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Proceedings of 26th International Scientific Conference. Transport Means 2022.

Special Features of the Vertical Loading on a Flat Car Transporting Containers with Elastic-Viscous Links in their Interaction Units

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Abstract

The research deals with the special features of determination of the vertical loads on the frame of a flat car transporting containers with elastic-viscous links in their interaction units. This modification will improve the strength values of a flat car through a decrease in the dynamic loading. The solution was substantiated with the modelling of the loading on a flat car. The maximum accelerations to a flat car were 5.4% lower than the accelerations in its typical diagram of interaction with the containers. The maximum stresses were by 7% lower than those in the typical structure. It should be noted that the measures proposed could improve the fatigue strength of the frame of a flat car by 5.2% in comparison with that of the typical structure.

The research will reduce the loading on the bearing structure of a flat car, and, consequently, the maintenance costs and the cost of storage of the freight transported, and contribute to the database of materials on design of promising flatcar structures.

KEY WORDS: *transport mechanics; flatcar; improved structure; vertical loading; strength of the frame; container transportation.*

1. Introduction

Higher efficiency of the transport industry determines the expediency of multimodal systems. And the promising among them is container transportation, including by flat cars. They are fitted with fixed or hinges fittings, i.e. units for fastening containers. The amount of containers transported by rail can be increased by the use of long-base flat cars. These cars are customized for simultaneous transportation of some containers, for example, four 1CC containers or two 1AA containers.

It should be noted that a longer flatcar frame causes the natural displacements of the bearing structures in the vertical plane. The cyclic nature of these displacements results in the accumulation of fatigue stresses and, consequently, crack development. Therefore, there is a need to repair the bearing structures of flat cars or withdraw them from the inventory fleet. Besides, such defects in operation endanger the safety of a flat car. It may also pose an ecological threat regarding freight transportation by rail. Therefore, there is a need to develop the methods aimed at lower loading on the frame of a long-base car.

2. Analysis of Publications

The issue of the determination of the loading on the construction of flat cars in operations and the measures for decreasing this loading was studied through the analysis of scientific publications.

Article [1] research with the issue of how deformations in the frame of a flat car can affect the strength. The authors used experimental methods of research, particularly, electric strain-gage testing. Strain gages were mounted on the most loaded zones of the structure calculated theoretically. They found the maximum loaded structural elements of a flat car; however, they did not consider any solutions of how to decrease stress state.

The special construction features of a long-base flat car are studied in [2]. The research presents the calculated of the stress state of a flat car during the main operational loads and the dynamic testing. The modelling of the strength of the flatcar frame for multimodal transportation is presented in [3]. The researchers determined the most loaded components of the flatcar structure during the main operational loads. It should be noted that the authors of these publications did not decisions any measures for decreasing the loading on the frame of the flat cars under study.

The peculiarities of the determination of the strength of a flat car are described in [4]. And the article presents the theoretical calculation and the testing of the stress. The engineering proposals taken at the creating stage of the car proved to be rather efficient; they authors also presented their substantiation. However, they did not analyze the effect of the structural peculiarities of the designed flat car on its fatigue strength.

The analysis of a new wagon structure for combined transportation is presented in [5]. The substantiation of the design solutions proposed was made through calculation of the loading of the wagon in ANSYS and ADAMS/Rail. It was found that the values of dynamics and strength under study did not exceed the allowable values. However, the researchers did not study the potential to decrease the stress state of the wagon construction in order to improve its fatigue strength.

The calculated of the stress state for a long-base car is presented in article [6]. The calculation was made for two loading variants, at which the maximum bending moments were obtained. The maximum stresses in the construction were calculated with the finite element method.

The issue of the possibility to apply the methods of theoretical and experimental research into the stress of the construction of long-base cars is studied in [7]. The article presents the calculation for the fatigue strength for the construction of cars.

It should be noted that the measures for obtaining better strength values in construction of flat cars were not proposed in the studies mentioned.

The use of flexible interactions in the construction of flat cars to ensure its better reliability under operational loads is substantiated in [8, 9]. The article presents the imitation models for determination of the loading on the construction of cars. However, the solutions proposed do not compensate the vertical loading on the construction of flat cars.

