**Determining the Influence of Wheelset Arrangement in the Model 18-100 Bogies on the Level of Steering Efforts in the Wheel-Rail Flange Contacts**

**Evgen Zub**
PhD Student*

**Viktor Tkachenko**
Doctor of Technical Sciences, Professor
Department of Electromechanics and Rolling Stock of Railways**

**Svitlana Sapronova**
Corresponding author
Doctor of Technical Sciences, Professor*

**Serhii Syvakivskiy**
PhD Student*

*Department of Wagons and Wagon Economy**
**State University of Infrastructure and Technologies**
Kryvliyska str., 9, Kyiv, Ukraine, 04071

1. Introduction

A structural feature of the model 18-100 bogies and their analogs is a three-element frame with a non-rigid connection of frame sides with an intermediate beam [1, 2]. Such a design of the bogie creates prerequisites for wheelsets in the bogies to warp during operation, which in turn is the cause of increased steering forces in the flange contacts of wheels with rails. According to statistics, more than 80% of cars with the model 18-100 bogies have misaligned wheelsets.

As is known, the level of steering effort affects a number of important technical and economic indicators of freight cars operation: the intensity of wear of the rolling surfaces of the wheels, resistance to movement, stability in relation to derailment.

The maintenance system of freight cars does not provide for technological operations to check the misalignment of wheelsets in bogies. Even in the bogies of model 18-100 after modernization with the installation of elements of the company “A. Stucki” and wheelsets with a non-linear profile of the ITM-73 wheels do not provide control of wheelset arrangement relative to the rated one.

In this regard, there is a need to clarify the dependence of the steering forces in the flange contacts of the wheels with rails on the distortions of wheelsets in the bogies of freight cars. This clarification can be a justification for the introduction of additional technological operations of monitoring the wheelset arrangement relative to the bogie frame in the maintenance system.

Therefore, studies on determining the influence of wheelset arrangement in the model 18-100 bogies on the level of steering efforts in the wheel-rail flange contacts are relevant.

2. Literature review and problem statement

The dynamics and characteristics of wheel-rail contact have been the subject of numerous studies since the middle of the 19th century [3]. However, there is very little data in open information sources regarding the statistics of deviations in the installation of wheelsets in bogies.

It is a general opinion that the misalignment of wheelsets in the model 18-100 cars is typical and covers more than
80% of cars. There are a number of reasons for this phenomenon. These include, for example, gaps in the box joints, horizontal deformations of springs, technological deviations in the geometric parameters of the side frames during the production process, etc. Together, these factors can create a stable skew of wheelsets in the bogie relative to the rated position up to 1.0° (0.018 rad) [4]. At the same time, the researchers confine themselves to a general statement about the presence of the influence of the geometric parameters of wheelset arrangement in bogies on the level of steering forces and wear in the flange contacts of the wheels with rails without specific quantitative dependences.

The development of modern railroad vehicles requires effective modeling taking into account complex operating conditions, especially this applies to switches, as noted in study [5]. Modeling the movement in turnouts of a freight car with a misalignment of the wheelset could expand and complement the theory of contact interaction.

Studies [6, 7] revealed a fundamental difference in the character of the wear of wheel flanges of wheelsets in the bogies of different designs: bogies with a rigid frame on passenger cars and bogies with a non-rigid two-element frame of model 18-100. At the same time, possible changes in the position of the wheelset and its effect on the wear of the flanges were not considered.

There are also opinions about the negative impact on flange wear of the use of heavy types of rail track [8] without calculations of the contact interaction between the wheel and rail with increased hardness.

The analysis of the main directions of reducing the intensity of wear of the wheel flanges is given in papers based on the justification of the optimal ratio of the wheel steel hardness to the rail steel hardness [9, 10]. At the same time, research is not conducted on a specific type of rolling stock, without taking into account design features.

It is believed that with a rigid track, most of this energy of the dynamic interaction of wheels and rails is transformed into the work of frictional forces. Even with 3D modeling of the high-frequency interaction between the wheel and rail, authors do not consider possible state changes due to the structural features of the railroad transport unit [11].

In studies [12, 13], the dynamic loading of the load-bearing structures of the main types of freight cars with actual dimensions and bogies of the 18-100 model was considered. These cars have an above-standard service life. Therefore, deviations from the rated wheelset arrangement in the bogies of these cars also occur. Without checking these structural deviations, it is not possible to give recommendations for extending the service life of the cars.

