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CREATION OF CONCEPTUAL SOLUTIONS FOR THE MANUFACTURE OF COMPONENT FREIGHT WAGONS FROM COMPOSITES

Purpose. To present the results on the possibility of increasing the efficiency of the use of the operated fleet of freight wagons by creating conceptual solutions for the manufacture of their component load-bearing systems from composites.

Methodology. To increase the efficiency of using the operating fleet of freight wagons measures are offered on the development of conceptual solutions for the manufacture of their components load-bearing systems made of composites. In order to determine the possibility of service life of the basic structures of the freight wagons, the methodology given in the works by A. V. Afanasyev was used. To study the dynamic loading of the freight wagon with the actual dimensions of the constituent elements, a calculation was made. At the same time, a mathematical model was used, formed by Professor G. I. Bogomaz, taking into account its adaptation to the determination of the dynamic loading. The vertical loading of the load-bearing structure of the freight wagon was also investigated. In this regard, a mathematical model formed by Professor Yu. V. Demin was used. The accelerations obtained in the simulation of dynamic loading were taken into account when calculating the strength of the basic structure of the freight wagon.

Findings. It has been established that the design service life of the load-bearing structure of a freight wagon is at least 50 years. The results of determining the longitudinal loading of the basic structures of the freight wagon established that the acceleration acting on it is 37.7 m/s^2, and with the vertical one – 5.5 m/s^2. The strength calculation of the basic structure of a freight wagon showed that the maximum equivalent stresses are recorded in the zone of interaction of the center beam with the pivot and amount to 333.4 MPa, i.e. do not exceed the permissible values.

Originality. The feasibility of manufacturing component load-carrying systems of freight wagons from composites is substantiated.

Practical value. The research carried out will contribute to an increase in the efficiency of the use of railway transport, the transportation process through international transport corridors, as well as the creation of developments in the design of multifunctional car structures.

Keywords: *freight wagon, composite, mechanical engineering, machine building*

Introduction. Geographically, Ukraine has a favorable transport location. This is explained by its location in the middle of the Euro-Asian transport routes, which ensures its advantages in interstate transportation. Today, three Pan-European international transport corridors pass through the territory of Ukraine, connecting it with Bulgaria, Georgia, Turkey, and other countries.

At the same time, meeting the growing needs in transportation requires a significant increase in the working fleet of freight cars. This can be done through the purchase of serial models of freight wagons, or through the creation and introduction into production of their more advanced designs. It should be noted that the second direction is more promising. One of the main directions of creating freight cars with improved technical and economic indicators is the use of the latest materials, in particular composites.

Unfortunately, in recent years, the fleet of freight cars has been replenished to a small extent. Which is explained by the need for significant costs for its replenishment.

It should also be noted that today the technical facilities of the domestic railway transport are in a critical state of wear and tear. Outdated freight wagons have a negative impact on the infrastructure and, accordingly, negatively affect the level of safety of railway transportation. They do not meet modern requirements for transportation efficiency. The urgent need to significantly improve the efficiency of rail freight transportation requires solving the scientific and technical problem of creating a fundamentally new generation of freight wagons made of composite materials.

Literature review. The issue of creating new general structures of freight cars or their components from composites is quite relevant. What has been said is confirmed by modern relevant positive experience in other branches of mechanical engineering: automotive, aircraft, and shipbuilding.

In particular, the work [1] substantiates the need to develop and use the latest models of equipment for railway transportation. It is noted that the use of railway rolling stock with improved technical and economic indicators will positively affect the cost of transporting goods through the territory of Ukraine. And it will also improve the competitiveness of railway transport, among other types of transport, on the domestic and interstate transport market. At the same time, the advantages of using composites in rolling stock structures are not presented.

The key aspects of extending the designated service life of hopper cars are discussed in the publication [2]. In this case, the experimental determination of the load level of the bearing railcar structures was carried out based on a range of tests.

Prediction of the residual life of a railroad car after long-term operation is carried out in the paper [3]. This publication presents the results of studies of the strength of the railcar bearing structure. However, these studies were performed in relation to hopper cars. The authors did not study the theoretical and applied aspects of increasing the service life of flat cars.

In publication [4], the authors substantiated the need to adjust the regulatory documents to extend the service life of freight cars for international traffic. The requirements for rolling stock, the service life of which is extended, are given.

