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Determination Of The Loading On The Open Wagon Body When Rolling On The Train Ferry

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ABSTRACT: The higher efficiency of international transportation necessitates the introduction of combined transport systems. One of the most successful among these is train ferry transportation. And in order to provide safe transportation of wagons by sea, it is important to formulate the operational requirements for railway-sea transportation. And one of the loading modes for wagons is rolling on the train ferry.
The article presents the results of determining the dynamic load of the open wagon body when rolling on the train ferry. The calculation was made for the open wagon placed on 18-100 bogies. A mathematical model was formed, which made it possible to determine the main dynamic indicators that characterize the movement of the wagon. The results of the calculations were used to determine the permissible inequality amplitude in the zone of interaction between the rail tracks of the bridge and the ferry deck so that the indicators of the car dynamics would be within the permissible values. The permissible value of the inequality amplitude was 0.021 m. The conducted studies will contribute to the database of developments on ensuring the operational safety of wagons used for international railway-sea transportation.

1 INTRODUCTION

The increase in the volume of freight transportation through international transport corridors has resulted in the development of combined transport systems. The possibility for European states of entering international transportation through the waters of the Black, Azov, Mediterranean, and Baltic Seas has led to the emergence and successful operation of train ferry transportation (Figure 1).

The loading of wagons on the train ferry is carried out by rolling them through the ramp to the deck (Figure 2).

For the safe rolling of wagons on the deck, it is im-portant to minimize the gap in the contact areas be-tween the bridge and the ferry deck. However, techno-logically it is quite difficult to ensure the complete ab-sence of such a gap. In this regard, when passing this area, there may be a load of the structure, which can lead to the derailment of the wagon.

2 ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The study of dynamic loads on the wagon bodies during transportation by train ferries is carried out in [1]. A mathematical model for determining the dynamic loads on the wagon body in the conditions of the main types of oscillations of the train ferry is given. The obtained results of theoretical research were verified by computer simulation of oscillations for the train ferry loaded with wagons. The studies made it possible to obtain refined values of accelerations on the wagon bodies during transportation by train ferries.

a)

b)

Figure 1. Train ferries with wagons on board
a) Greifswald;
b) Heroes of Sevastopol

An assessment of the external forces acting on the wagons during transportation by the train ferry is given in [2]. The accelerations acting on the wagon bodies in the conditions of the sea wave are determined on the basis of the calculation of the trail ferry rolling with six degrees of freedom at irregular three-dimensional rough sea and movement at a speed of 6.5 knots.

It is important to note that the studies pay no attention to the dynamic loads acting on the wagon bodies when loading on the train ferry, namely when the wagon passes over the zone of interaction between the ramp and train ferry.

The methodology for determining the dynamic loads acting on the wagon bodies during transportation by train ferry is given in [3]. At the same time, the accelerations acting on the wagon were determined by differentiating the law of motion of the sea wave. The calculations are made for the train ferry Soviet Azerbaijan, which connected Azerbaijan with Dagestan and Turkmenistan (Baku with Makhachkala, Baku with Turkmenbashy). It should be noted that the study of dynamic loads acting on the wagon when rolling on the train ferry is not carried out.

a)

b)

Figure 2. Loading of railway vehicles on train ferry
a) Heroes of Shipka;
b) Greifswald

In publications [4, 5], the authors determine the dynamic load and strength of the bearing structures of wagons transported by train ferries. The solutions proposed are aimed at adapting wagons to secure fastening on the deck. At the same time, the authors only focus on sea transportation of wagons. That is, the dynamic load of wagons when loading on the ship was not studied.

The loads acting on the wagon body when transported by the train ferry are determined in [6]. A technique that allows determining the pressure of bulk cargo on the wagon walls is proposed. However, the loading the wagon body when rolling on the train ferry was not studied.

Documents [7, 8] shows the loads that act on a wagon when transported on a rail ferry by sea. Possible schemes for fixing the car on the deck are indicated. The requirements for securing wagons are given. However, the issues of rolling wagons onto a ship are not considered in this publications.

Therefore, to ensure the safety of train ferry transportation, it is necessary to study the dynamic loads acting on the bearing structure of the wagon, and take into account their specified values at the design stage. Thus, studies on the determination of the dynamic load of wagons during train ferry transportation are quite relevant.

The objective of the research is to determine the load of the open wagon body when rolling on the train ferry. To achieve this objective the following tasks were set:

– to conduct mathematic modelling of the dynamic load on the open wagon body when rolling on the train ferry; and
– to determine the permissible inequality amplitude in the zones of interaction of the rail tracks between the bridge and the ferry deck.

3 MATHEMATIC MODELLING OF THE DYNAMIC LOAD ON THE OPEN WAGON BODY WHEN ROLLING ON THE TRAIN FERRY

To study the dynamic loads acting on the wagon body when passing over the zone of interaction between the bridge and the train ferry, the mathematical model given in [9-11] was used. The model describes the oscillation process for the wagon when it passes over an inequality; it takes into account the delay of the disturbing effect on the structural elements of the wagon. In this study the model has been modified taking into account an additional degree of freedom in the longitudinal plane. It is taken into account that the rail track has elastic-viscous properties and the track responds proportionally to both the deformation and the speed of this deformation.