With the use of classical provisions of theoretical mechanics, different methods for building a calculation model of the rolling flange of a wheelset of a car due to the movement of rolling stock on a curved section of the track are reported [14]. But the influence of the angles of approach of wheelsets on the rail and the gap in the track is not taken into account.

Ideas regarding the effect of steering forces in the contact of wheelsets with rails on the kinematic resistance of locomotives and cars were developed in works [15, 16]. In these studies, there is no analogy of the effect of skew on the resistance of rolling stock of railroads.

The mechanism for pressing the flanges of wheelsets to rails in straight sections of the track is considered in [17]. The role of the geometric parameters of wheelset arrangement and their deviation from the parallel position is noted. The impact of the deviation on the dynamic indicators, however, is not determined.

When studying many causes of increased wear of wheel flanges, modeling of the dynamic interaction of the wheel and rail is used, which makes it possible to obtain more accurate values of dynamic characteristics [18, 19]. To check the reliability of the obtained data in dynamic contact studies, developed and existing bench installations and mathematical models [20, 21] are used, which in no way take into account the angles of change of wheelset installation relative to the base of the bogie.

Our review of the literature [3–21] reveals that in most sources the contact interaction between the wheel and rail is investigated, the reasons for the wear of wheel flanges are proved on the basis of mathematical modeling and laboratory research. At the same time, none of these studies prove that the result of cumulative misalignment of wheelsets during the operation of cars is the wear of wheel flanges, increased resistance to movement, and the occurrence of a dangerous situation of car derailment.

This allows us to state that it is appropriate to conduct a study into the influence of deviation from the rated setting of wheelsets in the model 18-100 bogies on the level of steering forces in the flange contacts of wheels with rails. This will make it possible to determine the limits of permissible deviations of wheelset arrangement in bogie frames from the rated one, as a criterion for making a decision on the need for bogie repair.

### 3. The aim and objectives of the study

The purpose of our study is to determine the characteristics of influence of the deviation in wheelset arrangement in the 18-100 bogies on the level of steering forces in the flange contacts of the wheels with rails. This will provide an opportunity to justify changes to the procedure for maintenance and repair of the model 18-100 bogies, namely the introduction of a technological operation to control accumulated operational distortions of wheelsets in bogies.

To achieve the goal, the following tasks were set:

- to build a kinematic diagram of the movement of a bogie in a circular curve;
- to construct a mathematical model of the dynamic fitting of the 18-100 bogie into the curved section of the track.

### 4. The study materials and methods

The object of our research is the process of directing the bogies of the model 18-100 freight cars along the rail track, in particular, in the curved sections of the track.

The main hypothesis of the research assumes that the running of the sidewalls of the bogie frames and, as a result, the skew of wheelsets in the bogies of freight cars is the main reason for the increased intensity of wear in the contacts of wheel flanges with rails.

Frames of the model 18-100 bogies have a so-called three-element structure and consist of two side panels and a spring (pivot) beam.

These include models of the following bogies: 18-1711; 18-9817; 18-9902; 18-4129; 8-9844; 18-1750; 18-7020; 18-4129, etc.
Each of the modifications was designed with the hope of improving the operational characteristics of cars. The latest, most innovative modifications are bogies of models 18-4129 and 18-9817, which are a joint development by the companies ASF Keystone (USA) and PIG “Inter-Car-Group” (Ukraine). The bogie exploits technical solutions and technologies similar to the Motion Control bogie, which is successfully used in the USA and Canada. In particular, polymer adapters “AdapterPlus” are installed in the bushing holes of the sidewalls, the use of which significantly reduces the wear of wheels and rails.

Using the example of the 18-7055 bogie of the 12-7023 semi-car model by the Kryukiv Car Building Plant, a mathematical model was developed for fitting into the curved section of the track.

The study of fitting the bogie in curves is carried out to determine the influence of the geometric parameters of wheelset arrangement in the bogies on the wear indicators of wheel flanges.

The pseudo-static method of steady motion in a circular curve under the action of external forces of interaction with the rail track and the car body was used to simulate the movement of the bogie in the curved section of the track. The mathematical model of fitting a bogie into a curve is a system of d’Alembert-Lagrange equilibrium equations. This method was chosen as the simplest reliable method for describing the movement of a mechanical system with undeformed bodies, which provides a sufficient level of calculation accuracy. The Given-Minerr-Find calculation module in the Mathcad software package was used to solve the system of equilibrium equations.

