менные скорости точки контакта – вдоль циклоидального профиля и вдоль профиля цевочного колеса, причем векторы скоростей лежат на общей касательной в точке сопряжения, различные по модулю, а их знак зависит от фазы рабочего цикла.

Научная новизна. Определены законы движения контактных точек в зацеплении героторной пары, достоверно установлен переменный скоростной режим в зацеплении. В ходе исследований получена универсальная формула связи скоростей перемещения точек по криволинейной траектории и эквидистанте к ней, которая учитывает кривизну траектории. Установлено, что при взаимодействии выпуклого участка эквидистанты к циклоидальной кривой с сопряженной цевкой, имеет место трение скольжения, а при обкатке вогнутого участка – трение качения. Получены функции линеаризации, которые позволяют стабилизировать переменный скоростной режим.

Практическая значимость. Полученные в ходе исследования результаты позволяют оценить влияние скоростного режима на интенсивность трения в точках сопряжения профильных поверхностей, локализовать участки с наибольшей интенсивностью трения и найти пути уменьшения вредного влияния трения, тем самым повысить износоустойчивость профилей в зацеплении. Результаты также могут быть использованы при разработке технологии обработки циклоидальных профилей с функцией линеаризации скорости взаимной обкатки профилей инструмента и детали. Линеаризация позволит стабилизировать нагрузку и повысить точность обработки.

Ключевые слова: *точка контакта, скорость, героторная пара, циклоидальный профиль*

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O. V. Fomin[1], Dr. Sc. (Tech.), Assoc. Prof.,
orcid.org/0000-0003-2387-9946,
A. O. Lovska[2], Cand. Sc. (Tech.),
orcid.org/0000-0002-8604-1764,
O. A. Plakhtii[2], Cand. Sc. (Tech.),
orcid.org/0000-0002-1535-8991,
V. P. Nerubatskyi[2],
orcid.org/0000-0002-4309-601X

1 – State University of Transport Economy and Technologies, Kyiv, Ukraine, e-mail: fomin1985@list.ru
2 – Ukrainian State University of Railway Transport, Kharkiv, Ukraine, e-mail: alyonaLovskaya.vagons @gmail.com

THE INFLUENCE OF IMPLEMENTATION OF CIRCULAR PIPES IN LOAD-BEARING STRUCTURES OF BODIES OF FREIGHT CARS ON THEIR PHYSICO-MECHANICAL PROPERTIES

О. В. Фомін[1], д-р техн. наук, доц.,
orcid.org/0000-0003-2387-9946,
А. О. Ловська[2], канд. техн. наук,
orcid.org/0000-0002-8604-1764,
О. А. Плахтій[2], канд. техн. наук,
orcid.org/0000-0002-1535-8991,
В. П. Нерубацький[2],
orcid.org/0000-0002-4309-601X

1 – Державний економіко-технологічний університет транспорту, м. Київ, Україна, e-mail: fomin1985@list.ru
2 – Український державний університет залізничного транспорту, м. Харків, Україна, e-mail: alyonaLovskaya.vagons@gmail.com

ВПЛИВ УПРОВАДЖЕННЯ КРУГЛИХ ТРУБ ДО НЕСУЧИХ КОНСТРУКЦІЙ КУЗОВІВ ВАНТАЖНИХ ВАГОНІВ НА ЇХ ФІЗИКО-МЕХАНІЧНІ ВЛАСТИВОСТІ

Purpose. Implementation of the innovative draft system for automatic couplers of railway cars. Such a system is alternative to an existing one, where energy of longitudinal loads are absorbed by draw gears, the main working elements of which are absorbing devices.

Methodology. The research presented used the modern methods of the car dynamics and the theory of vibrations for designing a mathematical model to define accelerations in the supporting structure of the car body with viscous materials, the theoretical and applied mechanics for modelling dynamic processes in a new draft system, designing in modern engineering software applications for creating an adequate spatial virtual model of the supporting system of an railway cars, finite elements for calculations of accelerations occurring in the supporting structure of railway cars under longitudinal loading, and the F-test for the model adequacy. Generally, the algorithm of the research conducted included designing the mathematical model for the prospective supporting system of railway cars in order to ground the parameters of the viscous material used. Then the computer simulation of maximum longitudinal working loads was conducted for the new railway cars body. And the results obtained were analysed.

Findings. The comprehensive theoretical research has proved the hypothesis on efficient implementation of the concept of the draft system for railway cars. Its full-scale implementation will provide substantial reduction of construction and maintenance cost for freight cars. The models designed during the research are adequate and can be used for further similar research and development work.