Possible options for extending the service life of objects mechanical engineering are considered [5]. The article develops methods for variant-comparative assessment of extending the service life, taking into account the economic and financial component of these types of work.

The paper [6] considers the structural features of the innovative design of a flat car for operation in international traffic. The advantages of the proposed railcar design in comparison with known analogs are noted.

An analysis of the design of a railroad car for international transportation is given in [7]. The results of the calculation of the strength of the railroad car bearing structure are presented.

However, these railcars are intended for transportation of a given range of goods and these works do not address the possibility of their modernization if such a need arises.

The paper [8] determined the possibility of extending the service life of freight cars that have exhausted their standard service life. The results of determining their dynamic load and strength, as well as conclusions on further operation are presented. At the same time, the issue of their re-equipment for the transportation of the specified range of goods is not considered in the work.

Unsolved aspects of the problem. The analysis of the literature allows us to conclude that the issues of the efficiency of using the operating fleet of freight wagons measures of conceptual solutions for the manufacture of their components load-bearing systems made of composites are quite relevant but require further development. This necessitates the conduct of relevant research in this direction.

Purpose. The purpose of the article is to present the results on the possibility increasing the efficiency of the use of the operated fleet of freight wagons by creating conceptual solutions for the manufacture of their component load-bearing systems from composites.

The achievement of this goal included the following tasks:

- to determine the dynamic load of the bearing structure of the freight wagons from composites;
- to determine the stress state of the bearing structure of the freight wagons from composites.

Methods. The following methodology was used in the study: the problem and objectives of the study were determined (which included: information and patent search, analytical analysis of world experience, expert evaluation, systematic analysis of the current scientific and technical background on the profile of issues); the existing design of the freight wagon was analyzed in order to determine the existing reserves for improvement; on the basis of the previously developed theoretical, methodological and conceptual support, a number of constructive improvements were proposed; the study was carried out.

In the course of the study, the following were used: Interstate standards, DSTU, instructions, methodologies, regulations, and projects that are relevant to the research and implementation.

Results. The main advantages of composite materials are high strength values and lower, compared to similar materials, density values, high controllability of the corresponding physical and mechanical characteristics. Such advantages can be purposefully used and purposefully improved when creating various types of composites. At the same time, depending on the expected characteristics, it is possible to manage the availability of reinforcement and fastening means. And accordingly, such advantages and technological development of modern production increasingly lead to the use of composites in comparison with traditional structural materials.

It should be noted that the characteristics of composites directly depend on the quality and properties of the included component components. Namely matrices and reinforcement. At the same time, the composite connection of the included elements allows you to obtain their complementary properties. This cannot be achieved in traditional designs, where the included elements work in separate functional sectors.

The range of useful properties of composite materials is very significant. So, in particular, it is possible to distinguish: mass which is less by times, significantly increased service life, and others. Such advantages make composites undisputed leaders in fully ensuring the expected structural and functional properties in constructions of various purposes. Constructions of various types of mechanical engineering are characterized by exceptional perfection, controlled anisotropy of physical and mechanical properties, life cycle increased many times, resistance to aggressive environmental influences.

It can be argued that with the help of technologies for the production of composite materials, it is possible to create their samples for each individual structure. That is, to manufacture component structural elements that will fully satisfy functional needs.

In order to determine service life of the bearing structure of a freight wagon, we used the methodology given in the works by Afanasyev A. V.

In accordance with the methodology, the probability of failures P_i of the elements of the bearing structure of the car in operation is determined by the formula

$$P_i = \frac{\sum_{1}^{k} \frac{R_H}{R}}{k}, \qquad (1)$$

where k is the number of railcars examined; R_H – the number of defective elements of the same type in the car; R – the total number of elements of the same type.

The estimated design life was determined by the formula

$$T_k = \frac{\left(\frac{\sigma_{a_i N}}{[n]}\right)^m \cdot N_0}{N_{cI} \cdot \sum_j \left(\sigma^{\mathrm{I}}_{a_j}\right)^m \cdot P^{\mathrm{I}}_j + N_{c\mathrm{II}} \cdot \sum_k \left(\sigma^{\mathrm{II}}_{a_k}\right)^m \cdot P^{\mathrm{II}}_k}, \qquad (2)$$

where σ_{aiN} is the average value of the endurance limit; $[n]$ – permissible safety factor; N_0 – base of examinations; $N_{c\mathrm{I}}$, $N_{c\mathrm{II}}$ – the number of defective structural elements of the car under examination; m – the indicator of the degree of fatigue curve; $\sigma^{\mathrm{II}}_{aj}$, $\sigma^{\mathrm{II}}_{ak}$ – tensile strength of the studied structure material; P^{I}_j, P^{II}_k – probability of failure of a structural element.

