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Study of the interaction of the railway track and the rolling stock under conditions of accelerated movement

O Hubar^{1,4}, R Markul^{1,5}, O Tiutkin^{1,6}, V Andrieiev^{2,7}, M Arbuzov^{1,8} and O Kovalchuk^{3,9}

¹Dnipro National University of Railway Transport named after Academician V. Lazaryan, Lazaryan str., 2, Dnipro, Ukraine

²Laboratory of Engineering and Technical Studies, Dniprovsky Scientific Research Institute of Forensic Expertise, Sichaslavskaya Naberezhna str., 17, Dnipro, Ukraine

³Laboratory of Railway Transport Research, Lviv Research Institute of Forensic Science, Lipinsky str., 54, Lviv, Ukraine

⁴neris@ua.fm, ⁵guarangamr@gmail.com, ⁶alexeytutkin@gmail.com, ⁷avs_diit@ukr.net, ⁸10max@ukr.net, ⁹orestakovalchuk@ukr.net

Abstract. Comprehensive studies of the interaction of the railway track and the investigated rolling stock under accelerated conditions have been carried out. The basis of the research was to obtain and substantiate the process of stress state, force interaction of the railway track and the rolling stock under conditions of accelerated movement. Introduction of the new rolling stock into continuous operation is a serious task that must be solved comprehensively. The implementation of this direction significantly affects the reliability of the elements of the railway track. Within the framework of the research, the approach was used that takes into account theoretical and experimental parts of the research using the methodology of prof. O. P. Yershkov. As a result of the studies, average stress values were established: in rails, they vary within the range 44.37...70.99 MPa; in the sleeper, they reach 0.78 MPa; in the ballast layer, they have 0.13 MPa; in the body of the subgrade, they reach 0.04 MPa, which is significantly less than the maxima allowable values. While speed change from 140 to 160 km/h, the values of the studied parameters decrease: vertical force (9.39 %), lateral forces (19.79 %); stresses in the edge of the rail flange (15.86 %); stresses in the edge of the rail head (16.67 %); stresses in the neck of the rail (8.74 %). The obtained results made it possible to form trends and recommendations on the feasibility of further increasing speeds development. At the same time, this made it possible to substantiate in more detail the operation of the railway track in the case of accelerated movement.

1. Introduction

The introduction of a new rolling stock into continuous operation is a serious task that must be solved comprehensively. The possibility of further implementation of this direction substantially depends on the reliable operation of the elements of the railway track. The important component of solving this problem is the study of the interaction of the track and the rolling stock under operating conditions. Today, there is a lot of discussion as for the correctness of applying different techniques especially when studying the interaction of the track and the rolling stock under operating conditions. Each method is fundamental in its own way, and is applied depending on the specific task.

Schlumpf method [1-3] is widely used in the scientific research on the interaction of the railway track and the rolling stock. The essence of the method is to measure the dynamic stresses in the neck of a rail,



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measured in an individual cross section of the rail with strain gauge sensors [4-6]. It is established that this method, with insufficiently accurate sticking of sensors, has a significant dependence of measurement readings on the point of application of a vertical force relative to the rail axis «e» (eccentricity), inferior in accuracy to digital processing of experimental data.

The further development of the Schlumpf method [1–3], which increases the information content of experimental data, is the tensometric scheme of “piecewise continuous” registration. This method was applied by scientists and was tested to measure the vertical forces transmitted from the wheel to the rail [7]. An important advantage of the method is the possibility of using one recording channel for the experimental assessment of vertical force interaction. On the one hand, this provides savings in the use of channels while achieving the necessary reliable amount of experimental data. But the issues related to the registration of the lateral component of the force interaction of the railway track and the experimental rolling stock remained unresolved.

For 70 years, the method of experimental estimation of lateral forces by dynamic stresses in the edges of the flange and the outer section of the rail head has been widely used (method of prof. O. P. Yershkov) [8]. Normal stresses arising in rails from bending and torsion reach the greatest value at the edges of the rail flange. In [9], the adequacy of lateral forces estimation by the algebraic combination of measured edge stresses at the bottom of the rail flange was also noted.

