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DETERMINING THE INFLUENCE OF GEOMETRIC PARAMETERS OF THE TRACTION-TRANSPORTATION VEHICLE'S FRAME ON ITS TRACTIVE CAPACITY AND ENERGY INDICATORS

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This paper reports results of studying the influence of geometrical parameters of the frame in a traction-transportation vehicle on its traction and energy indicators. A method for estimating the influence of geometrical parameters of the frame in a traction-transportation vehicle on its traction and energy indicators has been substantiated, based on the traction calculation of the tractor and taking into consideration the change in the distance from the hinge of the traction-transportation vehicle to the front and rear drive axles. The method makes it possible to determine the normal reactions, tangent thrust forces, and traction power on the wheels of the machine. The method reported here enables defining the optimal geometric parameters for improving the traction-adhesion and fuel-economic indicators of the traction-transportation vehicle. It was theoretically established that the normal reactions on the front wheels of the studied traction-transportation vehicle are 27,800 N and exceed by 1.95 times the normal reactions on the rear wheels of 14,200 N. This is due to the fact that the distance from the hinge to the corresponding axles of the wheels is 1.89 m and 0.97 m. Increasing the distance from the hinge to the axle of the rear wheels to 1.17 m produces a positive effect on improving the tractive performance of the traction-transportation vehicle. There is an increase in the tractive power on rear wheels to 24.39 kW. The experimental study of the traction-transportation vehicle was performed using an all-wheel-drive machine with a hinge-connected frame as an example. The maximum traction power is 121 kW, which is achieved at a speed of 12 km/h, traction efficiency of 0.68, and a thrust force per hook of 30.2 kN. The difference between the results obtained theoretically and experimentally is 8 %. Applying the method could make it possible to provide designers and manufacturers with recommendations for the construction and improvement of a traction-transportation vehicle, to improve traction and adhesion properties, and reduce the anthropogenic impact on the soil

Keywords: tractive force, thrust force, normal reaction, geometric parameters, traction-transportation vehicle

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1. Introduction

To improve the efficiency of using mechanization tools in the agro-industrial sector, multi-operational combined assemblies with high productivity are increasingly used. One of the main components in combined assemblies is wheeled traction-transportation vehicles (TTV). Combined units make it possible to improve the efficiency of TTV use and reduce man-made effects on the soil by reducing the number of runs. At the same time, the application of modern agricultural machines involves the use of TTV with high tractive-adhesion properties [1]. However, while possessing a number of advantages, wheeled TTVs have insufficient traction and adhesion, in particular on soils with low carrying capacity. In addition, combined agricultural assemblies have a large mass compared to conventional ones, which limits their use due to insufficient longitudinal stability of several wheeled TTV in the execution of technological operations. Traction-adhesion properties are especially influenced by the location of the center of mass [2] and the geometric parameters of the TTV frame. The design of modern TTV for enhanced energy efficiency and energy saturation leads to an increase in the mass-geometric parameters of vehicles. The functioning of TTV of increased mass and engine power requires additional research on the impact of the location of the center of mass on their tractive and energy indicators. Therefore, it is a relevant task to assess the impact of geometrical parameters of the TTV frame on the tractive force and energy indicators.

2. Literature review and problem statement

In order to improve the efficiency of combined agricultural assemblies under actual operating conditions, loading on the drive and driven axles of TTV is increased by installing additional cargoes, which, in turn, enhances the anthropogenic impact of the vehicle on soil [2].

The analysis reported in [3] revealed that one of the promising ways to improve the efficiency of using wheeled TTV during field and transportation operations is to increase their tractive-adhesion properties. Man-made effects on the soil can be reduced by the rational utilization of adhesion weight. The authors failed to determine the influence of the position of the center of gravity on the redistribution of tractive force among TTV wheels.

The impact of the effective mass of a vehicle on the position of the center of gravity was not studied in detail in [4]. The influence of geometrical parameters on the energy indicators of vehicle operation was disregarded. It should be noted that the cited study was performed for a single-element vehicle while TTVs are most often multi-element assemblies.

The kinematics of individual components of the system discussed in work [5] are not investigated taking into consideration the location of the centers of mass of elements and geometrical parameters of the frame.

For multi-mass vehicles examined in [6], no influence of the location of the center of mass on energy indicators was determined. The dynamic and energy indicators of the unit that depend on the location of the center of mass were investigated by the authors of work [7]. Their study was performed on a single-mass vehicle.

While solving the problem of aerodynamics, the authors of [8] investigated the dynamics of a single-mass system in an airflow. The study does not take into consideration the influence of geometrical parameters of the single-mass system on energy indicators and their relationship with its dynamics.

