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THE DYNAMIC LOADING ANALYSIS OF CONTAINERS PLACED ON A FLAT WAGON DURING SHUNTING COLLISIONS

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ABSTRACT

There are given the features of the dynamic loading mathematical modeling of containers placed on a flat wagon during shunting collision in the article. The numerical values of the accelerations acting on the container are determined. The results are confirmed by computer simulation. The developed models are verified by the F-criterion. The conducted studies will contribute to the creation of recommendations on the creation of new generation containers on car-building enterprises and increase the efficiency of combined transport operations.

Keywords: container, dynamic loading, durability, maneuvering concussion, container transportation.

INTRODUCTION

It is well known that one of the most mobile transportation means used in international combined transportation is containers (Figure-1) [1-3].

The container interoperability is in a high demand in combined transportation. It requires development and implementation of the new generation containers of improved technical and economical characteristics.

a)

b)

Figure-1. Containers a) for liquid freight transport; b) for dry freight transport.

A higher efficiency of transportation along international transport corridors (ITC) requires development and implementation of new generation transport means. The existing mathematical models need optimization for obtaining improved values of the dynamic loads influencing carrying structures of containers in operation.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The analysis of dynamic loads influencing a tank container placed on a flat wagon at shunting impacts is given in [4].

The accelerations influencing the tank container were defined with consideration of gaps between fitting

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stops of the flat wagon and fittings of the tank container. The longitudinal force influencing the flat wagon from a hammer car was approximately 2.200-2.800 kN.

The research was conducted on tank containers for transportation of petrol and nitric acid; their gross weights were 21.9 tons and 24.0 tons respectively.

It should be noted that the maximum value of the longitudinal impact force which can influence the loaded flat wagon (including boiler containers) at shunting impacts is 3.5 MN [5, 6]. Thus, in order to get improved values of the acceleration influencing the tank container in operation, there is a need for some additional research.

The dynamic loading simulation of a tank container during transportation by road and rail is carried out in [7]. In this case, static conditions are modeled by using the implicit ANSYS 5.6 solver, and dynamic conditions are modeled by using the ANSYS processor and the explicit LSDYNA solver.

Research into the carrying structure capacity of a tank container with the improved operational values of loads (displacement of liquid freight, displacement of fittings relative to the fitting stops, etc.) was not conducted.

Problems of designing ideal carrying structures of freight wagon frames and requirements they have to meet at the current stage of the rail transport development are considered in [8, 9].

The study did not deal with the designing of ideal carrying structures of containers.

DETERMINE THE PURPOSE AND OBJECTIVES OF THE STUDY

Objective of the article is improvement of mathematical models and elaboration of values of dynamic loads influencing the carrying structures of containers in operation.

To achieve this goal, the following tasks are defined:

a) To carry out the dynamic loading mathematical modeling of the tank container placed on the flat wagon during shunting;

b) To carry out the dynamic loading mathematical simulation of a dry cargo container placed on a flat wagon during a shunting collision;

c) To verify the developed models of dynamic loading of containers placed on a flat wagon during a shunting collision.

THE MAIN PART OF THE STUDY

Analysis of the normative documents on providing operational tank container capacities made it possible to conclude that the highest dynamic loads influencing their carrying structures and fastening units are presented in GOST 31232 “Containers for transportation of dangerous freight. Operational safety requirements” [6]. It is supposed that the structure of a tank container must carry its own inertia forces appearing in operation and in shunting impacts of wagons, including shunting from humps, emergency braking at low speeds and under the following accelerations: in longitudinal direction P_{LD} - 2g; in transverse direction P_T - 1g, in vertical direction P_V - 2g; under shunting impacts for a loaded container - 4g; for an empty container (to check the accessories) - 5g.

In order to define operational values of the dynamic loads influencing the carrying structure of a tank container placed on the flat wagon at shunting impacts the mathematical model given in [4] was applied. The model considers that three tank containers were placed on a long-base flat wagon, and the link between them was imitated as spring frictional, i.e. each container had its own degree of freedom in the vertical plane. It should be noted that tank container transportation also uses framed flat wagons which can accommodate two containers. Such wagons have a shorter base, and, therefore, lower values of the carrying structure displacement under vertical loads from the containers.