5. Studying the influence of wheelset arrangement on the level of steering forces in the flange contacts of wheels with rails

5.1. Construction of the kinematic scheme of bogie movement in a circular curve

To study the influence of the deviation from the rated setting of wheelsets on the level of steering forces in flange contacts, we shall build a kinematic diagram of the movement of a bogie in a circular curve, which is shown in Fig. 1. Parameters for calculations (the letters \(y\) in the parameter indices mean the wheel number and the wheelset number, respectively):

- \(V_y\) — peripheral velocities of the centers of the corresponding wheels, associated with the rotation of wheelsets in the horizontal plane around the center of the curve, which depend on the radius of the curve of the track section \(\rho\);

\[
V_y = V \cdot \frac{\rho_i}{\rho} \quad (1)
\]

where \(V\) is the speed of the car; \(\rho, \rho_i\) are, respectively, the radii of the curved section of the track and the outer (\(i=1\)) and inner (\(i=2\)) rails:

\[
\rho_1 = \rho + A; \quad \rho_2 = \rho - A, \quad (2)
\]

where \(A\) is half the distance between the contact points of the wheels of a wheelset and rails. For a track of 1520 mm, this is approximately equal to 780 mm;

- \(\alpha_i\) — angles of attack, or approach angles, of wheelsets on the rails:

\[
\alpha_i = -\gamma - \delta_i, \quad (3)
\]

\[
\alpha_i = -\gamma + \delta_i, \quad (4)
\]

where \(\gamma\) is the angle of the radial wheelset arrangement in the curved section of the track:

\[
\gamma = \frac{C}{\rho}, \quad (5)
\]

where \(C\) is the bogie base, the distance between the axles; \(\sigma_1, \sigma_2\) — angles of deviation in wheelset arrangement in the bogie from the rated one; \(\delta\) — angle of skew of the bogie in the track due to the transverse displacement of wheelsets within the gaps between the wheel flanges and rails:

\[
\delta = \frac{y_{62} - y_{61}}{C}, \quad (6)
\]

where \(y_{61}, y_{62}\) are the lateral displacements of wheelsets, which determine their position in the curve;

- \(V_{y1} \omega_1 R_{1y}\) — circumferential velocities of contact points of wheels and rails in the plane of wheel rotation;

- \(R_{ij}\) — current wheel radii in contact with rails — contact radii.

Fig. 1. Kinematic diagram of bogie movement in a circular curve: velocity vectors of the relative movement of the contacting surfaces of the wheels and rails at the points of contact

5.2. Mathematical modeling of the dynamic fitting of the 18-100 bogie into the curved section of the track

The following functions are used to describe the geometric parameters of contact:

- \(R_{ij}(y_{ij})\) — dependence of the rolling radius of wheels \(R_{ij}\) on the transverse coordinate of the profile \(y_{ij}\).
An important component of the mathematical model is the determination of the sliding speeds in contact between the wheels and rails \( V_{ij} \) and \( V_{yij} \):

\[
V_{ij} = \sqrt{V_x^2 + V_y^2} - 2V_y\cos(\alpha_y), \quad (7)
\]

\[
V_{yij} = V_y\sin(\alpha_y), \quad V_y = \sqrt{V_y^2 - V_{yij}^2}, \quad (8)
\]

where \( V_{yij} \) is the sliding speed in the longitudinal direction, which is directed perpendicular to the plane of rotation of the wheels, that is, along the axis of the wheelset; \( V_{ij} \) is the sliding speed of the transverse direction, which is directed perpendicular to the plane of rotation of the wheels, that is, along the axis of the wheelset.

The sliding velocities are necessary for the calculation of contact forces of adhesion.

Fig. 2 shows the contact scheme of the wheelset and the rails: \( K_{ij} \) contacts of the wheels with rails; \( D \) is the difference between the track width and the distance between the inner surfaces of the wheel rim.

![Fig. 2. Contact scheme of the wheelset and rails](image)

Fig. 2. Contact scheme of the wheelset and rails

An important component of the mathematical model is the determination of the sliding speeds in contact between the wheels and rails \( V_{ij} \):

\[
F_{bog} = \frac{m_d}{\rho}V_x^2, \quad F_{out} = \frac{m_d}{\rho}V_y^2, \quad (9)
\]

where \( m_d \) is the total mass of the body; \( V \) is the speed of the car; \( F_{bog} \) is the centripetal force applied at the center of mass of the bogie radially to the center of curvature of the track.

