International Journal of Engineering & Technology, 7 (4.3) (2018) 125-129

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Scientific Substantiation of Thermal Leveling for Deformations in the Car Structure

Oleksiy Fomin[1*], Oleksandr Logvinenko[2], Oleksiy Burlutsky[2], Andriy Rybin[2]

[1]*State University of Infrastructure and Technologies,*
[2]*Ukrainian State University of Railway Transport*
**Corresponding author E-mail: fomin1985@ukr.net*

Abstract

Railway transport is the foundation of the transport complex and part of the transport network of logistics chains. However, significant deterioration of rolling stock units (especially freight cars accounting for the greater part of all transportation) is an urgent problem of the rail industry. Therefore, the problems of renovation of the existing freight car fleet by developing and introducing domestic models which can effectively compete in terms of the technical and economic and operational indexes are of crucial importance. But the car structure suffers from various deformations at all service stages (production, maintenance and operation). The main type of these deformations is residual ones developing during the welding procedure, due to the thermal effect. Therefore, the issues concerning elimination of these deformations in production and maintenance are becoming ever more urgent. In particular, the most recognized and economy-oriented approach in the field is the one based on the thermal leveling of welded structures. The implementation of this approach requires some research aimed at scientific substantiation of the thermal leveling, as well as, specification of forms and heating temperatures, determination of heating form sizes, thermal leveling simulation and experimental verification of the results, optical microscopy and determination of mechanical characteristics.

Keywords: *Experimental Research; Open-Top Car; Optimization Research; Railway Transport; Thermal Leveling.*

1. Introduction

One of the most important and prospective industries in transport engineering, which plays the basic role in rapid social and economic development of any country, is car production. At the same time, the issue concerning a higher technical level of the rolling stock is of urgent consideration; it can be achieved by applying innovative materials of improved characteristics, new welding methods, and also progressive technological processes.

Besides, as far as a greater amount of freight is transported by rail, the improved efficiency of rail operations is of high priority. One of the key points in providing higher efficiency of rail operations is introduction of more economical technologies for the car production and maintenance. One of the problems that may arise is various types of deformations in the car structure during the service life (in production, maintenance and operation).

2. The Problem Statement

A search for ways to prevent deformation development in freight car structures and to eliminate deformations efficiently is an important theoretical and practical task. Thus, there is a direct link between fewer deformations in the car structure and higher traffic safety and cargo security in transportation. Therefore, these issues are of particular importance in both scientific work and practical realization of their results. Hence, the scientific research and design works, aimed at enhancement of methods for eliminating deformations in rolling stock elements by introducing various technological approaches and engineering solutions, are constantly carried out.

3. Analysis of Recent Studies and Publications

The following was demonstrated. For example, study (1) presents promising ways towards improved technical-and-economic characteristics of freight cars. It singles out a method for improving characteristics by introducing effective techniques to prevent deformation development in car elements. But the results of the analysis concerning possible solutions were not considered.

Study (2) discusses a contrastive analysis of the cold and thermal leveling based on classification of existing leveling methods. Study (2) has to do with the results of comparative analysis of the cold and thermal leveling by operational, structural and organizational parameters based on the classification of existing leveling methods. It also covers advantages and disadvantages of the methods. It is mentioned that among the basic advantages of the thermal leveling (as economically reasonable) are: universal nature, absence of cumbersome stationary equipment, insignificant deterioration of properties in the basic metal, user-friendliness, flexibility and accuracy. But the problems of grounded choice of the thermal leveling parameters for car components are not considered.

Study (3) explores techniques for an improved carrying structure of the open-top car body aimed at fewer deformations in the fastening areas on the train ferry deck. Moreover, the study gives the results of the calculations of the body strength with consideration of the fastening of the body on the deck by applying the proposed structural units during sea rolling, thereby substantiating the solutions proposed.

Article (4) deals with the ways to improve anti-deformation characteristics of freight cars. It can be achieved by perfecting structural properties, for example, introducing materials of better characteristics (5).