Therefore, the study was conducted for a 13-4085 flat wagon build at the Dnipro Vahon Mash and for a TK25 tank container build at VAT Zarechenskii Zavod Himicheskogo Mashinostroeniia. This is a typical container ISO 1CC type and is intended for transportation of petroleum products and lubricants, petrol, diesel fuel, soot, solvent-naphtha, petroleum solvent and foaming agent.

The diagram of the longitudinal force influencing the flat wagon with containers on is given in Figure-2.

The tank container was considered as some additional mass relative to the flat wagon frame and longitudinally flexible due to gaps between fitting stops of the flat wagon and fittings of the tank container. Thus, the tank container has its own degree of freedom until the fitting rests against the fitting stop, and then the tank container repeats the movement pattern of the flat wagon.

Connection between the flat wagon frame and fittings of the tank container was simulated as frictional. Besides, the tank containers placed on the flat wagon were taken as those with the equal liquid freight [4].

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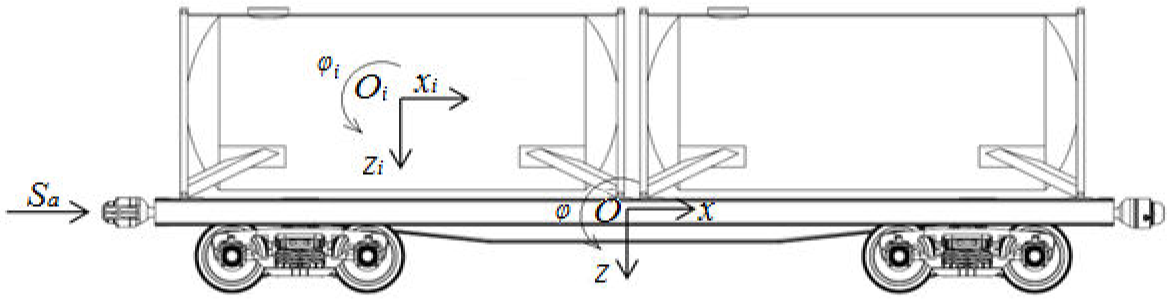

Figure-2. Diagram of the longitudinal force on the flat wagon with containers.

$$M'_{FL}\cdot\ddot{x}_{FL}+M_{FL}\cdot h\cdot\ddot{\varphi}_{FL}=S_a-\sum_{i=1}^{2}S_i, \quad (1)$$

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

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

$$\left(m_i+\sum_{j=1}^{k}m_{ij}\right)\cdot\ddot{x}_i+\left(m_i\cdot z_{ci}+\sum_{j=1}^{k}m_{ij}\cdot c_{ij}\right)\cdot\ddot{\varphi}_i-\sum_{j=1}^{k}m_{ij}\cdot l_{ij}\cdot\xi_{ij}=S_i, \quad (4)$$

$$\left(I_{\theta i}+\sum_{j=1}^{k}m_{ij}\cdot c_{ij}^2\right)\cdot\ddot{\varphi}_i+\left(m_i\cdot z_{ci}+\sum_{j=1}^{k}m_{ij}\cdot c_{ij}\right)\cdot\ddot{x}_i-\sum_{j=1}^{k}m_{ij}\cdot l_{ij}\cdot\xi_{ij}-$$

$$-g\cdot\left(m_i\cdot z_{ci}+\sum_{j=1}^{k}m_{ij}\cdot c_{ij}\right)\cdot\left(\varphi_{FL}-\varphi_i\right)=0, \quad (5)$$

$$\left(m_i+\sum_{j=1}^{k}m_{ij}\right)\cdot\ddot{z}_{FL}=0, \quad (6)$$

$$I_{ij}\cdot\ddot{\xi}_{FL}-m_{ij}\cdot l_{ij}\cdot\ddot{x}_{ij}-m_{ij}\cdot c_{ij}\cdot l_{ij}\cdot\ddot{\varphi}_{ij}+g\cdot m_{ij}\cdot l_{ij}\cdot\ddot{\xi}_{ij}=0, \quad (7)$$