Paper [9] reports a mathematical model of an element's dynamics under the influence of aerodynamic forces. The position of the center of gravity is investigated as static.

Study [10] describes an analytical technique to determine the coordinates of the center of gravity, which implies the knowledge of the mass and mutual location of individual nodes of the vehicle. It should be noted that the cited study was carried out for single-element units.

The researchers in [11] determined the impact exerted on the dynamic and energy indicators by changes in the position of the center of gravity. The cited study cannot be applied to TTV with a hinge-connected frame.

Our review of the scientific literature [2–11] revealed that the influence of the geometrical parameters of the frame of vehicles on their tractive capacity and energy indicators for multielement (multi-mass) units remains unexplored. In addition, the geometrical parameters of the location of the TTV mass center on its dynamics are not investigated in detail. TTV of enhanced mass and power mainly have a hinged-connected frame, which has features in the location of the center of its mass.

3. The aim and objectives of the study

The aim of this study is to determine the influence of the geometrical parameters of the frame of a traction-transportation vehicle on its tractive capacity and energy indicators. This will provide designers and manufacturers with recommendations for the construction and improvement of TTV, for improving traction and adhesion properties, and reducing the anthropogenic impact on soil.

To accomplish the aim, the following tasks have been set:

– to assess the influence of the geometrical parameters of the TTV frame on the normal reactions of the wheels to the supporting surface;

– to investigate the influence of geometrical parameters of the TTV frame on tractive capacity and energy indicators;

– to conduct experimental studies of TTV to confirm the adequacy of the method for assessing the effect of the geometrical parameters of the frame of the traction-transportation vehicle on its tractive capacity and energy indicators.

4. The study materials and methods

4. 1. This study's object

Studying the dynamics of traction-transportation vehicles with a hinge-connected frame requires the construction of appropriate kinematic and dynamic schemes and a mathematical model of the process under study.

The object of this study is the relationship between the geometrical parameters of TTV frame and its tractive capacity and energy indicators.

When building mathematical models of TTV, the following assumptions were accepted:

1. The TTV elements are investigated as absolute solids symmetrical to the longitudinal plane.

2. The oscillatory processes induced by the irregularities (profile) of the supporting surface and the heterogeneity of physical and mechanical properties of the soil are not taken into consideration.

3. We do not account for the processes that occur in the transmission.

4. 2. Method for estimating the influence of geometrical parameters of the frame in a traction-transportation vehicle on its tractive capacity and energy indicators

The method for constructing a mathematical model of TTV as a multi-element (multi-mass) machine is discussed in detail in [12, 13].

A kinematic-dynamic model of the traction-transportation vehicle with a hinge-connected frame has been built (Fig. 1).

The kinematic-dynamic model of the traction-transportation vehicle (Fig. 1) is depicted with the following designations: *XOYZ* is the global coordinate system; *xoyz* is the linked coordinate system with the center of TTV mass; $x_1o_1y_1z_1$, $x_2o_2y_2z_2$ – connected coordinate systems with the centers of gravity of the TTV first and second half-frame. The angles α_i, β_i, γ_i indicate the angles of rotation of the vehicle and half-frames around the corresponding axes *x*, *y*, *z*. m_1, J_1 and m_2, J_2 – the mass and moments of inertia of the TTV first and second half-frame.

The symbol υ indicates the translational speed of TTV movement, and ψ is the angle of breaking the half-frames. The height of the profile of the supporting surface for the front left, front right, rear left, rear right wheels is given by the symbols h_{11}, h_{12}, h_{21}, h_{22}. The distance from the centers of mass of the half-frames to the axles of the front and rear wheels is l_1, l_2, and the tracks are marked as b_1, b_2. For TTV wheels, we introduce the following designations: *i* is the corresponding TTV axle (*i*=1 – front axle; *i*=2 – rear axle), *j* – side (*j*=1 – left side; *j*=2 – right side). For TTV wheels: r_{ij} is the dynamic radius of wheels, P_{kij} – thrust force, M_{kij} – torque, P_{fij} – rolling resistance force, N_{zkij} is the normal reaction.

Tractor theory is the scientific basis for further improvement of machine design, improving its efficiency, as well as intensifying its use. The purpose of TTV traction calculation is to determine its main characteristics [14].

The high tractive-adhesion and fuel-economic indicators of TTV can be achieved only in the case of the optimal ratio of its main parameters, which are determined by estimation at the design stage and by comparing the parameters with existing TTV [15, 16]. Their relationship characterizes the main performance indicators [17].

Underlying our traction calculation is the equation of traction balance. The tractive capacity of the tractor is determined for the following modes of operation: from rated mode, $M_{e.\text{nom}}$, to the mode of maximum torque of the internal combustion engine (ICE), $M_{e.\max}$, for the range of working gears.

