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Determination of the dynamic load of an improved hatch cover of an open wagon during operating modes

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Abstract: The article presents the results of determining the dynamic load of the improved cover of an open wagon under operational conditions. The peculiarity of the manhole cover is that the canvas is formed by the upper and lower sheets, between which, there is an energy-absorbing material with viscous properties. The dynamic load of the cover when a load of 150 kg falls on it was studied. It was determined, that the use of energy-absorbing material contributes to the reduction of the cover load by 21 % compared to a typical original design. The main indicators of the dynamics of an open wagon equipped with improved manhole covers are calculated. The results of the calculations showed that the studied dynamic indicators are within the permissible limits. The conducted studies will contribute to the reduction of damage to manhole covers during operation and the cost of maintaining one wagons.

Keywords: transport mechanics, an open wagon, improved design, dynamic load.

INTRODUCTION

Harmonious functioning of the transport industry is one of the main factors in the successful development of the economy of *Eurasian* countries. It is known that railway transport is one of the most promising components of the transport infrastructure. Transportation of bulk and bulk cargoes, which make up a significant share of the total cargo turnover, is carried out in open wagons. At the same time, hatch covers are one of the most damaged elements of the load-bearing structures of open wagons (Fig. 1). This is due to their significant load in operation, as elements that form the floor of open wagons.

A frequent cause of damage to manhole covers is loading and unloading operations on open wagons in seaports and private enterprises (Fig. 2). At the same time, as the result of the shock load of the unloading means, damage to hatch covers such as deformations, cracks, fastening violations, etc. may occur.

It is necessary to implement measures aimed at improving their strength indicators during operational modes to ensure the strength of hatch covers of open wagons.

Many scientific publications are devoted to the research of the load of manhole covers in operation.

Thus, for example, the determination of the main strength indicators of the hatch cover of a universal open wagons, when the load falls on it, is carried out in the work [1]. The results of the study determined, that the typical design of the manhole cover does not meet the conditions of strength, as its damage occurs under the applied regime. However, the authors did not propose measures to improve the design of the hatch cover to ensure its durability in operation.

a)

b)

Fig. 1. Damage of hatch covers of open wagons:
a) deformation, b) damage of the cast

The features of the improvement of the cover of the half-car hatch are given in the work [2]. The authors suggested replacing the profile of the sheet, which has a stepped shape in the fastening part, with a more rational profile. The results of calculations on the strength of the manhole cover are given. At the same time, the proposed improvement does not contribute to reducing the dynamic load of the manhole cover during operational modes.

A description of the features of the resource tests of the welding seams of the hatch cover fastening elements in the open wagon with the purpose of determining their strength is carried out in the work [3]. It was established that the welding seams of the hinge holders and slats-holders of the hatch cover in the open wagon withstood the operational resource accepted for the hatch cover during the time from construction to major repair.

Factors affecting the durability of universal open wagons in operation were studied in [4]. To ensure sufficient strength and avoid the appearance of residual deformations, a new hatch cover design is proposed. A special feature of the manhole cover is the reinforced execution of the strapping, a smooth sheet of cladding and the installation of cast brackets. Also, the structure has additional braces to ensure sufficient strength. In addition, it is possible to modify the hatch cover with brackets from a corner profile.

a)

b)

Fig. 2. Unloading open wagons with grab buckets:
a) in seaport conditions, b) in the conditions of a private enterprise

However, the dynamic load of the manhole cover was not taken into account in the work carried out, as the mode of its greatest load in operation.

The substantiation of the use of polymer composite materials in railcar construction is carried out in [5]. At the same time, the proposed materials are supposed to be used for the flooring of the wagon floor. The results of experimental studies using the method of pressing the composite in the mold are highlighted. Along with this, the authors do not conduct a study of the introduction of advanced materials into the design of hatch covers of open wagons.

The paper [6] highlights the prospects for the use of polymer composite materials in railway vehicles design. The features of the use of such materials in relation to the hatch cover of the open wagon are given. The results of the calculation on the strength of the manhole cover are presented. However, the authors did not determine the dynamic load of the open wagon hatch cover, and when calculating it, the normative values of the loads were taken into account.

