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Testing of the device for transporting semi-trailers without tractor on 13-9004M model platforms

For the implementation of a mixed type of transportation on the territory of Ukraine, a stable saddle for transporting cargo semi-trailers without a tractor on railway platforms of the 13-9004M model was developed and manufactured. This device for the transportation of cargo semi-trailers is a four-sided structure of the "Eiffel Tower" type, the lower plane of which is fixed on the platform car through the plate with the help of bolted connections. This work describes the running tests of the 13-9004M model platform car with a saddle rack installed on it for the transportation of cargo semi-trailers without a tractor. According to the results of the tests of the saddle rack for the transportation of semi-trailers on the platform wagon model 13-9004M, the maximum values of the stresses that occur in the structure of the saddle rack during running strength tests, as well as compliance with such indicators as the coefficient of vertical dynamics of the sprung mass of the cart, the coefficient of vertical dynamics of the unsprung mass, were determined trolley frame, coefficient of horizontal dynamics, coefficient of reserve of stability of the wheel from derailment.

Keywords: *railway transport, wagon, tests, transportation of semi-trailers.*

Introduction. In order to evaluate quality indicators, the safety of the movement of wagons and other types of rails rolling stock, a variety of approaches to the assessment of safety conditions and the solution of the specified problem are noted.

In the study guide [1], the basics of theoretical and experimental methods of determining the dynamics of cars are laid out, information is given on the safety conditions of train movement based on dynamic indicators.

Standards DSTU 7598 (2014) [2] will describe requirements for calculations, design of new and modernized wagons of gauge 1520 mm, and requirements for their strength and dynamic qualities. Standards DSTU GOST 33211 (2017) [3] describes requirements for the strength and dynamic qualities of freight cars.

The coverage of the results of work on determining ways to increase the degree of ideality of freight cars and forecasting the evolution of the chassis of new-generation cars is described in the work [4]. Work [5] describes the principle of cataloguing the construction of the wagon according to its design and construction. In article [6] features of the mathematical modelling of the dynamic load of containers placed on the platform during a shunting collision are given. Numerical values of accelerations acting on the container are determined. The results are confirmed by computer simulation. The article [7] gives promising directions for constructing half-car frames and their features, which can be applied to other types of freight cars. The methods [8] for determining the locomotive wheel-rail angle of attack are considered. To reduce the power impact of the wheel flange with the rail head when the locomotive moves on curved sections of the track, it is advisable to change the locomotive wheel-rail angle of attack by turning the wheel pairs. Controlling the locomotive wheel pair position is possible by means of an operational measurement of the actual wheel-rail angle of attack. Measurement of the wheel-rail angle of attack is not performed because it is impossible to determine the value directly. In the [9] describes the method of determining the technological stresses that arise in the structure being repaired during the hardening of the composite patch. A special wagon for intermodal transportation is presented in the article [10], which can transport cars with a weight of up to 36 tons and a height of up to 4 m. These developments can be used in the design of new wagons for intermodal transportation. Identification of the causes of cracks in the frames of wagons for transporting containers and evaluation of the fatigue strength of welded joints is described [11]. In work [12] described the design of the car for various loading conditions, taking into account the actual condition of the track. The article [13] discusses the study of the elastic system dynamics for spindle assembly of drilling-milling-boring machining center type. A three-dimensional model of the spindle assembly on rolling bearings is built. A constructive and design diagram of the spindle assembly and a system of forces acting in the process of milling workpieces are formed. Work [14] is devoted to the development of electrohydraulic drives of technological equipment. The engineering method of calculating the automatic electro-hydraulic drive of rotary motion with volume regulation is presented. This method allows you to estimate the main parameters and select drive elements and devices based on the maximum load moment and rotation speed of the hydraulic motor, predict its static and dynamic characteristics. Analysis of wagon body strength calculations and real tests of the series wagon Sdggmrss-twin given in work [15].

