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Creating mathematical model of the bearing structure dynamic load of the flat wagon from round pipes in the main operational modes

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Abstract

At the present stage of development of the railway industry it is necessary to introduce new innovative solutions during the design of the flat wagons of articulated type for their structural design. To reduce the material consumption of flat wagons, in article was proposed to produce bearing elements of their structures from pipes of a circular cross section. Flat wagon of articulated type was designed on the basis of the developed construction in order to improve the operational efficiency of the wagon. The innovation design of a flat wagon of articulated type from round pipes are presented. The mathematical model of the bearing structure dynamic load of the flat wagon from round pipes in the main operational modes are made. Accelerations which act on the bearing structure of articulated flat wagon under I rated conditions (tension – jump) are presented.

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Keywords: flat wagon; round pipes; longitudinal force; acceleration.

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1. Introduction

The increase in the volume of freight traffic through international transport corridors necessitates the commissioning of container transportations. Transportation of containers in relation to main-line railways is carried out on flat wagons Štastniak (2015), Štastniak (2015). In recent years, flat wagons of articulated type have found use for increasing the efficiency of container transportation (Fig. 1). The peculiarity of such wagons is that their bearing structure consists of two sections, which support on three bogies.

a

b

Fig. 1. Flat wagons of articulated type: (a) Sggmrss_90; (b) model 13-1839.

At the present stage of development of the railway industry it is necessary to introduce new innovative solutions during the design of the flat wagons of articulated type for their structural design. Such a solution will reduce the materials consumption of the flat wagons bearing structures and accordingly the costs for their manufacturing providing the strength condition and operational reliability.

When designing modern structures of flat wagons of articulated type it is important to take into account the specified values of loads that can act on them during operation. The existing regulatory framework does not fully cover the peculiarities of bearing structures load of flat wagons of articulated type under main operating conditions. This causes the need for appropriate research in this field in order to develop recommendations for designing of modern structures of articulated flat wagons.

2. Analysis of recent research

The specific design features of the flat wagon for the intermodal transportations are considered in Nader et al. (2014). The general requirements for organizing the technology of intermodal transportations are described, and their advantages are determined.

An analysis of the design of a new-generation flat wagon is given in WBN Waggonbau Niesky GmbH (2016). The peculiarity of the flat wagon is the possibility of adjusting the useful length depending on the dimensions of the transported goods.

It is important to note that it was not given attention to the question of the dynamic load of bearing structures of wagons under operational modes in the considered works.

The research of the dynamic load of the bearing structure of the wagon body under operating conditions out in Fomin, Lovska (2020), Fomin et al. (2019), Fomin et al. (2019). The results of mathematical modelling are confirmed by computer modelling.

The issues of dynamic load and strength of articulated wagons are not considered in the work.

Modern requirements for railroad wagons systems are covered in Fomin et al. (2020). These requirements are proposed to be applied at the stage of manufacturing new constructions of wagons, as well as those are being modernized.

Requirements for the dynamic load of wagons of articulated structures are not highlighted in this work.

Flexible bodies' implementation into a rail vehicle multibody system considerably extends thepossibilities of computer simulations of rail vehicles running. In research Dižo et al. (2015) was presented inclusion of a flexible body into a multibody system of a rail vehicle bogie.

Determination of the modal properties belongs to the fundamental but very important step in the engineering design. Modal analyses of individual parts as well as substructures of rail vehicles is an inseparable part of the rail vehicles design process. In research Dižo et al. (2018) theoretical and practical consequences of obtained results from the modal analysis, i.e. eigenmodes and eigenfrequences of the analysed part of the bogie on its dynamic properties are presented.

Mathematical modelling of spatial variations of the "subframe – track" system is carried out in Myamlin et al. (2017). Calculation is made using the finite element method in the software environment Ansys.

The peculiarities of mathematical modelling of articulated wagons dynamics are not considered in the work.

Peculiarities of hot baking of materials under pressure with alternating current are given in Kondratiev A. V et al. (2019). It has been established that materials after this operation have higher hardness and some elasticity. The prospects of using this nanomaterial in wagon structures for reducing their dynamic load in operation are not highlighted in the work.