Originality. For the first time a new concept of the draft system of railway cars has been proposed and scientifically based. The longitudinal working loads are distributed to the centre sill, not to a separate absorbing device (by the way, a rather expensive one); the centre sill is made of circular pipe where the draft arms are filled with viscous material of damping characteristics. Mathematical and finite-element models were developed for defining accelerations in the supporting structure of the car body, which considered viscous connection, and the adequacy of the models was checked.

Practical value. The results of theoretical pre-design scientific substantiation of the proposed concept make it possible to proceed to the next design stages. Besides, such results will become the base for further dynamics and power calculations of the supporting structure of car bodies while implementing the innovative trend proposed.

Keywords: *railway transport, freight car, concept of the draft system, implementation of viscous materials, dynamic load of the structure*

Introduction. One of the key problems in rail transport development is designing samples of rolling stock with improved technical, economic and operational characteristics.

According to transport experts in Ukraine and other countries the coming years will witness increased volume of rail transportation. It explains the need to create the rolling stock which will provide maximal effectiveness and safe operation of railways. And the key role is fulfilled by freight cars. Therefore, development and operation of freight cars of the best performance characteristics will become the ground of economic prosperity for the rail transport in the world freight transportation market. It is especially acute for Ukraine being a machine building country (over 10 machine building plants) with a considerable domestic freight turnover and transit potential; though over two third of the rolling stock being obsolete both morally and physically. However, achieving the highest efficiency of freight cars with conventional approaches without developing absolutely new designs is an impossible task.

The experience in operating freight rolling stock in European countries and Ukraine, according to transport experts, indicates the absence of innovative knowledge-based structures and technologies. Most of innovative solutions are aimed at modernization of existing projects (car trucks, car bodies, unloading and braking systems, elastic and dissipative vibration control systems). It is obvious that such a situation can have a detrimental effect to the rail transport in its competition against other transportation modes. A conventional modern car cannot meet the requirements for the 21st century rolling stock.

Analysis of the recent research and unsolved aspects of the problem. Features of the structure and the architectural hierarchy of locomotive support systems and decision-making are considered in [1]. The description of the dynamic knowledge base was carried out using production model of knowledge representation.

With the aim of reducing the cost of manufacture and operation of cars a known technical solution is used, which consists in the manufacture of load-bearing structures made of circular tubes under the conditions of durability and operational reliability [2]. Obtaining the optimal parameters of circular tubes proposed for use as load-bearing elements for car bodies is carried out at the reserve strength of typical structural elements. The results of calculations on the strength of improved bearing structures for car bodies have shown the appropriateness of the proposed solutions provided by the conditions of strength.

Study of the dynamics of a railway car with an open loading platform is given in [3]. The calculation was done in the software MSC Adams.

Study of loading and durability of railway vehicle method dynamics of systems of bodies is carried out in [4]. The method is used in the study of dynamic response and fatigue life of the frame of long-wheelbase car-platform for transportation of containers.

The measures aimed at improvements in the supporting structure of the open boxcar body in order to provide their reliable fixation on the desk of railway ferry is given in [5]. The results of the body capacity calculations including their fixation on the desk in the proposed construction points in the conditions of sea dusting have confirmed the efficiency of the proposed solutions.

The investigation into dynamics of rail flatcars is given in [6]. The calculation has been carried out in MSC Adams software. The stability test against car rollover has been made on a 250 m radius curve at different speeds.

The issue of assessing the accuracy of capacity in railway networks for transportation of raw materials and finished products of mining and metallurgical industry is given in [7].

The results of the above-mentioned studies [1–7] are a sufficient basis for solving the problem, which has been posed for the first time and regards improvements in freight cars. The aim of the improvements is to decrease the car dynamic load by implementing the new draft system concept where longitudinal working loads are carried by the centre sill, not by a separate device (by the way, a rather expensive one); the centre sill is made of a circular pipe where the draft arms are filled with viscous material of damping characteristics.

The objective of the study. The study reveals the peculiarities and results of research into implementation of the innovative draft system for automatic couplers of open boxcars. Such a system is alternative to an existing one, where energy of longitudinal loads are absorbed by draw gears, the main working elements of which are absorbing devices. The concept of the new system is based on the above-mentioned functions performed by the centre sill of an open boxcar, made of a circular tube the draft arms of which are filled with viscous material of damping properties.

A description of the methodology of the study. The concept proposed suggests replacing a modern draft gear consisting of separate parts (absorbing devices, yokes, follower blocks, etc.) in order to reduce construction and maintenance cost of freight cars. The advantages mentioned are achieved due to higher effectiveness of the centre sill of the freight cars, namely, its ability to absorb tensile and compressive loads associated with impacts during shunting operations and transition operational modes. It is especially important in the conditions of higher train speeds, intensive shunting operations and for ensuring safety.