To take into account spatial elasticity characteristics of rail threads, in work [10], results were proposed on the adjustment of the method of prof. O. P. Yershkov [8]. The problem is reduced to the theoretical determination of the modulus of elasticity and stiffness of a rail thread during its torsion. But the use of this approach is justified only in the presence of practical (experimental) data. Moreover, with each introduction of a new rolling stock, the depressions of the flange and the rail head will be different. As part of the research, the approach was used that takes into account the theoretical and experimental parts of the study using Yershkov technique.

2. The purpose and objectives of the study

The aim of the work is to study the interaction of the railway track and the rolling stock under conditions of accelerated movement.

To achieve this goal, it is necessary to solve the following tasks:

- in order to obtain the results of the stress state of the elements of the upper and lower track structure, comprehensive studies of the interaction of the railway track and the rolling stock under conditions of accelerated movement should be carried out;
- based on the results of the research, to discuss and justify the results of the study in order to form an assessment of the state of the railway track at accelerated train traffic;
- to substantiate trends in the further development of increasing speeds.

3. Characterization of the experimental site, the methodology for testing and data processing

The experimental site is a direct line; rail construction is rails P65; reinforced concrete sleepers, 1840 pcs/km; crushed stone ballast under the sleeper 30...35 cm thick, intermediate fasteners of КБ and КПП-5 types, maximum speed during the experiment 176 km/h.

The interpretation of the experimentally obtained data was carried out according to the indicators of each sensor at a given speed of movement of the rolling stock. The gradations of speed movement of the experimental rolling stock were taken after 10...40 km/h, and their choice was carried out with respect to possible sharp impulse changes in dynamic indicators. In this work, the gradation in speed movement changes was taken every 20 km/h. In our case, this can be explained by the fact that, in the speed range from 10 to 20 km/h, the correlation dependence between the dynamic indicators was mainly observed.

The number of runs along the experimental section of the track was established by the technical task for testing, depending on the number of instruments-sensors installed along the way and the required number of measurements resulting in reliable statistical data. In accordance with the approved programme and methodology for testing the new rolling stock in terms of impact on the track, the obtained statistical data do not exceed the probability level $p = 0.994$, which is adopted in calculating

the track strength. Taking this into account and with the aim of obtaining reliable statistical data, the number of arrivals in each direction for one speed of movement was taken from 10 to 15 (but not less than 10). The experience of research and experiments [11-16] show that during the test the track and rolling stock parameters do not change significantly. It can be assumed with sufficient accuracy that the results of previous experiments do not affect subsequent ones. In this case, the observation results turn out to be independent random variables. As a rule, the work analyzed the results of the stress state and force interaction of the elements of the railway track from the axes of the rolling stock, which cause the greatest influence. For rolling stocks, this is, as a rule, the first ones along the axis in the guide trolley.

The scheme of the experimental site and the rail with the measuring devices installation is shown in Figures 1-2.

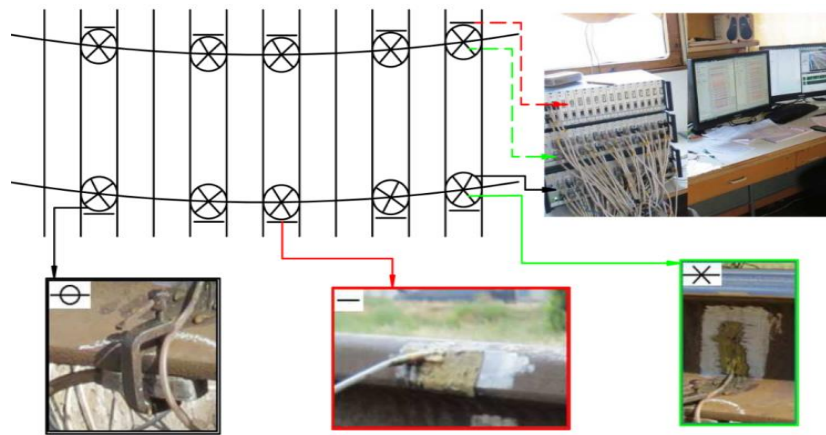


Figure 1. The scheme of measuring devices installation in the experimental site.