where

$$M'_{FL}=M_{FL}+2\cdot m_B+\frac{n\cdot I}{r^2};\ \Delta_1=z_{FL}-l\cdot\varphi_{FL};$$

$$\Delta_2=z_{FL}+l\cdot\varphi_{FL}$$

$$S_i=f_{FR}\cdot sign\cdot\left(x_{FL}-x_i\right)'$$

And $x_i<30$ mm [4, 6], if $x_i\geq 30$ mm, then $x_i=x$. Therefore,

$$M'_{FL}\cdot\ddot{x}_{FL}+M_{FL}\cdot h\cdot\ddot{\varphi}_{FL}=S_a, \quad (8)$$

$$I_{FL}\cdot\ddot{\varphi}_{FL}+M_{FL}\cdot h\cdot\ddot{x}_{FL}-g\cdot\varphi_{FL}\cdot M_{FL}\cdot h=l\cdot F_{FR}\left(sign\dot{\Delta}_1-sign\dot{\Delta}_2\right)+l\left(k_1\dot{\Delta}_1-k_2\dot{\Delta}_2\right), \quad (9)$$

$$M_{FL}\cdot\ddot{z}_{FL}=k_1\cdot\Delta_1+k_2\cdot\Delta_2-F_{FR}\left(sign\dot{\Delta}_1-sign\dot{\Delta}_2\right), \quad (10)$$

$$\left(m_i+\sum_{j=1}^{k}m_{ij}\right)\cdot\ddot{x}_{FL}+\left(m_i\cdot z_{ci}+\sum_{j=1}^{k}m_{ij}\cdot c_{ij}\right)\cdot\ddot{\varphi}_{FL}-\sum_{j=1}^{k}m_{ij}\cdot l_{ij}\cdot\ddot{\xi}_{ij}=0, \quad (11)$$

$$\left(I_{\theta i}+\sum_{j=1}^{k}m_{ij}\cdot c_{ij}^2\right)\cdot\ddot{\varphi}_{FL}+\left(m_i\cdot z_{ci}+\sum_{j=1}^{k}m_{ij}\cdot c_{ij}\right)\cdot\ddot{x}_{FL}+\sum_{j=1}^{k}m_{ij}\cdot c_{ij}\cdot l_{ij}\cdot\ddot{\xi}_{ij}-$$

$$-g\cdot\left(m_i\cdot z_{ci}+\sum_{j=1}^{k}m_{ij}\cdot c_{ij}\right)\cdot\varphi_{FL}=0 \quad (12)$$

$$\left(m_i+\sum_{j=1}^{k}m_{ij}\right)\cdot\ddot{z}_{FL}=0, \quad (13)$$

$$I_{ij}\cdot\ddot{\xi}_{ij}-m_{ij}\cdot l_{ij}\cdot\ddot{x}_{ij}-m_{ij}\cdot c_{ij}\cdot l_{ij}\cdot\ddot{\varphi}_{FL}+g\cdot m_{ij}\cdot l_{ij}\cdot\ddot{\xi}_{ij}=0, \quad (14)$$

where M_{FL} is the carrying structure mass of a flat wagon; I_{FL} is the inertia moment of a flat wagon relative to the longitudinal axis; S_a is the value of the longitudinal impact force toward the automatic coupling; f_{FR} is the peak value of a dry friction force; m_B is the bogie mass; I is the inertia moment of a wheel set; r is the radius of a wheel of the medium worn-out state; n is the number of bogie axes; l is a half wheelbase of the flat wagon; F_{FR} is the absolute value of the dry friction force in a spring group; k_1, k_2 is the spring rigidity of the spring suspension of flat wagon

