Наведені результати моделювання динамічної навантаженості вагона-платформи з контейнерами, розміщеними на ньому при маневровому співударянні. Отримано величини прискорень, які діють на вагон-платформу та контейнери при відсутності переміщень фітингів відносно фітингових упорів, а також при їх можливих переміщеннях. Проведені дослідження сприятимуть створенню вагонів-платформ нового покоління з підвищеними техніко-економічними показниками

Ключові слова: вагон-платформа, несуча конструкція, контейнер, динаміка, моделювання, маневрове співударяння, навантаження конструкції, прискорення, комбіновані перевезення

Приведены результаты моделирования динамической нагруженности вагона-платформы с контейнерами, размещенными на нем при маневровом соударении. Получены величины ускорений, которые действуют на вагон-платформу и контейнеры при отсутствии перемещений фитингов относительно фитинговых упоров, а также при их возможных перемещениях. Проведенные исследования способствуют созданию вагонов-платформ нового поколения с повышенными технико-экономическими показателями

Ключевые слова: вагон-платформа, несущая конструкция, контейнер, динамика, моделирование, маневровое соударение, нагружение конструкции, ускорение, комбинированные перевозки

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THE STUDY OF DYNAMIC LOAD ON A WAGON-PLATFORM AT A SHUNTING COLLISION

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1. Introduction

Increasing volumes of cargo transportation through the territory of Ukraine, which is a key element of international transport corridors led to the creation and operation of combined transport systems.

To ensure the efficiency of the transportation process, it is necessary to develop and implement wagon-platforms of a new generation with improved technical and economic indicators.

Therefore it is important to consider specified values of loads, which can act on their supporting structures, on the stage of design of such wagons.

The largest values of operating loads acting on the wagons are observed at shunting collisions. To ensure the safety of the wagon-platform with containers placed on, it is necessary to research into dynamic loads acting on them at shunting collisions.

2. Analysis of scientific literature and the problem statement

The problem of improving combined transportations, in particular, container transportation, is tackled in the paper [1], analysis of peculiarities of the container mounting on wagons-platforms is performed. To improve the technical-economic indicators of wagons at transportation of containers of different size, a justification of improvement of constructions of long wheelbase wagons-platforms and wagon-platforms articulated for this type of transportation, was conducted.

Research into the strength of a wagon-platform of a new generation with swivel frame for transportation of containers and their loading-unloading by ACTS system is shown in [2]. Calculation of the strength of bearing structure of the wagon-platform with a load of containers placed on it was carried out by the finite element method in the Nastran software medium. But the question of studying the dynamics of the wagon-platform with containers is not paid attention to in these papers.

Determining parameters of the strength of a wagon-platform for transportation of containers and their loading/unloading by the ACTS system is conducted in [3]. The calculation of the strength is carried out in a static environment in the Nastran software medium. Numerical values of estimated loads acting on a wagon-platform are adopted in accordance to the standards of PNEN12663 and BN-77/3532-40. The strength of a wagon-platform was determined considering the four schemes of loads on its construction:

– compressive efforts of 2 MN by the axes of buffers;

– compressive efforts of 0.4 MN, applied by the diagonal at a buffers level;

– stretching force of 1 MN by the axes of buffers;

– vertical inertial load acting on the bearing structure of the wagon-platform taking into account the acceleration of 1,95 g.

In calculating of the strength of a wagon-platform, the dynamic loads caused by possible movements of containers relative to the frame. are not taken into account.

The prospects of operation of a wagon-platform of a new generation for the transportation of supersize containers are given in [4]. At manufacturing the model, the task was given to reduce the air resistance while its motion, which was solved by optimizing the placement of containers along the length of the wagon-platform. The model of the wagon-platform was made in Germany and passed experimental research in the UK.

The expediency of operation of wagons-platforms for transportation of containers, including containers – tanks, made by "Transmash" factory (Russia) is specified in [5]. The structure of the wagon-platform has a loading capacity of 73 tons and can carry out container transportation of the dimensions 1CC, 1C and 1CX.