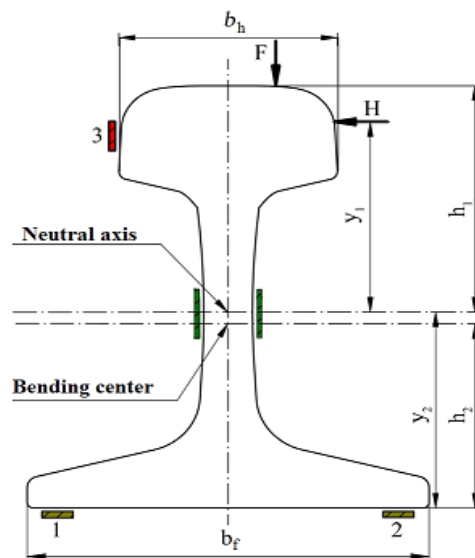


Figure 2. The calculating scheme of sensors distribution on a rail.

Figure 2 shows: 1, 2, 3 – strain gauge numbers; b_h , b_f , y_1 , y_2 , h_1 , h_2 – geometric characteristics of the rail; H – lateral force; F – vertical force.

To register the ohmic resistance of the strain gauge when it is powered by current, Wheatstone bridge circuits are used [17]. The circuit of the electrical installation for measuring edge stresses in the rail head is shown in Figure 3. The magnitudes of the stresses that occur in the edge of the rail head at different speeds of the experimental rolling stock are shown in Figure 4.

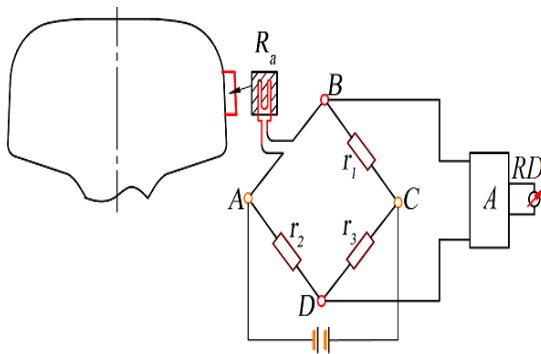


Figure 3. Half-bridge circuit of the electrical installation: R_a - active (working) strain gauge; r_1 , r_2 , r_3 resistance; A – amplifier; RD – recording device.

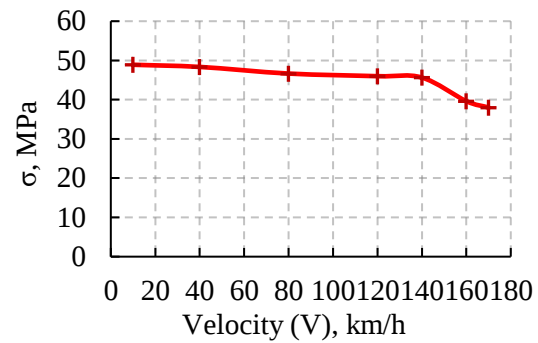


Figure 4. The dependence of stresses in the edge of the rail head on the speed of the experimental rolling stock.

The calculation of the vertical force «F» was determined by the preliminary calibration of sections where the stresses in a rail neck were recorded. Section calibration was performed when moving an experimental rolling stock at a speed of 5 km/h to 10 km/h (at a known static load of an experimental rolling stock). Stresses were recorded using strain gauges (R_a, R_c), which were stuck vertically in the neutral axis zone on both sides of the rail neck (Figure 5). The magnitudes of stresses that occur in the neck of the rail at different speeds of the experimental rolling stock are shown in Figure 6.

