ВЫВОДЫ

1. Максимальные значения ускорений, действующих на кузова вагонов при перевозке их паромами, для акватории Черного моря с учетом технических характеристик ЖДП типа «Герои Шипки» составили около 0,3 *g*, что отлично от величин ускорений, обозначенных в п. 2.18 «Норм для расчета и проектирования вагонов железных дорог МПС колеи 1520 мм (несамоходных)». Это указывает на необходимость пересмотра и дополнения норм, внесения в них величин ускорений, свойственных условиям перевозки различными типами морских паромов через акватории прохождения железнодорожно-паромных маршрутов.

2. Поскольку значения инерционных нагрузок, которые действуют на кузова вагонов при перевозке подвижного состава на ЖДП, превышают эксплуатационные на магистральных путях, требуется усовершенствование несущих вагонных конструкций для обеспечения их надежного закрепления на паромных палубах.

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A RAILWAY CAR ON A FERRY: IMPACT OF SEA WAVE

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ABSTRACT

The development of foreign economic relations between Europe and Asia promotes the establishment and operation of combined transport systems. The most promising among them are considered piggyback and container transportation. In countries with access to the sea area, ferry transportation has found a successful application. The process of loading of bearing structures of car bodies when they move on rail ferries by sea requires special attention, as the dynamic characteristics, which are typical of this type of combined transportation, significantly differ from the normal operating characteristics on main lines.

The statistics of damage of cars during ferry transportation in the Black Sea area show that each year about 10% of the units of rolling stock used in international rail and water transportation require repair with uncoupling. This is primarily due to the lack of structural adaptation of car bodies to their fastening on the decks of car ferries and increased loads influencing them during transportation in terms of sea waves.

The disadvantage of usually applied techniques of research on the conditions of freight transportation using car ferries is inability to account for wave angle with its disturbing influence relative to bodies of car ferries as well as for wind load on surface projection of a ferry with cars placed on its upper deck. The likelihood of moving of a car body during a sea wave is also disregarded.

The objective of the author is to present results of research on dynamics of bodies of freight cars during transportation on car ferries in confused sea with account of different wave angles in relation to the body of the car, using mathematical modeling, analysis, comparative method. The author presents the results of studies taking into consideration main types of vibration motion of a railway car at confused sea, which influence strength and stability of the body structure, located on the upper deck of the ferry. Since the revealed values of inertial loads that act on the bodies of cars for transportation of rolling stock on car ferries exceed operating loads on main routes, it is necessary to improve bearing car structures to ensure their secure fixing to the ferry decks.

Keywords: railway-sea transportation, ferry transportation, sea waves, freight car, impact dynamics, loading of the structure, mathematical model.

Background. *The development of foreign economic relations between Europe and Asia promotes the establishment and operation of combined transport systems. The most promising among them are considered piggyback and container transportation. In countries with access to the sea area, ferry transportation has found a successful application.*

The process of loading of bearing structures of car bodies when they move on rail ferries by sea requires special attention, as the dynamic characteristics, which are typical of this type of combined transportation, significantly differ from the normal operating characteristics on main lines.

The statistics of damage of cars during ferry transportation in the Black Sea area show that each year about 10% of the units of rolling stock used in international rail and water transportation require repair with uncoupling. This is primarily due to the lack of structural adaptation of car bodies to their fastening on the decks of car ferries and increased loads influencing them during transportation in terms of sea waves.

Objective. *The objective of the author is to present results of research on dynamics of bodies of freight cars during transportation on car ferries in confused sea with account for different wave angles in relation to the body of the car.*

Methods. *The author uses mathematical modeling, analysis, comparative method.*

Results.

Evaluation approaches

Research on the conditions of freight transportation using car ferries is considered in scientific works of different years, in particular in [1]. The disadvantage of techniques cited therein is inability to account wave angle with its disturbing influence relative to bodies of car ferries as well as wind load on surface projection of a ferry with cars placed on its upper deck. The likelihood of moving of a car body during a sea wave is also disregarded.

Study of external loads acting on the bodies of cars during ferry transportation was carried out by Marine Engineering Bureau (Odessa, Ukraine) [2]. In this case, the required data have been identified on the basis of calculation of vibrations of car ferries occurring with six degrees of freedom in terms of irregular three-dimensional sea disturbance when the vessel is at a speed of 6,5 knots. The methodology used is suitable only for single-deck ferry in restricted navigation area, besides it does not take into account the potential compliance of the car body with respect to the deck.

Acceleration model

To ensure the safety of freight cars' movement it is necessary to examine features of main types of loads that act on their body during ferry transportation. In this case, one of the defining loads is inertial load caused by sea waves.

Research schemes of fixing cars on the decks of Ukrainian car ferries at stations «Ilyichevsk-Ferry» and subsidiary «TIS-Crimea» showed that during sea transportation a compliance of bodies can occur, which is caused most often by one or more of following reasons:

– *Unevenness of the deck;*

– *Faulty device interaction of cars with a deck of a car ferry;*

– *Variations in the geometry of the body, its deformation;*

– *Asymmetry in loading of body with cargo;*

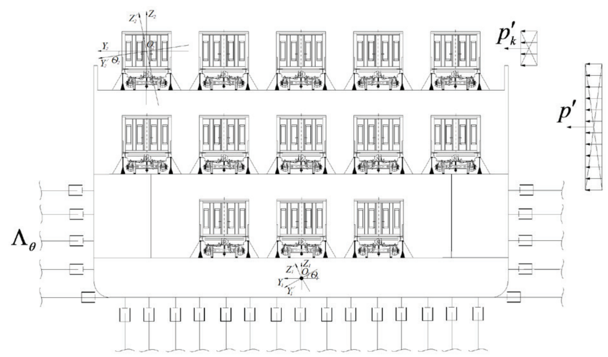
– *Human factor in fixing cars.*

To determine the acceleration acting on bodies of cars during ferry transportation, a mathematical model has been developed that describes the movement of car structures in roll as a form of vibration motion, having the greatest influence on the stability of the body relative to the deck. Design scheme of the car body, placed on a car ferry, is shown in Pic. 1.