Structural features of a wagon-platform for intermodal transportation are given in [6]. General requirements of organization of technology of intermodal transportation are described and their advantages specified. At the same time these studies do not specify taking into account in the design stage of the dynamic loads on the wagons-platforms, acting on them when shunting collisions and moving of container fittings relative to the fitting stops of a wagon-platform.

The study of the dynamics of a railway wagon with an open bootable platform is given in [7]. Calculation was conducted in the MSC Adams software medium. In this case, the study of the stability against overturning of a wagon was carried out at its incorporating in the curve with the radius of 250 meters taking into account different motion velocity.

Experimental research of a prototype model of a pivotally connected wagon-platform of model 13–1839 for the transportation of supersize containers is given in [8]. The peculiarity of the design of a wagon-platform is the use of two sections with a total bootable length of 80 feet installed on two trucks. In carrying out the testing of a wagon-platform prototype the following was held: static strength tests, collision tests, stationary brake test, test of passing of small radius curves and testing for the passage of sorting humps.

It is important to note that this work does not pay attention to the research into the wagon-platform dynamics with containers during shunting collisions, taking into account possible movements of containers relative to fitting stops.

3. The purpose and objectives of the study

The aim of the work is to study dynamic loads of a wagon-platform at shunting collision.

To achieve this goal, the following problems were identified:

– mathematical modeling of dynamic loads of a wagon-platform with containers placed on it at shunting collisions;

– computer simulation of dynamic loads of a wagon-platform with containers placed on it at shunting collisions.

4. Modeling of dynamic loads of a wagon-platform with containers placed on it at shunting collisions

4. 1. Mathematical modeling

To study the dynamic loads acting on a wagon-platform with containers placed on it at shunting collision, we applied a mathematical model which is given in [9], where the acceleration of the tank-container and wagon-platform with a longitudinal force of the hammer car acting on it is identified. The value of longitudinal force was adopted in the range of 2200–2800 kN. The link between the frame of the wagon-platform and container-tank fittings was imitated as spring-dissipative.

It is important to note that the maximal value of the longitudinal impact force that can act on the wagon-platform with a load placed on it, including containers, at the shunting collision amounts to 3.5 MN [10]. Therefore, in order to obtain the updated value of acceleration acting on the wagon-platform and containers in operation, it is necessary to conduct additional studies.

The scheme of the longitudinal force acting on the wagon-platform with containers placed on it taking into account the friction force between the fittings and the fitting stops are shown in Fig. 1.

The studies were conducted concerning the wagon-platform, model 13–4085, constructed by VAT "Dniprovagonmash" (Ukraine) and the container of a standard size according to ISO–1CC.

The container was considered as a fixed mass relative to the frame of the wagon-platform that has a compliance in a longitudinal direction due to the presence of gaps between the fitting stops of the wagon-platform and the container fittings. That is, the container has its own degree of freedom until the stop of the fitting by the fitting stop, after which the container repeats the trajectory of the wagon-platform move. The link between the frame of the wagon-platform and the container fittings was imitated as frictional.