The force of traction on each of the TTV wheels is determined depending on the ICE torque [18]:

$$P_{kij}=\frac{1}{2}M_e\cdot U_{tr}\frac{\eta_{tr}}{r_{kij}}\cdot\frac{l_i}{l_1+l_2},\ \text{N}, \qquad (1)$$

where M_e is the engine torque, Nm; U_{tr} is the transmission number; η_{tr} is the transmission efficiency.

The rolling resistance force for each tractor wheel is determined separately and takes into consideration the tire pressure, wheel load (normal reaction), and speed [19]:

$$P_f=\left(\frac{P_{ij}}{P_{0ij}}\right)^{\alpha}\left(\frac{N_{zkij}}{N_{zk0ij}}\right)^{\beta}N_{zk0ij}\cdot\left(A+B\left|\upsilon_{Cij}\right|+C\upsilon_{Cij}^2\right),\ \text{N}. \qquad (2)$$

Taking into consideration the formula for determining the tangent force of thrust (1) and the force of rolling resistance (2), the tractive effort on a tractor wheel is determined from the following expression:

$$P_{krij}=\frac{1}{2}M_e\cdot U_{tr}\frac{\eta_{tr}}{r_{kij}}\cdot\frac{l_i}{l_1+l_2}-$$
$$-\left(\frac{P_{ij}}{P_{0ij}}\right)^{\alpha}\left(\frac{N_{zkij}}{N_{zk0ij}}\right)^{\beta}N_{zk0ij}\cdot\left(A+B\left|\upsilon_{Cij}\right|+C\upsilon_{Cij}^2\right),\ \text{N}. \qquad (3)$$

The actual speed of TTV movement is determined via theoretical speed [19] taking into consideration the skidding of drive wheels:

$$\upsilon_a=\omega_e\cdot\frac{r_{kd}}{U_{tr}}\cdot(1-\delta),\ \text{m/s}, \qquad (4)$$

where δ is the skidding of drive wheels.

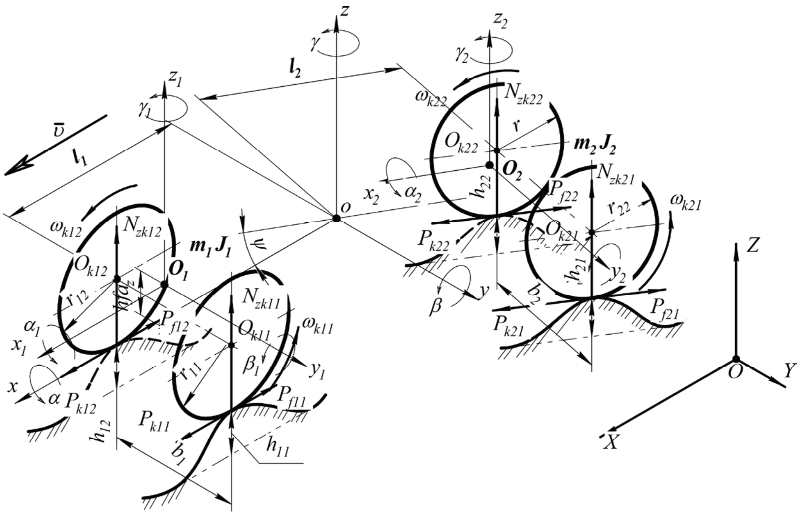

Fig. 1. A kinematic-dynamic model of the traction-transportation vehicle with a hinge-connected frame

The tractive force on TTV wheels is determined from the following expression:

$$N_{krij}=\frac{1}{2}M_eU_{tr}\frac{\eta_{tr}}{r_{kij}}\frac{l_i}{l_1+l_2}-$$
$$-\left(\frac{P_{ij}}{P_{0ij}}\right)^{\alpha}\left(\frac{N_{zkij}}{N_{zk0ij}}\right)^{\beta}\cdot N_{zk0ij}\left(A+B\left|\upsilon_{Cij}\right|+C\upsilon_{Cij}^2\right)\upsilon_a,\ \text{W}. \qquad (5)$$

The method of assessing the effect of the geometric parameters of the TTV frame on its tractive capacity and energy indicators is based on the traction calculation of the tractor and takes into consideration the change in the distance from the TTV hinge to the front and rear drive axles.

4. 3. A system to measure the dynamics and energy of mobile machines

To check the adequacy of the proposed method for assessing the impact of the geometrical parameters of the frame in a traction-transportation vehicle on its tractive capacity and energy indicators, we employed a system to measure the dynamics and energy of mobile machines; its structural diagram is shown in Fig. 2.