The results of the study of the loading of the hatch cover of the open wagon of the improved design are given in the publication [7]. It has been established that the proposed solutions for improving the hatch cover are appropriate. Along with this, the authors did not determine the dynamic load of the hatch cover.

The article [8] considered the features of the concept of modernization of freight wagons, including an open wagon type. The authors proposed measures to adapt the supporting structures of the wagons to the operating conditions of the load. The results of the calculation of the strength of the modernized load-bearing structures of the wagons are presented.

It is important to note that when designing the load-bearing structures of the wagons, measures are not provided to reduce their dynamic load during operation.

The results of determining the load bearing structures of railway vehicles during operational modes are highlighted in the works [9, 10]. At the same time, the authors proposed measures to reduce the load by introducing flexible connections in their construction. This implementation is effective, however the authors did not consider its application in relation to hatch covers of open wagons.

Features of the optimization of load-bearing structures of freight wagons are covered in the article [11]. The goal of the optimization was to reduce the material capacity of the supporting structure of the car by using aluminum panels in the body. The use of the proposed panels also helps to reduce the dynamic load of a wagon due to the presence of flexible connections in them. However, the authors did not investigate the issue of reducing the dynamic load of open wagon hatch covers.

The analysis of literature sources [1-11] allows us to conclude that the issue of reducing the dynamic load of the components of the load-bearing structures of wagons is quite relevant. However, due attention has not yet been paid to the improvement of hatch covers of open wagons to ensure their strength by reducing the dynamic load.

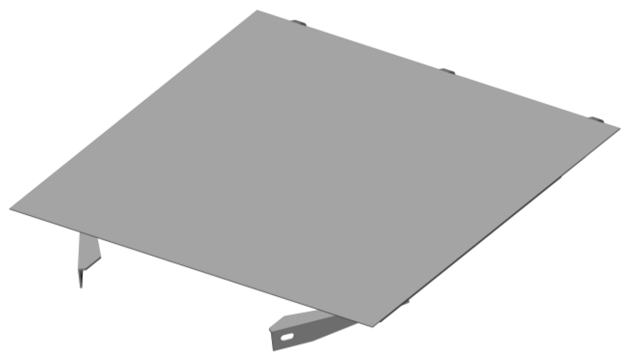
In this regard, the purpose of the article is to highlight the results of determining the dynamic load of the hatch cover of the open wagon of the improved design during operational modes. This will contribute to the reduction of damage to manhole covers during operation and the cost of maintaining open wagons. To achieve this goal, the following tasks are defined:

- determine the dynamic load of the improved design of the open wagon hatch cover,
- determine the dynamic load of an open wagon equipped with improved manhole covers.

2 METHODOLOGY

One of the most damaged components of the manhole cover is its fabric. To ensure the strength of the fabric, it is proposed to improve the hatch cover.

a)



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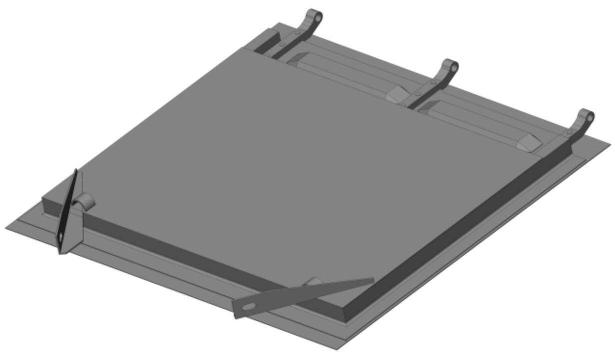

Fig. 3. Manhole cover: a) top view, b) bottom view

At the same time, it is assumed that the canvas is formed by the upper and lower sheets, between which there is an energy-absorbing material with viscous properties (Fig. 3). The thickness of the canvas is about 3 mm. Aluminum foam was considered as an energy-absorbing material.