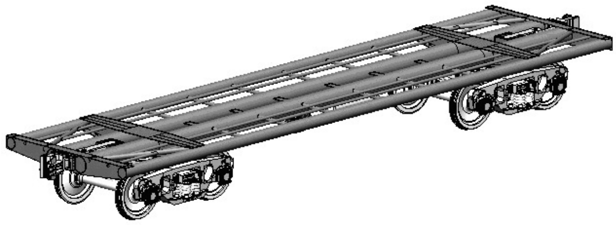
General operational algorithm:

1. Theoretical estimation of dynamic load of the supporting structure of the freight car body under longitudinal loads during shunting impacts (the most extreme operational conditions) using modern research methods for investigation into the wagon dynamics and the theory of vibrations.
2. Computer simulation of dynamic loads on the supporting structure of the freight car body under the influence of longitudinal loads during shunting impacts with the use of engineering software.
3. Theoretical model verification to provide the theoretical substantiation of necessity to create a prospective concept of the draft system of freight cars.

Presentation of the main research. The aim involved reducing the consumption of materials supporting body structure freight cars while ensuring strength and robustness optimization of their constituent elements and the selected optimal parameters. Spatial models of improved body structure freight cars with regard to measures for their improvement are shown in Fig. 1.

The calculation of the strength was produced by the method of finite elements in the environment of the software CosmosWorks. The calculations have allowed concluding that the maximum equivalent stress in load-bearing structures of improved bodies of railway carriages does not exceed the allowable stress.

In order to reduce dynamic loads influencing the supporting structure of the freight cars body the study proposes to remove draft gears of automatic couplers and transfer their function of absorbing energy associated with operational loads to the centre sill and upper and lower coverings of side walls; they are proposed to be made of circular pipes and filled with materials of damping and anticorrosion properties, that will allow a lower material consumption for the car, an increased carrying capacity and loading volume of the body, as well as a longer repair-free service life.



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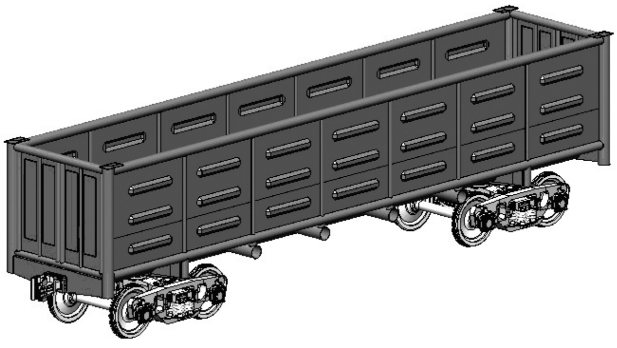

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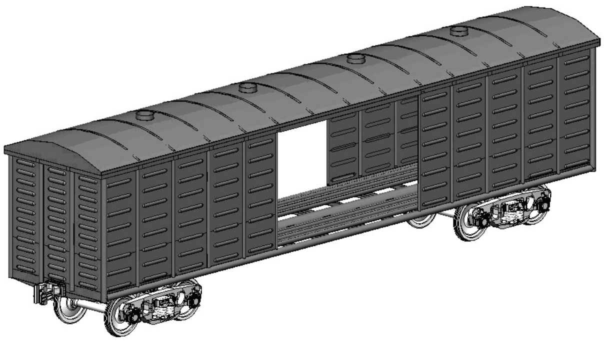

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Fig. 1. Computer models of rail cars, whose load-bearing body components are made of pipes of circular cross-section:
a – the car platform; b – open box car; c – boxcar

In order to define dynamic loads influencing the car body during shunting impacts, as the most intensive loads on its supporting structure in operation, the mathematical model of G. Bogomaz was used. The model is designed for defining accelerations being components of the dynamic loads on the flatcar loaded with container tankers during shunting impacts. Therefore, it has been improved for defining accelerations as components of the dynamic loads on the car under longitudinal impact forces.