The measuring system used in our experimental studies refers to the technical means of diagnosing and operational control. It can be used in the agricultural and machine-building industries. The system is designed to determine the kinematic, dynamic, power, and energy characteristics of mobile machines and their elements during road, field, and bench tests [1].

The measuring system includes inertial measuring devices (IMU) consisting of gyroscopes (G) and acceleration sensors (A), navigation receiver (GPS), wheel dynamics sensors (WDS), electronic dynamometer (ED), and fuel consumption sensor (Q). For this measuring system, DASys PC Suite software was developed, which is responsible for storing information from sensors on an internal or external media carrier. Communication between sensors and computing module employs the CAN bus and radio channel in the range of 2.4 GHz [20].

5. Results of studying the influence of geometrical parameters of the frame in a traction-transportation vehicle on tractive capacity and energy indicators

5. 1. Influence of the geometrical parameters of the frame in a traction-transportation vehicle on the normal reactions of its wheels to the supporting surface

Our theoretical studies of TTV were carried out using all-wheel-drive tractors with a hinge-connected frame as an example. The static normal reactions of the supporting surface to TTV wheels were determined, equal to $N_{zk11}=N_{zk12}=2.78\cdot10^5$ N; $N_{zk21}=N_{zk22}=1.42\cdot10^5$ N at $\alpha=\beta=\gamma=\alpha_1=\beta_1=\gamma_1=\alpha_2=\beta_2=\gamma_2=0°$, that is, a TTV half-frame parallel to plane of the supporting surface.

The dependence of normal reactions on TTV wheels on the distance between the hinge and the axles of the front (Fig. 3) and rear (Fig. 4) half-frames has been established.

Our study was carried out for tractors in which the distance from the hinge to the corresponding wheel axles is $l_1=1.89$ m and $l_2=0.97$ m. Reducing the distance to $l_1=1.69$ m leads to a decrease in the normal reactions on the TTV front wheels to $N_{zk11}=N_{zk12}=2.67\cdot10^5$ N and an increase in the values of reactions on the TTV rear wheels to $N_{zk21}=N_{zk22}=1.53\cdot10^5$ N (Fig. 3). The increase in l_1 to 2.09 m leads to an increase in the normal reactions on the TTV front wheels to $N_{zk11}=N_{zk12}=2.87\cdot10^5$ N and a decrease in the rear ones to $N_{zk21}=N_{zk22}=1.35\cdot10^5$ N.

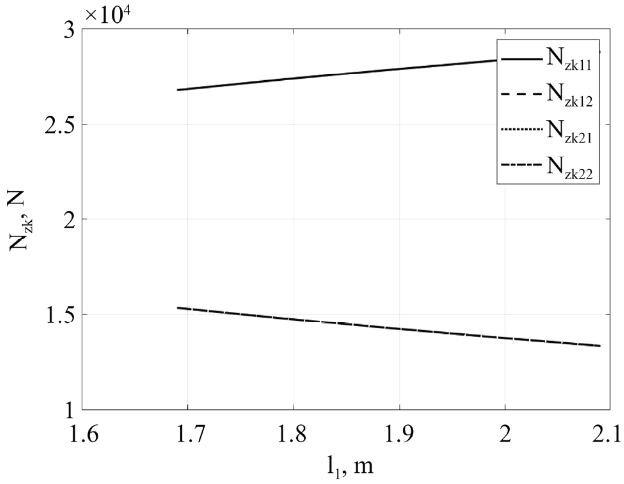

Fig. 3. Dependence of normal reactions on the wheels of a traction-transportation vehicle on the distance between the hinge and the axle of the front half-frame

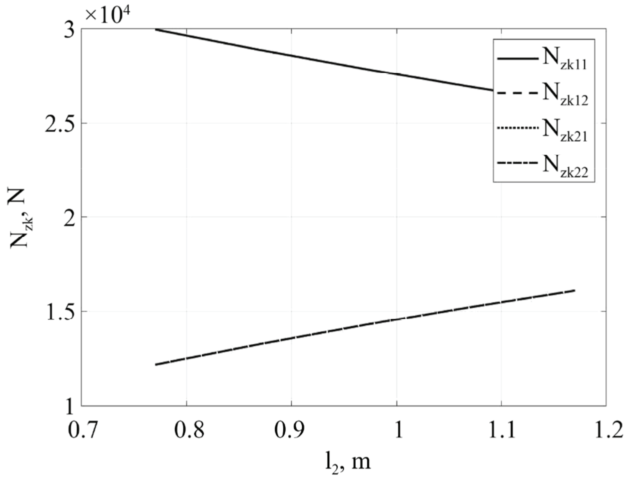

Fig. 4. Dependence of normal reactions on the wheels in a traction-transportation vehicle on the distance between the hinge and the axle of the front half-frame

Reducing the distance of l_2 to 0.77 m leads to an increase in the normal reactions on the TTV front wheels to $N_{zk11}=N_{zk12}=2.99\cdot10^5$ N and a decrease in the values of reactions on the TTV rear wheels to $N_{zk21}=N_{zk22}=1.21\cdot10^5$ N (Fig. 4). The increase in l_2 to 1.17 m leads to a decrease in the normal reactions on the TTV front wheels to $N_{zk11}=N_{zk12}=2.60\cdot10^5$ N and an increase in the rear ones to $N_{zk21}=N_{zk22}=1.51\cdot10^5$ N.