At the first initial stage of the research, the dynamic loading of the manhole cover when a load weighing 150 kg falls on it was determined in accordance with [12]. The calculation scheme of the hatch cover is shown in Fig. 4. The calculation was carried out in a flat coordinate system. It is taken into account that the cover of the hatch tightly fits around the perimeter to the components of the supporting structure of the open wagon.

The impact of the hatch cover comes after its center and is absolutely hard.

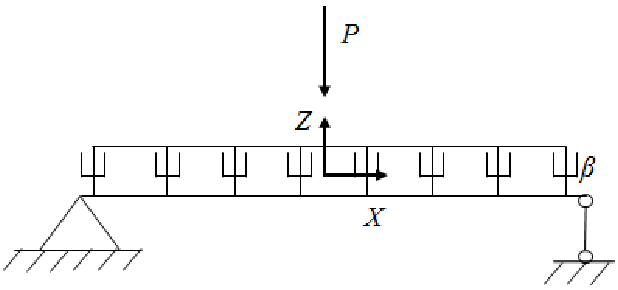

Fig. 4. A calculation diagram of the hatch cover when it is subjected to the shock load

The mathematical model of the dynamic load of the manhole cover looks like this:

$$M_K \cdot \ddot{z} + C \cdot z = P - \beta \cdot \dot{z}, \qquad (1)$$

where M_K - hatch cover mass,

C - hatch cover stiffness,

P - impact force acting on the hatch cover,

β - coefficient of viscous resistance of the energy-absorbing material

$\ddot{z}, \dot{z}, z$ - the generalized acceleration, speed and displacement of the hatch cover under the impact load on it, respectively,

It is taken into account that the origin of the coordinate system is located in the center of mass of the hatch cover. The input parameters to the mathematical model are the characteristics of the hatch cover, as well as the impact force.

The mathematical model was solved in the *MathCad* software [13, 14]. At the same time, the *Runge-Kutta method* was used [15, 16]. It is assumed that the initial velocities and displacements are zero.

In connection with the fact that the improvement of the manhole cover helps to reduce its mass by 10.6 % compared to the typical design, the main indicators of the dynamics of an open wagon equipped with improved manhole covers were determined. The open wagon model 12-757 was chosen as the prototype wagon.

It is taken into account that the open wagon moves in an empty state along a rail unevenness that has joints [16]. At the same time, the track has elastic-viscous properties.

The wagon is considered as a system consisting of three elements - a body and two bogies. It is taken into account that each component of the oscillating system has two degrees of freedom relative to the vertical axis, i.e. bouncing and galloping oscillations are considered.

The calculation scheme of the open wagon is shown in Fig. 5. The origin of the coordinate system is located at the center of mass of the open wagon. The input parameters to the mathematical model are the technical characteristics of the open wagon, as well as the rail unevenness.

The system equations of motion (2) of the open wagon in the vertical plane have the following form:

$$\begin{cases} M_1 \cdot \frac{d^2}{dt^2} q_1 + C_{1,1} \cdot q_1 + C_{1,3} \cdot q_3 + C_{1,5} \cdot q_5 = \\ = -F_{FR} \cdot \left(sign\left(\frac{d}{dt}\delta_1\right) + sign\left(\frac{d}{dt}\delta_2\right)\right), \\ M_2 \cdot \frac{d^2}{dt^2} q_2 + C_{2,2} \cdot q_2 + C_{2,3} \cdot q_3 + C_{2,5} \cdot q_5 = \\ = F_{FR} \cdot l \cdot \left(sign\left(\frac{d}{dt}\delta_1\right) + sign\left(\frac{d}{dt}\delta_2\right)\right), \\ M_3 \cdot \frac{d^2}{dt^2} q_3 + C_{3,1} \cdot q_1 + C_{3,2} \cdot q_2 + C_{3,3} \cdot q_3 + \\ + B_{3,3} \cdot \frac{d}{dt} q_3 = F_{FR} \cdot sign\left(\frac{d}{dt}\delta_1\right) + \\ + k_1 (\eta_1 + \eta_2) + \beta_1 \left(\frac{d}{dt}\eta_1 + \frac{d}{dt}\eta_2\right), \\ M_4 \cdot \frac{d^2}{dt^2} q_4 + C_{4,4} \cdot q_4 + B_{4,4} \cdot \frac{d}{dt} q_4 = \\ = -k_1 (\eta_1 - \eta_2) - \beta_1 \cdot a \cdot \left(\frac{d}{dt}\eta_1 - \frac{d}{dt}\eta_2\right), \\ M_5 \cdot \frac{d^2}{dt^2} q_5 + C_{5,1} \cdot q_1 + C_{5,2} \cdot q_2 + C_{5,5} \cdot q_5 + \\ + B_{5,5} \cdot \frac{d}{dt} q_5 = F_{FR} \cdot sign\left(\frac{d}{dt}\delta_2\right) + k_1 (\eta_3 + \eta_4) + \\ + \beta_1 \left(\frac{d}{dt}\eta_3 + \frac{d}{dt}\eta_4\right), \\ M_6 \cdot \frac{d^2}{dt^2} q_6 + C_{6,6} \cdot q_6 + B_{6,6} \cdot \frac{d}{dt} q_6 = \\ = -k_1 \cdot a \cdot (\eta_3 - \eta_4) - \beta_1 \cdot a \cdot \left(\frac{d}{dt}\eta_3 - \frac{d}{dt}\eta_4\right), \end{cases} \qquad (2)$$

where M_1, M_2 corresponds to the mass and moment of inertia of the supporting structure of the open wagon during jumping and galloping oscillations,

M_3, M_4 - mass and moment of inertia of the first cart in the course of its movement,

M_5, M_6 - mass and moment of inertia of the second cart in the course of its movement,

C_{ij} - characteristic of the elasticity of the elements of the oscillating system,

B_{ij} - scattering function,

a - half of the cart base,

q_i - generalized coordinates corresponding to bouncing and galloping oscillations,

k_b - stiffness of spring suspension system,

β_i - damping coefficient,

F_{FR} - frictional force in the spring assembly.

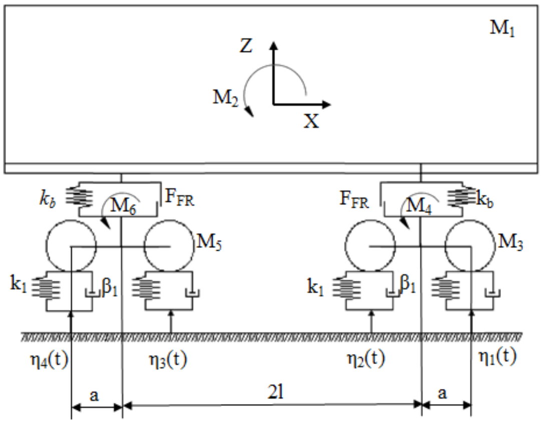

Fig. 5. A calculation scheme of an open wagon

The solution of the system of differential equations (2) was carried out in the *MathCad* software complex using the *Runge-Kutta method* under initial conditions close to zero.

3 RESULTS

Based on the calculations of the dynamic load of the hatch cover when a load weighing 150 kg falls on it, it was established that the acceleration acting on it is of 6.3 $m{\cdot}s^{-2}$ (Fig. 6).

At the same time, it is important to say that the use of energy-absorbing material helps reduce the load on the hatch cover by 21 % compared to a typical design.

The results of the calculations of the main indicators of the dynamics of an open wagon equipped with an improved design of hatch covers are shown in Fig. 7 to Fig. 9.

The maximum accelerations acting in the center of mass of the supporting structure of the one wagon amounted to the value of 4.7 $m{\cdot}s^{-2}$. The acceleration of the supporting structure in the zones of support on the trolleys is equal to 6.0 $m{\cdot}s^{-2}$. The coefficient of vertical dynamics is equal to 0.63.