The first equation of the mathematical model describes the movement of the ferry, and the second equation describes the movement of the car body relative to the deck. The calculations were performed on the example of a car ferry type «Heroes of Shipka».

$$\begin{cases} \left(\dfrac{D}{12\cdot g}(B^2+4{z_g}^2)\right)\ddot{q}_1+\left(\Lambda_\theta\cdot\dfrac{B}{2}\right)\dot{q}_1= \\ =p'\cdot\dfrac{h}{2}+\Lambda_\theta\cdot\dfrac{B}{2}\cdot\dot{F}(t), \\ I_y^\kappa(\ddot{q}_1+\ddot{q}_2)=p'\cdot\dfrac{h_\kappa}{2}, \end{cases} \qquad (1)$$

where $q_1=\theta_1,\ q_2=\theta_2$ *are generalized coordinates (* θ_1 *corresponds to angular displacement of the ferry relative to the longitudinal axis (heeling) passing through its center of figure;* θ_2 *corresponds to the angular displacement of a car body relative to the longitudinal axis passing through its center of gravity); D is weight displacement of a car ferry, kN; B is its width, m;* z_g *is coordinate of the center of gravity of the ferry, m; h is height of the side, m;* Λ_θ *is coefficient of resistance to fluctuations, kN·s·m* $^{-1}$*;* p' *is wind load on the surface projection of a car ferry, kN; F (t) is law of action of a force, which disturbs the movement of the ferry with bodies of cars, placed on its decks;* I_y^κ *is moment of inertia of the car body relative to its longitudinal axis, t·m* ^{2}*;* p'_κ *is wind load on the side wall of the car body, located on the upper deck, kN;* h_κ *is height of the car body, m.*



Pic. 1. Design scheme of the car body, placed on the deck of a car ferry.

The coefficient of resistance to angular displacement of a car ferry relative to the longitudinal axis is determined by:

$$\Lambda_\theta = \int_{-L/2}^{L/2} l' \cdot \rho \cdot \omega \cdot T^2 dL, \qquad (2)$$

where l' *is dimensionless damping coefficient per unit length of the ferry and determined on the basis of reference books, depending on the specifications of a car ferry;* ρ *is density of sea water, kN/m*^{3}*;* ω *is frequency of disturbance, s*$^{-1}$*; T is draft of the ferry, m. Disturbance is given in the form of a trochoidal law of sea wave motion [3].*

The input parameters of the mathematical model are specifications of a car ferry, car body, as well as meteorological data of navigation area. Initial displacement and speed of the ferry are assumed to be zero, for the car initial displacement was determined by possible yielding of its nodes relative to the deck (axle equipment relative to the axis of the wheelset, bogie frame relative to the axis of the axle equipment, the friction wedge relative to the middle of the sidewall, bolster relative to the friction wedge, center plate on center pad [4]) and was 31 mm.

In drawing up the mathematical model a blow of a sea wave on the side of a car ferry was not considered.

Solution of differential equations was carried out in an environment of software Mathcad [5, 6] using the Runge-Kutta method.

The calculation results are summarized in Pic. 2. Moreover, the total value of acceleration that acts on bodies of cars during their transportation with car ferries also includes a horizontal component of gravitational acceleration. With account of this, the total value of acceleration acting on the body of the car on the outer track relative to the bulwark, was about 0,3 g; on the body located on the second track relative to the bulwark – 0,24 g, placed on the middle track – 0,22 g.

The obtained values of acceleration exceed acceleration acting on the body of cars in operation on main lines [7].

Conclusions.

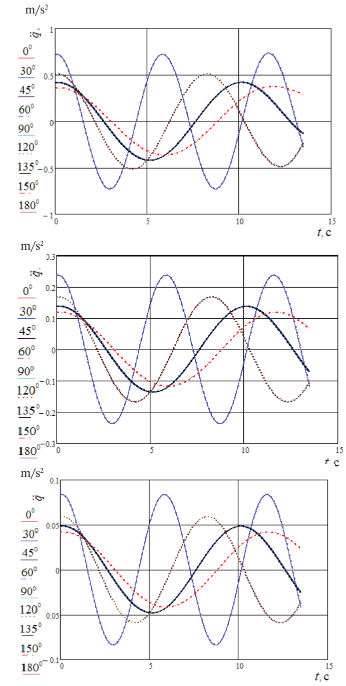
1. The maximum acceleration acting on the body of cars during ferry transportation for the Black Sea area, taking into account technical characteristics of a car ferry like «Heroes of Shipka» amounted to about 0,3 g, which differs from the value of the acceleration indicated in paragraph 2.18 «Standards for calculation and design of cars of railways of Ministry of Transportation with gauge 1520 mm (non-self propelled)». This implies the need to revise and supplement the rules, adding to them the values of acceleration, peculiar to conditions of transportation with different types of sea ferries passing through waters of rail ferry routes.

2. Since the values of inertial loads that act on the bodies of cars during transportation of rolling stock on car ferries exceed operating loads on main routes, require it is necessary to improve of bearing car structures to ensure their secure fixing to the ferry decks.

a)

b)

c)



Pic. 2. The accelerations that act on the body of the car during transportation by a car ferry: a) the body is on the outer track relative to the bulwark; b) the body is on the second track relative to the bulwark; c) the body is on the middle track.

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