The design diagram of the open wagon when passing over the zone of interaction of the rail tracks between the ramp and the train ferry is shown in Figure 3.

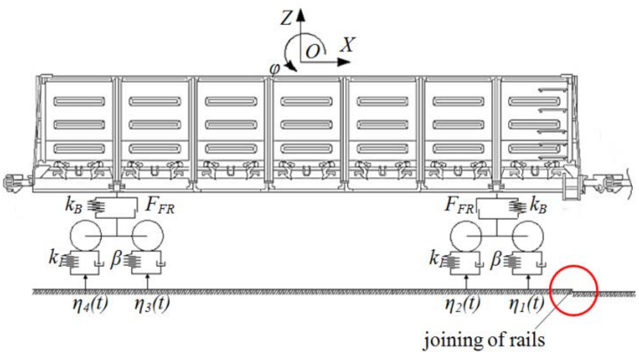


Figure 3. The design diagram of the wagon when passing over the zone of interaction of the rail tracks between the ramp and the train ferry

The system of nonlinear differential equations, which describes the oscillations of the wagon when passing the zone of interaction of the rail tracks between the bridge and of the train ferry, has the form:

$$M_1' \cdot \frac{d^2}{dt^2} q_1 + M_1 \cdot h \cdot \frac{d^2}{dt^2} q_3 = P_l, \tag{1}$$

$$\begin{aligned} & M_1 \cdot \frac{d^2}{dt^2} q_1 + C_{1,1} \cdot q_1 + C_{1,3} \cdot q_3 + C_{1,5} \cdot q_5 = \\ & = -F_{FR} \cdot \left(sign\left(\frac{d}{dt} \delta_1 \right) + sign\left(\frac{d}{dt} \delta_2 \right) \right), \end{aligned} \tag{2}$$

$$\begin{aligned} & M_2 \cdot \frac{d^2}{dt^2} q_2 + C_{2,2} \cdot q_2 + C_{2,3} \cdot q_3 + C_{2,5} \cdot q_5 = \\ & = F_{FR} \cdot l \cdot \left(sign\left(\frac{d}{dt} \delta_1 \right) + sign\left(\frac{d}{dt} \delta_2 \right) \right), \end{aligned} \tag{3}$$

$$M_3 \cdot \frac{d^2}{dt^2} q_1 = H_1, \tag{4}$$

$$\begin{aligned} & M_3 \cdot \frac{d^2}{dt^2} q_3 + C_{3,1} \cdot q_1 + C_{3,2} \cdot q_2 + C_{3,3} \cdot q_3 + B_{3,3} \cdot \frac{d}{dt} q_3 = \\ & = F_{FR} \cdot sign\left(\frac{d}{dt} \delta_1 \right) + k_1 \left(\eta_1 + \eta_2 \right) + \beta_1 \left(\frac{d}{dt} \eta_1 + \frac{d}{dt} \eta_2 \right), \end{aligned} \tag{5}$$

$$M_4 \cdot \frac{d^2}{dt^2} q_1 = H_2, \tag{6}$$

$$\begin{aligned} & M_4 \cdot \frac{d^2}{dt^2} q_4 + C_{4,4} \cdot q_4 + B_{4,4} \cdot \frac{d}{dt} q_4 = \\ & = -k_1 \left(\eta_1 - \eta_2 \right) - \beta_1 \cdot a \cdot \left(\frac{d}{dt} \eta_1 - \frac{d}{dt} \eta_2 \right), \end{aligned} \tag{7}$$

$$\begin{aligned} & M_5 \cdot \frac{d^2}{dt^2} q_5 + C_{5,1} \cdot q_1 + C_{5,2} \cdot q_2 + C_{5,5} \cdot q_5 + B_{5,5} \cdot \frac{d}{dt} q_5 = \\ & = F_{FR} \cdot sign\left(\frac{d}{dt} \delta_2 \right) + k_1 \left(\eta_3 + \eta_4 \right) + \beta_1 \left(\frac{d}{dt} \eta_3 + \frac{d}{dt} \eta_4 \right), \end{aligned} \tag{8}$$

$$\begin{aligned} & M_6 \cdot \frac{d^2}{dt^2} q_6 + C_{6,6} \cdot q_6 + B_{6,6} \cdot \frac{d}{dt} q_6 = \\ & = -k_1 \cdot a \cdot \left(\eta_3 - \eta_4 \right) - \beta_1 \cdot a \cdot \left(\frac{d}{dt} \eta_3 - \frac{d}{dt} \eta_4 \right), \end{aligned} \tag{9}$$

where M_1, M_2 – the mass and the moment of inertial of the wagon body; M_3, M_4 – the mass and the moment of inertia of the first bogie facing the engine; M_5, M_6 – the mass and the moment of inertia of the second bogie facing the engine; C_{ij} – the elasticity characteristics of the oscillation system elements determined by the values of the stiffness coefficients of the springs; k_b; B_{ij} – the dissipation function; a – the half of the bogie base; k – the track stiffness; β – the damping coefficient; $\eta_i(x)$ – the function describing the track inequality; δ_i – the deformation of elastic elements of the spring suspension; F_{FR} – the friction force in the spring group; H_1, H_2 – the values of horizontal forces applied to the centre plates of first and second bogies; h – the height of the centre of mass of the bearing structure of the wagon.

$$M_1' = M_1 + (M_3 + M_5) + \frac{n \cdot I}{r^2}, \tag{10}$$

where n – the number of axles in the bogie; I – the moment of inertia of the wheel set; r – the wheel radius.

