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RESEARCH OF DEFORMED STATE OF RAILWAY TRACK JOINT ZONES IN COMPLEX OPERATING CONDITIONS OF RAIL TRANSPORT

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Abstract. The article presents the results of experimental studies on residual deformations of external and internal rail threads, which reveal patterns in change of track gauge depending on the magnitude of the transported load under real operational conditions. The research is aimed at identifying the causes of track gauge expansion up to the critical value in order to determine the actual resource and service life of railway and industrial rail transport. As a result of sequential systematic measurements of horizontal irregularities in the track joint zone (-3 m …+3 m), it has been established that with transported loads of 20, 26, and 31 million gross tons, the deformation values reach 1.7 mm, 1.9 mm, and 3.2 mm, respectively. The intensity of residual track deformation accumulation in the joint zone in the transverse direction averages 1mm per 10 million gross tons of transported load. It has been determined that the rate of rail track disruption due to the formation of spatial residual deformations of rail threads on average is 1mm per 1.3 million gross tons of transported load. It has been established that after a transported load of 31 million gross tons, the maximum magnitude of horizontal displacements of residual deformations of the external rail thread relative to the baseline design line reaches 6.6 mm with a plan deviation of 12.8 mm (-6.6 mm … +6.2 mm), and for the internal rail thread, it amounts to 11.7 mm. It was found that the cumulative magnitude of the residual deformations of both rail threads is 24-25 mm of rail gauge expansion with a value of transported loads up to 31 million gross tons. Scientifically proven is that, with the accumulation of gauge widening within the normal tolerances in the short term, up to 12 mm (+8 mm … -4 mm), the existing rail track structure can accommodate a load of 15.6 million gross tons. To ensure the normal service life of the track for 800 million gross tons, multiple violations of the normative requirements of state standards are expected. The creation of a new railway track structure design is envisaged to meet the needs of railway and industrial rail transport of a new technical level to eliminate the identified critical shortcomings and ensure the adaptation the rail fastening design for curved sections with small radii of curvature.

Keywords: rail track, curved sections, connection joints, residual deformations.

1. Introduction

The analysis of the track performance under challenging operating conditions of railway and industrial rail transport has shown that the use of jointed tracks in current operational conditions is associated with rail connection joints.

Jointed tracks are located both on straight sections and on curves with small radii ranging from 300 to 650 m.

The most critical failure condition occurs in the operational conditions of connection joints on curved sections with small radii, where practically every joint has local irregularities in the horizontal and vertical planes.

Rail joints are the main stress source of dynamic interaction between the track and rolling stock. As a result, additional disturbances in the track, deviations from the planned track profile, and disruptions occur. The processes of dynamic interaction between the rolling stock and track occur most intensively on curves with small radii, accompanied by track disturbances. These processes are further complicated by the heavy weight of freight trains and longitudinal profile gradients. During uphill movement or on downhill sections during regenerative braking, longitudinal compressive forces arise in the rolling stock. The transverse component of these forces is directed towards the outer curve, loading the outer rail.

Rail joints make train movement on curved sections unstable, leading to the accumulation of residual deformations in both the vertical and transverse horizontal planes of the track. This also affects the accumulation of side wear on rail heads and flange wear on the wheelsets of the rolling stock, resulting in subsequent derailments of wagons, locomotives, or traction units [1].

At the current level of scientific and experimental research, there has been insufficient accumulation of residual deformation data in the zone of connection joints of the jointed rail track on operational sections of railway and industrial rail transport, particularly for curves with small radii and complex working conditions.

At the current state of scientific experimental research, insufficient work has been done to accumulate residual deformation data in the area of jointed rail track connections on operational sections of industrial and railway rail transport, especially on curves with small radii of curvature and complex operating conditions.

Given these research directions, the objective of this work is to present the results of experimental studies on the intensity of residual deformations accumulation under operational conditions of jointed tracks, their generalization, and analysis of trends in the formation of the main causes of track disruption, wear of rail heads and wheel flanges, safety violations of rolling stock movement, and the formation of significant operating costs.

2. Research methods

The scientific work methodology includes systematic experimental investigations under operational conditions in the zone of connection joints of the rail track, with sections of up to 300 cm in length measured from the center of the joint in each direction.

The accumulation of residual deformations in the rails, both vertically and transversely, depends on the magnitude of the passing tonnage in gross tons over the duration of the research period.