Purpose and objectives of the study. The purpose of the research is to carry out tests of the saddle rack for the transportation of semi-trailers without a tractor on platform wagons of the 13-9004M model for further safe operation.

Materials and methods of research. For the introduction of a mixed type of transportation on the territory of Ukraine, a device for transporting semi-trailers on railway platforms of the 13-9004M model was developed and manufactured, and a set of tests aimed at evaluating the dynamics of the car and the strength of the device for transporting cargo semi-trailers was conducted. The device for the transportation of cargo semi-trailers is a four-sided construction of the "Eiffel Tower" type, the lower plane of which is fixed on the platform car through the plate with the help of bolted connections. A saddle with a lock is installed on the upper plane of the device to fix the semi-trailer against longitudinal and transverse movements. This design makes it possible to obtain optimal strength properties and uniform distribution of weight transmitted from the semi-trailer seat. If necessary, such a structure can be flexibly folded for the transportation of containers on platform wagons of the 13-9004M model. The wheels of the cargo semi-trailer have 2 fixing options:

1) supports that are installed in the corresponding grooves;

2) special platforms installed under the wheels and stretched by cables attached to the external brackets of the 13-9004M platform car.

From the lateral displacement of the rear part of the semi-trailer, the design of the platform car model 13-9004m provides for the lowering of the floor with the formation of the corresponding side walls due to the external longitudinal beams of the car.

The test facility, consisting of a 13-9004M platform car with a device for transporting semi-trailers and a loaded semi-trailer installed on it, is shown on Fig. 1.

In accordance with the test program according to the layout of tensor resistors shown in Fig. 2 and 3, strain gauges were installed on the elements of the device for transporting semi-trailers on the platform wagon and on the carriage of the platform wagon model 13-9004M and their connection into a Wheatstone half-bridge circuit with one active and compensating strain gauge. Such a scheme provides a measuring channel, which is supplemented by a strain gauge module NI 9237, which performs scaling of instantaneous values of the input voltage and analog-digital conversion into a digital signal. After connecting and checking the performance of the measuring equipment, stress measurements were made in the elements of the device for transporting semi-trailers on the 13-9004M platform car during experimental trips in a loaded state at speeds up to 90 km/h to evaluate the strength indicators and natural frequencies of oscillations.

Fig.1. **Platform car model 13-9004M with a device installed on it for transporting semi-trailers and loaded semi-trailers**

Processing of the test results was performed on a computer using specialized mathematical software for statistical processing of the primary results obtained during the experimental trip. The measuring complex for diagnostics and testing of rolling stock consists of a software-hardware automatic recorder, a set of communication cables, a computer and software. The automatic hardware and software recorder based on the NI 9012 controller consists of the NI 9237 ADC strain gauge modules, the NI 9205 ADC modules and the GPS module.

In order to evaluate the running qualities based on the values of the measured dynamic indicators of the car, the probable maximum values of the coefficients of vertical dynamics of the sprung K_{do} and non-sprung K_{dn} masses of the car, lateral (frame) forces, and the value of the coefficients of the reserve of stability from falling off the K_{yc} rails are determined using ratios taking into account the calibration data.

The maximum values of the coefficients of vertical dynamics and frame forces are determined with a confidence probability of 0.97 (according to the amplitude value) and 0.97 (according to the instantaneous values), and the minimum values of the coefficients of the stability margin against derailment, with a confidence probability of no more than 0.0001. The sum of the frame forces acting at the same instant of time on the frame from each axle of one wheel pair is taken as the value of the lateral (frame) force of the H_p.

The calculation of the coefficient of stability of the wagon against derailment when the wheel ridge creeps onto the rail under the action of dynamic forces arising during movement, the coefficients of vertical dynamics of the sprung and unsprung masses of the wagon are given below. The coefficient of vertical dynamics K_d is generally determined from the following expression:

$$К_d = \frac{\sigma_d}{\sigma_{ct}}, \quad (1)$$

where σ_d - is the dynamic stress from the vertical load in the section of this element; σд;
σ_{ct} - static load from vertical load in the same section.