$$M'_C \cdot \ddot{x}_C + M_C \cdot h \cdot \ddot{\varphi}_C = S_a ;$$
$$I_C \cdot \ddot{\varphi}_C + M_C \cdot h \cdot \ddot{x}_C - g \cdot \varphi_C \cdot M_C \cdot h =$$
$$= l \cdot F_{FR}\left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2\right) + l\left(C_1 - C_2\right);$$
$$M_C \cdot \ddot{z}_C = C_1 + C_2 - F_{FR}\left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2\right),$$

where

$$M'_C = M_C + 2 \cdot m_b + \frac{n \cdot I_W}{r^2}; \quad \Delta_1 = z_C - l \cdot \varphi_C ;$$
$$\Delta_2 = z_c + l \cdot \varphi_c; \; C_1 = k_1 \cdot \Delta_1; \; C_2 = k_2 \cdot \Delta_2,$$

where M_c is the mass of the supporting structure of the car; I_c is the inertia moment of the car relative to the longitudinal axis; S_a is the value of the longitudinal impact force upon the automatic coupler; m_b is the body mass; I_W is the inertia moment of the wheel set; r is the radius of the half worn wheel; n is the number of the body axes; l is the half of the bogie centre distance; F_{FR} is the absolute value of the dry friction force in the spring group; k_1, k_2 are the rigidities of springs in the spring suspension of the car bodies; x_c, φ_c, z_c are the coordinates corresponding to longitudinal, angular around the lateral axis and vertical displacement of the car respectively.

The solutions of the differential equations were found in the MathCad software, where they were reduced to a normal Cauchy-Euler equation, and then integrated with the Runge-Kutta method.

The initial displacements and speeds were taken equal to zero. The input parameters of the mathematical model are technical characteristics of the car body, parameters of spring suspension, and also values of longitudinal impact force upon the automatic coupler.

The 12-757 open boxcar was taken as an example with its supporting structure made of circular pipes. The spring suspension parameters considered in the calculations were taken the same as for a standard bogie of the 18-100 model.

The longitudinal impact force influencing the vertical surface of the rear draft lug of the coupler is taken equal to 3.5 MN [8].

The results of the research made it possible to conclude that the acceleration influencing the supporting structure of the car during shunting co-impacts is approximately 40 m/s^2 (Fig. 2, *a*).

In order to define accelerations influencing the supporting structure of the car body with consideration of circular pipes filled with elastomeric material of damping and anticorrosion properties, the mathematical model mentioned above is reduced

$$M'_C \cdot \ddot{x}_C + M_C \cdot h \cdot \ddot{\varphi}_C = S_a - \beta \cdot \dot{x}_C \,;$$

$$I_C \cdot \ddot{\varphi}_C + M_C \cdot h \cdot \ddot{x}_C - g \cdot \varphi_C \cdot M_C \cdot h = \\ = l \cdot F_{FR}\left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2\right) + l\left(C_1 - C_2\right) \,;$$

$$M_C \cdot \ddot{z}_C = C_1 + C_2 - F_{FR}\left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2\right),$$

where β is the viscous resistance coefficient of the material inside the supporting structure elements of the car.

The investigations into accelerations influencing the supporting structure of the car body with viscous material inside its supporting elements made it possible to conclude that efficiency of this solution can be achieved at the viscous resistance coefficient values lower than 120 kN·s/m.

The results of the research considering the viscous resistance coefficient values of the material 120 kN · s/m made it possible to conclude that the acceleration influencing the supporting structure of the car during shunting co-impacts is about 34 m/s^2 (Fig. 1, *b*), and lower by 10 % than the values of accelerations achieved for a standard loading scheme and exerted on the centre sill of the car.

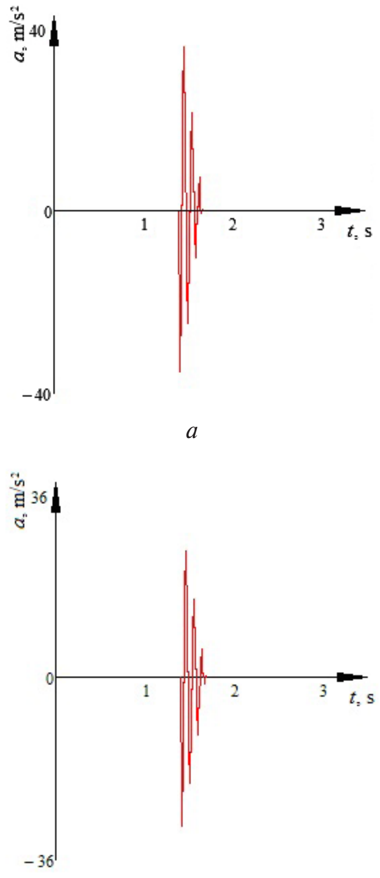


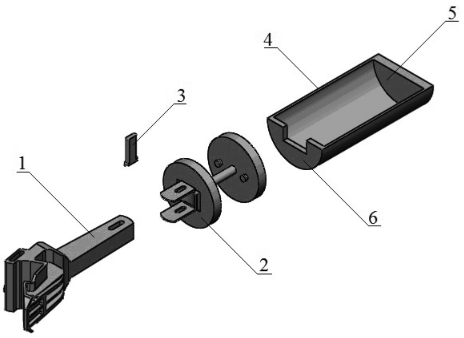
Fig. 2. The accelerations influencing the car during shunting co-impacts:
a – for the standard scheme of carrying loads by the centre sill of the car; b – for the scheme of carrying loads by the centre sill filled with viscous material

It should be mentioned that the value of the acceleration obtained can be reduced by selecting the best parameters of viscous materials used in industry.