Study (6) highlights the issue of designing rolling stock for transporting heavy freight with consideration of anti-deformation techniques. The dynamics and strength were investigated with advanced methods in ProMechanica and CosmosWorks software. Besides, while designing the carrying structure the possibility to use various materials was also investigated.
Study (7) reviews structural features of a wagon intended for intermodal transportation. It is also mentioned that the car has a lower middle part, and the presence of the rear part makes it possible to load/unload the motor vehicles using gravity without deformations.
Study (8) examines the results of the research into determination of the character and influence of various freight bogies on the strength of car carrying structures. However, such research does not consider the influence of springs on resistance to operational deformations.
Research (9) analyses the results of the resistance and elimination of possible deformations in the 12-9745 open-top car structure. But, the thermal leveling of its elements is not considered.
Article (10) discusses the influence of the rolling profile of the bogies' fore wheelset on the general dynamics of the vehicle. However, connection between possible deformations was not identified.
Research (11) analyses peculiarities of movement and interaction between rolling stock units parameters of which comply with the engineering solutions. Unfortunately, the investigation into the vehicles with the parameters of advanced engineering solutions was not done.
Research (12) pertains to the results of the dynamic characteristics of vehicles with improved structural elements when running on curves. Moreover, it covers possibilities and impact in terms of the innovation implementation for the worn-out rolling stock.
Article (13) discusses the influence of the determination of the degree of influence of repair processes on serviceability of units of the traction rolling stock. But, the thermal leveling of its elements is not considered.
Thus, by analyzing publications and studies the authors arrived at a conclusion on insufficient scientific substantiation of the thermal leveling for deformed car structures.

4. The Research Methodology

Welding is the basic technological process in the car production and maintenance. And it leads to thermal residual stresses in the heating area, which can result in residual deformations in car elements. The review of existing approaches aimed at their elimination made it possible to single out leveling methods, among which the thermal leveling is of special consideration; it is based on local heating and consequent cooling of specific zones. Basic stages in development and elimination of post-welded deformations, with reference to a conventional beam, are given in Fig. 1. An equilateral triangle, called "wedge", was taken for a heating area form.