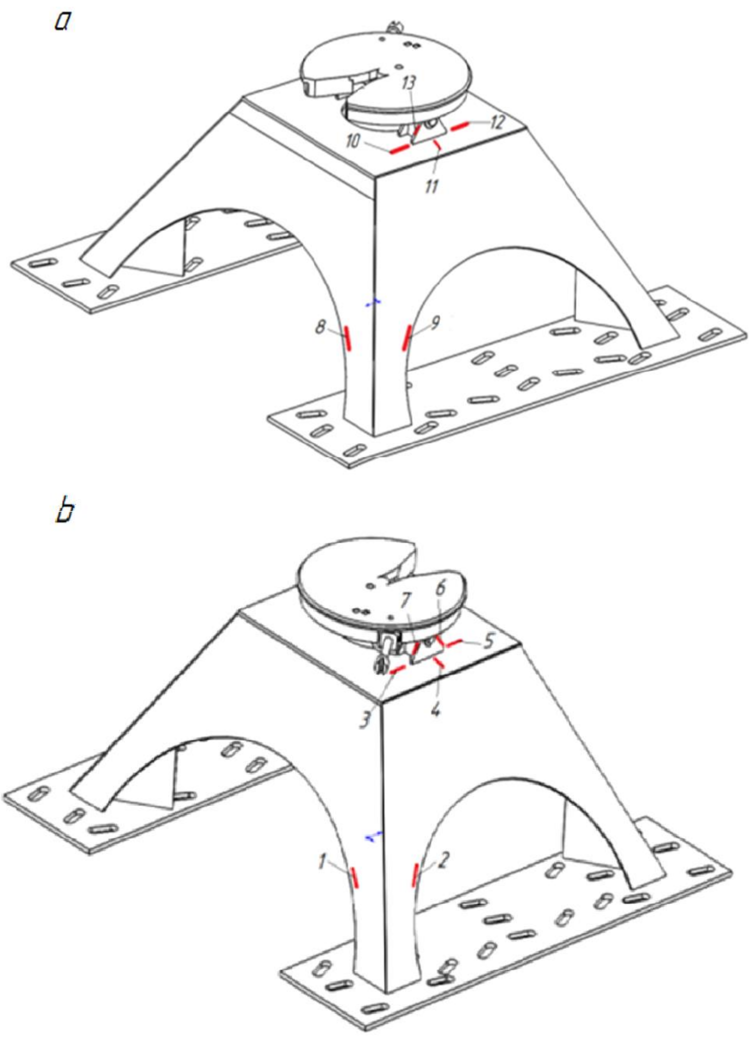

Fig. 2. **Locations of strain gauges on the device for transporting semi-trailers on a platform wagon(a) front view; (b) back view**.

The coefficient of horizontal dynamics (frame force in portions of the axial load) – $К_{dg}$ is determined by the formula:

$$К_{dg} = \frac{H_r}{P_o}, \quad (2)$$

where Hr – horizontal lateral frame force;
P_o - vertical static load from the axle to the rails.