In order to implement the proposed scheme for carrying longitudinal loads by the centre sill of the car, structural changes in automatic coupling devices are suggested, namely, removal of draft gears, as well as follower blocks and transfer their functions to less structurally complicated elements (Fig. 3) that considerably reduce construction and repair cost of such open boxcars.

The automatic coupler consists of CA-3 standard frame *1* interacting with the intermediate adapter *2* consisting of the front follower with a standard follower block on. Through the rod the front follower of the adaptor is connected with the piston with two throttle valves – input and output. The viscous material is located to the right and left of the piston. To create the pressure in the viscous material when the piston moves during impact force in centre sill *4*, bottom *5* is provided. To limit the movements of the adaptor during jerks and stretches the limiter *6* is provided.

Considering the viscous materials as springs for longitudinal forces on the supporting structure of the car body the automatic coupling device operates as follows (Fig. 4). Through automatic coupler body 1 the loads are trans-



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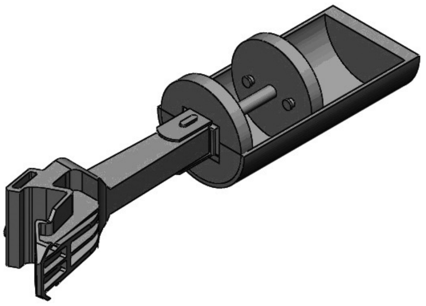


b

Fig. 3. Structural peculiarities of the automatic coupling device considering implementation of viscous materials as springs for longitudinal forces on the supporting structure of the car body:

a – the assembly with element separation; b – the assembly (overview); 1 – body of the automatic coupler; 2 – adaptor; 3 – key; 4 – centre sill made of circular pipe; 5 – bottom; 6 – the limiter

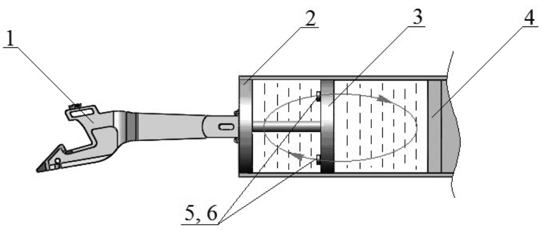


Fig. 4. The operation of the automatic coupling device considering implementation of viscous materials as springs for longitudinal forces to the supporting structure of a car body:

1 – body of the automatic coupler; 2 – follower block; 3 – piston; 4 – bottom; 5, 6 – throttle valves

ferred to the adaptor front follower *2* through the shark end. Under the loads the adapter moves in longitudinal direction and presses the viscous material located in the gap between piston 3 and bottom *4*. It provides the flow through the throttle valve to the gap between the front follower of the adapter and the piston. At the backspacing of the piston the viscous material flows through the other throttle valve. The energy generated dissipates in the environment. Thus the work of the viscous material is similar to the work of a hydraulic shock absorber (damper).

In order to improve the efficiency of the proposed draft system of the car, it is necessary to provide the air-tightening (absence of possible outputs of the viscous material out of the centre sill).

In order to theoretically check the obtained results of mathematical modelling and investigations into acceleration field distribution in the supporting structure of the freight cars made of circular pipes, the spatial computer model in SolidWorks software was designed with subsequent dynamics modelling in CosmosWorks software. The accelerations were defined by the finite-element method.

The values of loads influencing the supporting structure of the open boxcar body for calculation mode I as the most intensive mode for the body is given in Table. It was taken into account that the total freight capacity of the car was used. Black coal was used as the bulky freight being the most frequently transported in Ukraine. In the Table the sign* marks the pressure of the bulky load on the lower part of the studs and the sign** marks the pressure on the upper part of the studs.

The longitudinal impact force was applied to the vertical surface of the front follower of the adaptor and the opposite end was fixed for simulating the maximum pressure on the supporting structure.

The model was also fixed in the areas of its support on riding parts, namely, body centrals and crossbars.