The analysis of literature makes it possible to conclude that there is a need to investigate the possibility to compensation the vertical loading on the construction of a flat car for better operational efficiency.

3. Purpose and Main Objectives of the Article

The objective of the article is to study of the vertical loading on a flat car transporting containers with elastic-viscous interactions in the units during bouncing oscillations. Tasks to achieve the objective:

- mathematical modelling of the dynamic loading of construction of a flat car; and
- stress calculation of the construction of a flat car.

4. The Main Material of the Article

The dynamic loading on construction of a flat car and, consequently, on the containers placed on it, can be compensated by means of introduction of elastic-viscous links in the interaction units And this decrease is achieved through transformation of the kinetic energy to the construction of a flat car from the containers during bouncing oscillations into the work of elastic-viscous friction forces occurring in the superstructures for container fittings.

This solution requires the mounting of fixed fittings on special superstructures (Fig. 1).

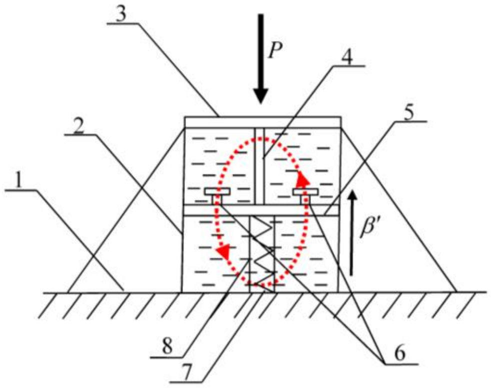

Fig. 1 Principal diagram of the superstructure for fixed fittings

In its middle superstructure 1 has cage *2* covered with plate *3* for mounting a container fitting. Plate *3* through shaft *4* interacts with piston *5*, which has two throttle valves *6*, inlet and exhaust. A viscous substance is placed above and under the piston. During bouncing oscillations the vertical loading P transfers to plate *3*, and from it – to piston *5*. Thus, piston *5* moves downward and the viscous substance flows through the open throttle valve from the hollow under the piston to the hollow over it. When piston *5* moves upwards the substance moves in the opposite direction. The return of piston *5* is fulfilled with a spring *7* located in the lower part of the cage in telescopic-type element *8*.

It should be noted that the use of the superstructures proposed can increase the tare weight of a flat car, therefore, their components can be made of composite materials that are lighter than steel and can ensure the required strength in operation.

The solution proposed was substantiated with the mathematical model of the loading for a car. The research was conducted by the example of a long-base car of Model 13-7024 (Ukraine), (Fig. 2 [10]).

Fig. 2 Flat car Model 13-7024

The construction of this car contains of the frame of two sub-frames in the end parts, two T-section welded side walls with variable rigidity consisting of 22-mm top and bottom sheets and 8-mm vertical sheets, two end beams, six intermediate beams, two additional intermediate beams, four T-section diagonal braces, which transfer the longitudinal loading from the center sills of the sub-frames to the side walls.

The calculation diagram of the car is shown in Fig. 3. The flat car consisted of three bodies – one bearing structure and two 18-100 bogies. It was also assumed that the two containers displaced symmetrically.

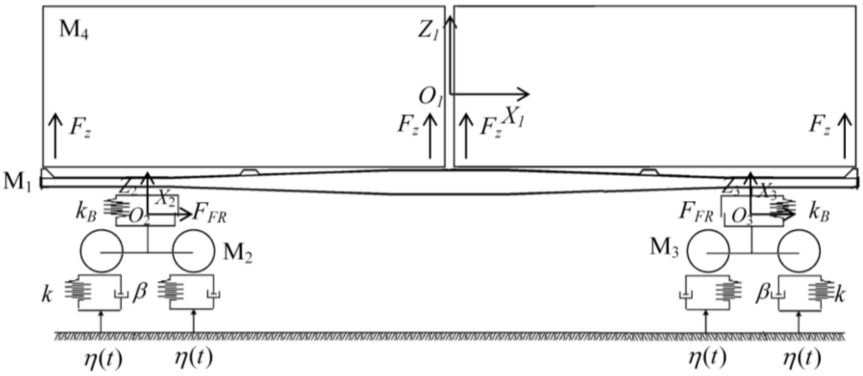

Fig. 3 Calculation diagram of a long-base car

The system of differential motion equations has the form:

$$\begin{cases} M_1 \cdot \ddot{q}_1 + N_{1,1} \cdot q_1 + N_{1,2} \cdot q_2 + N_{1,3} \cdot q_3 = -F_{FR} \cdot \left(sign\left(\dot{\delta}_1\right) + sign\left(\dot{\delta}_2\right)\right) - k'\left(y_1 - y_4\right) - \beta'\left(\dot{y}_1 - \dot{y}_4\right)_z; \\ M_2 \cdot \ddot{q}_2 + N_{2,1} \cdot q_1 + N_{2,2} \cdot q_2 + B_{2,2} \cdot \dot{q}_2 = F_{FR} \cdot sign\left(\dot{\delta}_1\right) + k\left(\eta(t) + \eta(t)\right) + \beta\left(\dot{\eta}(t) + \dot{\eta}(t)\right); \\ M_3 \cdot \ddot{q}_3 + N_{3,1} \cdot q_1 + N_{3,3} \cdot q_3 + B_{3,3} \cdot \dot{q}_3 = F_{FR} \cdot sign\left(\dot{\delta}_2\right) + k\left(\eta(t) + \eta(t)\right) + \beta\left(\dot{\eta}(t) + \dot{\eta}(t)\right); \\ M_4 \cdot \ddot{q}_4 = \left(-k'\left(y_1 - y_4\right) - \beta'\left(\dot{y}_1 - \dot{y}_4\right)\right) - M_4 \cdot g, \end{cases}$$

where M_1 – the mass of the construction of a long-base car; M_2, M_3 – the masses of running parts of the car; M_4 – the mass of the containers; N_{ij} – the elasticity characteristics; B_{ij} – the energy dissipation function; k – the rail rigidity; β – the damping factor; F_{FR} – the friction force in the in suspension of the running parts; δ_i – the deformation of the suspension; $\eta_i(t)$ – the rail irregularity; k' – the rigidity of the pullback spring; β' – the coefficient of viscous resistence of the substance in the cage.

Equation included that:

$Z_1 \sim q_1$ – the coordinate describing the bouncing of the frame of the flat car;
$Z_2 \sim q_2$ – the coordinate describing the bouncing of the first running part;
$Z_3 \sim q_3$ – the coordinate describing the bouncing of the second running part; and
$Z_4 \sim q_4$ – the coordinate describing the bouncing of a container.

The system of differential equations was solved with the method of variations for arbitrary constants. And the results obtained were tested in MathCad. The starting conditions were assumed to be zero [11-13]. The acceleration of the flat car was 2.61 m/s^2, which is 5.4% lower than the accelerations to a flat car with consideration of the typical diagram of interaction with the containers.

The acceleration obtained was used in the stress state calculation for the flatcar construction. Its spatial model was created in SolidWorks (Fig. 4). The stress state determination was made with the FEM in SolidWorks Simulation [14-16]. The calculation model takes into account the vertical load P_v to the bearing structure (Fig. 5), which consisted of the static and dynamic loadings calculated with the imitation model.

The continuum model of the bearing structure was formed with tetrahedrons [17, 18]. The model consisted of 58375 elements and 20219 units. Steel 09C2Cu with a yield stress of 345 MPa was chosen as the structural material [19, 20]. The model was fastened to the center plates. The von Mises criterion was used as the design criterion [21, 22].

The stress state of the construction of a flat car is presented in Fig. 6. The maximum stresses were arise in the central part of the frame – 147.1 MPa, which is 7% lower those in the basic design.