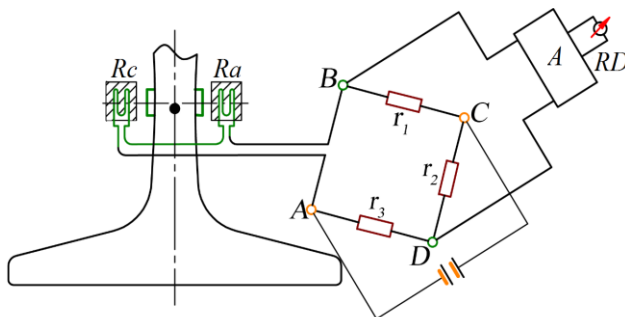


Figure 5. The bridge circuit of the electrical installation: R_a - active (working) and R_c - compensation strain gauges; r_1 , r_2 , r_3 - resistance; A – amplifier; RD – recording device.

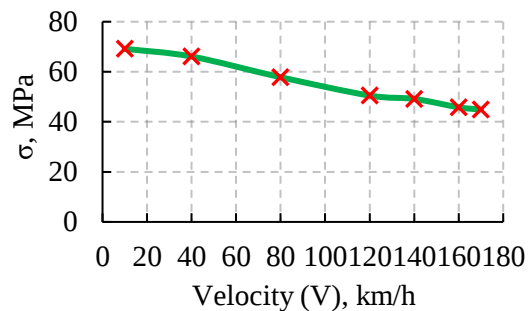


Figure 6. Dependence of stresses in the neck of the rail on the speed of the experimental rolling stock.

Since the scattering of the range of these vertical forces is insignificant, the measurement results were reduced to one sample. The sampling results are presented in Figure 7.

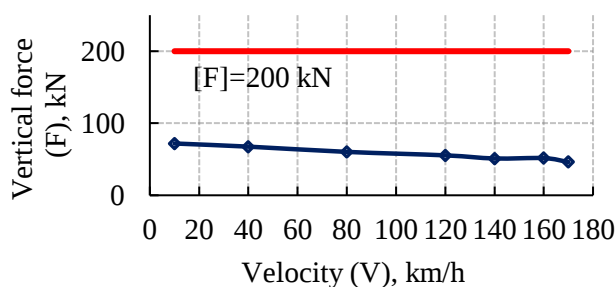


Figure 7. Dependence of vertical forces in rails on speed of movement.

To determine the horizontal force, we used the values of stresses obtained experimentally in the edges of the rail flange, as shown in Figure 8. Stresses arising along the outer edge of the rail flange from the action of lateral forces are shown in Figure 9.

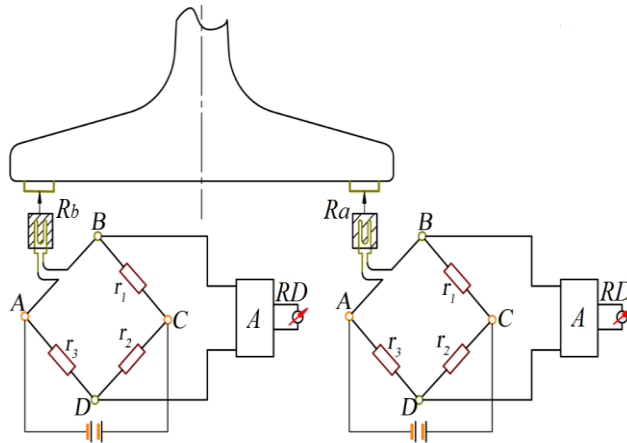


Figure 8. Half-bridge circuits of the electrical installation: R_a , R_b – active (working) strain gauge; r_1 , r_2 and r_3 – resistances; A – amplifier; RD – recording device.