The research was conducted on the bearing structure of the load-bearing structure of the model 12-4745 freight wagon (Fig. 1). At the same time, computer models were built based on its existing (Fig. 1) and prospective (Fig. 2) structural schemes from composite materials.

The geometric parameters of the main bearing elements of the frame were determined during field studies and reported in the work [8].

The results obtained allowed us to conclude that the design service life of the bearing structure of the freight wagon is at least 50 years.

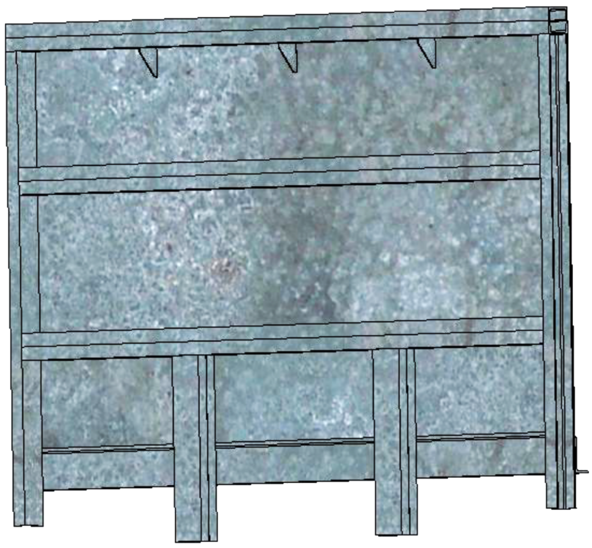

Fig. 1. End wall of freight wagon model 12-4745. Existing design scheme

Fig. 2. End wall of freight wagon model 12-4745. Prospective design scheme

To study the dynamic load of a freight wagon a calculation was performed. The mathematical model formed by Professor Bogomaz H. I. was used, taking into account its adaptation to determine the dynamic.

At the initial stage of research, the longitudinal load of the bearing structure of the freight wagon under shunting collision was taken into account.

$$M'_B \cdot \ddot{x}_B + M' \cdot \ddot{\varphi} = P_l; \tag{3}$$

$$I_B \cdot \ddot{\varphi}_B + M' \cdot \ddot{x}_B - g \cdot \varphi_B \cdot M' = \\ = l \cdot F_{TP}(sign\dot{\Delta}_1 - sign\dot{\Delta}_2) + l(C_1 - C_2); \tag{4}$$

$$M_B \cdot \ddot{z}_B = C_1 + C_2 - F_{TP}(sign\dot{\Delta}_1 - sign\dot{\Delta}_2), \tag{5}$$

where

$$M'_B = M_B + 2 \cdot m_T + \frac{n \cdot I_{kp}}{r^2}; \quad M' = M_B \cdot h;$$

$$C_1 = k_1 \cdot \Delta_1; \quad C_2 = k_2 \cdot \Delta_2;$$

$$\Delta_1 = z_B - l \cdot \varphi_B; \quad \Delta_2 = z_B + l \cdot \varphi_B,$$

where M_B is mass characteristics of the load-bearing structural component of the freight wagon; I_B – the moment of inertia of the flat car relative to the longitudinal axis; P_l – the value of the shock load in the auto coupling along the axis; m_T – cart weight; I_{kp} – the moment of inertia of the wheel pair; r – the radius of the average worn wheel; n – presence of the crew; l – half base of the freight wagon; F_{TP} – absolute value of the dry friction force in the spring set; k_1, k_2 – spring stiffness of the spring suspension of the freight wagon carts; x_B, φ_B, z_B – corresponding coordinates.

It is taken into account that the freight wagon is loaded with a conditional cargo, taking into account the use of the full load capacity. The flat car is assumed to be supported by 18–100 carts. The impact on the coupler is considered to be absolutely rigid.