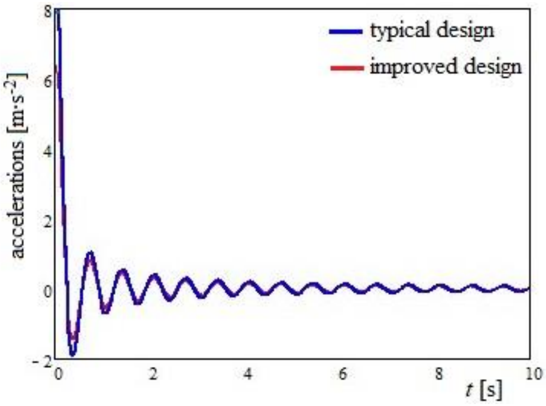

Fig. 6. Accelerations acting on the hatch cover

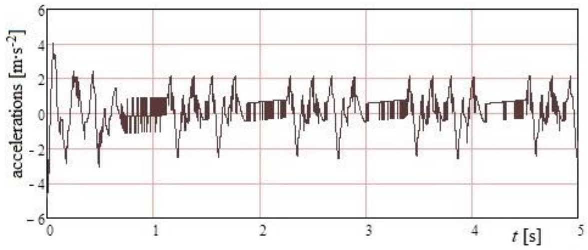

Fig. 7. Accelerations of the supporting structure of the open wagon in the center of mass

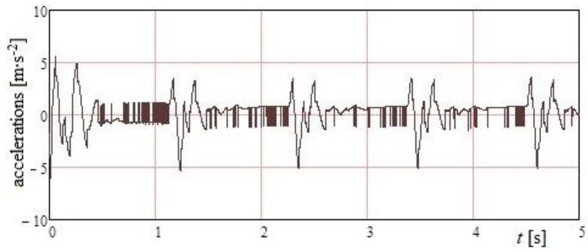

Fig. 8. Accelerations of the bearing structure of the open wagon in the areas of support on the carts

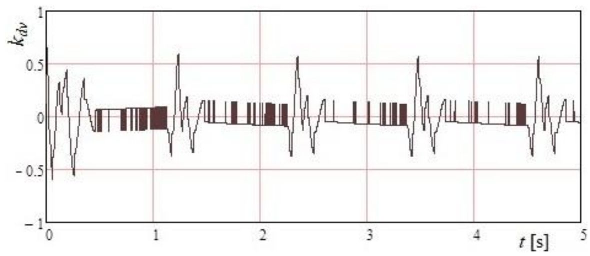

Fig. 9. The coefficient of vertical dynamics of the open wagon

Therefore, the indicators of the dynamics of the open wagon are within the permissible limits and the course of movement in accordance with the regulatory documents is assessed as "*excellent*" [12]. It should be said that the obtained dynamics indicators slightly exceed those for the prototype wagon, since the structure has a smaller container. At the same time, it becomes possible to increase the carrying capacity of the wagon by the size of the reduced container, which will contribute to the increase in the volume of cargo transportation.

CONCLUSIONS

The dynamic load capacity of the improved design of the open wagon hatch cover was determined. The case of a load weighing 150 kg falling on it is taken into account. At the same time, the acceleration acting on the improved hatch cover was 6.0 $m \cdot s^{-2}$. Therefore, the use of energy-absorbing material helps reduce the load on the hatch cover by 21 % compared to a typical design.

The dynamic load capacity of an open wagon equipped with improved manhole covers was determined. The maximum accelerations acting in the center of mass of the supporting structure of the open wagon amounted to 4.7 accelerations [$m \cdot s^{-2}$]. The coefficient of vertical dynamics is equal to the value of 0.63. Therefore, the dynamics indicators of the open wagon are within the permissible limits, and the course of movement is assessed as "*excellent*" in accordance with the regulatory documents.

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REFERENCES

[1] PUTYATO, A. V. (2011): *Modeling the stress-strain state of an open wagon hatch cover when pieces of cargo fall.* In: Mechanics. Scientific research and educational and methodological developments (In Russian), 5, pp. 113–122.