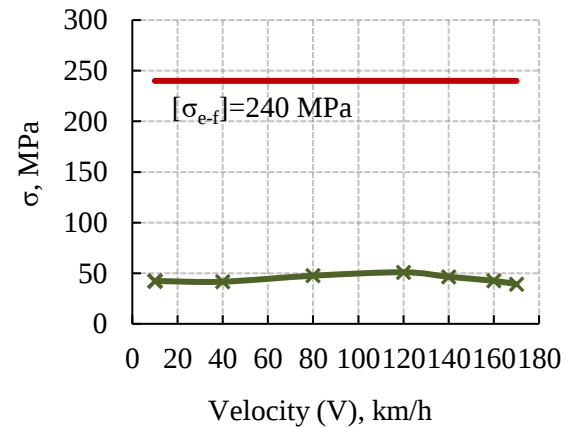


Figure 9. The dependence of stresses in the edge of the rail flange on the speed of the experimental rolling stock.

Based on the results (Figure 9), we can conclude that the stress in the edge of the rail flange does not exceed the allowable and recommended values. The values of lateral forces were calculated according to the method of prof. O. P. Yershkov [8] using experimentally obtained values of edge stresses in the flange and in the outer face of the rail head. The final expression for determining the lateral forces by this technique is:

$$H = B \cdot \sigma_{e-f}^o. \quad (1)$$

where H – lateral force (kN); coefficient for determining forces in (cm^2); σ_{e-f}^o – stresses at the edge of the rails flange (MPa); o – outer; e – edge; f – flange.

The results of the horizontal forces are shown in Figure 10.

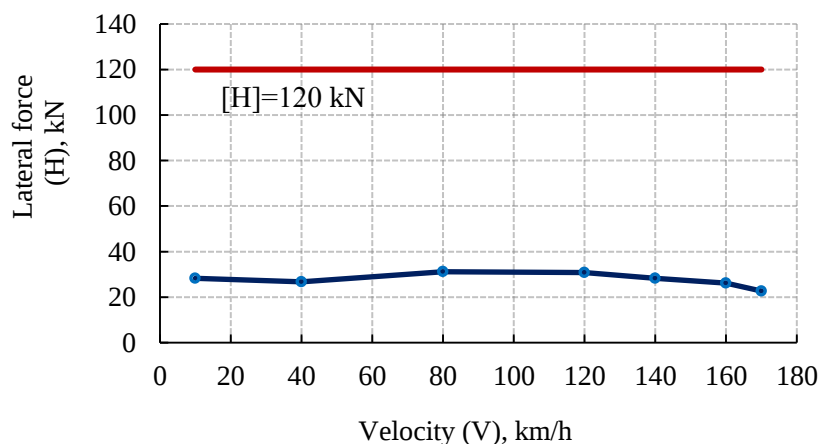


Figure 10. Dependence of horizontal forces in the rails on the speed of movement.

Ensuring the bearing capacity and operation of the railway track structure is characterized by not exceeding the design stresses of their maxima permissible values. The conditions must be met:

$$\begin{cases} \sigma_{sleep}^{calc} \leq [\sigma_{sleep}], \\ \sigma_{ball}^{calc} \leq [\sigma_{ball}], \\ \sigma_{subgr}^{calc} \leq [\sigma_{subgr}]. \end{cases} \quad (2)$$

where σ_{sleep}^{calc} - calculated compressive stresses in the sleepers under the pad, MPa; $[\sigma_{sleep}]$ – allowable compressive stresses in the sleepers under the pad, MPa; σ_{ball}^{calc} - calculated compressive stress in the ballast under the sleeper, MPa; $[\sigma_{ball}]$ – allowable compressive stress in the ballast under the sleeper, MPa; σ_{subgr}^{calc} - calculated stresses of soil compression in the main site of the subgrade, kPa; $[\sigma_{subgr}]$ - permissible soil compression stresses in the main site of the subgrade, kPa.

The calculation results are shown in figures 11–13.