Determination of the dynamic load of wagons when transported on railroad ferries is carried out in Fomin et al. (2019). The obtained values of dynamic loads are taken into account when calculating the strength of bearing structures of wagons.

The research of dynamic load of articulated wagons is not carried out in the work.

Strength characterization of the flat wagon for the transportation of containers and their loading / unloading by the ACTS system is carried out in Krason (2014). In this case, the calculation of strength is carried out in statics in the software environment Nastran. Numerical values of the calculated loads acting on the flat wagon are taken in accordance with the norms PNEN12663 and BN – 77/3532 – 40.

The justification of the expediency of the flat wagons operation for transportation of containers, including tank containers made in "Transmash" plant (Russia), is indicated in Switching over to the home platform (2015). The construction of a flat wagon has a carrying capacity of 73 tons and is able to carry containers of dimension type 1CC, 1C, as well as 1CX.

However, the peculiarities of bearing structures load of flat wagons under operating conditions are not highlighted in the considered works.

3. The aim and objectives of the article

The aim of the article is to determine the dynamic loading of the flat wagon of articulated type made from round pipes. In order to achieve this aim, the following objectives are defined:

1. To create a design of a flat wagon of articulated type from round pipes.
2. To make a mathematical model of the bearing structure dynamic load of the flat wagon from round pipes in the main operational modes.

4. The main body of the article

To reduce the material consumption of flat wagons, it was proposed to produce bearing elements of their structures from pipes of a circular cross section Fomin et al. (2018). In this case, the improved bearing structure of the flat wagon has dead weight of 5% less than the prototype-wagon.

Flat wagon of articulated type was designed on the basis of the developed construction in order to improve the operational efficiency of the wagon (Fig. 2).

The provision of fitting stops is foreseen for the possibility of transportation of containers on a flat wagon.

There are folded fittings in the middle of the sections that allow transporting containers of different sizes on a flat wagon.

The mathematical model presented in Bogomaz et al. (2018) was used to research the dynamic load of a flat wagon of articulated type. In this case, this model was improved by taking into account the movements of the two sections of the flat wagon at operating load conditions in order to determine the acceleration of the bearing structure of the flat wagon. In addition, it was eliminated the elastic connections between the containers and the bearing structure of the flat wagon, due to the shorter length of the section, made on the basis of the flat wagon model 13-401 in comparison with the long flat wagon, the dynamics of which was researched in Bogomaz et al. (2018).

Universal container of dimension type 1CC has been chosen as a researched container model. The container is considered as an attached mass in relation to the frame of the flat wagon. That is, the container completely repeats the trajectory of moving of the flat wagon. The connection between the flat wagon frame and the container fittings was simulated as rigid.

The study of the movements of the flat wagon with containers was carried out in a longitudinal and vertical plane. Flat wagon with containers is considered as a flat analytical model Fomin et al. (2019).

When developing the mathematical model it is taken into account that each section of the flat wagon has its own degree of freedom, since the structural characteristics of the joining device allow them to move in space Boronenko, et al. (2013), Boronenko, et al. (2009).

The scheme of action of longitudinal force on a flat wagon of articulated type with containers placed on it in the absence of possible movements of fittings relative to fitting stops is shown on Fig. 3.

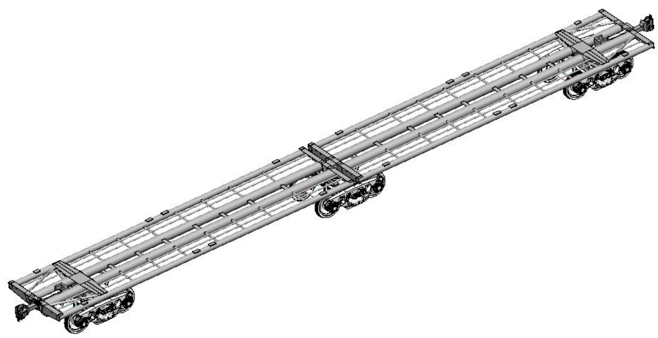

Fig. 2. Articulated flat wagon made from pipes of a circular cross section.

