching the brink of their normal effectiveness, as they are aimed at solving the consequences of the problem, and not eliminating the cause.

It is necessary to increase the resource of wheels and rails during the movement of non-traction rolling stock in curved sections of the track by reducing the magnitude of the longitudinal friction forces and sliding speeds at the contact points of the wheels with the rails by developing wheel sets of differential design [3, 4].

Studies show that the main reasons for turning solid-rolled wheels of freight cars for the past 15 years or more are wear, undercutting, and pointed crest rolling, which on average account for 27.8–39.3% of all turns. Five years ago, the share of wheel turning due to wear of the wheel pair flanges was ten times higher than the share of wheel turning for rolling the wheel, as a result of which there was a loss of metal along the thickness of the rim and an intensive decrease in the resource of wheel pairs compared to turning over the natural wear of the wheel. Since to increase the thickness of the
ridge by 1 mm from the surface of the wheel, an average of at least 1.5 mm of the thickness of the wheel rim must be removed. Today, due to the widespread use of lubrication methods, the number of wheel pair linings along a thin ridge is three times higher than the number of natural rolling linings over a skating circle [5, 6].

Numerous observations of the dynamics of the wear of the wheels along the route allow us to conclude that the resource of the wheelset of a freight car does not exceed 600 thousand kilometers. It should also be noted that the intensity of lateral rail wear has not changed since 2012, this suggests that the applied lubrication tools are approaching the limit of their normal efficiency [7, 8].

To assess the significance of the above indicators, you should refer to the characteristics of the results of the operation of the wheel-rail system in Russia and the USA. In Russia, wheel flange turning over the ridge exceeds the similar US indicators by more than 10 times, and rail removal by lateral wear is more than three times [9].

Thus, the presented picture clearly shows that, despite the success of the measures applied, the problem of intensive wear of the wheels and rails in the curves is not completely resolved. The costs of material resources in locomotive, carriage and track facilities associated with excess wear in the wheel-rail system, primarily in curved sections of the track, are at a fairly high level and require continued work to reduce them. Annual expenditures for 2016 on the Russian Railways road network only for eliminating the consequences of intensive wear of the elements of the wheel – rail interaction pair (turning, replacing wheels and rails, shifting rails with a change in working edge, etc.) amounted to about 2.9 billion rubles [10, 11].

Currently, the use of rolling stock with wheelsets providing independent rotation of the wheels is being studied in the USA, Great Britain, Sweden, Germany, Bulgaria, Canada, Spain, Italy, France, Poland and Japan. This problem, as can be seen from the above analysis, becomes one of the most urgent. As a result of the analysis, more than 45 technical solutions were identified [12, 13].

A design of the wheelset was proposed, which eliminates the disadvantages of the prototypes, in particular, provides the necessary connection between the angular speeds of the wheels, the necessary strength and durability (increase the service life) of the railway wheelset and the safety of the rolling stock [14].

2. Research Methods and Results
The main goal of constructive improvement of the wheelset is to implement the subcritical level of relative sliding in the contact of each wheel with the rail and to eliminate the mutual influence of unequal contact conditions of both wheels. This will minimize wear on the contact surfaces of the wheel and rail when moving in curved sections of the track [15].

The proposed wheelset (Figure 1) consists of an axis of differential execution on the indentation necks, which wheels 9 are pressed on. An axis of differential execution consists of two semi-axles with a cavity of 8 and a solid section 7. Nested axles can rotate relative to each other along axial line due to bearings 2, 5, 13.

![Figure 1. Wheel set with differential axis.](image)
The axis of the solid section 7 is made integral with the thrust collar 10, the protrusions 4 and two necks for landing radial 2 and persistent 5 bearings. To reduce the weight of the axle shaft 7 between the bearing surfaces for bearings 2 and 13, it is made conical, with a constant safety factor for the axle shaft along the length. For mounting, the diameter of the landing surface of the axle shaft 7 under the sliding bearing 13 is made so that it is greater than or equal to the diameter of the wheel hub.

In the semiaxis with a cavity of 8 at the point of transition from the solid section to the cavity, the necessary transition radius is maintained between the bottom surface and the inner cylindrical surface of the cavity to eliminate stress concentration at the transition point.

The sliding bearing 13 is planted together with the labyrinth ring 11 from the wheel side onto the semiaxis 7 until it stops at the shoulder 10, at the other end of the semi-axis 7, radial 2 and persistent 5 sliding bearings are mounted on the necks, which are closed by the glass 1. The glass 1 is intended for ensure the necessary accuracy of the seating surfaces of the outer rings of bearings 2 and 5. The outer edge of the bottom of the glass has the required radius of rounding to be able to install the glass on the bottom of the cavity of the axle shaft 8. To comply with the radius rounded I outer edge of the bottom nozzle and to provide the necessary seating surface of the thrust bearing outer ring 5, the bottom nozzle has an increased thickness compared with the walls.

It can be conditionally determined that cup 1 together with thrust 5 and radial 2 bearings represent an internal bearing assembly, and bearing 13 together with a cover 14 and a labyrinth ring 11 represent an outer bearing assembly.

The connection of the axle shafts is carried out by the cover 14 using bolts 12. The cover 14, due to the grooves made on the inside, forms a seal (labyrinth) with the labyrinth ring 11, which protects the bearings from dust, moisture and dirt. Sealing the connection of the cover with the bearing housing is carried out by a rubber ring-gasket, which is put on the cover. With its protrusion, the cover abuts against the outer ring of the bearing 13.