Differential equations (3–5) were solved in the MathCad software package [9, 10]. The initial displacements and velocities were set to zero [11, 12]. The longitudinal shock load acting on the vertical surface of the rear stop of the auto coupling is set at zero level 3.5 MN [13, 14].

As a result of the calculations, it was found that the acceleration acting on the load-bearing structural system of the freight wagon is equal to 37.7 m/s^2.

The vertical load of the bearing structure of the flat car was also investigated. The study used a mathematical dependence developed by Dr. tech., prof. Yuriy Demin. It was established that the main indicators of the flat car dynamics do not exceed the permissible ones. At the same time, the acceleration of the bearing structure of the freight wagon in the center of mass was 5.5 m/s^2. The calculated accelerations do not exceed the standard values [13, 14].

The force of bulk load spacer on the side walls and end doors of the freight wagon body is determined according to the methodology given in [9, 10, 14]. According to this methodology, it is assumed that the load of the bulk cargo spacer on the side walls of the car body is distributed according to the law of a triangle with a maximum at its base, and on the end wall – according to the law of a trapezoid. The maximum loads near the bases of the side wall racks are determined

$$q_1 = 0.5 \cdot p_a \cdot l_1; \tag{6}$$

$$q_2 = 0.5 \cdot p_a \cdot (l_1 + l_2); \tag{7}$$

$$q_3 = 0.5 \cdot p_a \cdot (l_2 + l_3); \tag{8}$$

$$q_4 = 0.5 \cdot p_a \cdot (l_3 + l_4), \tag{9}$$

where p_a is active (static) pressure of bulk load spacer, which occurs per unit surface area of the vertical wall at floor level, kPa; l_1 – the distance from the end beam of the frame to the geometric axis of the wagon center plate, m; l_2 – the distance from the geometric axis of the wagon center plate to the second body rack, m; l_3 – the distance from the second pillar of the body to the third one, m; l_4 – the distance from the third pillar of the body to the vertical geometric axis of the wagon body, m.

The active pressure of the spacer of the bulk cargo is determined by the formula

$$p_a = \gamma \cdot g \cdot H \cdot \mathrm{tg}^2\left(\frac{\pi}{4} - \frac{\varphi}{2}\right), \tag{10}$$

where γ is density of bulk cargo, t/m^3; H – height of the side wall, m; φ – the angle of the natural slope of the load, rad; g – acceleration of gravity, m/s^2.

Taking into account the characteristics of hard coal, the active pressure of the bulk cargo on the side wall of the wagon body was (kN/m^2)

$$P_a^{\mathrm{I}} = 0.9 \cdot 9.81 \cdot 2.315 \cdot \mathrm{tg}^2\left(\frac{\pi}{4} - \frac{0.52}{2}\right) = 6.86;$$

$$P_a^{\mathrm{III}} = 0.9 \cdot 9.81 \cdot (1 + 0.12) \cdot 2.315 \cdot \mathrm{tg}^2\left(\frac{\pi}{4}\right) = 22.86.$$

The calculated values of the forces of bulk cargo spacer on the side walls of the freight car body are given in Table 1.

The pressure of an unevenly distributed load, which is applied to the end door leaf, is determined by the formula

$$p = p_a + p_n, \tag{11}$$

where p_n is passive pressure of bulk cargo, in which the square of the tangent of the difference of two angles is replaced by the square of the tangent of their sum and taking into account the coefficient of vertical dynamics, as well as the angle of natural slope (kN/m^2)

$$P_i^{\mathrm{I}} = 0.9 \cdot 9.81 \cdot 2.315 \cdot \mathrm{tg}^2\left(\frac{\pi}{4} + \frac{0.52}{2}\right) = 60.7;$$

$$P_i^{\mathrm{III}} = 0.9 \cdot 9.81 \cdot 2.315 \cdot \mathrm{tg}^2\left(\frac{\pi}{4}\right) = 24.9.$$

The intensity of the trapezoidal load falling on the corner post is determined

$$q_{T1}^e = 0.5(p_a + p_n) \cdot b_1; \tag{12}$$

$$q_{T1}^i = 0.5 \cdot p_n \cdot b_1; \tag{13}$$

Table 1

The numerical value of the pressure of the spacer of the bulk cargo on the elements of the side wall of the body of the freight wagon