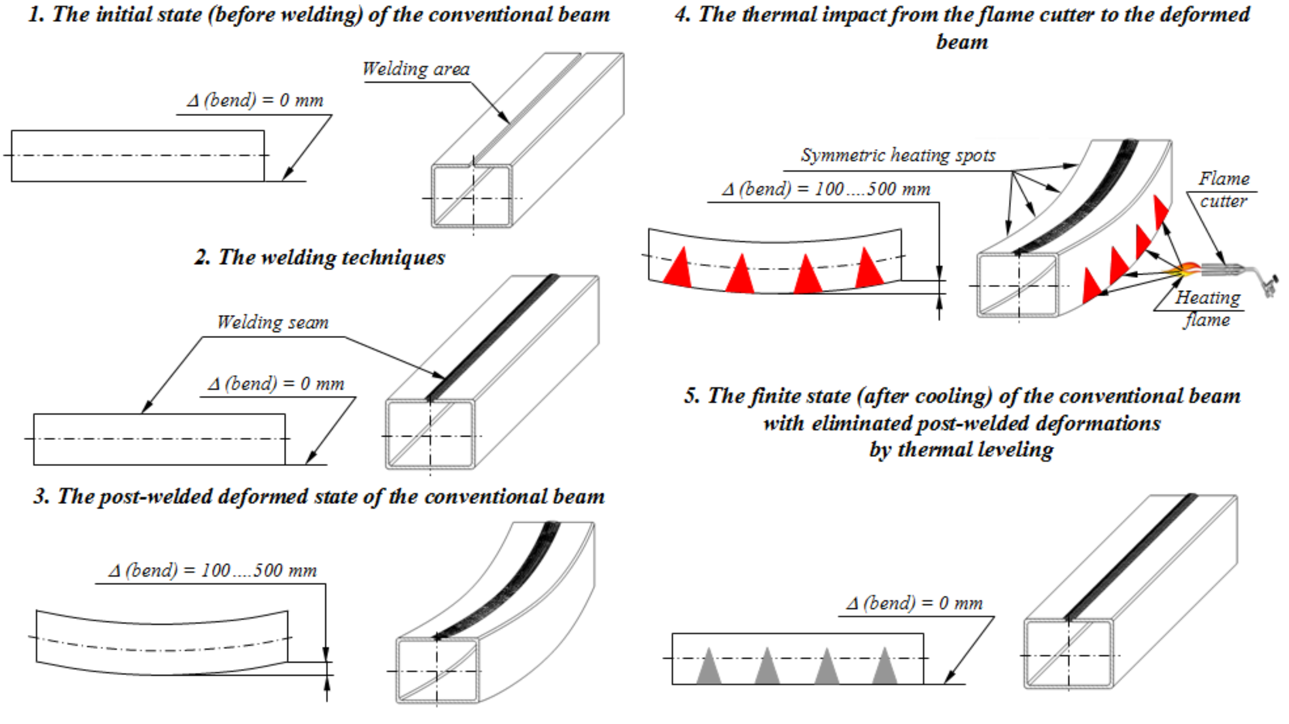

Fig. 1: Principle diagram of the development of post-welded deformations in a conventional beam of a freight car with thermal leveling.

In order to investigate the processes running during the thermal leveling on car elements, the authors developed a mathematical tool based on the optimization methods and mathematical planning of the experiment. Below is a generalized universal mathematical notation of optimization research into the thermal leveling for any car metalwork:

$$\begin{aligned} &F(\overline{X}) \rightarrow extremum \\ &\overline{X} \in D_x \in D \end{aligned} \qquad (1)$$

where F is the main criterion of the optimality;

D_x is the region of admissible solutions;

D is the area of feasible solutions.

The preliminary research showed that considering the problem of optimization research of the thermal leveling in order to decrease post-welded deformations in car metalwork, it is reasonable to use deformation f (bend) as the main (basic) criterion of optimization. Taking into account the chosen criterion, the generalized universal mathematical notion of the task of optimization research into thermal leveling in order to decrease post-welded deformations looks as follows:

$$f(\overline{X}) \to min$$
$$\overline{X} \in D_x \in D. \qquad (2)$$

In the given mathematical notion the area of feasible solutions D is defined by the limits of corresponding values of variable factors x_i (parametrical limitations), that is, by variable parameters which characterize the geometric dimensions of heating zones (height x_{Ha}, length x_{Ld}, width x_{We}, number of heating spots (x_{Sj}); heating temperature T in thermal leveling (x_{Tk}).

Considering the above-mentioned, the area of feasible solutions D can be presented as the following:

$$D = \left\{ \overline{X} \left| \begin{array}{l} x_{Ha\,min} \le x_{Ha} \le x_{Ha\,max}, x_{Ld\,min} \le x_{Ld} \le x_{Ld\,max}, \\ x_{We\,min} \le x_{We} \le x_{We\,max}, x_{Sj\,min} \le x_{Sj} \le x_{Sj\,max}, \\ x_{Tk\,min} \le x_{Tk} \le x_{Tk\,max}; a \in [1:n], d \in [1:c], \\ e \in [1:s], j \in [1:h], k \in [1:m]. \end{array} \right. \right\}. \qquad (3)$$

The region of feasibility D_x with the solution is sorted out of zone D by operational requirements (limitations of secondary criteria). The preliminary research demonstrated that it is reasonable to study the following as the stated criteria and their corresponding limitations: the maximum stress σ_{max} in a dangerous cross-section of the metalwork, which should not exceed the admissible value $[\sigma]$ for the material chosen; rigidity c_{max} the value of which should not exceed the admissible value $[c]$; stability stress $\sigma_{sus.max}$, which should not exceed the admissible value $[\sigma_{sus}]$; module of longitudinal elasticity E which is chosen in accordance with the material and marked for steel E_{st}; coefficient of efficiency η of metalwork heating.