5. 2. Influence of the geometrical parameters of the frame in a traction-transportation vehicle on its tractive capacity and energy indicators

We shall theoretically examine the influence of the geometrical parameters of the TTV frame on its tractive capacity and energy indicators using method (1) to (5). The dependence of tangent thrust forces on TTV

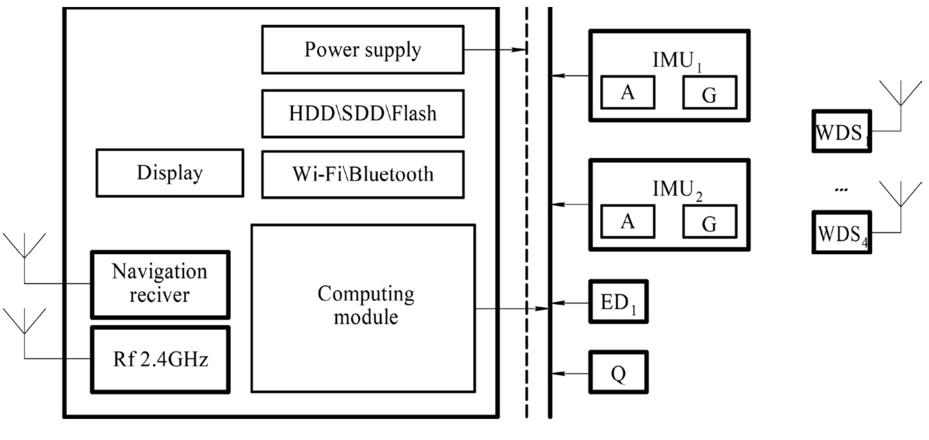

Fig. 2. Structural diagram of a system to measure the dynamics and energy of mobile machines

wheels on the distance between the hinge and the axles of the front (Fig. 5) and rear (Fig. 6) half-frames and the speed of rotation of ICE crankshaft has been established.

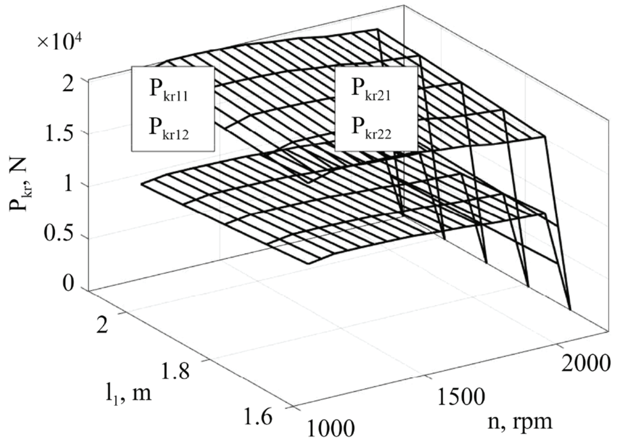

Fig. 5. Dependence of tangent thrust forces on the wheels in a traction-transportation vehicle on the distance between the hinge and the axle of the front half-frame and the speed of rotation of the crankshaft in an internal combustion engine

Reducing the distance from the TTV hinge to the front axle from l_1=2.09 m to l_1=1.69 m leads to a decrease in the tangent thrust forces on the TTV front wheels from $P_{kr11}=P_{kr12}=19512$ N to $P_{kr11}=P_{kr12}=18149$ N at n=1000 rpm, and from $P_{kr11}=P_{kr12}=18517$ N to $P_{kr11}=P_{kr12}=17223$ N at n=2100 rpm. The increase in l_1 to 2.09 m leads to a decrease in tangent thrust forces on the TTV rear wheels from $P_{kr21}=P_{kr22}=10410$ N to $P_{kr21}=P_{kr22}=9048$ N at n=1000 rpm, and from $P_{kr21}=P_{kr22}=9879$ N to $P_{kr21}=P_{kr22}=8711$ N at n=2100 rpm (Fig. 5).