Side wall vertical stay	Flowable freight pressure, kPa
side: I r. c.	6.104
III r. c.	22.5
the first vertical stay from the side of the stub end I r. c.	12.45
III r. c.	42.37
the second vertical stay from the side of the stub end I r. c.	10.987
III r. c.	38.75
the third vertical stay from the side of the stub end I r. c.	7.63
III r. c.	28.68

on the intermediate rack

$$q_{T2}^{e} = 0.5(p_a + p_n)\cdot(b_1 + b_2); \quad (14)$$

$$q_{T2}^{i} = 0.5\cdot p_n\cdot(b_1 + b_2); \quad (15)$$

on the middle rack

$$q_{T3}^{e} = 0.5(p_a + p_n)\cdot b_2; \quad (16)$$

$$q_{T3}^{i} = 0.5\cdot p_n\cdot b_2. \quad (17)$$

The calculated values of the forces of bulk cargo spacer on the end wall of the freight wagon body are given in Table 2.

In addition, the model takes into account the reactions in the hinge nodes caused by the action on the supporting structure of lateral and longitudinal forces.

The accelerations obtained during the modeling of dynamic loading were used to determine the strength characteristics of the load-bearing structural system of the freight wagon. This was done by applying the finite element method on the software and computer base of the engineering software packages SolidWorks Simulation and CosmosWorks [15, 16].

Table 2

The numerical value of the pressure of the spacer of the bulk cargo on the elements of the end wall of the body of the freight wagon

Gangway door element	Flowable freight pressure, kPa
corner vertical stay I r. c.	49.73 43.55
III r. c.	34.81 17.36
intermediate vertical stay I r. c.	99.78 88.76
III r. c.	69.88 35.76
middle vertical stay: I r. c.	49.37 43.88
III r. c.	34.53 17.47

The graph-analytical method was used to determine the number of finite elements [17, 18]. Tetrahedra with isoparameters were used as finite elements [19, 20]. Quantitatively, the mesh includes: 922,345 elements, 301,567 nodes. The size of the maximum element was 90 mm, the minimum – 15 mm, the sides have a maximum ratio of 5042.7, the percentage of elements with sides less than 3 is 37.4, and more than 10–10.2. The model was fixed in areas that rely on running modules (carts). The structural material used was composites.

To determine the profile of the vertical posts, a calculation was performed using the method of sections [13, 15]. The results of the calculations allowed us to determine a possible profile of the racks Ω – a similar profile with a value of $Wx = 118.2$ and $Wy = 119.3$ cm^3. The geometric parameters of the body cladding were assumed to be identical to the prototype car.

The following loads were taken into account when drawing up the design scheme of the bearing structure of the freight wagon: vertical Pv and longitudinal N. It was also taken into account that the full carrying capacity of the freight wagon loaded with a conditional load was used. The calculation was performed for the main design modes.

The maximum values of equivalent stresses were recorded at the points of interaction between the girder beam and the pivot beam and amounted to 333.4 MPa, and, accordingly, did not exceed the maximum permissible values, which are equal to the yield strength of the material.

With other loading schemes, the strength of the flat car's supporting structure is also ensured.

Taking into account the capabilities of transportation of steel in coils on the flat car model 13-401, it is proposed to install cradles on its supporting structure for fastening steel coils (Figs. 3–5).

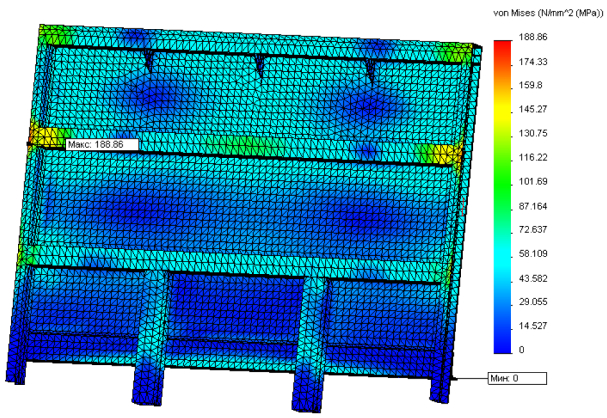

Fig. 3. A fragment (end wall) of the strength calculation results. Existing design scheme