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bogies; k is the number of oscillations frequencies of the liquid freight; m_i is the mass of a body equivalent to the *i*-th tank container with part of the liquid freight unmovable relative to the boiler; m_{ij} is the mass of the *j*-th pendulum in the *i*-th tank container; z_{ci} is the height of the tank container load centre; c_{ij} is the distance between the plane $z_i = 0$ and the fixation point of the *j*-th pendulum in the *i*-th tank container; l_{ij} is the length of the *j*-th pendulum; I_θ is the reduced inertia moment of the *i*-tank container and liquid freight unmovable relative to the boiler; I_{ij} is the inertia moment of a pendulum; x, φ, z are the coordinates corresponding to the longitudinal, angular (around the longitudinal axis) and vertical movements of a flat wagon; x_i, φ_i are the coordinates corresponding to longitudinal, angular (around the longitudinal axis) movements of a tank container; ξ_{ij} is the deviation angle of the *j*-th pendulum off the vertical line.

The vertical displacements of the tank container relative to the flat wagon frame were not considered. The displacement of the liquid freight relative to the walls of the boiler was taken into account. The liquid freight movement was described as a set of mathematical pendulums [4]. The value of the longitudinal impact influencing the flat wagon was taken as 3.5 MN.

The hydrodynamic characteristics of the liquid freight were defined by the method presented in [11]. Petrol was taken as the liquid freight. On the base of the calculations conducted for the case of the maximum possible loading on the boiler of the tank container in accordance with [10], the values $m_{ij} \approx 6,8$ t and $I_{ij} \approx 250$ $\mathrm{t \cdot m^2}$ were obtained.

The differential equations were solved by the Runge -Kutta method in MathCad.

Results of the research allowed the authors to conclude that without gaps between fitting stops of the flat wagon and fittings of the tank container, the acceleration influencing the carrying structure of the tank container was approximately 40 m/s². The maximum acceleration was obtained for a gap between a fitting stop and a fitting of 30 mm, the acceleration being about 300 m/s².

In modelling dynamic loading for a dry freight container the above mentioned mathematical model was reduced to [4]:

$$M'_{FL} \cdot \ddot{x}_{FL} + M_{FL} \cdot h \cdot \ddot{\varphi}_{FL} = S_a - \sum_{i=1}^{2} S_i, \quad (15)$$

$$I_{FL} \cdot \ddot{\varphi}_{FL} + M_{FL} \cdot h \cdot \ddot{x}_{FL} - g \cdot \varphi_{FL} \cdot M_{FL} \cdot h = \\ = l \cdot F_{FR} \left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2 \right) + l \left(k_1 \cdot \Delta_1 - k_2 \cdot \dot{\Delta}_2 \right), \quad (16)$$

$$M_{FL} \cdot \ddot{z}_{FL} = k_1 \cdot \Delta_1 + k_2 \cdot \Delta_2 - F_{FR} \left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2 \right), \quad (17)$$

$$m_i \cdot \ddot{x}_i + \left(m_i \cdot z_{ci} \right) \cdot \ddot{\varphi}_i = S_i, \quad (18)$$

$$I_i \cdot \ddot{\varphi}_i + \left(m_i \cdot z_{ci} \right) \cdot \ddot{x}_i - g \cdot \left(m_i \cdot z_{ci} \right) \cdot \left(\varphi_{FL} - \varphi_i \right) = 0, \quad (19)$$

$$m_i \cdot \ddot{z}_{FL} = 0. \quad (20)$$

The vertical displacements of the container relative to the flat wagon frame were not considered.

The results of the research allowed the authors to conclude that with gaps between fittings of the container and fitting stops of the flat wagon the accelerations influencing the carrying structure was approximately 110 m/s².

In order to define the acceleration influencing the container placed on the flat wagon at shunting impacts without gaps between fittings and fitting stops, the mathematical model was reduced to:

$$M'_{FL} \cdot \ddot{x}_{FL} + M_{FL} \cdot h \cdot \ddot{\varphi}_{FL} = S_a, \quad (21)$$

$$I_{FL} \cdot \ddot{\varphi}_{FL} + M_{FL} \cdot h \cdot \ddot{x}_{FL} - g \cdot \varphi_{FL} \cdot M_{FL} \cdot h = \\ = l \cdot F_{FR} \left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2 \right) + l \left(k_1 \cdot \Delta_1 - k_2 \cdot \dot{\Delta}_2 \right), \quad (22)$$