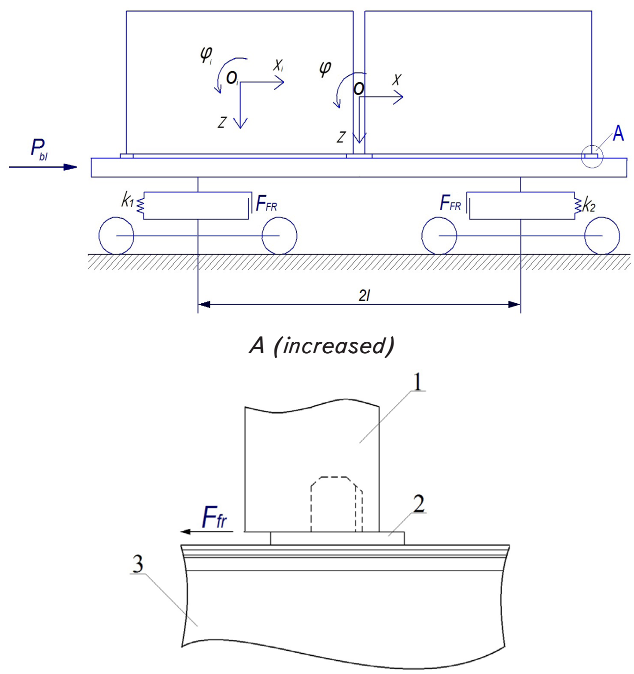


Fig. 1. Scheme of the longitudinal force acting on the wagon-platform with containers placed on it: 1 – fitting; 2 – fitting stop; 3 – longitudinal beam of the wagon-platform

$$M'_{PL} \cdot \ddot{x}_{PL} + M_{PL} \cdot h \cdot \ddot{\varphi}_{PL} = S_a - \sum_{i=1}^{2} F_{FR}^{K} + F_i, \quad (1)$$

$$I_{PL} \cdot \ddot{\varphi}_{PL} + M_{PL} \cdot h \cdot \ddot{x}_{PL} - g \cdot \varphi_{PL} \cdot M_{PL} \cdot h = = l \cdot F_{FR} \left(\operatorname{sign}\dot{\Delta}_1 - \operatorname{sign}\dot{\Delta}_2\right) + l\left(k_1 \cdot \Delta_1 - k_2 \cdot \dot{\Delta}_2\right), \quad (2)$$

$$M_{PL} \cdot \ddot{z}_{PL} = k_1 \cdot \Delta_1 + k_2 \cdot \Delta_2 - F_{FR}\left(\operatorname{sign}\dot{\Delta}_1 - \operatorname{sign}\dot{\Delta}_2\right), \quad (3)$$

$$m_i \cdot (\ddot{x}_{PL} - \ddot{x}_i) + (m_i \cdot z_{ci}) \cdot (\ddot{\phi}_{PL} - \ddot{\phi}_i) = F_i - F^{K}_{FR}, \quad (4)$$

$$I_i \cdot (\ddot{\phi}_{PL} - \ddot{\phi}_i) + (m_i \cdot z_{ci}) \cdot (\ddot{x}_{PL} - \ddot{x}_i) - $$
$$-g \cdot (m_i \cdot z_{ci}) \cdot (\phi_{PL} - \phi_i) = 0, \quad (5)$$

$$m_i \cdot \ddot{z}_{PL} = 0, \quad (6)$$

where

$$M'_{PL} = M_{PL} + 2 \cdot m_{truck} + \frac{n \cdot I}{r^2};\ \Delta_1 = z_{PL} - l \cdot \phi_{PL};\ \Delta_2 = z_{PL} + l \cdot \phi_{PL}.$$

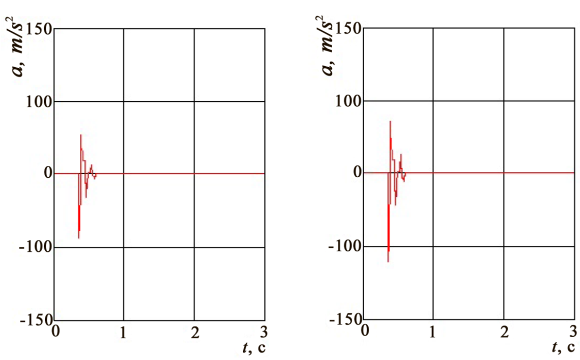
M_{PL} is the bearing structure weight of the wagon-platform; I_{PL} is the inertia moment of the wagon-platform relative to longitudinal axis; S_a is the value of the longitudinal impact of force against automatic coupling; F^{K}_{FR} is the friction that occurs between the fitting stop and the fitting at longitudinal movement of the container; m_T is the mass of the truck; I is the inertia moment of the wheelset; r is the radius of the average worn tires; n is the number of axis of truck; l is the half of spacing of wagon-platform; F_{FR} is the absolute value of dry friction forces in the spring set; k_1, k_2 are the stiffness of the springs of the spring suspension of the trucks of wagon-platform; m_i is the mass of container; z_{ci} is the height of center of gravity of the container; I_i is the inertia moment of i-th container; x_{PL}, ϕ_{PL}, z_{PL} are the coordinates that accordingly refer to longitudinal, angular, around a transverse axis, and a vertical movement of the wagon-platform; x_i, ϕ_i are the coordinates that accordingly refer to longitudinal, angular, around a transverse axis, movement of the container.