Measurements were performed using calibrated measuring instruments relative to a stationary base reference point along the length of the rail joint, up to 6 m, and with the track inspection station equipment Pioneering Station No. 1 of JSC “Ukrainian railways” under the supervision of Yu.O. Makarov and V.V. Hovorukha.

3. Operational and experimental investigations

According to the methodology of experimental investigations of the jointed track, each of the transition curves (entry and exit) with standard rails is equipped with four joint irregularities (two of them are located at the junctions of the straight track with the transition curve and the transition curve with the circular curve), and the circular curve has eight joints. Thus, the total number of joints in the track with standard rails is 16.

Along the entire curved section with elongated rails, there are only four joint irregularities. The first joint is located on the straight track, 12.5 m before the beginning of the entry transition curve; the second is at the end of this transition curve, 10 m before the start of the circular curve; the third is on the exit transition curve, 10 m from the end of the circular curve, and the fourth is on the straight track, 12.5 m from the end of the exit transition curve.

Considering the experimental data from the measurements of track joint irregularities, the calculated disturbances in the vertical and horizontal directions are modeled according to the research [2–5]:

$$\eta_i(x) = \frac{a_i}{2}\left(1 - \cos\frac{2\cdot\pi\cdot x}{L_i}\right),$$

where a_i is the amplitude of the irregularity, m; L_i is the total length of the irregularity, m; x is the distance from the beginning of the irregularity to the ordinate $\eta_i(x)$, m; i is the direction of the joint disturbance (z, y).

Lengths of joint irregularities were determined based on the results of experimental measurements on test sections of the rail track ($R = 274$ m): $L_z = 3$ m, $L_y = 6$ m. Four variants of amplitude values for the irregularities were considered (corresponding to different values of passed tonnage): 2 mm, 4 mm, 6 mm, and 8 mm in the vertical direction, and half of those values in the horizontal direction, namely 1 mm, 2 mm, 3 mm, and 4 mm. The elevation of the outer rail was taken as 80 mm, and the track width in the circular curve was 1540 mm compared to the nominal track width of 1520 mm.

For curves with small radii, investigations were conducted on the geometric parameters of rail irregularities in the joint zone, both before and after the physical joint of the rails, considering the intensity of accumulated horizontal and vertical deviations from the baseline.

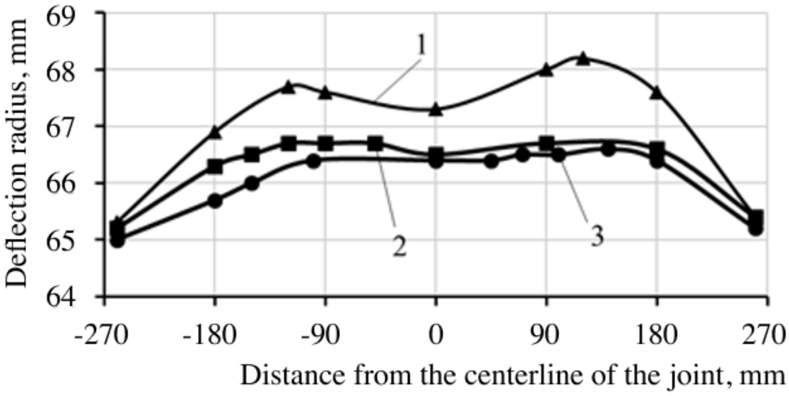
4. Results and discussion

Based on the survey data of the rail track, graphs of geometric parameters for the active rail track of curved sections with a radius of 274 m were constructed with a measurement step of 0.2 m.

Figure 1 shows the accumulation of horizontal irregularity in the plan in the zone of joint with the outer rail of curved sections. Variable values of residual deformation curvature are depicted in the vertical cross-section of the joint and at distances of 90, 180, and 270 mm in opposite directions from the joint. The figure presents the results of consecutive measurements for passed tonnages of 20 million gross tons, 26 million gross tons, and 31 million gross tons. In this case, the maximum values of residual deformations reach 1.7 mm, 1.9 mm, and 3.2 mm for the corresponding magnitude of passed freight load. The intensity of accumulation of residual deformations in the transverse direction in the track joint zone averages 1 mm per 10 million gross tons of passed tonnage.