$$M_{FL} \cdot \ddot{z}_{FL} = k_1 \cdot \Delta_1 + k_2 \cdot \Delta_2 - F_{FR} \left(sign\dot{\Delta}_1 - sign\dot{\Delta}_2 \right), \quad (23)$$

$$m_i \cdot \ddot{x}_{FL} + \left(m_i \cdot z_{ci} \right) \cdot \ddot{\varphi}_{FL} = 0, \quad (24)$$

$$I_i \cdot \ddot{\varphi}_{FL} + \left(m_i \cdot z_{ci} \right) \cdot \ddot{x}_{FL} - g \cdot \left(m_i \cdot z_{ci} \right) \cdot \varphi_{FL} = 0, \quad (25)$$

$$m_i \cdot \ddot{z}_{FL} = 0, \quad (26)$$

thus, it disregarded the friction forces between fitting stops and fittings and the inertia forces appearing when the container moved relative to the flat wagon frame. The calculation showed that the maximum acceleration influencing the container was nearly 50 m/s².

In order to approve the acceleration values obtained the computer modelling of dynamics for the containers placed on the flat wagon under a longitudinal force of 3.5 MN on the back stop of the automatic coupling was conducted in Cosmos Works (version 2015) [12-14].

The calculation was made by the Finite Element Method. The finite element model was built with spatial isoparametrical tetrahedrons.

The capacity model considered both the longitudinal force and the vertical force influencing the flat wagon in areas where the containers rested upon fitting stops. It was considered that the container was influenced by the vertical force in areas where the fitting rested upon the fitting stop. To consider friction forces in the areas of interaction between the flat wagon and the containers the coefficient of modal damping was applied.

The 09G2S steel of the capacity limit $\sigma_B = 490$ MPa and the fluidity limit $\sigma_T = 345$ MPa was taken as material for the carrying structure of the flat wagon and the containers.

Numerical values of accelerations influencing the carrying capacity of the containers placed on the flat wagon while shunting impacts are given in Figure-3.

The adequacy of the designed models was checked by an F-test. The conducted calculation made it possible to conclude that the hypothesis on adequacy of the models was not rejected.

The conducted research showed that accelerations influencing containers placed on the flat wagon while shunting impacts considerably exceeded the normative values, a possible movement of fittings relative to fitting spots being taken into account [6]. Therefore, there is a need to improve the normative documents by adding boundary values of the maximum acceleration, potentially acting on containers placed on the flat wagon while shunting impacts, and also to consider specified values of dynamic loads already in the stage of wagon and its facilities designing.

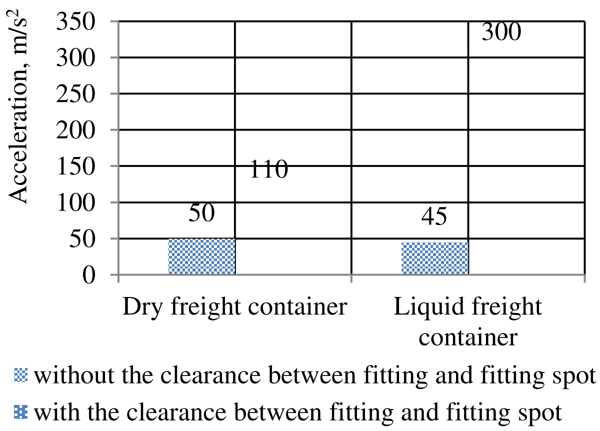

Figure-3. The numerical values of the acceleration influencing the carrying structures of the containers placed on the flat wagon while shunting impacts.

CONCLUSIONS

The research conducted led to the following conclusions:

a) The research into the dynamic loads on containers placed on the flat wagon provided improved values of accelerations influencing the containers in operation. It has been proved that accelerations influencing a container at shunting impacts greatly depended on gaps between fittings and fitting stops and exceeded the normative values [6].

b) The safety requirements should be provided by limiting movements of containers placed on the flat wagon relative to their frames at shunting impacts.

c) Consideration of improved values of accelerations influencing containers in operation is required for designing new generation containers.

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