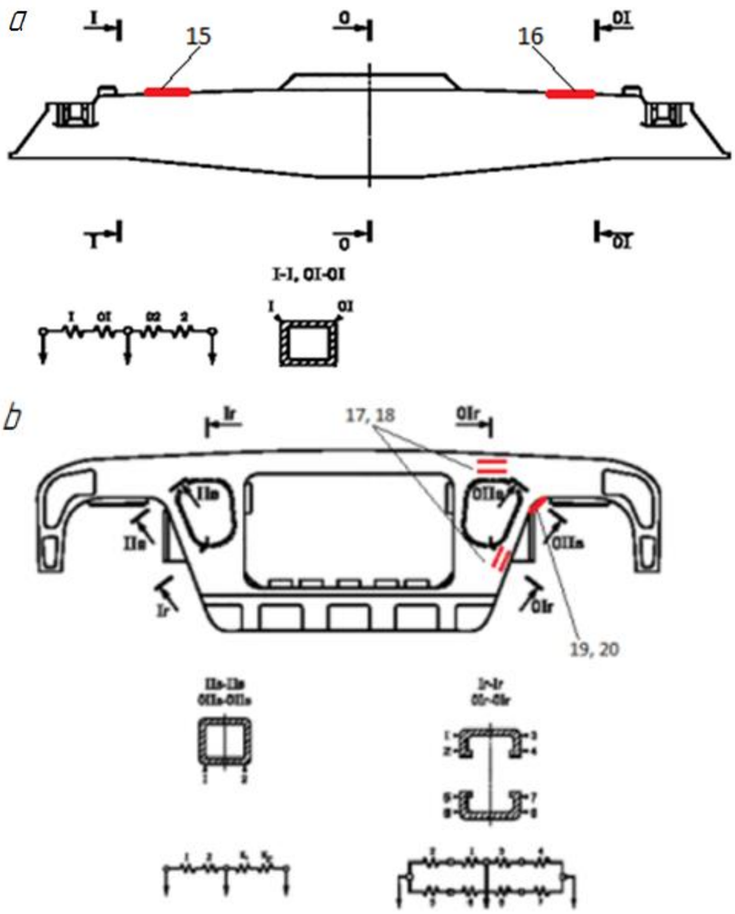

Fig. 3. **Location of strain gauges (a) on cart beam; (b) on cart frame**

The coefficient of stability of the wheel from derailment is determined by calculation based on the integral coefficient calculated for the range of operating speeds with a probability of 0.001. The stability of the wheel against derailment was evaluated using the following formulas:

$$К_{yc} = Ɛ\frac{P_v}{P_b} \geq [К_{yc}] , \quad (3)$$

$$Ɛ = \frac{tg\beta - \mu}{1+\mu tg\beta}, \quad (4)$$

where β - angle of inclination of the generating ridge of the wheel to the horizontal axis;
$\beta = 60°$;
μ - coefficient of friction, = 0.25;
R_v - the vertical component of the reaction force of the running wheel on the head of the rail;
R_b - the horizontal component of the reaction force of the running wheel on the head of the rail, which acts simultaneously with P_v;
$[К_{yc}]$ - is the permissible value of the stability margin coefficient.

When using type 2 wheelbarrows, the formula looks like this:

$$К_{yc} = \frac{tg\beta-\mu}{1+\mu tg\beta} * \frac{Q_{sh}\left(1{,}03-1{,}17К_d^h+К_d^{hh}\right)+0{,}15q_{kp}+0{,}305Н_p}{Q_{sh}\left(0{,}242+0{,}042К_d^{hh}-0{,}285К_d^{hh}\right)+0{,}121q_{kp}+0{,}92Н_p}, \quad (5)$$

where $К_d^h$ - coefficient of vertical dynamics on the running wheel;
$К_d^{hh}$ - coefficient of vertical dynamics on a non-running wheel;
$Н_p$ - horizontal lateral frame force;
Q_{sh} - the force of gravity of the over-spring parts of the car, acting on the neck of the axle of the wheel pair, kN, is determined by the formula:

$$Q_{sh} = \frac{Q-nq_{kp}}{2n_o}, \quad (6)$$

where Q - weight of the wagon, kN,
q_{kp} - the force of gravity of unreinforced parts, which falls on the wheel pair, kN;
n_o - the number of wagon axles;

The value of $Н_r$ is accepted as positive in the case of directing it in the direction of the wheel run-up, and - in the case of unloading the wheels.

The results of running strength testssaddle racks for transporting semi-trailers on platform wagons 13-9004M with an installed semi-trailergiven in Table1 and 2.Figs 4 and 5 show the histograms of the speed ranges during the experimental trip on the section of Art. Darnytsia - art. Nizhin - st. GiftAccording to the registered data of dynamic processes, the indicators of the running dynamic qualities of the car with a stable saddle with an installed semi-trailer in the loaded state were calculated. The results are given in Table 3 and 4.