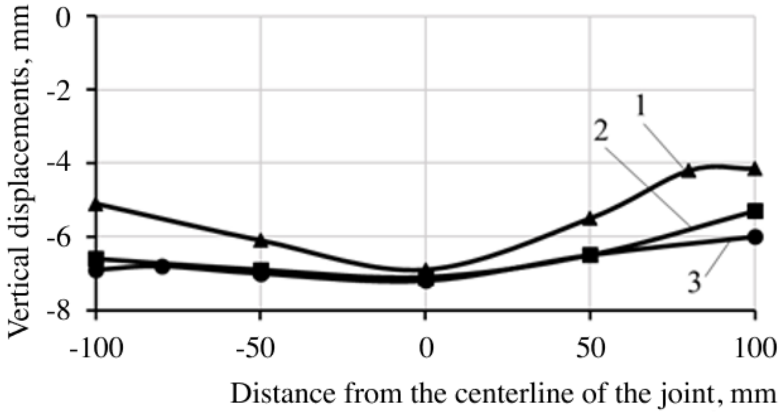
Figure 2 displays the accumulation of vertical irregularity in the profile in the zone of joint with the outer rail of curved sections in the vertical cross-section of the joint and at distances of 50 and 100 mm in opposite directions from the joint. The figure also includes the results of consecutive measurements for passed tonnages of 20 million gross tons, 26 million gross tons, and 31 million gross tons. In this case, the maximum magnitude of residual deformations in the vertical direction amounts to

5.0 mm, 6.9 mm, and 7.1 mm, respectively. The average intensity of accumulation of residual deformations in the track joint zone is 1 mm per 4 million gross tons. A comparison of the magnitudes of residual deformation in the horizontal and vertical directions indicates that the intensity of accumulation of residual deformations in the horizontal (transverse) direction is 2.5 times greater than in the vertical direction.



1 – passed tonnage of 31 million gross tons; 2 – passed tonnage of 26 million gross tons; 3 – passed tonnage of 20 million gross tons

Figure 1 – Graph of the dependency of accumulated horizontal irregularities in the joint zone of the outer rail of a curved section on the magnitude of passed tonnage

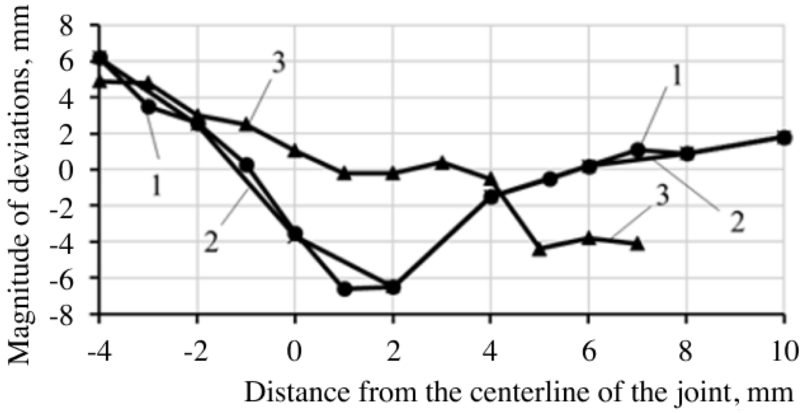


1 – passed tonnage of 20 million gross tons; 2 – passed tonnage of 26 million gross tons; 3 – passed tonnage of 31 million gross tons

Figure 2 – Graph of the dependency of accumulated vertical irregularities in the joint zone of the outer rail of a curved section on the magnitude of passed tonnage

Critical values of accumulated residual deformations in the rail-sleeper grid in the transverse direction of curved sections with small radii confirm the potential reliability of further track displacement and the creation of an emergency state.

The comparison of horizontal displacements of residual deformations in the joint of the outer rail at different magnitudes of passed tonnage in curved sections with small radii (R = 274 m) is presented in Figure 3. The graph shows the actual track alignment at different values of passed tonnage. The maximum values of horizontal displacements of the outer rail's residual deformations in the joints from the basic design line reach 6.6 mm when the passed tonnage is 31 million gross tons, with a difference of 12.8 mm (-6.6 mm …+6.2 mm) between the points of maximum deviations in the plan. It has been observed that the accumulation of residual deformations tends to increase their intensity with an increase in the magnitude of passed tonnage to 26–31 million gross tons compared to the passed tonnage of 20 million gross tons.