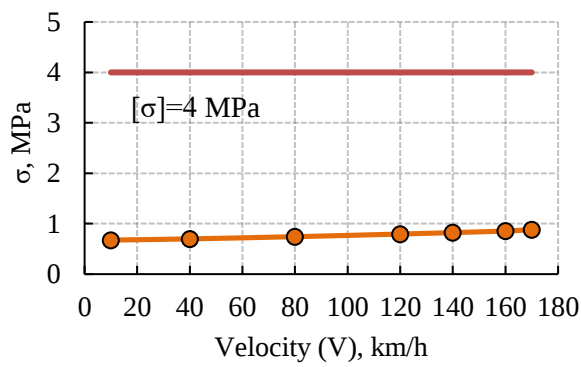


Figure 11. Dependence of stresses in the sleeper on the speed of movement.

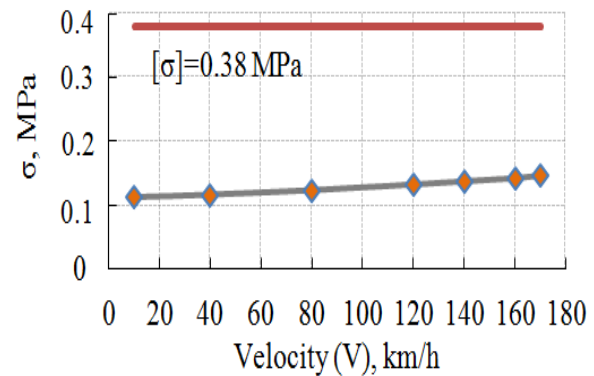


Figure 12. Dependence of stresses in the ballast on the speed of movement.

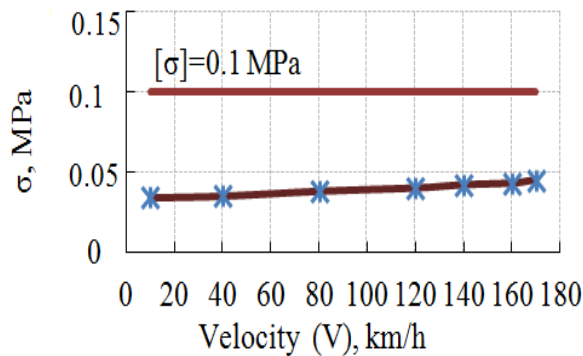


Figure 13. Dependence of stresses in the subgrade on the speed of movement.

Based on the results that are shown in Figures 11–13, the conclusion can be made that the calculated stresses in the elements of the railway track do not exceed the allowable and recommended values. This makes it possible to suggest the possibility of a further increase in the speed of movement on the railways of Ukraine. Trends on the possibility of increasing speeds, and ensuring rail transit traffic between Ukraine and the European Union have also been substantiated in [18].

4. Discussion of the results of the study with the aim of forming an assessment of the state of the railway track under condition of accelerated movement of trains

Comprehensive studies of the interaction of the track and the rolling stock under operation have been carried out. The basis of the research is an assessment of the power component, stresses in the elements of the upper and lower structure of the track from the effect of the rolling stock of a new generation. The average stress values in the elements of the upper and lower structure of the track do not exceed the

maxima allowable values, which is shown graphically in Figure 14.

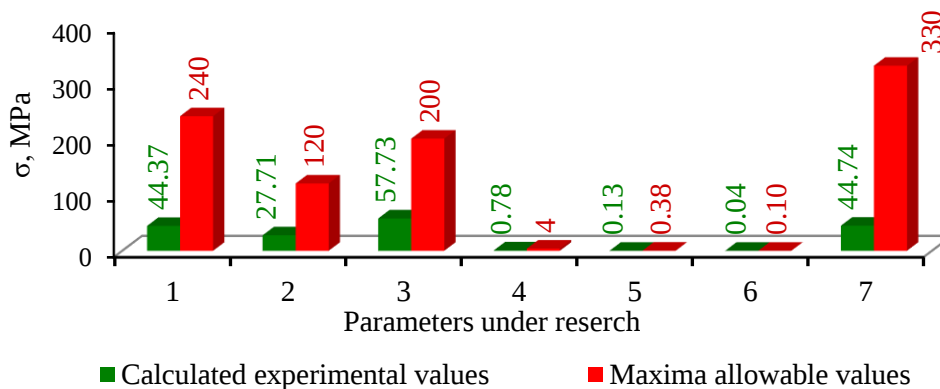


Figure 14. Comparable values of the obtained results.