And the region of admissible solutions D_x takes on the following form:

$$D_x = \left\{ \overline{X} \left| \begin{array}{l} \sigma_{max} \le [\sigma], c_{max} \le [c], \sigma_{susmax} \le [\sigma_{susmax}], \\ E = E_{st}, \eta \ge \eta_{min}, \eta \le \eta_{max} \\ \\ x_{Ha\,min} \le x_{Ha} \le x_{Ha\,max}, x_{Ld\,min} \le x_{Ld} \le x_{Ld\,max}, \\ x_{We\,min} \le x_{We} \le x_{We\,max}, x_{Sj\,min} \le x_{Sj} \le x_{Sj\,max}, \\ x_{Tk\,min} \le x_{Tk} \le x_{Tk\,max}; a \in [1:n], d \in [1:c], e \in [1:s], \\ j \in [1:h], k \in [1:m] \end{array} \right. \right\}. \qquad (4)$$

On the base of the above-mentioned generalized mathematical notion of thermal leveling the mathematical dependencies for thermal leveling of deformations in the center sill and top cord of universal open-top cars, which describe the change in the basic factor (deformation bend Δy of the center sill (5) and top cord profile (6)) in dependence on variation of controlled variables (geometrical parameters of the "wedge" – width b and height h, as well as heat temperature t) are created:

$$\begin{aligned} \Delta y = {} & 1304.30333 - 55.074 \cdot b + 25.86856 \cdot h - \\ & - 0.90952 \cdot t + 0.21511 \cdot b^2 - 0.13489 \cdot h^2 + \\ & 0.00108 \cdot t^2 + 0.115 \cdot b \cdot h + 0.0056 \cdot b \cdot t - \\ & - 0.00805 \cdot h \cdot t \end{aligned} \qquad (5)$$

$$\begin{aligned} \Delta y = {} & -1889.03858 + 25.19875 \cdot b + 18.71944 \cdot h + \\ & + 2.57497 \cdot t - 0.08472 \cdot b^2 + 0.1403 \cdot h^2 - \\ & - 0.00108 \cdot t^2 - 0.17688 \cdot b \cdot h - 0.00142 \cdot b \cdot t - \\ & - 0.01692 \cdot h \cdot t. \end{aligned} \qquad (6)$$

5. The Results of the Research

The above-mentioned mathematical dependencies allow building additional diagrams (binary cross-sections) and analyzing them so that to thoroughly choose the geometrical parameters of heating zones (width b^* and height h^*). So, Fig. 2 and Fig. 3 present the examples of such diagrams for the center sill and top cord of universal open-top cars.