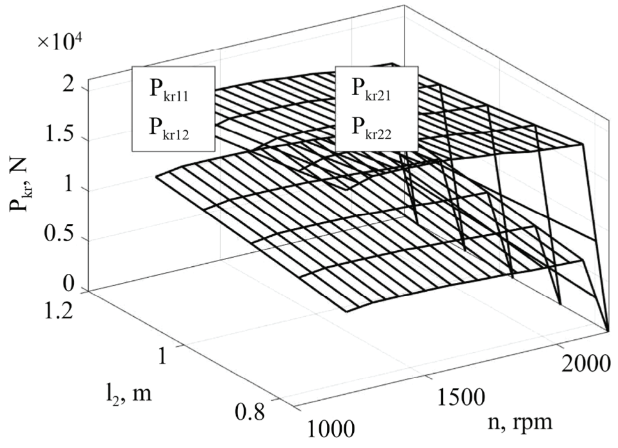

Fig. 6. Dependence of tangent thrust forces on the wheels in a traction-transportation vehicle on the distance between the hinge and the axle of the rear half-frame and the speed of rotation of the crankshaft in an internal combustion engine

Reducing the distance from the TTV hinge to the rear axle from l_2=1.17 m to l_2=0.77 m leads to an increase in the tangent thrust forces on the TTV front wheels from $P_{kr11}=P_{kr12}=17580$ N to $P_{kr11}=P_{kr12}=20370$ N at n=1000 rpm, and from $P_{kr11}=P_{kr12}=16681$ N to $P_{kr11}=P_{kr12}=19335$ N at n=2100 rpm. The increase in l_2 from 0.77 m to 1.17 m leads to an increase in the tangent thrust forces on the TTV rear wheels from $P_{kr21}=P_{kr22}=8189$ N to $P_{kr21}=P_{kr22}=10979$ N at n=1000 rpm, and from $P_{kr21}=P_{kr22}=7767$ N to $P_{kr21}=P_{kr22}=10423$ N at n=2100 rpm (Fig. 6).

We have calculated the dependence of tractive force on TTV wheels on the distance between the hinge and the axles of the front (Fig. 7) and rear (Fig. 8) half-frames and the speed of rotation of the ICE crankshaft.

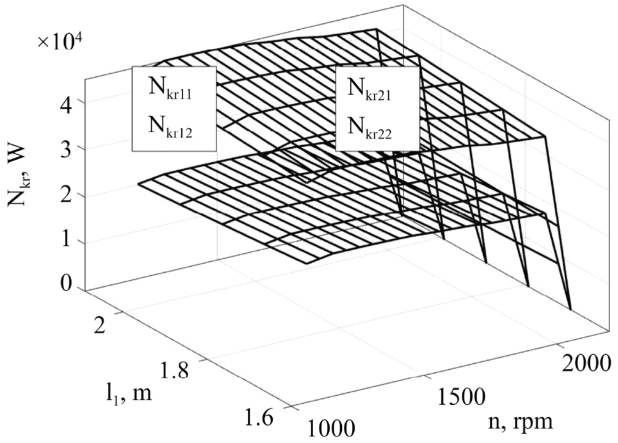

Fig. 7. Dependence of tractive force on the wheels in a traction-transportation vehicle on the distance between the hinge and the axle of the front half-frame

Increasing the distance from the TTV hinge to the front axle from l_1=1.69 m to l_1=2.09 m leads to an increase in the tractive force on the TTV front wheels from $N_{kr11}=N_{kr12}=40.33$ kW to $N_{kr11}=N_{kr12}=43.36$ kW at n=1000 rpm, and from $N_{kr11}=N_{kr12}=38.27$ kW to $N_{kr11}=N_{kr12}=41.11$ kW at n=2100 rpm. The increase in l_1 to 2.09 m leads to a decrease in the tractive force on the TTV rear wheels from $N_{kr21}=N_{kr22}=23.13$ kW to $N_{kr21}=N_{kr22}=20.10$ kW at n=1000 rpm, and from $N_{kr21}=N_{kr22}=21.95$ kW to $N_{kr21}=N_{kr22}=19.08$ kW at n=2100 rpm (Fig. 7).