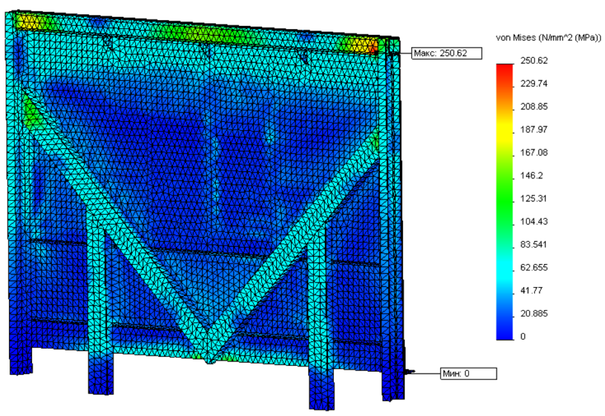

Fig. 4. A fragment (end wall) of the strength calculation results. Prospective design scheme

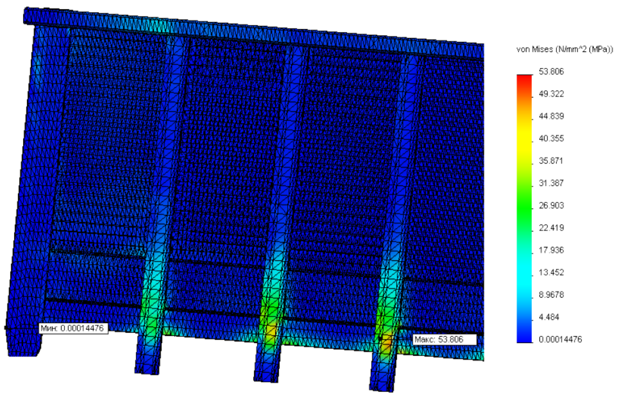

Fig. 5. A fragment (side wall) of the strength calculation results. Existing design scheme

The results of the calculations showed that the strength of the improved bearing structures of freight wagons is ensured. At the same time, the maximum stresses were recorded in the zones of interaction between the girder beam and the pivot beams, but these stresses do not exceed the permissible ones.

It is important to note that the proposed improvement is also possible by using other composite components in the bearing structures of wagons. Preliminary calculations conducted by the authors showed that this solution is effective. In this case, a composite with a titanium matrix is used, which is reinforced with boron, borsic, silicon carbide, beryllium, and molybdenum fibers. Such a composite has high heat resistance and significant tensile strength: in the fiber direction it is 1100–1300 MPa, in the transverse direction – 650 MPa. However, the widespread introduction of such an improvement is constrained by the cost of the material.

Conclusions.

1. The dynamic load of the bearing structure of a freight wagon was determined. The longitudinal and vertical loadings of the bearing structure of the freight wagon were considered. The results of determining the longitudinal load of the bearing structure of a freight wagon have established that the acceleration acting on the bearing structure is 37.7 m/s^2, and the vertical acceleration is 5.5 m/s^2. The obtained acceleration values do not exceed the permissible ones.

2. The stress state of the bearing structure of the freight wagon was determined. The maximum values of equivalent stresses were recorded at the points of interaction between the girder beam and the pivot beam and amounted to 333.4 MPa, and, accordingly, did not exceed the maximum permissible values.

3. Measures are proposed to improve the structures of freight wagons by making them from composite materials. The maximum stresses are recorded in the areas of interaction between the girder beam and the pivot beams, but these stresses do not exceed the permissible ones.

4. The development of conceptual solutions for the manufacture of components of freight wagons load-bearing systems made of composites (microstructures based on composite materials, in particular: carbon fiber, fiberglass, metal shell (hollow and layered), etc.) will allow domestic freight car designs to achieve technical and economic indicators of the new generation level and thereby significantly improve the profitability and competitiveness of rail freight transportation, reduce resource consumption and improve traffic safety. This, in turn, will significantly improve the economic efficiency of cargo transportation by domestic railways both in the domestic market and in interstate transit. It will also allow numerous domestic railcar engineers to compete in the relevant global market.

5. The research will help to increase the efficiency of rail transport, the transportation process through international transport corridors, as well as create developments in the design of multifunctional railcar structures.

References.

1. Bibik, S., Strelko, O., Nesterenko, H., Muzykin, M., & Kuzmenko, A. (2020, November). Formulation of the mathematical model for the planning system in the carriage of dangerous goods by rail. *IOP Conference Series: Materials Science and Engineering, 985*(1), 012024. https://doi.org/10.1088/1757-899X/985/1/012024.