Table 1. **Maximum stresseson the Darnytsia - Nizhyn section**

Strain gauge	Speed ranges km/h															
	10-20		20-30		30-40		40-50		50-60		60-70		70-80		80-90	
	MAKC MPa	SKO	MAX MPa	SKO	MAX MPa	SKO	MAX MPa	SKO	MAX MPa	SKO	MAX MPa	SKO	MAX MPa	SKO	MAX MPa	SKO
1	7.22	1.06	4.43	0.97	3.51	0.98	5.28	1.40	6.94	2.13	8.02	2.14	8.91	2.20	7.34	2.12
2	19.92	3.26	12.51	3.23	10,15	2.70	14.71	4.08	15.61	4.80	18.81	5.51	21.34	5.50	17.85	5.54
3	4.31	0.66	3.44	0.88	2.47	0.71	4.19	1.15	4.26	1.28	5.58	1.48	7.38	1.41	4.80	1.31
4	8.37	1.66	4.72	1.42	6:00 a.m	1.89	7.21	2.16	9.37	3.21	11,24	3.50	15.25	3.96	12.91	3.85
5	2.15	0.40	1.59	0.49	1.23	0.39	2.09	0.53	2.31	0.66	3.12	0.86	4.76	0.99	3.70	0.98
6	2.03	0.47	1.64	0.46	1.48	0.38	1.88	0.53	2.61	0.72	3.56	0.92	7.45	1.20	4.60	1.21
7	3.10	0.80	3.51	1.21	2.99	0.94	4.80	1.64	5.73	1.90	6.51	2.10	8.73	2.13	6.80	2.25
8	8.75	1.66	5.87	1.68	5.06	1.61	7.85	2.23	8.87	2.78	10,15	2.96	10.97	2.93	9.17	2.89
9	6.34	1.93	5.88	1.86	5.45	1.74	8,11	2.66	9.97	3.27	11.75	3.80	14,28	4.17	13.31	4.22
10	2.37	0.65	2.14	0.78	1.93	0.57	2.61	0.76	3.19	0.96	4.29	1.29	7.32	1.71	5.56	1.67
11	12.70 p.m	3.22	13.38	5.04	10.60	3.43	17.93	5.47	19.42	5.80	24,14	7.40	28,42	9,14	26.79	8.86
12	3.95	1.11	4.97	1.67	4.39	1.42	6.95	2.43	8.42	2.86	8.93	2.98	10.91	2.78	8.57	2.64
13	11.33	1.68	8.32	1.78	6.21	1.31	7.52	1.79	8,13	2.07	11.08	2.83	26.61	3.93	11,10	3.41

Table 2. **Maximum stresses on theNizhyn - Darnytsia section**

Strain gauge	Speed ranges km/h													
	10-20		20-30		30-40		40-50		50-60		60-70		70-80	
	MAKC MPa	SKO	MAX MPa	SKO	MAX MPa	SKO	MAX MPa	SKO	MAX MPa	SKO	MAX MPa	SKO	MAX MPa	SKO
1	2.68	0.67	3.72	1.09	3.10	0.99	3.74	1.22	4.99	1.57	5.99	1.70	6.08	1.85
2	6.90	2.15	11,12	3.42	9,13	2.88	10.92	3.74	12.67	4.21	12.79	4.12	17.96	5.74
3	1.40	0.45	2.91	0.94	2.46	0.76	3.21	0.96	3.73	1.18	5.00	1.15	3.55	1.12
4	5.50	1.35	6.28	1.46	6.71	1.73	7.61	2.17	8.57	2.72	10.52	3.40	11.41	3.75
5	1.01	0.31	1.45	0.43	1.31	0.40	1.65	0.50	2.63	0.77	2.99	0.87	3.61	0.99
6	1.30	0.42	2.16	0.57	1.97	0.50	3.10	0.65	3.05	0.82	3.70	0.99	5.31	1.42
7	2.40	0.69	4.26	1.40	3.31	1.08	4.29	1.37	5.40	1.74	5.45	1.67	6.66	2.19
8	4.49	1.21	6.02	1.71	5.09	1.48	6.59	2.17	7.22	2.27	7.23	2.30	8.02	2.41
9	5.30	1.68	7.51	2.22	6.37	1.89	8,17	2.69	10,13	3.23	10.98	3.47	14,22	5.01
10	1.68	0.56	2.10	0.63	1.79	0.53	2.64	0.80	3.73	1.14	4.20	1.31	5.22	1.72
11	9.38	2.54	12.90	4.00	9.94	3.05	15.39	4.61	20.89	6.44	21.61	7.09	25.49	8.28
12	3.07	0.95	5.66	1.86	4.72	1.52	6.23	2.11	6.98	2.40	6.66	2.23	7.78	2.41
13	5.49	1.32	12.49	2.68	13.54	1.86	18.48	2.73	9.53	2.44	13,24	2.79	11.05	3.60