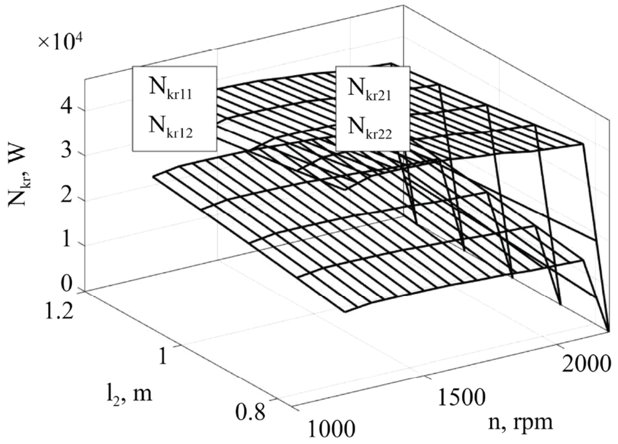

Fig. 8. Dependence of tractive force on the wheels in a traction-transportation vehicle on the distance between the hinge and the axle of the rear half-frame

Reducing the distance from the TTV hinge to the rear axle from l_2=1.17 m to l_2=0.77 m leads to an increase in the tractive force on the TTV front wheels from $N_{kr11}=N_{kr12}=39.06$ kW to $N_{kr11}=N_{kr12}=45.26$ kW at n=1000 rpm, and from $N_{kr11}=N_{kr12}=37.07$ kW to $N_{kr11}=N_{kr12}=42.96$ kW at n=2100 rpm. The increase in l_2 to 1.17 m leads to an increase in the tractive force on the TTV rear wheels from $N_{kr21}=N_{kr22}=18.19$ kW to $N_{kr21}=N_{kr22}=24.39$ kW at $n=1000$ rpm, and from $N_{kr21}=N_{kr22}=17.26$ kW to $N_{kr21}=N_{kr22}=23.16$ kW at $n=2100$ rpm (Fig. 8).

The normal reactions on the front wheels of the examined TTV are $N_{zk11}=N_{zk12}=2.78 \cdot 10^5$ N and exceed by 1.95 times the normal reactions on the rear wheels $N_{zk21}=N_{zk22}=1.42 \cdot 10^5$ N. This is due to the fact that the distances from the hinge to the corresponding axles of the wheels are $l_1=1.89$ m and $l_2=0.97$ m. Increasing the distance from the hinge to the rear wheel axle to 1.17 m has a positive effect on increasing the TTV tractive capacity. There is an increase in the tractive force on the rear wheels to $N_{kr21}=N_{kr22}=24.39$ kW.

5. 3. Results of the experimental study into a traction-transportation vehicle to confirm the adequacy of the proposed method

Our experimental studies of TTV were performed using an all-wheel-drive tractor with a hinge-connected frame as an example involving the devised measuring system. During the experiments, the tractive force of TTV on different transmissions was determined. Tractor tractive force is an integrated TTV characteristic.

The methodology for conducting experimental studies using a system to measure the dynamics and energy of mobile machines is based on GOST 30745-2001, GOST 7057-2001, and GOST 24055-88. It makes it possible to briefly determine the energy and dynamic performance of machines and assemblies. When preparing for the study, the operator selects the required number of sensors that measure the parameters of TTV functioning, the error of which does not exceed 2 %.

The adequacy test of our method (1) to (5) was carried out by comparing the tractive force of the tractor, determined experimentally, and the capacity calculated theoretically (Fig. 9). This method for confirming adequacy is given in [1, 3, 13], which proved its effectiveness.

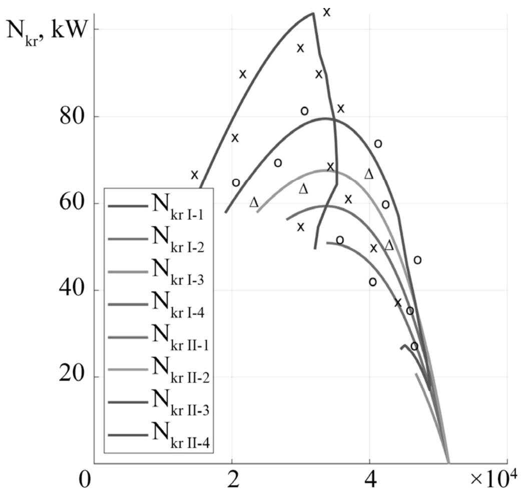

Fig. 9. The tractive force of an all-wheel-drive tractor with a hinge-connected frame: determined theoretically (———) and experimentally (x, o, Δ)

The tractive force was determined for 8 gears (4 gears in I and II bands). The maximum tractive force $N_{kr}=121$ kW is achieved at a speed of $\upsilon=12$ km/h, traction efficiency $\eta_t=0.68$, and tractive force on the hook $P=30.2$ kN (Fig. 9). The difference between the results obtained theoretically and experimentally is 8 %. Therefore, the method for assessing the influence of the geometrical parameters of the frame in a traction-transportation vehicle on its tractive capacity and energy indicators should be considered adequate.