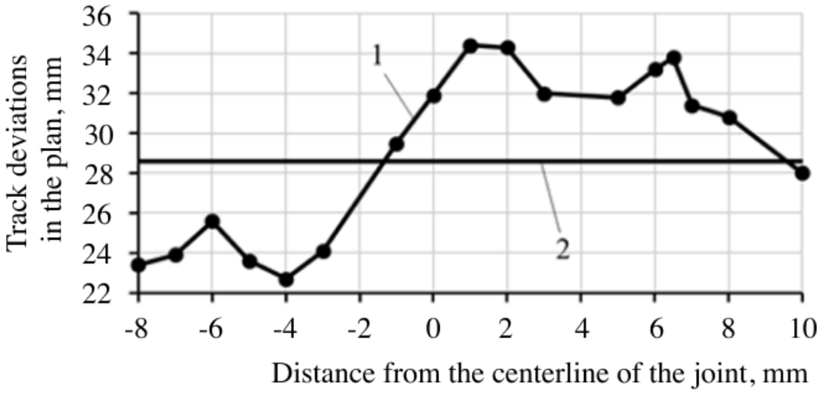
1 – passed tonnage of 31 million gross tons; 2 – passed tonnage of 26 million gross tons;
3 – passed tonnage of 20 million gross tons

Figure 3 – Comparison of horizontal displacements in the joint
for different magnitudes of passed tonnage

The obtained dependencies of critical accumulations of residual deformations in the joints of curved sections with respect to the magnitude of passed tonnage, as shown in Figures 1–3, confirm the need to increase the strength and load-bearing capacity of intermediate rail fastenings and components of the entire track structure, including the sleeper foundation, to ensure the required stability indicators of the rail-sleeper grid against lateral displacement and track instability during the operation of the rail track in curved sections with small radii of curvature.

Residual deformations of the inner rail thread of the rail track in the joints of small radius curved sections are shown in Figure 4. The maximum deviation of the inner rail thread from the baseline state is 11.7 mm after the passage of a 31 million gross tonnage load. The obtained values of transverse residual deformations (Figure 4) confirm the relative displacement of the inner rail thread, which causes additional expansion of the rail track compared to the expansion of the outer rail thread (Figures 1–3) up to a total expansion of the rail track to dimensions of 24-25 mm with a load of up to 31 million gross tons. The intensity of accumulated residual deformations of the rail track expansion (distance between the inner edges of the heads of the outer and inner rails in curved sections of small radii) is 1 mm per 1 million gross tons of passed load.

According to the obtained indicators of rail track expansion intensity between rail gauge at a rate of 1 mm per 1.3 million gross tons of passed load, an accumulation of track width to the allowable limits occurs in a short period. This does not meet the normative requirements for the service life of track structures, which is 5 years, and the operational resource of 800 million gross tons of passed load.



1 – base measurement line; 2 – value of relative residual deformation of the rail track

Figure 4 – Residual deformations of the inner rail thread at the joint zone

According to the normative requirements of the State Construction Norms of Ukraine "Transport Facility. Railways with a gauge of 1520 mm. Design Standards" [6] and the "Instruction for the Construction and Maintenance of Rail Tracks of Ukrainian Railways" [1], deviations from the established gauge width (1520 mm) that do not require correction on straight and curved track sections should not exceed +8 mm in expansion and -4 mm in contraction, with a total expansion of the outer and inner rails of 12 mm.

With a permitted total track expansion of 12 mm and an intensity of accumulation of residual deformations of rail displacement of 1 mm per 1.3 million gross tons of passed load, the rail track can accommodate up to 15.6 million gross tons. Therefore, with the required operational resource of 800 million gross tons and the actual capacity to accommodate 15.6 million gross tons, there is a negative deviation from the normative requirements [1, 6].

Significant costs are incurred to rectify deviations from operational norms in the track.

Such intense accumulation of rail track expansion beyond normative requirements indicates inadequate track maintenance quality and a low technical level of the existing track structure in curved sections with small radii, equipped with outdated intermediate rail joint screw fastening on wooden sleepers, in the zone of connection joints and at adjacent track sections.

5. Conclusions

1. Experimental studies have been conducted on the accumulation of residual deformations of the outer and inner rail threads in the zone of connection joint of the jointed track under complex conditions of curved sections with small radii of curvature.

2. Dependencies have been established between the accumulation of residual deformations of the outer and inner rail threads in the horizontal and vertical planes of the zone of connection joints of the rails and the magnitude of the passed load.

3. Regularities have been obtained regarding the formation of residual deformations of the outer and inner rails in connection joints, with the potential for track expansion when changing the magnitude of the passed load on experimental curved sections.

4. As a result of consecutive systematic measurements of the accumulations of horizontal irregularities in the joint zone (-3 m …+3 m), it has been determined that at a passed load of 20, 26, and 31 million gross tons, the deformation magnitudes reach 1.7 mm, 1.9 mm, and 3.2 mm, respectively. The intensity of the accumulation of residual track deformation in the joint zone in the transverse direction averages 1 mm per 10 million gross tons of the passed load.