The study was carried out on the example of an open wagon based on 18-100 bogies. It was assumed that the freight was distributed evenly relative to the horizontal plane, i.e., without a heap, and did not move relative to the open wagon body. That is, the own degree of freedom of the freight was not taken into ac-count when modelling the dynamic load of the wagon.

The differential equations were solved with the Runge–Kutta method in MathCad [12 – 14]. The initial displacements and speeds were taken equal to zero [15 – 17].

The dependence of the acceleration of the wagon body in the centre of mass on the inequality amplitude in the interaction zone of the rails is shown in Figure 4.

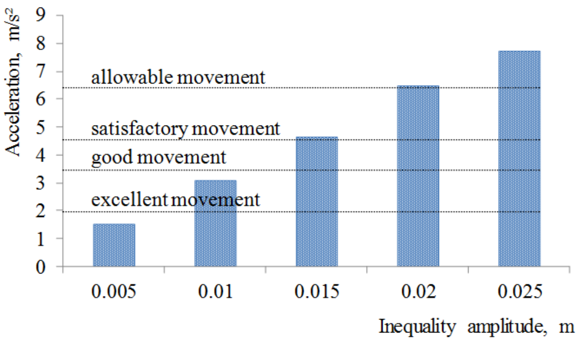


Figure 4. Dependence of the wagon body acceleration in the centre of mass on the inequality amplitude

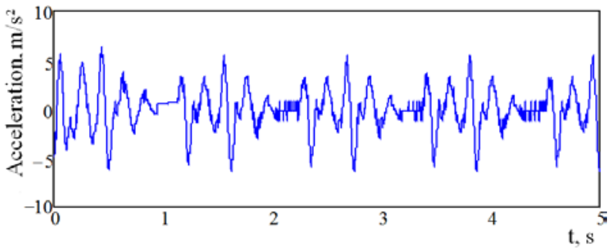
The results of the study made it possible to determine the inequality amplitude in the zone of interaction between the ramp and the train ferry, which can ensure the permissible dynamic load of the open wagon body in accordance with document [18]. The permissible value of the inequality amplitude is 0.021 m.

The main dynamic indicators of the open wagon, which characterize its movement, when passing over the interaction zone of the rail tracks between the ramp and the train ferry at the given inequality amplitude, are shown in Figure 5.

In this case, the coefficient of vertical dynamics is determined as follows [9]

$$k_{dv} = \frac{P_{sp}}{P_b}, \quad (11)$$

where P_{sp} – the force arising in the spring suspension of the bogie; P_b – the load force of the bogie from the wagon body.

a)


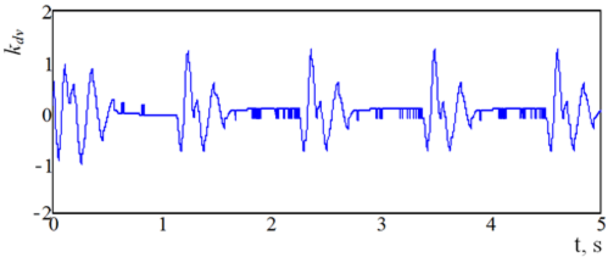
b)


Figure 5. Indicators of dynamics of the open wagon when passing over the zone of interaction of the rail tracks between the ramp and the train ferry
a) acceleration at the centre of mass;
b) coefficient of vertical dynamics

To determine the force in the spring suspension, formula [9] was used

$$P_{sp} = k_b \cdot \delta + F_{FR} \cdot sign\dot{\delta}, \quad (12)$$

where $\delta, \dot{\delta}$ – the deformation of the elastic elements of the spring suspension and the speed of deformation, respectively.

Thus, analysing the dependencies shown in Figure 4, it can be concluded that the maximum acceleration value acting on the open wagon body at the given inequality amplitude is 6.4 m/s², and the coefficient of vertical dynamics is 0.65. These indicators of dynamics correspond to the permissible movement of the wagon.

4 CONCLUSIONS

1. A mathematic simulation of the dynamic load on the open wagon body when rolling on the train ferry is carried out. The dependences of accelerations acting in the centre of mass of the body on the inequality amplitude in the zone of interaction of the rail tracks between the ramp and the ferry deck are obtained.
2. The permissible inequality amplitude in the zone of interaction of the rail tracks between the ramp and the ferry deck, so that the indicators of the wagon dynamics are within the permissible values, is determined. The permissible value of the inequality amplitude is 0.021 m.
   The conducted study will contribute to the database of developments on ensuring the operational safety of wagons used in international railway sea transportation, including the creation of an improved loading scheme by modernizing the transition bridge.

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