6. Discussion of results of studying the influence of geometrical parameters of the frame in a traction-transportation vehicle on its tractive capacity and energy indicators

The method for estimating the effect of the geometric parameters of the TTV frame on its tractive capacity and energy indicators (1) to (5) is based on the traction calculation of the tractor and makes it possible to investigate the influence of the distance from the TTV hinge to the front and rear drive axles. This method allows us to determine the normal reactions (Fig. 3, 4), the tangent thrust forces (Fig. 5, 6), and the tractive force on TTV wheels (Fig. 7, 8). A given method makes it possible to determine the optimal geometric parameters for improving the tractive-adhesion and fuel-economic indicators of TTV.

It has been established that the normal reactions on the front wheels of the studied TTV exceed, by 1.95 times, the normal reactions on the rear wheels (Fig. 3), which leads to power consumption for kinematic inconsistency. Increasing the distance from the half-frame hinge to the axle of the front wheels increases the kinematic discrepancy.

An increase in l_1 to 2.09 m leads to a decrease in the tractive force on the TTV rear wheels (Fig. 7), which occurs due to a decrease in the normal reactions on rear wheels.

An increase in the tractive capacity and energy indicators can be achieved by reducing the distance l_1 or by increasing l_2, or ballasting the TTV rear half-frame.

We have built the dependence of the normal reactions, tangent traction forces, and traction capacities on TTV wheels on a change in the distance from the hinge to the axles of drive wheels (Fig. 3–8). Unlike known methods, the proposed method makes it possible to determine the tractive capacity and energy parameters for the functioning of TTV for all drive wheels.

A limitation accepted in assessing the influence of geometrical parameters of the TTV frame on its tractive capacity and energy indicators is that the frame of the unit is symmetrical. Such a restriction is legitimate because there is no mixing of the center of gravity from the longitudinal axial.

The method for estimating the influence of the geometric parameters of the TTV frame on the tractive capacity-energy indicators does not take into consideration the slope of the supporting surface in the longitudinal and transverse directions.

Future studies will be aimed at taking into consideration the slope of the supporting surface when investigating the influence of the geometrical parameters of the TTV frame on the tractive capacity and energy indicators.

7. Conclusions

1. The normal reactions on the front wheels of the studied TTV are $N_{zk11}=N_{zk12}=27800$ N and exceed by 1.95 times the normal reactions on the rear wheels $N_{zk21}=N_{zk22}=14200$ N. This is due to the fact that the distances from the hinge to the corresponding axles of the wheels are $l_1=1.89$ m

and l_2=0.97 m. The increase in l_1 to 2.09 m leads to an increase in the normal reactions on the TTV front wheels to $N_{zk11}=N_{zk12}=2.87105$ N and a decrease in the rear ones to $N_{zk21}=N_{zk22}=1.35\cdot10^5$ N. The increase in l_2 to 1.17 m leads to a decrease in the normal reactions on TTV front wheels to $N_{zk11}=N_{zk12}=2.60\cdot10^5$ N and an increase in the rear ones to $N_{zk21}=N_{zk22}=1.51\cdot10^5$ N.

2. It has been established that the increase in l_1 to 2.09 m leads to a decrease in the tractive force on the TTV rear wheels from $N_{kr21}=N_{kr22}=23.13$ kW to $N_{kr21}=N_{kr22}=20.10$ kW at n=1000 rpm, and from $N_{kr21}=N_{kr22}=21.95$ kW to $N_{kr21}=N_{kr22}=19.08$ kW at n=2100 rpm. It is determined that the increase in l_2 to 1.17 m leads to an increase in the tractive force on the TTV rear wheels from $N_{kr21}=N_{kr22}=18.19$ kW to $N_{kr21}=N_{kr22}=24.39$ kW at n=1000 rpm, and from $N_{kr21}=N_{kr22}=17.26$ kW to $N_{kr21}=N_{kr22}=23.16$ kW at n=2100 rpm. Increasing the distance from the hinge to the axle of the rear wheels to 1.17 m has a positive effect on increasing the TTV traction performance. There is an increase in the tractive force on the rear wheels to $N_{kr21}=N_{kr22}=24.39$ kW.

3. To check the adequacy of the method for assessing the impact of the geometrical parameters of the frame in a traction-transportation vehicle on its tractive capacity and energy indicators, we used a system to measure the dynamics and energy of mobile machines. The experimental studies of TTV were performed using an all-wheel-drive tractor with a hinge-connected frame as an example. The tractive force was determined for 8 gears (4 gears in I and II bands). The maximum tractive force is N_{kr}=121 kW; it is achieved at a speed of υ=12 km/h; traction efficiency, η_t=0.68; the traction force on the hook, P=30.2 kN. The difference between the results obtained theoretically and experimentally is 8 %. The devised method for assessing the influence of the geometrical parameters of the frame in a traction-transportation vehicle on its tractive capacity and energy indicators should be considered adequate.

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