[2] MYAMLIN, S. V. - BARANOVSKYI, D. N. - KEBAL, I. Y. (2015): *Hatch cover of a universal open wagon*. In: Bulletin of scientific works of the Bryansk branch of MIIT (In Rusian), 7, pp. 45–48.

[3] BORODAI, O. O. - PASKO, V. V. - STRYNZHA, A. M. - KHUDIENKO, V. A. (2017): *Carrying out resource tests of welding seams of hatch cover fastening elements in an open wagon in order to determine their strength*. In: Collection of scientific works of SE "UkrNDIV". Rail rolling stock (In Russian), 14, pp. 20–24.

[4] VIZNYAK, R. I. - CHEPURCHENKO, I. V. - YATSENKO, A. O. (2016): *Peculiarities of determining the operating loads of the open wagon body and ways of improving its design in order to ensure strength and preservation.* In: Collection of scientific works of the Ukrainian State University of Railway Transport (In Russian), 159, pp. 91 – 97.

[5] ZAYNITDINOVA, O. I. - RAHIMOV, R. V. - WAAIL, M. L. - RUZMETOV, Y. O. (2020). *Development of new polymer composite materials for the flooring of rail carriage*. In: International Journal of Engineering and Technology, 9(2), pp. 378–381.

[6] KARAKAYEV, A. K. - ZARIPOV, R. Y. (2016): *Composite materials in freight car construction*. In: Science and technology of Kazakhstan (In Russian), 1-2, pp. 39–47.

[7] FOMIN, O. - GERLICI, J. - LOVSKA, A. - GORBUNOV, M. - KRAVCHENKO, K. - PROKOPENKO, P. - HAUSER, V. (2019): *The improved hatch cover construction for universal open box-type wagon from the strength and durability point of view*. In: Manufacturing Technology, 19, 2, pp. 216–221.

[8] PŁACZEK, M. - WRÓBEL, A. - BUCHACZ, A. (2016): *A concept of technology for freight wagons modernization.* In: IOP Conference Series: Materials Science and Engineering, 161, pp. 1–12.

[9] VATULIA, G. - GERLICI, J. - LOVSKA, A. - KRASNOKUTSKYI, Y. (2023): *Analýza pozdĺžneho zaťaženia kontajnera so stenami vyrobenými zo sendvičových panelov.* In: Technológ, 15, 1, pp. 80–83.

[10] VATULIA, G. - GERLICI, J. - LOVSKA, A. (2023): *Study of the loading of the body of an open wagon with a floor made of sandwich panels*. In: Railway transport of Ukraine (In Ukrainian), 2, pp. 33–41.

[11] LEE, H.-A. - JUNG, S.-B. - JANG, H.-H. - SHIN, D.-H. - LEE, J.-U. - KIM, K.-W. - PARK, G.-J. (2016): *Structural-optimization-based design process for the body of a railway vehicle made from extruded aluminum panels*. In: Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, 230, 4, pp. 1283–1296.

[12] DSTU 7598:2014. *Vantage carriages. For the first time to rebuild and design new and modernized cars with a gauge of 1520 mm* (non-self-propelled). Kiev, 2015. 250 p.

[13] ZADACHIN, V. M. - KONIUSHENKO, I. H. (2014): *Numerical methods: tutorial* (in Ukrainian). Kharkov, 180 p.

[14] HOI, T. P. - MAKHNEI, O. V. (2012): *Differential equations: a study* guide (In Ukrainian). Ivano-Frankivsk, 352 p.

[15] LOVSKAYA, A. (2014): *Assessment of dynamic efforts to bodies of wagons at transportation with railway ferries.* In: Eastern-European Journal of Enterprise Technologies, 3, 4, pp. 36-41.

[16] DOMIN, Y. V. - CHERNIAK, G. Y. (2003): *Fundamentals of wagon dynamics: a study guide* (In Ukrainian). Kyiv: KUETT, 269 p.