Dynamic loading of the tank container on a flat wagon considering fittings displacement relating to the stops

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Abstract. The mathematical modelling of the dynamic loading of the container-tank during maneuvering collision of the flat wagon has made it possible to obtain an accurate value of the accelerations acting on its supporting structure. At the same time, possible movements of the tank-container relative to the frame of the flat wagons due to the presence of a technological gap in the pair “fitting stop-fitting” are taken into account. It is established that this acceleration, which is a component of the dynamic load, exceeds the one permitted by the regulatory documents. A computer simulation of the dynamic loading of the tank container in the CosmosWorks software environment was also carried out. The calculation was carried out using the finite element method. The results of the simulation made it possible to determine the distribution fields of the accelerations acting on the supporting structure of the tank-container during the shunting of the flat wagon, as well as their numerical values. Checking the adequacy of the mathematical and computer models using the Fisher criterion allowed us to conclude that the hypothesis of adequacy is not rejected.

1 Introduction

Ensuring the effectiveness of the developing economic ties between the states of Europe and Asia calls for the introduction of combined transport operations. To date, one of the most promising vehicles that have found application in combined transport is a container, and for the carriage of fluid cargo – a container-tank.

The increase in the volume of fluid cargo transportations towards the international transport corridors foreshows an increase in the level of demand for container-cisterns. In connection with this, there is a need to develop and put into operation new tank-container with improved technical and economic indicators [1-5].

2 Analysis of recent research and publications

A study of the dynamic loads acting on the tank-container placed on the flat wagon during the manoeuvring collision is presented in [6]. The determination of the accelerations acting on the tank-container was carried out taking into account the gaps between the fitting stops of the flat wagon and the fittings of the tank-container. The longitudinal force acting on the flat wagon from the wagon-striker was about 2200-2800 kN, depending on the capacity of the tank-container. The studies were carried out on tank containers for transportation of gasoline and nitric acid with a gross mass of 21.9 tons and 24.0 tons, respectively.

It is important to note that the maximum value of the longitudinal impact force, which can act on the flat wagon with the cargo placed on it, including the tank containers, with a shunting collision, is 3.5 MN [7, 8]. Therefore, in order to obtain an accurate value of the accelerations acting on the container-tank in operation, additional studies are needed.

A study of the strength of tank-container model TK25 and the optimization of its supporting structure are given in [9, 10]. When compiling the model of the strength of the tank-container, the normative values of the loads given in [11] are taken into account.

A study of the strength of the load-bearing structure of the tank-container, taking into account the specified operational values of the loads (the compliance of the fluid cargo, the movement of fittings relative to the fitting stops, etc.) is not carried out.

In works [12, 13], the feasibility of designing and commissioning tank containers as vehicles has been justified, the results of optimizing the design of tank containers are given. Advanced designs of tank containers for transportation of oil products have been developed.

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The structural features of tank-containers for transportation of liquefied gases are discussed in [14]. The material of the supporting structure of the container is stainless steel. To limit the thermal impact of the environment on the container, it is proposed to encapsulate it with an insulating system.

Features of computer modelling of the supporting structure of a tank-container are given in [15]. The finite element method is used as the calculation method.

A study of the transfer of heat flow through the internal supports of cylindrical vessels using the example of a tank-container was considered in [16]. The paper simulates the heat flow through a multilayer support made of plastic.

Tests of metal and composite containers under the impact of low temperatures are given in [17]. It repeats the trajectory of \(\alpha\sum\Delta = \Delta\sum\), therefore it is an attached container placed on the flat wagon frame, and the connection between them was simulated as an elastic-friction one, that is, each tank-container has its own degree of freedom up to the moment of fitting in the fitting stop, after which the container-tank repeats the trajectory of moving the flat wagon (Fig. 1).

![Fig. 1. Scheme of action of the longitudinal force on the flat wagon with the tank-containers placed on it.](image)

**3 Exposition of the object of research**

An analysis of the regulatory documents on the issues of ensuring the strength of tank containers in operation allowed us to conclude that the greatest values of the dynamic loads acting on their load-bearing structures and fastening devices are indicated in [11].