In this case, $x_i < 30$ mm [9, 11], if $x_i \geq 30$ mm, then $x_i = x$.

The vertical movement of the container relative to the frame of the wagon-platform was not considered. The value of the force of longitudinal impact acting on the wagon-platform is adopted as 3.5 MN.

The solution of differential equations is performed using the Runge-Kutta method in the MathCad software medium [12, 13].

The research results made it possible to conclude that with the gaps available between the fitting stops of the wagon-platform and fittings of the container, the acceleration acting on their supporting structures is respectively about 90 m/s² and 110 m/s² (Fig. 2, *a*, *b*).



a *b*

Fig. 2. Accelerations acting on the wagon-platform and on the containers, placed on it at shunting collision, taking into account the available gaps between the fitting stops and fittings: *a* — wagon-platform; *b* — container

To determine the acceleration acting on the wagon-platform with containers placed on it at shunting collision in the case of absence of gaps between the fitting stops and fittings, the above attached mathematical model reduced to the following:

$$M'_{PL} \cdot \ddot{x}_{PL} + M_{PL} \cdot h \cdot \ddot{\phi}_{PL} = S_a, \quad (7)$$

$$I_{PL} \cdot \ddot{\phi}_{PL} + M_{PL} \cdot h \cdot \ddot{x}_{PL} - g \cdot \phi_{PL} \cdot M_{PL} \cdot h =$$
$$= l \cdot F_{FR} \left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2 \right) + l \left(k_1 \cdot \Delta_1 - k_2 \cdot \dot{\Delta}_2 \right), \quad (8)$$

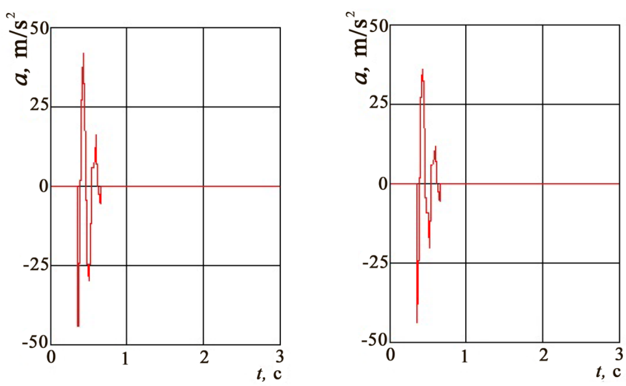
$$M_{PL} \cdot \ddot{z}_{PL} = k_1 \cdot \Delta_1 + k_2 \cdot \Delta_2 - F_{FR} \left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2 \right), \quad (9)$$

$$m_i \cdot \ddot{x}_{PL} + (m_i \cdot z_{ci}) \cdot \ddot{\phi}_{PL} = 0, \quad (10)$$

$$I_i \cdot \ddot{\phi}_{PL} + (m_i \cdot z_{ci}) \cdot \ddot{x}_{PL} - g \cdot (m_i \cdot z_{ci}) \cdot \phi_{PL} = 0, \quad (11)$$

$$m_i \cdot \ddot{z}_{PL} = 0, \quad (12)$$

it means it cancels the friction force between the fitting stops and fittings, and inertial forces that arise during the movement of the container relative to the frame of the wagon-platform. The calculation results are shown in Fig. 3, *a, b*.



a *b*

Fig. 3. Acceleration acting on the wagon-platform and containers placed on it at shunting collision in the case of the absence of gaps between the fitting stops and the fittings: *a* — wagon-platform; *b* — container

It is established that the maximal value of acceleration acting on the wagon-platform and the containers placed on it at shunting collision is about 50 m/s².