In order to model the properties of the viscous material the study uses the spring-damper link taken from the fastening examples presented in the software, and installs it between the piston and the bottom. The coefficient of viscous resistance of the material was taken 120 kNH·s/m and the spring rigidity was taken equal to zero, because the proposed scheme of carrying longitudinal loads does not consider spring linkage.

The calculations have demonstrated that the shift of the adaptor under a longitudinal impact force of $3.5 \cdot 10^3$ kN and an impact force speed of 0.03 m/s is 875 mm.

Table

The values of loads influencing the supporting structure of the open boxcar body

Loads	Values
Vertical static, kN	829.926
Pressure from bulky load, kPa	
Side wall stud:	
angular	7.083
the first from the arm	13.03
the second from the arm	11.895
the third from the arm	8.92
Front (end) wall stud:	
angular	50.06* 44.98**
intermediate	100.12* 89.96**
middle	50.06* 44.98**

** – the pressure of the bulky load on the lower part of the studs and the sign; ** – the pressure on the upper part of the studs*

The calculation results are given in Fig. 5. The research conducted makes it possible to conclude that maximum accelerations of the car body occur in the area from the arm to the area where the centre sill interacts with the bolster beam and are about 50 m/s^2 (≈5 g). In the area between the bolster beam to the middle part of the centre sill the value of accelerations decreases and is about 30 m/s^2 (≈3 g).

The distribution of accelerations along the centre sill of freight cars frame is given in Fig. 6.

Thus, maximum accelerations in the freight cars frame with viscous materials under the impact force occur in the zone from the frontal beam to the bolster beam, and without viscous materials – in the central area of the centre sill. It is conditioned by the fact that kinetic energy of the impact force is dampened by the draft system and turns into the dissipative energy.

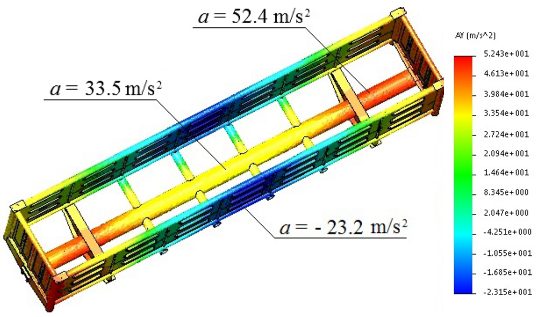
In order to test the adequacy of the designed model the F-test has been applied.

$$F_p = \frac{S_{ad}^2}{S_r^2},$$

where S_{ad}^2 is the dispersion of adequacy; S_r^2 is the dispersion of restorability.

The dispersion of adequacy can be defined by the formula

$$S_{ad}^2 = \frac{\sum_{i=1}^{n}\left(y_i - y_i^p\right)}{f_i},$$



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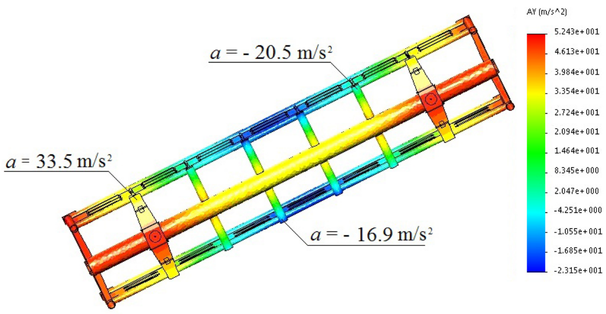
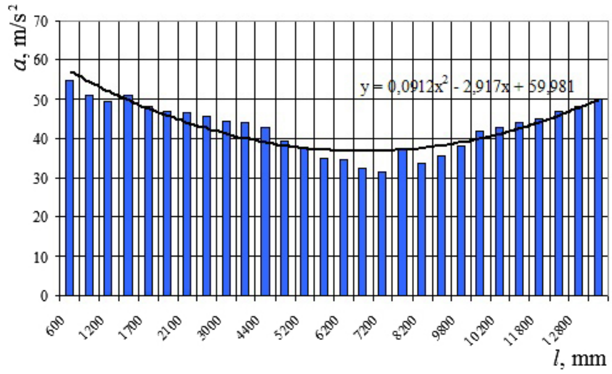


b

Fig. 5. The distribution of acceleration fields influencing the supporting structure of the body of an open boxcar considering implementation of viscous materials as springs for longitudinal forces upon the centre sill:
a – top view; b – bottom view