The axial integrity of the wheelset is provided by a thrust collar 10, a protrusion on the cover 14 and a sliding bearing 13, capable of absorbing axial loads. During the movement of the wheel pair along the rail, under a number of circumstances, the axle shaft 7 tends to exit the cavity of the axle shaft 8 and abuts against the inner ring of the bearing 13 with a stop shoulder 10, then the force is transmitted through the sliding surfaces of the bearing rings to the outer ring of the bearing, which abuts against the protrusion on the cover 14. The cover 14 with bolts 12 is connected to the axle shaft 8.

The optimal operation of the proposed design of the wheelset is assumed in a compromise between a typical wheelset with wheels rigidly mounted on the axle and wheels freely rotating on the axis, for which purpose it was proposed to provide the necessary elastic-friction connection between the angular speeds of the wheels of the wheelset by including an elastic between axles 8 and 7 elastomeric element 6. For reliable fastening to the inner surface of the cylindrical cavity of the axle shaft 8, the elastic elastomeric element 6 is installed close to the edge of the glass 1 so that it grooves into the guides of the glass. On the inner cylindrical surface of the elastic elastomeric element 6 are elastic protrusions 3, which are engaged with the protrusions 4 of the axle shaft 7.

Due to the fact that structural changes affect only the middle part of the axle of the wheelset, interchangeability of wheel sets of standard and differential design is ensured, therefore, it is not necessary to change the designs of the cargo models 18-100 (TsNII-X3) and passenger KVZ-TsNII carts wagons (Figure 2).

Since the sliding bearings 2, 5, 13 have some frictional resistance, the connection between the wheels can be considered elastic-friction. Moreover, the set of elements that directly or indirectly impede the relative rotation of the wheels can be called an elastic-friction coupling.

The wheelset works in two modes. When the wheelset moves on straight sections of the track at the contact points of the wheels with the rails, relatively small slip friction forces arise, which are not equal to each other and are often directed in opposite directions; moments twisting axis, formed from these forces, are also relatively small. Under the action of these forces, the semiaxes 7 and 8 will make relative rotations around their common axis. In this case, the following occurs in the elastic joint of the
The elastic protrusions 3 of the elastomeric element 6 are deformed, moving along concave surfaces between the protrusions 4 of the axle shaft 7. In proportion to the displacement and deformation of the protrusions 3 from the initial position, the moment of resistance to rotation between the wheels also increases. As a result, the external moment, the twisting axis, is less than the maximum transmitted by the connection of the semi-axes, the value of which is determined by calculation and is determined by selecting the number of protrusions 4 and elastic protrusions 3 and their contact parameters, i.e., the proposed wheelset works like an ordinary torsion-elastic one. When the wheel pair moves in the curved sections of the track, the resulting longitudinal wheel slipping forces on the rails become much larger and, consequently, the moments twisting the wheel pair axis increase. If the external torsional moment is greater than the maximum set between the half axles of the proposed axis, the relative rotation of the semi-axes of the wheelset occurs. In this case, the elastic protrusions 3 move along the surface of the protrusions 4 of the axle shaft 7 from one cavity to another without returning to the original position. Thus, the paths traveled by the left and right wheels of the wheelset on the curved section of the track can be equalized, respectively, the paths of the pure sliding of the wheels at the points of contact along the rails will decrease.

**Figure 2.** Design of modernized wagon trolleys.

It can be concluded that the greater the distance between the radial plain bearings, the smaller the load attributable to them. Therefore, to reduce the forces attributable to radial bearings, when designing the proposed axis of differential execution, the largest length between them was provided in its design.

The main objective of a theoretical study of the movement of a model 18-100 wagon carriage in curves is a comparative analysis of the design criteria for the intensity of wear of wheels and rails when moving with wheelsets of standard and differential design.

To carry out studies of carts with typical and proposed wheelsets of differential design, a mathematical model of movement in a curved section of the track is developed. In developing the mathematical model, the scientific works of Professor V.B. Medel [14]. The developed mathematical model is calculated and implemented as independent software. The calculation is made by the method of successive approximations.

A numerical assessment of the movement of the model 18-100 trolley in a curve with a radius of 200 m was carried out. Based on the results of a comparative assessment, it was determined that when the trolley with wheelsets moves in differential mode, compared with typical, depending on the amount of coupling between the wheels, the average decreases: lateral force by 20.5–40.2%, and the specific work of the displacement friction forces at the contact points by 26.6%. The criteria for reducing wheel wear along the surface of the ridge and the ridge, as well as the specific wear of the vertical and lateral rail, when the connection between the wheels (to critical to slip) increases, practically do not change and, accordingly, make up 36.8%, 13.2% and 33.5% and 25.5%.

3. **Conclusions**

1. The analysis of technical solutions aimed at reducing the wear of wheels and rails, consisting in ensuring the difference in the frequency of rotation of the wheels in the design of the wheelset when moving in curved sections of the track.
2. A new method has been developed to increase the resource of wheels and rails, which consists in using the axle of a pair of wheels of differential design, characterized in that the proposed axis consists of two semi-axes embedded in each other with a given elastic-friction coupling and the possibility of axial rotation relative to each other, which provides the necessary difference in the frequency of rotation of the wheels when they occur to the critical (under the condition of sliding) longitudinal forces.

3. A new methodology for assessing the health of the proposed differential axis has been developed, characterized in that the axle structure is two semi-axes embedded in one another with the possibility of axial rotation relative to each other, including an estimate of the fatigue strength of the structure and analytical expressions for the selection and calculation of bearings in the axis differential performance.

4. A refined mathematical model of the movement of a biaxial rolling stock carriage in curved sections of the track has been developed, characterized by taking into account the elastic-friction coupling, the difference in rotational speed between the wheels and the two-point contact of the rolling wheels on the rail, as well as the condition for the transition from joint rotation of the wheels to differential.

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