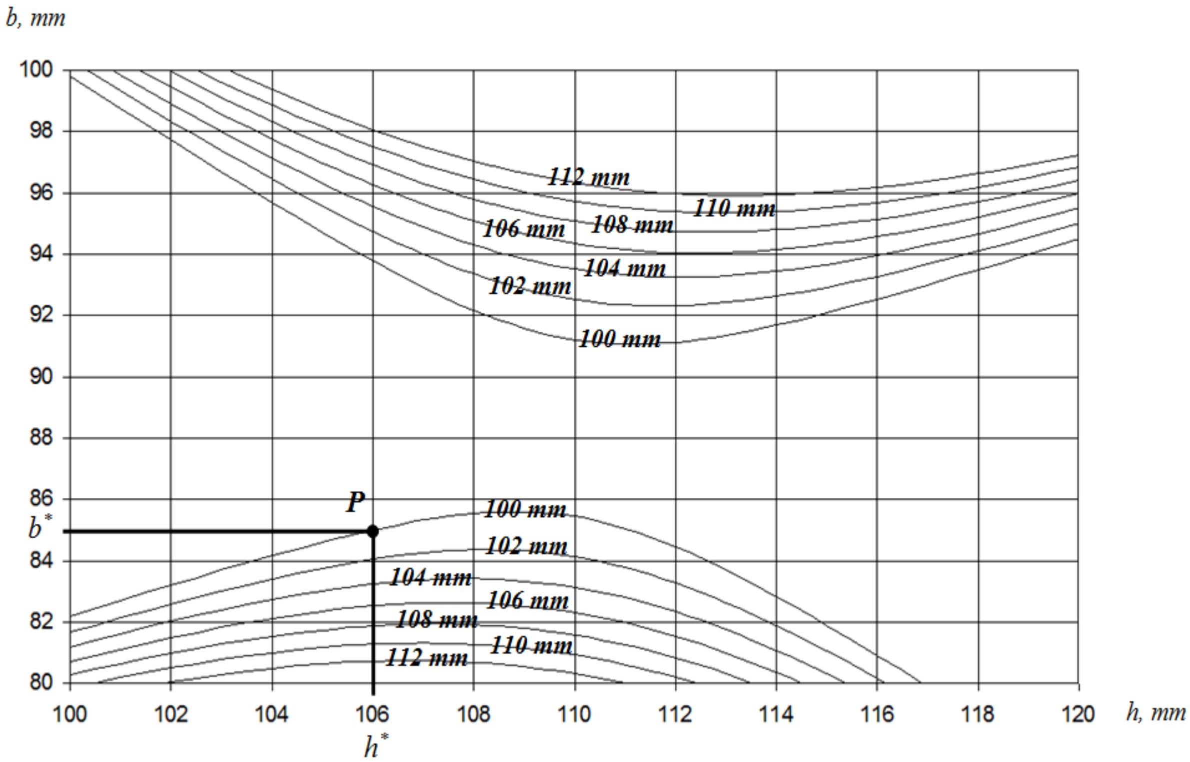

Fig. 2: Additional diagram for sorting out the dimensions of a "wedge" for the center sill leveling at $t = 790\ ^\circ C$

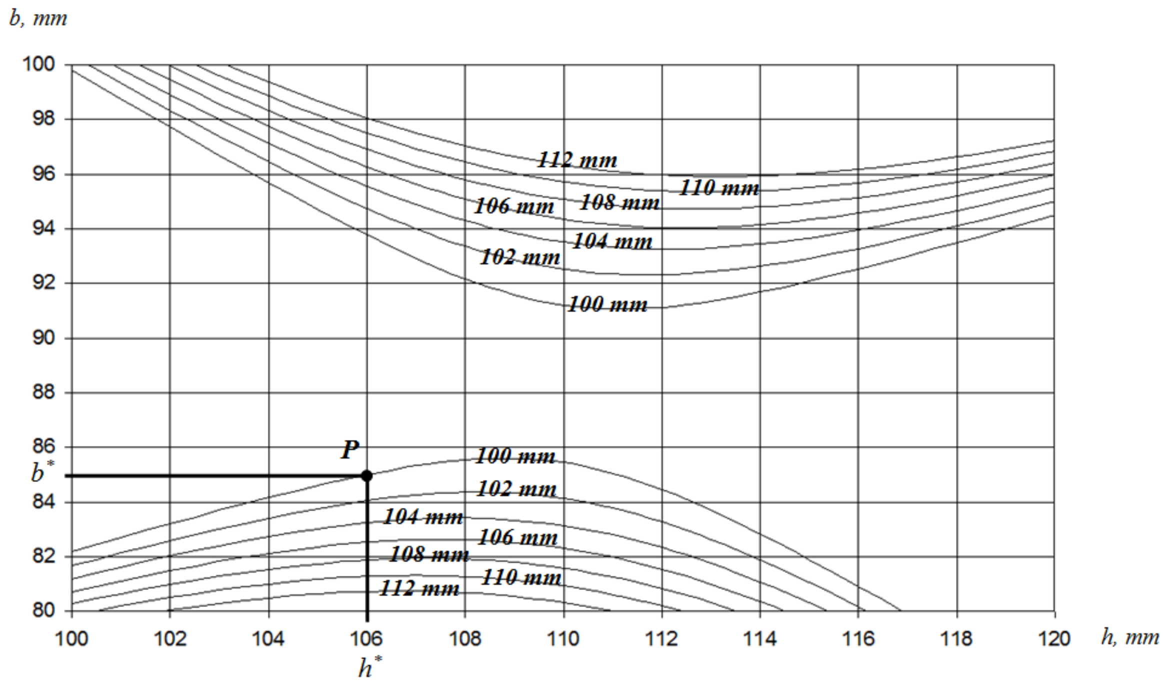

Fig. 3: Additional diagram for sorting out the dimensions of a "wedge" for the top cord leveling at $t = 600\ ^{\circ}C$

The results obtained made it possible to launch the next stage of the research, therein the thermal leveling efficiency must be confirmed. As a result, the authors noted that it can be verified by the results of thermal leveling simulation with special software complexes of CAD systems, such as ANSYS, Nastran, MARK, SolidWorks, T-flex and others. For that reason, he authors simulated thermal leveling of the top cord of an open-top car and the center sill (with the finite element models developed) applying SolidWorks complex.