The force \( F_{g} \) is the component of the weight of the car \( Q \), which is related to the tilt of the car due to the rise of the outer rail \( h \). Adhesion contact forces \( F_{wij}, F_{yij} \) are determined as functions from pseudo-slippage in wheel-rail contact determined according to the methodology outlined in [22].

The mathematical model of fitting a bogie into a circular curve is constructed as a system of equations of the bogie’s balance under the action of external forces and moments. The mechanical system of the bogie is represented as three subsystems: the bogie frame system; the system of the first wheelset; the system of the second wheelset.

Fig. 4 shows the diagram of horizontal forces acting on the first subsystem – the bogie frame. Four equilibrium equations can be drawn up for this subsystem.

Equation 1: the sum of the projections of the forces acting on the bogie frame onto the horizontal longitudinal axis of the OX coordinates:

\[
\sum F_x = -(F_{bx1} + F_{bx2})\cos(\chi_1) + (F_{bx1} + F_{bx2})\cos(\chi_2) - F_{by1}\sin(\chi_1) - F_{by2}\sin(\chi_2) = 0. \quad (10)
\]

Equation 2: the sum of the projections of the external forces acting on the bogie frame onto the horizontal transverse axis of coordinates OY:

\[
\sum F_y = F_{in} - F_{g} - F_{by1}\cos(\chi_1) + F_{by2}\cos(\chi_2) + (F_{bx1} - F_{bx2})\sin(\chi_1) + (F_{bx2} - F_{bx1})\sin(\chi_2) = 0. \quad (11)
\]

In equations (10), (11) \( \chi_1, \chi_2 \) are the angles determining the position of the wheelsets relative to the OY coordinate axis. Angles \( \chi_1, \chi_2 \) take into account the tech-
nological deviation in wheelset arrangement in the bogie from the rated – angles \( \sigma_1, \sigma_2 \) and the skew of the bogie in the track as a whole – angle \( \vartheta \), which is determined from formula (6):

\[
\chi_j = \sigma_j - \vartheta.
\]

Equation 3: the sum of the moments of external forces acting on the bogie frame relative to the center of the OXY coordinate system in the horizontal plane:

\[
\sum M_{OXY} = (F_{by1} \cdot \cos(\chi_j) + F_{by2} \cdot \cos(\chi_j)) \cdot C / 2 - (F_{bx1} + F_{bx2}) \cdot \cos(\chi_j) \cdot B - (F_{bx1} + F_{bx2}) \cdot \cos(\chi_j) \cdot B = 0.
\]

Equation 4: the sum of moments of external forces acting on the bogie frame relative to the center of the OYZ coordinate system in the transverse vertical plane:

\[
\sum M_{OYZ} = \text{Find} \cdot \text{bd} + \text{Finb} \cdot \text{hb} - F_{g1} \cdot \text{hv} + (F_{by1} - F_{by2}) \cdot \text{R0} \cdot (P_{11} + P_{12} - P_{21} - P_{22}) \cdot B = 0.
\]

The scheme of external forces acting on wheelsets is shown in Fig. 5.

Equations 5, 6: the sums of the projections of the forces acting on the wheelsets onto the horizontal longitudinal axes of the coordinates O\( jx_j \):

\[
\sum F_{x1} = (F_{t11} - F_{t12} + F_{bx1} - F_{bx2}) \cdot \cos(\chi_j) + (Y_{21} - Y_{22} - F_{by1} + F_{by2}) \cdot \sin(\chi_j) = 0;
\]

\[
\sum F_{x2} = (F_{t12} - F_{t11} + F_{bx2} - F_{bx1}) \cdot \cos(\chi_j) + (Y_{21} - Y_{22} - F_{by2} + F_{by1}) \cdot \sin(\chi_j) = 0.
\]

Equations 7, 8: sums of torques acting on wheelsets in the horizontal plane relative to the proper centers of the O\( jx_j y_j \) coordinate systems:

\[
\sum M_{Oxj} = \left[ (F_{bx1} + F_{bx2}) \cdot B - (F_{t11} + F_{t12}) \cdot A \right] \cdot \cos(\chi_j) = 0;
\]

\[
\sum M_{Oyj} = \left[ (F_{bx1} + F_{bx2}) \cdot B - (F_{t12} + F_{t22}) \cdot A \right] \cdot \cos(\chi_j) = 0.
\]