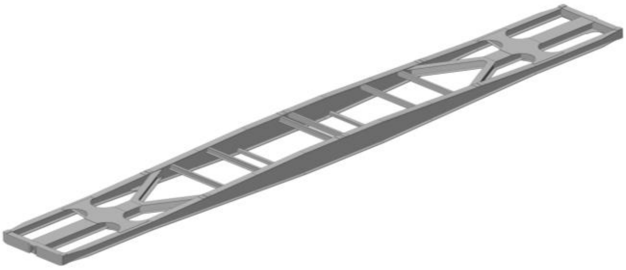

Fig. 4. Spatial model of construction of a flat car

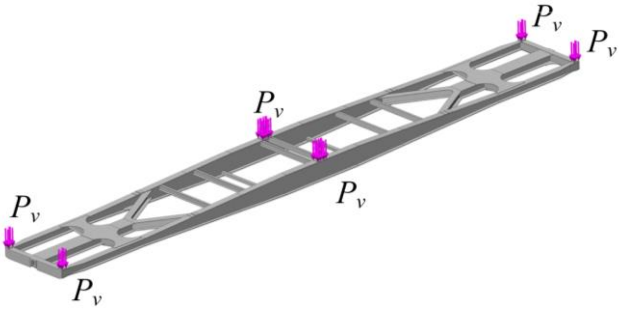

Fig. 5 Calculation diagram of a flat car

The static analysis of the construction of a flat car were use in the fatigue strength research. And it was found that the measures proposed would improve the fatigue strength of the construction by 5.2%. The results of the research were used for calculation of the biaxiality indicator of the construction of a car (Fig. 7).

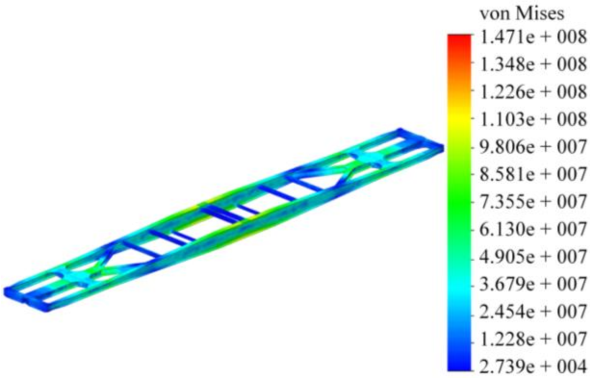

Fig. 6. Stress in the construction of a flat car

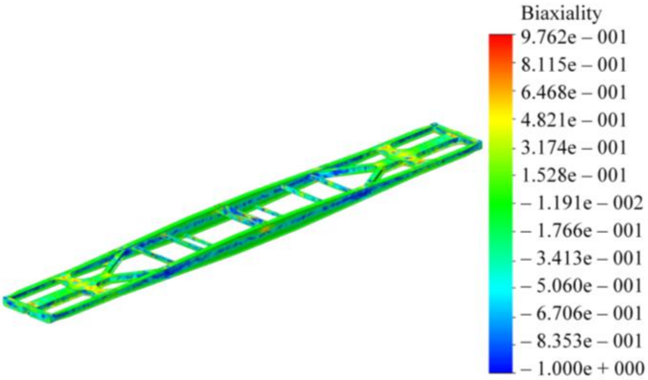

Fig. 7 Biaxiality indicator of the construction of a flat car

This indicator characterizes the ratio of the minimal stress in the bearing structure to its maximal value. Thus, the maximal indicator was recorded in the vertical sheets of the bolster beams.

5. Conclusions

The article deals with the imitation modelling of the loading on the construction of a flat car. It was found that the acceleration the flat car was 2.61 m/s^2, which was 5.4% lower than the accelerations on the typical flat car.

The research also included the strength determinate for the construction of a flat car. The maximum stresses were recorded in the middle part of the frame and amounted to 147.1 MPa which is 7% lower those in the basic design.

The results of the determination for the fatigue strength of the construction of a flat car demonstrated that the measures proposed would improve the fatigue strength by 5.2%.

The research will reduce the loading on the bearing structure of a flat car, and, consequently, the maintenance costs and the cost of storage of the freight transported, and contribute to the database of materials on design of promising flatcar structures.

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