It is agreed that the construction of the tank-container must withstand the inertia forces arising during the movement of the vehicle, as well as during the shunting of the wagons, including during the dissolution from the hills, emergency braking in trains at low speeds, with the following accelerations: in the longitudinal direction \(P_l = 2g\); in the transverse direction \(P_t = 1g\); in the vertical direction \(P_v = 2g\); at impact: for the loaded container – 4g; for empty container (for the purpose of checking the fittings) – 5g.

To determine the operational values of the dynamic loads acting on the supporting structure of the tank-container placed on the flat wagon during manoeuvring collision, the mathematical model given in [6] was used. This model takes into account that three tank-containers are placed on a long-based flat wagon, and the connection between them was simulated as an elastic-friction one, that is, each tank-container has its own degree of freedom in the vertical plane (formulas: 1-7).

The components of a mathematical model are determined by the formulas (8-11).

It is important to note that in the transportation of tank-containers, flat wagons on the frame of which two containers can be accommodated are also used. Such wagons have a smaller base, and accordingly less than the amount of movement of the supporting structure under the influence of the vertical load from the containers [21].

Therefore, in this study, research was conducted on the 13-4085 flat wagon model, the construction of JSC Dniprovagonmash and the TK25 tank-container model, built JSC Zarechesky Chemical Mechanical Engineering Factory. The tank-container is of ISO-1CC standard size and is intended for transportation of fuels and lubricants, gasoline, diesel fuel, engine oil, oil, oil solvents, nefras, foaming agents.

The tank-container was considered as an attached mass in relation to the flat wagon frame, having long-distance compliance due to the presence of gaps between the fitting stops of the flat wagon and the container-tank fittings. That is, the tank-container has its own degree of freedom up to the moment of fitting in the fitting stop, after which the container-tank repeats the trajectory of moving the flat wagon (Fig. 1).

The connection between the frame of the flat wagon and the container-tank fittings was simulated as frictional. At the same time, it is taken into account that the tank-containers placed on the flat wagon have the same boiler workload of the fluid cargo.

\[
M_{f_w} \ddot{x}_{f_w} + M_{f_w} h \dot{\varphi}_{f_w} = S_c - \sum_{k=1}^{\Delta} S_c, \quad (1)
\]

\[
l_{f_w} \dot{\varphi}_{f_w} + M_{f_w} h \dot{x}_{f_w} - g \varphi_{f_w} M_{f_w} h = l \cdot F_{af}(\text{sgn} \Delta_1 - \text{sgn} \Delta_2) + l(k_1 \cdot \Delta_1 - k_2 \cdot \Delta_2), \quad (2)
\]

\[
M_{f_w} \dot{x}_{f_w} = k_1 \Delta_1 + k_2 \Delta_2 - F_{af}(\text{sgn} \Delta_1 - \text{sgn} \Delta_2), \quad (3)
\]

\[
(m_1 + \sum_{k=1}^{\Delta} m_{ij})(\ddot{x}_{f_w} + \ddot{\varphi}_{f_w}) + (m_1 z_{ci} + \sum_{k=1}^{\Delta} m_{ij} c_{ij}) \times \nabla \dot{\varphi}_{f_w} = \sum_{k=1}^{\Delta} m_{ij} \dddot{\xi}_{ij} - S_i, \quad (4)
\]

\[
\left( \frac{1}{g} + \sum_{k=1}^{\Delta} m_{ij} c_{ij} \left( \ddot{x}_{f_w} + \ddot{\varphi}_{f_w} \right) + \left( m_1 z_{ci} + \sum_{k=1}^{\Delta} m_{ij} c_{ij} \right) \left( \dot{x}_{f_w} + \dot{\varphi}_{f_w} \right) + \sum_{k=1}^{\Delta} m_{ij} c_{ij} l_{ij} \dddot{\xi}_{ij} - g \left( m_1 z_{ci} + \sum_{k=1}^{\Delta} m_{ij} c_{ij} \right) \left( \varphi_{f_w} - \varphi_{f_w} \right) \right) = 0, \quad (5)
\]

\[
\left( m_1 + \sum_{k=1}^{\Delta} m_{ij} \right) \dot{x}_{f_w} = 0, \quad (6)
\]