5. It has been established that after a passed load of 31 million gross tons, the maximum magnitude of horizontal displacements of residual deformations of the outer rail thread relative to the basic design line reaches 6.6 mm with a plan deviation of 12.8 m (-6.6 mm … +6.2 mm), while for the inner rail thread, it amounts to 11.7 mm.

6. It has been determined that the total magnitude of residual deformations of both rail threads results in track expansion of 24–25 mm with a passed load of up to 31 million gross tons. The intensity of the accumulation of residual track deformation (distance between the inner edges of rail heads in the transverse cross-section of the track) in curved sections amounts to 1 mm per 1 million gross tons of the passed load.

7. It has been established that the indices of track disruption intensity due to the formation of spatial residual deformations of rail threads average 1 mm per 1.3 million gross tons of the passed load. When the track expansion reaches the permissible limits, it occurs in a short period, which does not meet the normative service life requirements of track structure technical means of 5 years and a work resource of 800 million gross tons of the passed load. With track expansion tolerances of +8 mm and track narrowing of 4 mm, resulting in a total track expansion of 12 mm according to normative documents, the existing track structure design can handle a throughput of 15.6 million gross tons. However, ensuring the normative resource of 800 million gross tons creates violations of normative state standards [1, 6].

8. The conducted scientific research confirms the urgent need for the development and implementation of a new progressive technology and intermediate rail fastenings of a new technical level in production and railway and industrial rail transport. This should include the adaptation of rail fastening design for curved sections with small radii of curves and straight sections of track of comprehensive significance.

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ДОСЛІДЖЕННЯ ДЕФОРМОВАНОГО СТАНУ ЗОНИ СТИКОВИХ З'ЄДНАНЬ ЛАНКОВОЇ КОЛІЇ В СКЛАДНИХ УМОВАХ ЕКСЛУАТАЦІЇ РЕЙКОВОГО ТРАНСПОРТУ

Говоруха В.В., Говоруха А.В., Макаров Ю.А., Собко Т.П., Семидітна Л.П.

Анотація. В статті наведені результати експериментальних досліджень залишкових деформацій зовнішніх і внутрішніх рейкових ниток, які формують закономірності зміни ширини рейкової колії в залежності від величини пропущеного вантажу в реальних експлуатаційних умовах.

Дослідження направлені на пошук причин формування розширення рейкової колії до критичної величини для одержання фактичного ресурсу і терміну роботи рейкового транспорту залізничних і промислових підприємств. В результаті послідовних систематичних замірів накопичень горизонтальних нерівностей в плані в зоні стику (-3 м …+3 м) встановлено, що при пропущеному тоннажі 20; 26 і 31 млн т брутто величини деформацій досягають відповідно 1,7 мм; 1,9 мм і 3,2 мм. Інтенсивність накопичень залишкової деформації в зоні стику в поперечному напрямку складає в середньому 1 мм на 10 млн т брутто пропущеного тоннажу. Встановлено, що показники інтенсивності розладнання рейкової колії від формування просторових залишкових деформацій рейкових ниток в середньому складає 1 мм на 1,3 млн т брутто пропущеного тоннажу.

Встановлено, що після пропущеного вантажу 31 млн т брутто максимальна величина горизонтальних переміщень залишкових деформацій зовнішньої рейкової нитки відносно базової проектної лінії досягає величини 6,6 мм з відхиленням в плані на 12,8 м (-6,6 мм…+6,2 мм), а внутрішньої рейкової нитки відповідно складає 1,7 мм.

Одержано, що сумарна величина залишкових деформацій обох рейкових ниток складає розширення рейкової колії на 24–25 мм при величині пропущеного вантажу до 31 млн т брутто. Науково підтверджено, що при накопиченні розширення колії до нормальних допусків в короткий термін до величини 12 мм (+8 мм…-4 мм) існуюча конструкція рейкової колії забезпечує пропуск 15,6 млн т брутто. Для забезпечення нормального ресурсу колії 800 млн т брутто створюється багатократне порушення нормативних вимог державних стандартів.

Передбачається створення нової конструкції колійної структури для потреб залізничного та промислового рейкового транспорту нового технічного рівня для усунення виявлених критичних недоліків.

Ключові слова: рейкова колія, криволінійні ділянки, стикові з'єднання, залишкові деформації.