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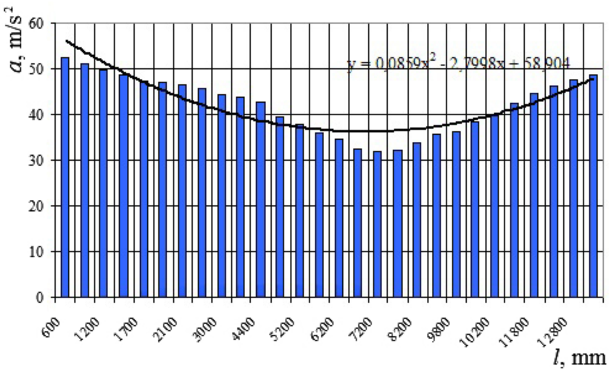

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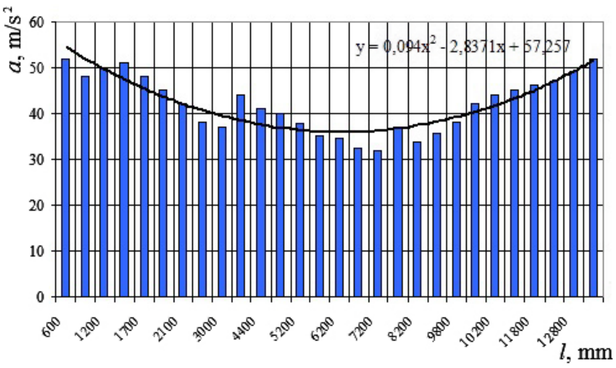

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Fig. 6. The distribution of accelerations along the centre sill of a freight car frame under the impact force on the adapter:
a – the car platform; b – open box car; c – boxcar

where y_i^p is the calculated value obtained by modelling; f_i is the number of freeness levels.

$$f_i = N - q,$$

where N is the number of tests in the planning matrix; q is the number of equilibrium ratios.

The dispersion of restorability is defined by the formula

$$S_r^2 = \frac{1}{N}\sum_{i=1}^{n} S_i^2,$$

where S_i^2 is the dispersion in each line, where parallel tests were conducted.

It has been stated that the model under consideration is a linear one and characterizes the change in the car accelerations due to the longitudinal force exerted upon the adaptor. Here, the number of freeness at $N = 5\,\text{N} = 5$ will be $f_1 = 3$.

While defining the adequacy of the model it has been established that if the dispersion of restorability is $S_y^2 =$ 1.95 and the dispersion of adequacy is $S_{ad}^2 = 2.0$, the actual value of the F-test is $F_p = 1.03$, which is lower than the table value of the test, namely, $F_t = 5.41$. Thus, at a significance level of $p = 0.05$ the hypothesis about adequacy of the model designed is not denied. The approximation accuracy is 8.76 %.

During preliminary exploratory research the possible variants have additionally been studied regarding filling the lower and upper covering of walls of freight cars with viscous materials, though at present such variants have not provided a sufficient level of economic justification.

Conclusions and recommendations for further research. The results of the research conducted have demonstrated that implementation of the proposed concept regarding construction of the draft system for freight cars will allow improving dynamic operational qualities of their structure, promoting their preservation during shunting impacts, and also reducing construction and operational cost.

The proposed concept of the draft system for freight cars makes it possible to reduce the maximum equivalent stresses exerted on its supporting structure during shunting impacts over 15 %. Besides, viscous material in the structural elements of freight cars will allow reduction of their corrosion in operation. Among disadvantages one should mention technological approaches in its implementing for the supporting structure of a car.

Further development and implementation of the proposed concept require investigations into peculiarities of operating regimes (besides the extreme one considered), as well as further bench and field tests.

According to the results of the study the application for a patent has been submitted which also considers other possible wagon structural variants with implementation of units filled with viscous material.

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Мета. Впровадження концептуально нової упряжної системи автозчепів залізничних вагонів. Така система є альтернативою до існуючої, де функції із поглинання енергії поздовжніх навантажень виконують упряжні пристрої з основними робочими органами – поглинаючими апаратами.

Методика. При проведенні дослідження використані сучасні методи: динаміки вагонів і теорії коливань при розробленні математичної моделі для визначення прискорень у несучій конструкції кузова вагона з урахуванням наявності в’язкого зв’язку в ній; теоретичної та прикладної механіки для моделювання процесів динаміки в новій упряжній системі; конструювання в сучасних інженерних розрахункових програмних комплексах для створення адекватної просторової віртуальної моделі нової несучої системи напіввагонів; скінчених елементів для проведення розрахунків прискорень, що виникають у несучій конструкції кузова напіввагону при дії повздовжнього навантаження; критерій Фішера для перевірки адекватності розробленої моделі. Узагальнено алгоритм проведених досліджень включав створення математичної моделі перспективної несучої системи напіввагонів для обгрунтування параметрів упроваджуваного в’язкого матеріалу. Після чого здійснювалося комп’ютерне розрахункове моделювання процесів сприйняття максимальних поздовжніх експлуатаційних навантажень новим кузовом напіввагону. Далі проводився аналіз отриманих розрахункових даних.