Moreover, the accuracy and modeling effect (the bend on a car structure element occurred during welding was eliminated) were confirmed in the framework of the experimental research into a full-scale sample of the top cord of an open-top car.

The stages of computer modeling and experimental research of basic structural elements of an open-top car are presented in Fig. 4.

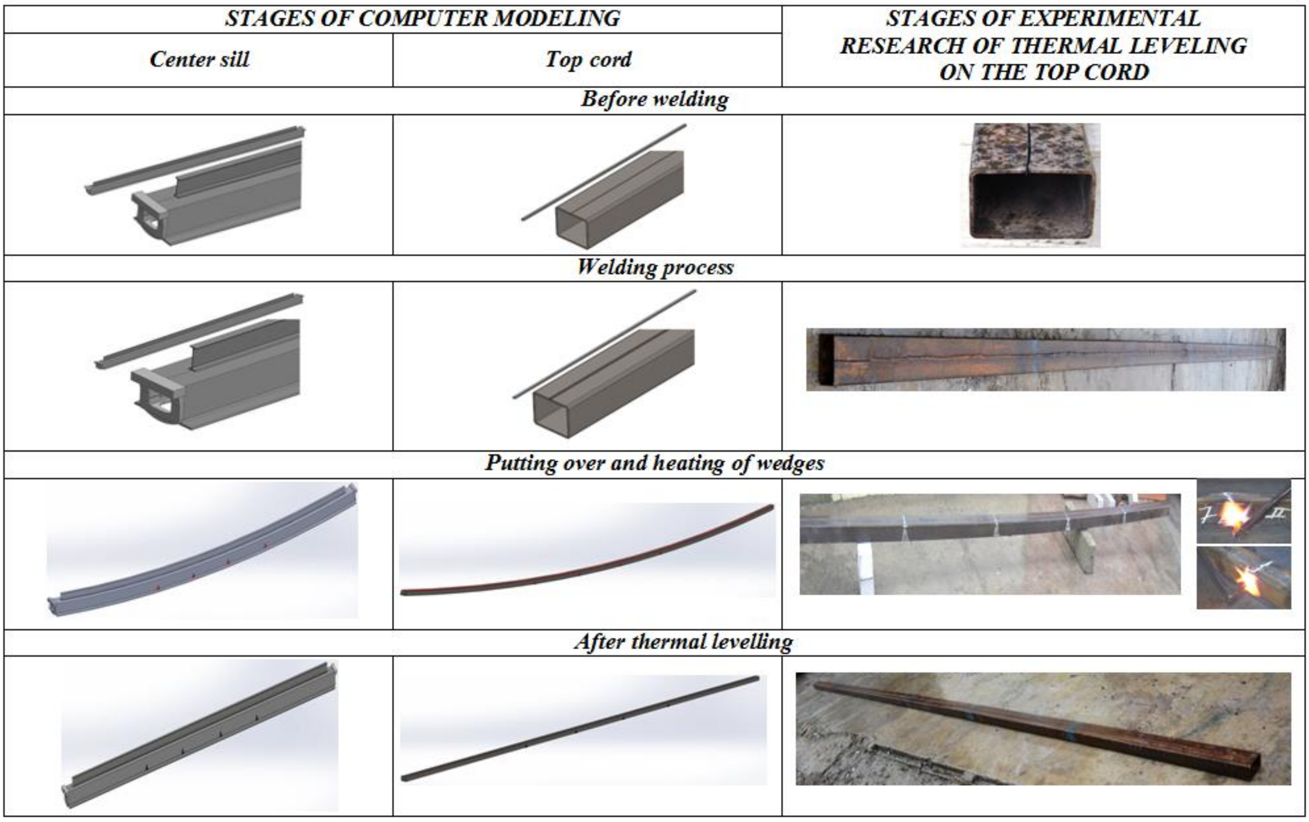

Fig. 4: Stages of the thermal leveling process of computer and experimental research into car structures