4. 2. Computer simulation

For the purpose of testing the obtained values of acceleration, a computer simulation was performed of the dynamics of the wagon-platform with containers placed on it under the action of longitudinal force of 3.5 MN on the back gauge of automatic coupling in the CosmosWorks software medium, version 2015 [14]. The spatial model of the bearing structure of the wagon-platform with containers is shown in Fig. 4.

The calculation is made using a finite element method.

In building up a finite-element model, spatial isoparametric tetrahedrons are used. The number of grid nodes reached 669705, the elements – 2010206. The maximal size of an element is 50 mm, the minimal – 10 mm. The minimal number of elements in the circle was 9, the ratio of the size increase of elements in a grid – 1.7. The maximal ratio of sides is 16258, the percentage of elements with a ratio of sides less than 3–47.6, larger than 10–20.4.

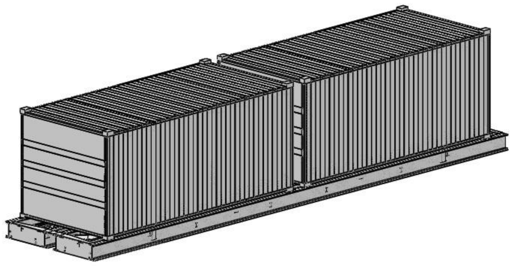
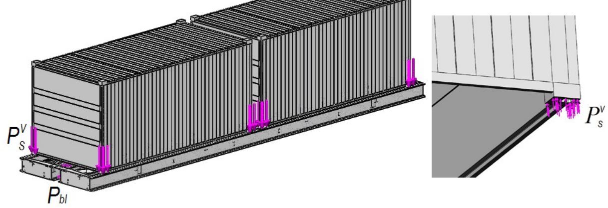


Fig. 4. Spatial model of the wagon-platform with containers placed on it

When drawing up a model of strength, it was taken into account that besides the longitudinal force P_{bl}, acting on the wagon-platform, vertical forces act as well, in the areas of the container leaning on the fittings stops (Fig. 5). It was taken into account that the vertical reaction acts on the container in the zone of leaning of the fitting on the fitting stop P_s^v. When constructing a computer model, the action of the cargo, placed in a container, on its walls, is not taken into account. For consideration of friction forces in the areas of interaction between the wagon-platform with containers, a modal damping factor is used.

We used the steel of grade 09G2S with a value of tensile strength $\sigma_B = 490$ MPa and yield limits $\sigma_T = 345$ MPa as the material for the bearing structure of the wagon-platform and containers.

The results of computer simulation are shown in Fig. 6, *a, b*.



a *b*

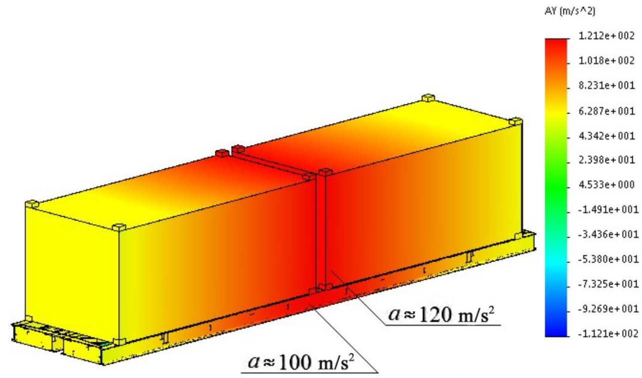
Fig. 5. A model of strength of a wagon-platform with containers placed on it under the action of longitudinal force on the back gauge of automatic coupling: a is the general view; b is the action of vertical reaction on the container fitting from the bearing surface of the fitting stop

By these studies we can conclude that the maximal acceleration, acting on the wagon-platform, having the gaps of 30 mm between the fitting stops and the fittings, is about 100 m/s², with no gaps it is about 60 m/s², for the container the acceleration values amounted to about 120 m/s² and 50 m/s².