Equations 9, 10: sums of torques acting on wheelsets in the transverse vertical plane relative to the proper centers of the O\( jy_j z_j \) coordinate systems:

\[
\sum M_{Oyj} = (B_{11} - B_{21}) \cdot B + (P_{21} - P_{11}) \cdot A + (F_{by1} + F_{by2} - Y_{21} - Y_{22}) \cdot A = 0.
\]

Equations 11, 12: sums of torques acting on wheelsets relative to their own axes of rotation:

\[
\sum M_1 = F_{t11} \cdot R_{11} - F_{t12} \cdot R_{12};
\]

\[
\sum M_2 = F_{t12} \cdot R_{21} - F_{t22} \cdot R_{22}.
\]
The range of values of the outstanding lateral acceleration \( a_y \) is selected in accordance with the Memorandum of the Organization for Co-Operation between Railroads (OSJD) [23], namely:

\[
1.0 \geq a_y \geq -0.4 \text{ m/s}^2.
\]

The clearances of the wheelset in the rail track in operation can take values in the range from 9 to 76 mm [24]. The gap in the rail track has a significant effect on the approach angles of the wheelsets when the bogies are installed at an angle. Fig. 6 shows the estimated dependences of the approach angles of wheelsets installed in the carriage without skew and the radius of the curve \( \rho \). The following signs are used for approach angles: “+” – for lagging wheelset; “−” – for the approaching wheelset.

Fig. 7 shows the dependence of the approach angles of wheelsets \( \alpha \) on the lateral movement of wheelsets \( y_1, y_2 \) relative to the track axis for different curve radii. For internal and external chord installations, the approach angles of wheelsets are: for a 300 m curve – first wheelset \( \alpha_{11} = -0.28^\circ \) (−0.005 rad), second wheelset \( \alpha_{12} = 0.28^\circ \) (0.005 rad); for the 1200 m curve \( \alpha_{21} = -0.114^\circ \) (−0.002 rad); \( \alpha_{22} = 0.114^\circ \) (0.002 rad).

The estimation dependences of the guiding flange force \( Y \) on the skew angles of the wheelsets in the bogie \( \sigma \), the speed of movement \( V \), and the radius of the curve \( \rho \) are shown in Fig. 8.
Dependences are represented in the form of level lines, i.e., constant values of guiding forces Y. This made it possible to determine the zone of safe combinations of distortions $\sigma$ and movement speeds $V$ – the “safety zone” (green-yellow zone) and the “dangerous zone” (red zone). The dangerous zone is limited by the maximum permissible value of the guiding force $|Y| = 70$ kN.

6. Discussion of results of determining the influence of wheelset arrangement on the level of steering forces in flange contacts

The lack of uniform international requirements for the maintenance of freight cars with bogies of type 18-100 and their analogs leads to the fact that the misalignment of wheelsets is not controlled. As a result of its occurrence, the wear of wheel flanges increases, resistance to movement grows, which lead to the occurrence of a dangerous situation of derailment of the car.

Our research is based on the fact that, according to statistics, the majority of 18-100 bogies in operation have misalignment of wheelsets in the bogies. Moreover, these misalignments have an accumulative progressive nature and can be up to 0.02 rad in operation. This is confirmed by the significant operational difference in the thicknesses of the flanges of the right and left wheels of wheelsets, as a result of long-term pressing of one side of the wheelset against one of the rails [6, 7].

Our research results can be explained by the fact that the structural distortions of the wheelsets in bogies increase the angles of approach of the wheelsets on rails and, as a result, increase the forces of pressing the flanges against the side surfaces of the rails. This, in turn, is the cause of increased wear of wheel flanges and side surfaces of the rails, as well as the deterioration of a number of operational indicators of the car: an increase in movement resistance, a decrease in the margin of resistance against derailment, etc.

The results (Fig. 8) showed that an increase in the misalignment angles of wheelsets from $\sigma = 0$ for the rated position to the maximum possible misalignment angles in operation ($\sigma = 0.02$ rad) leads to an increase in the steering forces $Y$ by an average of 1.5–2.0 times. Moreover, the degree of increase practically does not depend on the radius of the curve and on the speed of movement.