6. Conclusions and Recommendations

The thermal leveling method proposed in the article makes it possible to eliminate developing deformations in any car structure. The mathematical tool presented and additional diagrams built allow efficient and quick selection of necessary parameters for thermal leveling and introduction of the approach aimed at eliminating welded deformations in existing working environment.

Acknowledgement

Besides, the results of the optical microscopy conducted and mechanical characteristics of the top cord of an open-top car obtained make it possible to conclude that thermal leveling does not change the structure of the basic metal, and deviations in mechanical characteristics before and after the process are insignificant (in a range of 3%).

References

[1] Fomin OV, "Increase of the freight wagons ideality degree and prognostication of their evolution stages", *Scientific Bulletin of National Mining University*, No.3, (2015), pp.68-76.
[2] Burlutskyi OV, "Application methods changes plastic deformation after welding sill gondola cars", *Metallurgical and mining industry*, No.10, (2015), pp.190-197.
[3] Lovska AA, "Peculiarities of computer modeling of strength of body bearing construction of gondola car during transportation by ferry-bridge", *Metallurgical and Mining Industry,* No.1, (2015), pp.49-54.
[4] Fomin OV, Burlutsky OV, Fomina YuV, "Development and application of cataloging in structural design of freight car building", *Metallurgical and Mining Industry*, No.2, (2015), pp.250-256.
[5] Danchenko Yu, Andronov V, Barabash E, Obigenko T, Rybka E, Meleshenko R, Romin A, "Research of the intermolecular interactions and structure in epoxyamine composites with dispersed oxides", *Eastern-European Journal of Enterprise Technologies*, Vol.6, No12 (89), (2017), pp.4−12.
[6] Divya Priya G, Swarnakumari A, "Modeling and analysis of twenty tonne heavy duty trolley", *Intern. J. of Innovative Technology and Research*, Vol.2, No. 6, (2014), pp.1568–1580.
[7] Krason W, Niezgoda T, "Fe numerical tests of railway wagon for intermodal transport according to PN-EU standards", *Bulletin of the Polish Academy of Sciences Technical Sciences*, Vol.62, No.4, (2014), pp.843-851.
[8] Myamlin S, Lingaitis LP, Dailydka S, Vaičiūnas G, Bogdevičius M, Bureika G, "Determination of the dynamic characteristics of freight wagons with various bogie", *Transport,* Vol. 30(1), (2015), pp.88-92.
[9] Fomin O, "Improvement of upper bundling of side wall of gondola cars of 12-9745 model", *Metallurgical and Mining Industry,* No1, (2015), pp.45-48.
[10] Hauser V, Nozhenko OS, Kravchenko KO, Loulová M, Gerlici J, Lack T, "Impact of wheelset steering and wheel profile geometry to the vehicle behavior when passing curved track", *Manufacturing Technology*, Vol.17(3), (2017), pp.306 – 312.
[11] Tartakovskyi E, Gorobchenko O, Antonovych A, "Improving the process of driving a locomotive through the use of decision support systems", *Eastern-European Journal of Enterprise Technologies*, Vol.5, No. 3(83), (2016), pp.4 – 11.
[12] Hauser V, Nozhenko O, Kravchenko K, Loulová M, Gerlici J, Lack T, "Proposol of a Mechanism for Setting Bogie Wheelsets to Radisl Position while Riding Along Track Curve", *Manufacturing Technology*, Vol.17, No. 2, (2017), pp.186 – 192.
[13] Datsun Y, "Determination of the degree of influence of repair processes on serviceability of units of the traction rolling stock", *Eastern-European Journal of Enterprise Technologies*, Vol.1, No. 7(79), (2016), pp.56-61.