\[
l_{ij} \dddot{\xi}_{f_w} - m_{ij} l_{ij} \dddot{x}_{f_w} - m_{ij} c_{ij} l_{ij} \dddot{\varphi}_{f_w} + g m_{ij} l_{ij} \dddot{\xi}_{ij} = 0, \quad (7)
\]

where

\[
M_{f_w} = M_{f_w} + 2m_2 + \frac{n_i}{r^2}, \quad (8)
\]

\[
\Delta_1 = z_{f_w} - l \cdot \varphi_{f_w}, \quad (9)
\]

\[
\Delta_2 = z_{f_w} + l \cdot \varphi_{f_w}, \quad (10)
\]

\[
S_i = f_{af} \cdot \text{sgn} \left( x_{f_w} - x_i \right), \quad (11)
\]
The calculation was carried out using the finite element method. When compiling the finite element model, spatial isoparametric tetrahedra are used. The number of grid nodes was 707359, the elements — 2150500. The maximum element size was 50 mm, the minimum — 10 mm. The minimum number of elements in the circle was 9, the ratio of the increase in the dimensions of the elements in the grid is 1.7. The maximum aspect ratio is 689.01, the percentage of elements with aspect ratio of less than 3 — 52.1, more than 10 — 4.75.

When compiling the strength model (Fig. 3), it is taken into account that, apart from the longitudinal force \( P_h \), kN, there are vertical forces acting on the flat wagon in the container support areas on the fitting stops. The container has a vertical response in the fitting area of the fitting to the fitting stop, the internal pressure of the fluid cargo \( P_0 \), kPa on the boiler, the longitudinal load \( P_l \), kN on the bottom of the boiler when the fluid cargo moves, due to the action of the longitudinal force \( P_h \) on the rear stop of the coupler and the movement of the fittings relative to the fitting stops by the amount of the technological gap. To account for the frictional force in the areas of interaction between the flat wagon and the containers, the modal damping coefficient was used.

![Fig. 2. Spatial model of the flat wagon with tank containers placed on it.](image)

![Fig. 3. The model of the strength of the flat wagon with tank containers placed on it under the action of longitudinal force on the rear stop of the automatic coupler.](image)
Fig. 4. Acceleration of the flat wagon with the containers placed on it when the longitudinal force acts on the rear stop of the automatic coupler.

It was established that the considered model is linear and characterizes the change in the acceleration of the tank-container placed on the flat wagon from the longitudinal force acting on the rear fence of the automatic coupler. In this case, the number of degrees of freedom for $N = 6$ will be $f = 4$.

On the basis of the calculations, it has been established that the actual value of criterion $F_{cl} = 1.6$ is less than the table value of criterion $F_t = 6.16$. Consequently, the hypothesis of adequacy is not rejected.

The obtained results for the accelerations, as components of the dynamic load, are taken into account in the study of the strength of the load-bearing structure of the tank-container. The results of the calculations made it possible to conclude that the maximum equivalent stresses in the construction of a tank container arise in the zone of interaction between the boiler support and the fitting stop and are about 1015 MPa (Fig. 5), the maximum displacements in the structural units were 13.6 mm, the deformations $-6.08 \times 10^3 [21]$

The distribution of stresses along the length of the lower transverse belt of the tank-container frame is shown in Fig. 6. It can be seen from the figure that the maximum equivalent stresses are concentrated in the areas of placement of the container-tank fittings, and they decrease towards the central part of the belt.

4 Conclusion

The conducted research allowed us to define the specified value of acceleration, which acts on the supporting structure of the tank-container taking into account the movements of the fittings relative to the fitting stops of the flat wagon. Calculation of the strength showed that with possible movements of the tank container relative to the platform car frame in the conditions of the shunting collision and the underload of the boiler with the fluid load, the stresses in the load-bearing structure exceed the permissible ones. The results of the research will contribute to the creation of a new-generation tank-containers with improved technical and economic parameters that will improve the efficiency of the transport process towards international transport corridors.

Fig. 5. Results of the calculation of the strength of the load-bearing structure of the tank-container TK25.

Fig. 6. Distribution of stresses along the length of the lower transverse belt of the tank-container frame.

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