According to the results of our calculations (Fig. 6), it was confirmed that the angles of approach of wheelsets on rails increase significantly with the increase in the total clearances in the rail track. For example, when a bogie is installed diagonally in a track in a curve with a radius of 250 m, with a gap of 14 mm, the angle of approach of the first pair of wheels is $-0.84° (-0.002$ rad), and with a gap of 50 mm $-1.95° (-0.034$ rad). In the 1000 m curve $-0.54° (-0.009$ rad) and $-1.65° (-0.029$ rad), respectively. Thus, in the range of possible operational clearances of wheelsets in the rail track – from 14 to 65 mm – the angles of attack of wheelsets increase from minimum to maximum by 2.3–3.5 times for different curve radii. The nature of the change in the angles of approach of the wheelsets to rails due to the gaps in the track $\delta$ does not depend on the skew angles of the wheelsets $\sigma$ (Fig. 6). The difference in the angles of attack of the first and second wheelsets $\Delta \alpha$ of the bogie depends on the radius of the curve and does not depend on wheelset arrangement in the bogie and the clearances of the wheelsets in the track. Moreover, $\alpha$ decreases from 0.5° (0.01 rad) for $r = 300$ m to 0.15° (0.003 rad) for $r = 1250$ m. These results indirectly contradict the conclusions by some researchers regarding the influence on the intensity of wear of transition flanges of the Ukrainian Railroads from the 1524 mm gauge to the 1520 mm gauge. It was found that there is a slight narrowing of the track, on the contrary, reduces the value of the probable angles of contact of the wheels on rails and, as a result, should reduce the intensity of wear of wheel flanges.

When the misalignment of wheelsets in the bogie increases from $0°$ to $+0.5°$, the approach angles of the approaching wheelsets increase by 2–3 times.

Analysis of the calculated results confirms the assumption of a significant dependence of the steering contact forces on wheelset arrangement in the bogie, which is determined by the misalignment of the axes relative to their rated position. At the maximum operating angles of misalignment of the wheelsets, the lateral steering forces in the flange contacts increase by 40–60 % compared to the rated setting in a wide range of speeds and curve radii.

The chosen calculation scheme can be considered correct because it takes into account the geometric and kinematic parameters of wheel and rail contact, both for new rolling surface profiles and for worn ones. Expressions (1) to (6) describe the dependence of the contact angles of wheelsets on the rails on movement parameters.

The results shown in Fig. 9 prove the significant dependence of the steering forces in the flange contacts of wheels with the rails on wheelset arrangement in the bogie frame, namely the misalignment of the axes relative to their rated position. The value of the skew should be a criterion for making a decision about the need to repair the bogie.

Countries that operate freight cars with bogies of type 18-100 and their analogs (Poland, Ukraine, Lithuania, Latvia, etc.) should pay attention to such an important factor as the cumulative skew of wheelsets in bogies.

As a further advancement of this study, we consider it expedient to carry out extensive monitoring of the condition of 18-100 bogies in the fleet of freight cars regarding the presence of misalignment of wheelsets. Taking into account that there are currently no devices for monitoring the parameters of wheelsets in bogies, designing such a measuring system is planned in the further research by our team.

7. Conclusions

1. The calculation scheme, based on a detailed description of the geometric and kinematic parameters of the flange contact of wheels and rails, is correct. On the basis of the developed calculation scheme, the dynamic fitting of bogies with different profiles of the surfaces of wheels and rails, both new and worn, can be investigated.

2. The study of the process of fitting 18-100 bogies into the curve of the track section was performed on the mathematical model of the dynamic equilibrium of the bogie when moving in a circular curve. The value of the structural deviations in the position of wheelsets in the bogies from the rated value was obtained. They significantly affect the level of lateral steering forces in the flange contacts of the wheels with rails. This, in turn, is the cause of one-sided wear of the flanges of wheelsets. At the maximum values of skew angles of 0.5° and more, the lateral steering forces in the flange con-
tects of wheels with rails exceed the load by 40–60% during normal installation at any speed and in curves of any radius. Therefore, there is a need to introduce into the maintenance system of model 18-100 bogies the technological operation of controlling the deviation in wheelset arrangement in the bogie.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

References


23. Agreement on use of freight wagons in international traffic (the PGV Agreement) (with amendments and additions as of 1 January 2024) (2024). Official publication OSJD Committee, Warsaw, 168. Available at: https://en.osjd.org/en/8911/page/106077?id=2858