Результати. У результаті проведеного комплексу теоретичних досліджень підтверджена гіпотеза щодо ефективності впровадження запропонованого концепту упряжної системи залізничних вагонів. Його натурна реалізація дозволить суттєво знизити собівартість виготовлення та експлуатації вантажних вагонів. Розроблені у ході досліджень моделі є адекватними, їх доцільно використовувати у відповідних подальших науково-дослідних і дослідно-конструкторських роботах.

Наукова новизна. Уперше запропоновано й науково обґрунтовано новий концепт упряжної системи залізничних вагонів, де функції з поглинання поздовжніх експлуатаційних навантажень замість окремого поглинального пристрою (у тому числі високовартісного апарата) виконує хребтова балка шляхом виконання її із круглої труби із заповненими консольними частинами в'язким матеріалом із демпфуючими властивостями. Розроблені математичні й скінчено-елементні моделі для визначення прискорень у несучих конструкціях кузовів вагонів з урахуванням наявності в'язкого зв'язку в них, та перевірена їх адекватність.

Практична значимість. Результати теоретичного передпроектного наукового обґрунтування запропонованого концепту дозволяють перейти до наступних стадій його проектування. Також такі результати стануть основою при подальших динамічних і міцнісних розрахунках несучих конструкцій кузовів вагонів у рамках реалізації запропонованого інноваційного напряму.

Ключові слова: *залізничний транспорт, вантажний вагон, концепт упряжної системи, впровадження в'язких матеріалів, динамічна навантаженість конструкції*

Цель. Внедрение концептуально новой упряжной системы автосцепок железнодорожных вагонов. Такая система является альтернативой к существующей, где функции по поглощению энергии продольных нагрузок выполняют упряжные устройства с основными рабочими органами – поглощающими аппаратами.

Методика. При проведении исследования использованы современные методы: динамики вагонов и теории колебаний при разработке математической модели для определения ускорений в несущей конструкции кузова вагона с учетом наличия вязкой связи в ней; теоретической и прикладной механики для моделирования процессов динамики в новой упряжной системе; конструирования в современных инженерных расчетных программных комплексах для создания адекватных пространственных виртуальных моделей новых несущих систем вагонов; конечных элементов для проведения расчетов ускорений, которые возникают в несущих конструкциях кузовов вагонов при действии продольной нагрузки; критерий Фишера для проверки адекватности разработанных моделей. Обобщенно алгоритм проведенных исследований включал создание математических моделей перспективных несущих систем вагонов для обоснования параметров внедряемого вязкого материала. После чего осуществлялось компьютерное расчетное моделирование процессов восприятия максимальных продольных эксплуатационных нагрузок новыми кузовами вагонов. Далее проводился анализ полученных расчетных данных.

Результаты. В результате проведенного комплекса теоретических исследований подтверждена гипотеза об эффективности внедрения предложенного концепта упряжной системы железнодорожных вагонов. Его натурная реализация позволит существенно снизить себестоимость изготовления и эксплуатации грузовых вагонов. Разработанные в ходе исследований модели являются адекватными, их целесообразно использовать в соответствующих дальнейших научно-исследовательских и исследовательско-конструкторских работах.

Научная новизна. Впервые предложен и научно обоснован новый концепт упряжной системы железнодорожных вагонов, где функции по поглощению продольных эксплуатационных нагрузок вместо отдельного поглощающего устройства (в том числе высокостоимостного аппарата) выполняет хребтовая балка путем изготовления ее из круглой трубы с заполненными консольными частями вязким материалом с демпфирующими свойствами. Разработаны математические и конечно-элементные модели для определения ускорений в несущих конструкциях кузовов вагонов с учетом наличия вязкой связи в них, и проверена их адекватность.

Практическая значимость. Результаты теоретического предпроектного научного обоснования предложенного концепта позволяют перейти к следующим этапам его проектирования. Также такие результаты станут основой при дальнейших динамических и прочностных расчетах несущих конструкций кузовов вагонов в рамках реализации предложенного инновационного направления.

Ключевые слова: *железнодорожный транспорт, грузовой вагон, концепт упряжной системы, внедрение вязких материалов, динамическая нагруженность конструкции*

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