Figure 14 shows: 1 – stresses in the edge of the rail flange, 2 – horizontal force, 3 – vertical force, 4 – stresses in the sleeper, 5 – stresses in the ballast, 6 – stresses in the subgrade, 7 – stresses in the edge of the rail head.

At an increase in speed hidden (dynamic) uneven paths may appear that leads to additional dynamic forces at oscillations of galloping and rolling motion of a car. In such cases, unloading of car truck wheels is observed that cause an alternating change of dynamic additives on rails. Since the sensors are placed discretely on the way, it is not possible to take into account the influence of various dynamic factors fully. In addition, a decrease of vertical force, when a passenger rolling stock is moving, can become the reason for not coinciding of an elastic line of rail deflection under the influence of dynamic forces at high speed indicators with the elastic line under a static load. One of the first who made a research in this area was prof. G. M. Shakhunyan [19].

With the aim of determining the lateral force, the method of prof. O. P. Yershkov [8] was used applying experimentally obtained values of edge stresses in the foot and head of the rail. But there is also a second widely used method of experimental determination of the lateral force (determination of the force effect on the rail by measuring the elastic deformation of the rail web) – the Schlumpf method [1-3]. In accordance with the comparative tests of JSC VNIIZHT, to which references were made in the work, it was established that the discrepancy in values of the lateral force with the use of O. P. Yershkov and Schlumpf methods did not exceed 4–9 %. This is mainly due to the accuracy of the choice of cross-sections for mounting strain gauges and their number on the rail neck (Schlumpf's method [1-3]). In order to save material resources, it was decided to use the method of prof. O. P. Yershkov [8] during the experiment.

5. Conclusions

The obtained maxima values of vertical and lateral forces from the interaction of the rolling stock are 115.5 kN and 53.38 kN, respectively, which is significantly less than the permissible value (200 kN, 120 kN).

Average stress values: in rails vary in the range 44.37...70.99 MPa; in the sleepers – 0.78 MPa; in the ballast layer – 0.13 MPa; in the body of the subgrade – 0.04 MPa, which is significantly less than the maximum allowable value.

Based on the experimental studies, it was found out that with the existing design of the railway track, it is advisable to develop trends for further increase in speed. With an increase in the speed of movement from 140 to 176 km/h, the values of the studied parameters decrease: vertical force (9.39 %), lateral force (19.79 %); stresses in the edge of the rail flange (15.86 %); stresses in the edge of the rail head (16.67 %); stresses in the neck of the rail (8.74 %). This indicates a sufficiently large margin of safety of the elements of the railway track. Knowing the sections of the railway track where the increase in speed will be implemented, it is necessary to carry out control and elimination of

deviations from norms timely.