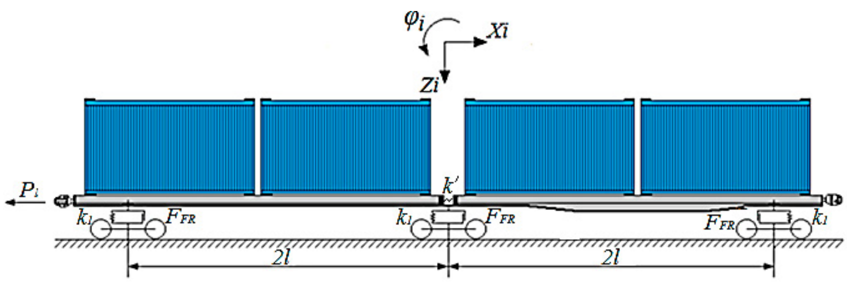

Fig. 3. The scheme of action of longitudinal force on a flat wagon of articulated type with containers placed.

$$M'_{FL_1} \cdot \ddot{x}_{FL_1} + M_{FL_1} \cdot h \cdot \ddot{\varphi}_{FL_1} + k'\left(x_{FL_1} - x_{FL_2}\right) = P_l, \tag{1}$$

$$I_{FL_1} \cdot \ddot{\varphi}_{FL_1} + M_{FL_1} \cdot h \cdot \ddot{x}_{FL_1} - g \cdot \varphi_{FL_1} \cdot M_{FL_1} \cdot h = l \cdot F_{FR}\left(sign\dot{\Delta}_1^{FL_1} - sign\dot{\Delta}_2^{FL_1}\right) + l\left(k_1 \cdot \dot{\Delta}_1^{FL_1} - k_2 \cdot \dot{\Delta}_2^{FL_1}\right), \tag{2}$$

$$M_{FL_1} \cdot \ddot{z}_{FL_1} = k_1 \cdot \Delta_1^{FL_1} + k_2 \cdot \Delta_2^{FL_1} - F_{FR}\left(sign\dot{\Delta}_1^{FL_1} - sign\dot{\Delta}_2^{FL_1}\right), \tag{3}$$

$$m_i \cdot \ddot{x}_{FL_1} + \left(m_i \cdot z_{ci}\right) \cdot \ddot{\varphi}_{FL_1} = 0, \tag{4}$$

$$I_i \cdot \ddot{\varphi}_{FL_1} + \left(m_i \cdot z_{ci}\right) \cdot \ddot{x}_{FL_1} - g \cdot \left(m_i \cdot z_{ci}\right) \cdot \varphi_{FL_1} = 0, \tag{5}$$

$$m_i \cdot \ddot{z}_{FL_1} = 0 \tag{6}$$

$$M'_{FL_2} \cdot \ddot{x}_{ПЛ_2} + M_{FL2} \cdot h \cdot \ddot{\varphi}_{FL_2} - k'\left(x_{FL_1} - x_{FL_2}\right) = 0, \tag{7}$$

$$I_{FL_2} \cdot \ddot{\varphi}_{FL_2} + M_{FL_2} \cdot h \cdot \ddot{x}_{FL_2} - g \cdot \varphi_{FL_2} \cdot M_{FL2} \cdot h = l \cdot F_{FR}\left(sign\dot{\Delta}_1^{FL_2} - sign\dot{\Delta}_2^{FL_2}\right) + l\left(k_1 \cdot \dot{\Delta}_1^{FL_2} - k_2 \cdot \dot{\Delta}_2^{FL_2}\right), \tag{8}$$

$$M_{FL_2} \cdot \ddot{z}_{FL_2} = k_1 \cdot \Delta_1^{FL_2} + k_2 \cdot \Delta_2^{FL_2} - F_{FR}\left(sign\dot{\Delta}_1^{FL_2} - sign\dot{\Delta}_2^{FL_2}\right), \tag{9}$$

$$m_i \cdot \ddot{x}_{FL_2} + \left(m_i \cdot z_{ci}\right) \cdot \ddot{\varphi}_{FL_2} = 0, \tag{10}$$