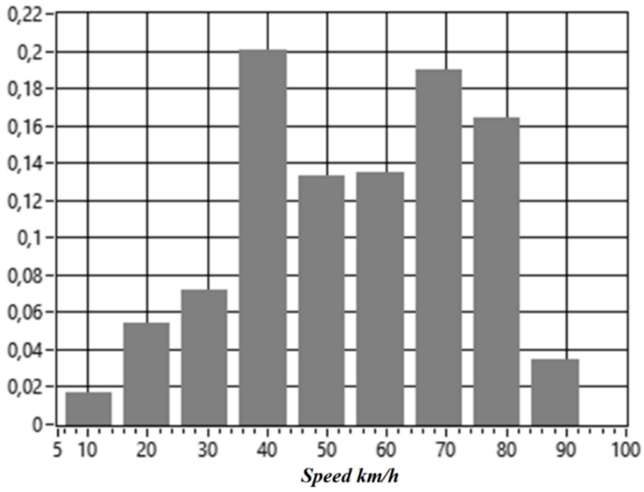

Fig. 4. **Histogram of speedon the Darnytsia - Nizhyn section**

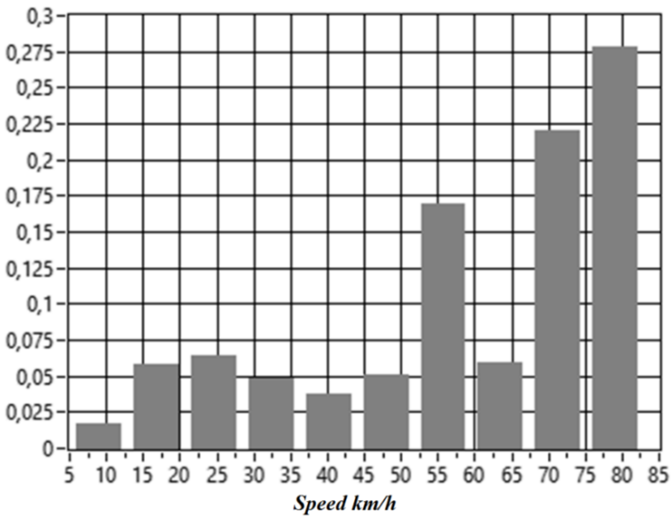

Fig. 5. **Histogram of speedon the Nizhyn - Darnytsia section**

Table 3. **Results of running dynamic testsplatform car 13-9004Mfromdevicefor transportation of semi-trailers on a platform wagonand an installed semi-trailer in a loaded state on the Darnytsia - Nizhyn section**