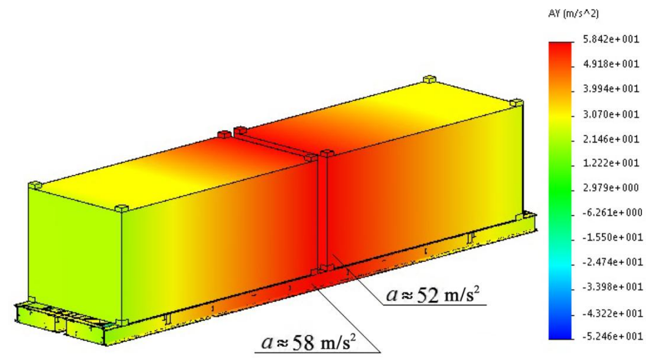
In order to test the adequacy of the developed model, the Fischer criterion test was applied.

It was established that the considered model is linear, and characterizes the change in acceleration of the wagon-platform with containers placed on it from the longitudinal force acting on the back gauge of the automatic coupling. The number of degrees of freedom at $N = 5$ amounts to $f_1 = 3$.

While determining the adequacy of the model, taking into account the gaps between the fitting stops and the fittings, it was established that at the variable of precision $S_{rv}^2 = 2{,}5$ and the variable of adequacy $S_{ad}^2 = 6{,}67$, the actual value of Fischer criterion is $F_P = 2{,}67$, that is less than the tabular value of $F_t = 5{,}41$. So the hypothesis of the adequacy of the model is not disputed. Approximation error amounted to 4.27 %.



a



b

Fig. 6. Acceleration of the wagon-platform with containers placed on it with the action of the longitudinal forces acting on the back gauge of automatic coupling: *a* – in case of the gaps between the fitting stops and the fittings; *b* – with no gaps between the fitting stops and the fittings

With no gaps between the fitting stops and the fittings, it was established that at the variable of precision $S_{rv}^2 = 2{,}5$ and the variable of adequacy $S_{ad}^2 = 3{,}33$, the actual value of Fischer criterion is $F_P = 0{,}24$, that is less than the tabular value of $F_t = 1{,}33$. So the hypothesis of the adequacy of the model is not disputed. Approximation error amounted to 7.77 %.

The conducted studies have shown that the acceleration acting on the wagon-platform and containers at shunting collision, taking into account the possible movements of the fittings relative to the fitting stops, exceed considerably standard values [10]. Therefore, it is necessary to clarify the regulations considering adding the maximal acceleration values that can act on the wagon-platform and containers atn shunting collision, and taking into account the specified values of dynamic loads in the stage of their design under conditions of wagon-building enterprises.

6. Conclusions

1. The conducted studies of the dynamics of the wagon-platform with containers placed on it enabled obtaining the accelerations that occur at shunting collision taking into account the container movement relative to the frame of the wagon-platform. Maximal acceleration acting on the wagon-platform and containers, having gaps between the fitting stops and fittings, are, respectively, about 100 m/s² and 120 m/s², with no gaps, respectively, about 60 m/s² and 50 m/s².

It was established that in the absence of gaps between the fitting stops and fittings we can reduce the value of acceleration acting on the wagon-platform and containers placed on it, respectively, by 40 % and 60 %.

2. To ensure the strength of wagon-platforms and containers at shunting collisions, it is necessary to limit the movement of the containers relative to the frame of the wagon-platform, which will enable to reduce the value of dynamic loads acting on them.

3. When designing the wagon-platforms of new generation for transportation of removable transport units and containers, specified acceleration values must be taken into account that can act in operation, which will ensure the strength of the bearing structures at shunting collisions.

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