2. Anofriev, V.G., Rejdemejster, A.G., Kalashnik, V.A. & Kuleshov, V.P. (2016). To the issue of extending the service life of cars for transportation of pellets. *Nauka ta progres transportu. Visnik Dnipropetrovskoho Natsionalnoho Universytetu Zaliznychnoho Transportu*, *3*(63), 148-160. https://doi.org/10.15802/stp2016/74749.

3. Putyato, A.V., Konovalov, E.N., & Afanas'kov, P.M. (2016). Forecasting the remaining life of a hopper-dozer car after long-term operation taking into account the actual physical and mechanical characteristics of the material of the bearing structure. *Mekhanika mashin, mekhanizmov i materialov*, *1*(34), 26-35.

4. Fesovets, O., Strelko, O., Berdnychenko, Y., Isaienko, S., & Pylypchuk, O. (2019). Container transportation by rail transport within the context of Ukraine's European integration. *Proceedings of the 23rd international scientific conference Transport Means,* (pp. 381-386). Part 1, 2019-October. Kaunas University of Technology, Kaunas. Retrieved from https://transportmeans.ktu.edu/wp-content/uploads/sites/307/2018/02/Transport-means-2019-Part-1.pdf.

5. Kondratiev, A., Gaidachuk, V., Nabokina, T., & Kovalenko, V. (2019). Determination of the influence of deflections in the thickness of a composite material on its physical and mechanical properties with a local damage to its wholeness. *Eastern-European Journal of Enterprise Technologies*, *4*(1(100)), 6-13. https://doi.org/10.15587/1729-4061.2019.174025.

6. Krasoń, W., Niezgoda, T., & Stankiewicz, M. (2016). Innovative Project of Prototype Railway Wagon and Intermodal Transport System. *Transportation Research Procedia*, *14*, 615-624.

7. Divya Priya, G., & Swarnakumari, A. (2014). Modeling and analysis of twenty tonne heavy duty trolley. *International Journal of Innovative Technology and Research*, *2*(6), 1568-1580.

8. Fomin, O., Logvinenko, O., Burlutsky, O., & Rybin, A. (2018). Scientific Substantiation of Thermal Leveling for Deformations in the Car. *International Journal of Engineering & Technology*, (4.3), 125-129. https://doi.org/10.14419/ijet.v7i4.3.19721.

9. Fomin, O., Kulbovsky, I., Sorochinska, E., Sapronova, S., & Bambura, O. (2017). Experimental confirmation of the theory of implementation of the coupled design of center girder of the hopper wagons for iron ore pellets. *Eastern-European Journal of Enterprise Technologies*, *5*(1(89)), 11-18. https://doi.org/10.15587/1729-4061.2017.109588.

10. Fomin, O. (2014). Modern requirements to carrying systems of railway general-purpose gondola cars. *Metallurgical and Mining Industry, 5*, 31-43. Retrieved from https://www.metaljournal.com.ua/assets/Journal/9-Fomin.pdf.

11. Gubarevych, O., Goolak, S., Daki, O., & Yakusevych, Y. (2021). Determining an additional diagnostic parameter for improving the accuracy of assessment of the condition of stator windings in an induction motor. *Eastern-European Journal of Enterprise Technologies, 5*(5(113), 21-29. https://doi.org/10.15587/1729-4061.2021.239509.

12. Goolak, S., Gubarevych, O., Gorobchenko, O., Nevedrov, O., & Kamchatna-Stepanova, K. (2022). Investigation of the influence of the quality of the power supply system on the characteristics of an asynchronous motor with a squirrel-cage rotor. *Przegląd Elektrotechniczny, 98*(6), 142-148. https://doi.org/10.15199/48.2022.06.26.

13. Yakovlieva, A., & Boichenko, S. (2020). Energy Efficient Renewable Feedstock for Alternative Motor Fuels Production: Solutions for Ukraine. *Studies in Systems, Decision and Control, 298*, 247-259. https://doi.org/10.1007/978-3-030-48583-2_16.

14. *Freight wagons. general requirements for calculations and design of new and modernized wagons of 1520 mm gauge (non-self-propelled. DSTU 7598:2014* (2015). Retrieved from http://online.budstandart.com/ua/catalog/doc-page.html?id_doc=73763.