References

- [1] Ward C, Weston P, Stewart E, Li H, Goodall R, Roberts C, Mei T, Charles G and Dixon R 2011 Condition monitoring opportunities using vehicle-based sensors *Proc. Inst. of Mech. Eng. Part F: Journal. of Rail and Rapid Transit* **225** 2 pp 202-218
- [2] Mei T and Li H 2008 Measurement of vehicle ground speed using bogie-based inertial sensors *Proc. of the Inst. of Mech. Eng. Part F: Journal of Rail and Rapid Transit* **222** 2 pp 107-116
- [3] Lunin A A 2017 Force impact of freight wagons with axial loads of 23.5 and 25 tnf on the track structure *Transport of the Russian Federation* **6** 73 pp 73-75
- [4] Gapanovich V A 2016 Questions of the interaction of rolling stock and infrastructure under heavy traffic *Railway transport* **10** pp 10-15
- [5] Romen Y S, Suslov O A, Balyaeva A A 2017 Determining the force of interaction in a wheel - rail system based on measuring stresses in rails neck *Vestnik of the Railway Research Institute* **76** 6 pp 354-361
- [6] Brzhezovskiy A M 2017 Methods of experimental evaluation of lateral forces (review) *Vestnik of the Railway Research Institute* **76** 1 pp 10-18
- [7] Zhou L, Brunskill H, Pletz M, Daves W, Scheriau S and Lewis R 2019 Real-Time Measurement of Dynamic Wheel-Rail Contacts Using Ultrasonic Reflectometry *Journal of Tribology* **141** pp 061401-1-061401-9
- [8] Gerlici J, Nozhenko O, Cherniak G, Gorbunov M, Domin R, and Lack T 2018 The development of diagnostics methodological principles of the railway rolling stock on the basis of the analysis of dynamic vibration processes of the rail *MATEC Web of Conf.* **157** 2 03007
- [9] Romen Yu S and Tikhov M S 2007 The volume of information for establishing the permissible speeds of movement based on the results of complex tests *Rolling stock of the XXI century: ideas, requirements, projects. Coll. of scientific papers. St. Petersburg, (PGUPS)* **4** pp 87-94
- [10] Danilenko E I 2016 Calculation of characteristics of stiffness and elasticity of rail threads when torsion under combined action of vertical and horizontal forces *Science and Transport Progress* **5** 65 pp 79-91
- [11] Pshinko A, Petrenko V, Tiutkin A, Andreev V, Gubar A, Ihnatenko D and Markui R 2019 Comparative analysis of calculation results of supporting structure of soil-cement piles *Proc. of 23rd Int. Sci. Conf. Transport Means 2019* pt. II (Kaunas, Lithuania: Kaunas Univ. of Technology) pp 820-828
- [12] Lunys O, Neduzha L and Tatarinova V 2019 Stability research of the main-line locomotive movement *Proc. of the 23rd Int. Sci. Conf. Transport Means 2019* pt. III (Palanga, Lithuania: Kaunas Univ. of Technology) pp 1341–1345
- [13] Pshinko O, Patlasov O, Andrieiev V, Arbuzov M, Hubar O, Hromova O and Markul R 2018 Research of railway crashed stone use of 40-70 mm fraction *Proc. of the 22rd Int. Sci. Conf. Transport Means 2018* pt. I (Trakai, Lithuania: Kaunas Univ. of Technology) pp 170-178
- [14] Bondarenko I 2016 Development of algorithm for calculating dynamic processes of railroad track deformability work *Eastern-European Journal of Enterprise Technologies* **84** 6/7 pp 28-36
- [15] Kovalchuk V, Markul R, Bal O, Milynych A, Pentsak A, Parneta B and Gajda O 2017 The study of strength of corrugated metal structures of railroad tracks *Eastern-European Journal of Enterprise Technologies* **2** 7(86) pp 18-25
- [16] Bondarenko I, Lunys O, Neduzha L and Keršys R 2019 Dynamic track irregularities modeling when studying rolling stock dynamics *Proc. of the 23rd Int. Sci. Conf. Transport Means 2019* pt. II (Palanga, Lithuania: Kaunas Univ. of Technology) pp 1014-1019
- [17] Dolidze D E 1975 *Test of constructions and constructions* (Moscow: Higher School) p 252
- [18] Kurhan M and Kurhan D 2019 Providing the railway transit traffic Ukraine-European Union *Pollack Periodica* **14** 2 pp 27-38
- [19] Shakhunyants G M 1959 *Calculation of track superstructures* (Moscow: Transzheldorizdat) p 264