$$I_i \cdot \ddot{\varphi}_{FL_2} + \left(m_i \cdot z_{ci}\right) \cdot \ddot{x}_{FL_2} - g \cdot \left(m_i \cdot z_{ci}\right) \cdot \varphi_{FL_2} = 0, \tag{11}$$

$$m_i \cdot \ddot{z}_{FL_2} = 0 \tag{12}$$

where

$$\Delta_1^i = z_{FL_i} - l \cdot \varphi_{FL_i};\ \ \Delta_2^i = z_{ПЛ_i} + l \cdot \varphi_{ПЛ_i} \tag{13}$$

M´FLi – gross weight of the i-th section of the flat wagon; MFLi – weight of the bearing structure of the i-th section of the flat wagon; IFLi – moment of inertia of the i-th section of the flat wagon; h – height of the center of gravity of the carrying structure of a flat wagon section; Pl – the magnitude of the longitudinal force acting on the automatic coupler; l – half of the basis of the flat wagon section; FFR – absolute value of dry friction force of in the coil spring group; Δ1i, Δ2i – deformation of spring suspension elastic elements; k´ – rigidity of connection between sections; k1, k2 – rigidity of springs of coil spring groups of flat wagon bogies (bogie model 18-100); mi – weight of the container; zci – height of the weight centre of the container; Ii – moment of inertia of the i-th container; xFLi, φFLi, zFLi – coordinates determining the movement of sections of the flat wagon relative to the corresponding axes.

The magnitude of the longitudinal force acting on the bearing structure of the flat wagon is assumed to be 2.5 MN [DSTU 7598:2014, GOST 33211-2014, DIN EN 12663-2-2010]. The solution of differential equations was carried out using the Runge-Kutta method in the software environment MathCad Vatulia et al. (2018), Vatulia et al. (2019), Kiryanov et al. (2006).

The results of the researches allowed to conclude that the acceleration, which corresponds to supporting structure of the first section of the flat wagon from the side force action is 37.5 m/s², and the second – about 38.2 m/s² (Fig. 4).

The next stage of this research is the determination of the structural strength parameters of the articulated flat wagon.

5. Conclusions.

Based on the research carried out the following conclusions can be drawn:

1. Construction of a flat wagon of an articulated type from round pipes was developed. The provision of fitting stops is foreseen for the possibility of transportation of containers on a flat wagon. In the middle of the frame there are folded fitting stops that allow flat wagon transportation of containers of various sizes;
2. A mathematical model of the dynamic load of the flat wagon construction made from round pipes in the main operating modes is developed. It was taken into account when developing the mathematical model that each section of the flat wagon has its own degree of freedom, since the structural characteristics of the joining device allow them to be moved in space.

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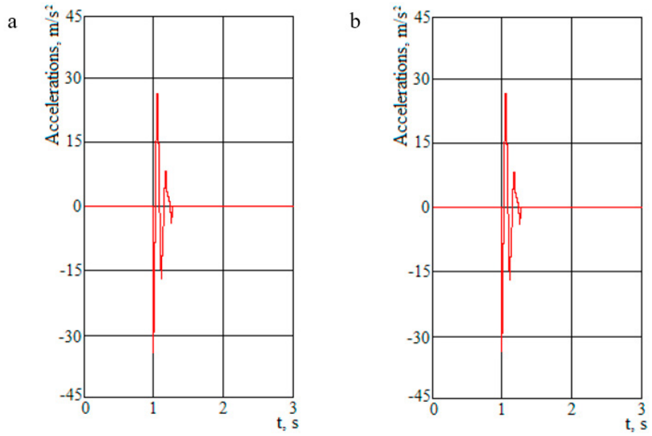

Fig. 4. Accelerations which act on the bearing structure of articulated flat wagon under I rated conditions (tension – jump): a) first section of flat wagon from the side of longitudinal force action; b) second section of flat wagon from the side of longitudinal force action.

The obtained results will be taken into account in the research of the bearing structure strength parameters of articulated flat wagon.

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