Monitored characteristics	Normative value	The value of the indicator at a speed of km/h							Unrecognized honesty, %
		20	30	40	50	60	70	80	
The coefficient of stability margin of the wheel from derailment on straight and curved sections of the track	At least 1.3	1.9	1.85	1.75	1.67	1.62	1.48	1.46	2.1
Frame forces Nr, t	-	0.38	0.47	0.5	0.69	0.9	1.1	1.3	2.1
Coefficient of horizontal dynamics (frame force in parts P0 (Hp/P0), from the wheel pair to the trolley frame)	Not more than 0.4	0.07	0.09	0.1	0.13	0.18	0.22	0.26	2.1
Coefficient of vertical dynamics of the suspended mass of the cart, Kd,	Not more than 0.75	0.16	0.19	0.2	0.22	0.25	0.28	0.3	2.1
Coefficient of vertical dynamics of the unreinforced trolley frame, Kdn	Not more than 0.90	0.24	0.26	0.29	0.32	0.37	0.43	0.46	2.1

Table 4. **Results of running dynamic testsplatform car 13-9004Mfromdevicefor transportation of semi-trailers on a platform wagonand an installed semi-trailer in a loaded state at the Nizhyn - Darnytsia section**

Monitored characteristics	Normative value	The value of the indicator at a speed of km/h							Unrecognized honesty, %
		20	30	40	50	60	70	80	
The coefficient of stability margin of the wheel from derailment on straight and curved sections of the track	At least 1.3	1.92	1.83	1.78	1.65	1.6	1.49	1.47	2.1
Frame forces Nr, t	-	0.39	0.45	0.52	0.72	0.95	1.2	1.32	2.1
Coefficient of horizontal dynamics (frame force in parts P0 (Hp/P0), from the wheel pair to the trolley frame)	Not more than 0.4	0.07	0.09	0.1	0.14	0.19	0.24	0.26	2.1
Coefficient of vertical dynamics of the suspended mass of the cart, Kd,	Not more than 0.75	0.18	0.20	0.23	0.24	0.27	0.31	0.32	2.1
Coefficient of vertical dynamics of the unreinforced trolley frame, Kdn	Not more than 0.90	0.26	0.27	0.31	0.34	0.38	0.46	0.48	2.1

Conclusions. According to the results of the tests of the saddle rack for the transportation of semi-trailers on the platform wagon model 13-9004M, it was established:

1. During running strength tests, the maximum stress values:
   - on the siteArt. Darnytsia - art. Nizhin – 28.42 MPa, channel 11 speed range 70-80 km/h;
   - on the siteArt. Nizhin - st. Darnytsia – 25.49 MPa, channel 11 speed range 70-80 km/h.
2. Platform wagon model 13-9004M withsemi-trailer rack for cargo semi-trailers without a tractor with an installed semi-trailer in a loaded state meets the requirements [2] according to the following parameters: the coefficient of vertical dynamics of the sprung mass of the trolley, the coefficient of vertical dynamics of the unsprung trolley frame, the coefficient of horizontal dynamics, the coefficient of the reserve of stability of the wheel from derailment in the range of speeds up to and including 80 km/h.

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Випробування пристрою для перевезення напівпричепів без тягача на платформах моделі 13-9004М

Для впровадження змішаного виду перевезень на території України розроблено та виготовлено стійку сыдельну для транспортування вантажних напівпричепів без тягача на залізничних платформах моделі 13-9004М. Даний пристрій для перевезення вантажних напівпричепів являє собою чотиригранну конструкцію типу «Ейфелева вежа», нижня площина якої закріплена на вагоні-платформі через плиту за допомогою болтових з'єднань. В даній роботі описано проведення ходових випробувань вагона-платформи моделі 13-9004М з встановленій на ній стійко сідельної для перевезення вантажних напівпричепів без тягача. За результатми випробувань стійки сідельної для перевезення напівпричепів на вагоні-платформі моделі 13-9004М встановлено максимальні значення напружень, що виникають в конструкції стійки сідельної під час ходових міцнісних випробувань, а також відповідність таким *показникам як коефіцієнт вертикальної динаміки обресореної маси візка, коефіцієнт вертикальної динаміки необресореної рами візка, коефіцієнт горизонтальної динаміки, коефіцієнт запасу стійкості колеса від сходу з рейок.*

Ключові слова: *залізничний транспорт, вагон, випробування, перевезення напівпричепів.*