15. Boichenko, S., Zubenko, S., Konovalov, S., & Yakovlieva, A. (2020). Synthesis of camelina oil ethyl esters as components of jet fuels. *Eastern-European Journal of Enterprise Technologies, 1*(6), 42-49. https://doi.org/10.15587/1729-4061.2020.196947.

16. Sokolov, V., Porkuian, O., Krol, O., & Stepanova, O. (2021). Design Calculation of Automatic Rotary Motion Electrohydraulic Drive for Technological Equipment. In: Advances in Design, Simulation and Manufacturing IV. DSMIE 2021. *Lecture Notes in Mechanical Engineering, 1*, 133-142. Springer, Cham. https://doi.org/10.1007/978-3-030-77719-7_14.

17. Krol, O., & Sokolov, V. (2020). Modeling of Spindle Node Dynamics Using the Spectral Analysis Method. In: Advances in Design, Simulation and Manufacturing III. DSMIE 2020. *Lecture Notes in Mechanical Engineering, 1*, 35-44. Springer: Cham. https://doi.org/10.1007/978-3-030-50794-7_4.

18. Varbanets, R., Fomin, O., Píštěk, V., Klymenko, V., Minchev, D., Khrulev, A., Zalozh, V., & Kučera, P. (2021). Acoustic Method for Estimation of Marine Low-Speed Engine Turbocharger Parameters. *Journal of Marine Science and Engineering*, *9*, 321. https://doi.org/10.3390/jmse9030321.

19. Iakovlieva, A., Vovk, O., Boichenko, S., Lejda, K., & Kuszewski, H. (2016). Physical-chemical properties of jet fuel blends with components derived from rapeseed oil. *Chemistry and Chemical Technology, 10*(4), 485-492. https://doi.org/10.23939/chcht10.04.485.

20. Kondratiev, A. (2019). Improving the mass efficiency of a composite launch vehicle head fairing with a sandwich structure. *Eastern-European Journal of Enterprise Technologies*, *6*(7(102)), 6-18. https://doi.org/10.15587/1729-4061.2019.184551.

Створення концептуальних рішень із виготовлення складових вантажних вагонів із композитів

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Мета. Висвітлення результатів щодо можливості підвищення ефективності використання експлуатованого парку вантажних вагонів шляхом створення концептуальних рішень із виготовлення їх складових несучих систем із композитів.

Методика. Для підвищення ефективності використання експлуатованого парку вантажних вагонів запропоновано створення концептуальних рішень з виготовлення їх складових несучих систем зі композитів. З метою визначення можливості строку служби несучої конструкції вантажних вагонів використана методика, наведена у працях Афанасьєва А. В. Для дослідження динамічної навантаженості вантажного вагону з фактичними розмірами складових елементів проведено розрахунок. При цьому використана математична модель, сформована професором Богомазом Г. І., з урахуванням її адаптації до визначення динамічної навантаженості. Також досліджена вертикальна навантаженість несучої конструкції вантажного вагону. При цьому використана математична модель, сформована професором Дьоміним Ю. В. Отримані під час моделювання динамічної навантаженості прискорення враховані при розрахунках на міцність несучої конструкції вантажного вагону.

Результати. Установлено, що проектний строк служби несучої конструкції вантажного вагону складає не менше 50 років. Результати визначення повздовжньої навантаженості несучої конструкції вантажного вагону показали, що прискорення, яке діє на нього, складає 37,7 м/с^2, а при вертикальній навантаженості – 5,5 м/с^2. Розрахунок на міцність несучої конструкції вантажного вагону показав, що еквівалентні максимальні напруження зафіксовані в місцях взаємодії балки хребтової зі шворневою та складають 333,4 МПа, і, відповідно, не перевищують гранично-допустимих.

Наукова новизна. Обґрунтована доцільність виготовлення складових несучих систем вантажних вагонів із композитів.

Практична значимість. Проведені дослідження сприятимуть підвищенню ефективності використання залізничного транспорту, перевізного процесу через міжнародні транспортні коридори, а також створенню напрацювань щодо проектування мультифункціональних конструкцій вагонів.

Ключові слова: *вантажний вагон, композит, механічна інженерія, машинобудування*

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