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DETERMINATION OF THE VALUE OF TANGENTIAL FORCE FOR THE HALF-TRACK TRACTION VEHICLE WITH RUBBER TRACKS

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Practice shows that with insufficiently high traction qualities of traction vehicles deteriorate its operational properties. At present, extensive research is under way at home and abroad to find inexpensive but highly effective ways and techniques to improve the traction qualities of vehicles. The design of running systems with reduced resistance to movement and slipping will help to significantly increase the productivity of vehicles and reduce fuel consumption. This, in turn, will contribute to greater operational efficiency for traction vehicles. The authors of this study have developed the design of a traction vehicle with a half-tracked propulsor. The objective of the study is to develop a mathematical model for calculating the efficiency of operating a traction vehicle equipped with a half-tracked propulsior with rubber tracks. The proposed mathematical expression takes into account the deformability of the rubber tracks of the propulsor, the uneven distribution of normal pressure along the length of the track, slipping, geometric parameters of the propulsor and the physical and mechanical properties of the soil. Using numerical methods, calculations were carried out to determine the effect of the tangential tractive force on the slipping of a wheeled traction vehicle with a different layout of the running system. The dependences of the amount of slipping on the tangential thrust force are determined. It has been found that with an increase in the traction force, the slipping increases, however, the intensity of growth of a half-tracked propulsor compared to a wheeled propulsor is much lower.

Keywords: traction and transport vehicle, half-track propulsor, tangential tractive force, ground, normal ground pressure

1 INTRODUCTION

Traction and transport vehicles of various types and designs with various technical characteristics have been developed for operations in various conditions. The type and purpose of the vehicle determine the design of its running system. Traction and transport vehicles are widely used in agriculture, public utilities, construction, mining and exploration.

The modern development of traction vehicles is characterized by an increase in their power, traction qualities, cross-country ability, increased reliability and others. These trends in machine development can be addressed by creating new vehicle models or upgrading existing designs of individual components and aggregations of traction vehicles. The modernization of tracked vehicles is due to an increase in the energy saturation of the power plant, which leads to an increase in the mass of the vehicle, without significant improvements in the design of the running system. This leads to a more intense impact of the propulsors of the vehicles on the ground, to the destruction of ground structure and, as a result, to a significant decrease in the traction efficiency of vehicles. Consequently, there is a need to improve the performance of the running systems of wheeled traction vehicles [1, 2].

An analysis of the well-known scientific and technical literature has shown that this problem can be solved by setting double wheels, placing the front and rear wheels on different track widths, using an additional drive axle, using various reloaders. A promising way to solve this problem is to install a half-tracked propulsor on a wheeled vehicle, which will expand its functionality and increase their annual load. A half-tracked propulsor is a combination of wheeled and tracked propulsors. As a rule, the track is the main propulsor, and is installed at the place of the rear wheel, and the wheel propulsor is in the front [3].

As part of the research work a team of authors developed the design of a half-tracked propulsor for a traction vehicle. Its half-tracked propulsor contains a track contour of a triangular shape, it enfolds the drive wheel and the track bogie with front and rear guide wheels, as well as track rollers. The track bogie is connected to the frame of the vehicle through a trailing arm. The trailing arm is pivotally attached to the track bogie at one end, and to the vehicle frame at the other. The propuslor is equipped with rubber-reinforced tracks, which are monolithic structures reinforced with steel cables vulcanized into a cord rubber tape [4, 5].

In order to conduct experimental studies in order to confirm the results of theoretical calculations, a prototype of a half-tracked propulsor was made. Progressive processing methods were used for the manufacture of parts and components of the propulsor [6, 7, 8, 9, 10]. The improvement of the manufacturing technology of parts plays an important role in increasing the efficiency of use and prolonging the operational period of transport equipment.

The movement of the traction and transport vehicle is inextricably linked with the physical and mechanical properties of the support surface. In this connection, the characteristics of the soil are largely determining in the choice of the design features of the vehicle and its operating modes. The components of the resistance to the movement of the vehicle in this case are extremely important.

The analysis of the works devoted to the determination of the values that make up the resistance to the movement of a wheeled and tracked traction vehicle shows that the greatest interest of researchers is aimed at finding the resistance caused by the deformation of the soil under the propulsor and that this deformation is associated with the process of track formation, which depends on the normal pressure on the ground.

In this context, it is advisable to consider the results of research on the direct interaction of propulsors with the ground. [11, 12, 13]. As a result, it was found that the pressure distribution over the support surface of the track is rectangular in nature. This representation of the pressure diagram is based on the following assumptions: the number of support rollers is infinite; the track chain is a beam on an elastic base; the stiffness of the beam compared to the stiffness of the base is infinitesimal.

With regards to the unquestionably positive results from the aforementioned studies, it should be noted that the accumulated material cannot be considered sufficient. The interaction of the rubber-track propulsor with the ground has received little attention and the physical essence of the process of formation of the tangential thrust force is not fully explained.

The analysis of the state of the issue allowed us to outline further ways of research:

1. Consider the general dynamics of a traction vehicle with a half-tracked propulsor;
2. Create a mathematical apparatus for determining the tangential traction force developed by a wheeled traction vehicle with all-wheel drive on a half-tracked propulsor with rubber tracks;
3. Carry out calculations to determine the effect of the tangential traction force on the slipping of a wheeled traction vehicle with different layouts of the running system.

2 RESEARCH METHODOLOGY

2.1 General dynamics of traction vehicle

The movement of the traction vehicle is carried out due to the interaction of the propulsor with the bearing surface. Due to the torque on the drive wheels M_k, tangential reactions occur between the propulsor and the bearing surface. Tangential reactions acting on the propulsor push the vehicle forward. The resultant of the tangential reactions F_k is the pushing force. As a result of the interaction of the propulsor with the bearing surface (ground), the latter is subjected to deformation in different directions.

From the side of the ground, as a result of its deformation, a reaction occurs, and it the horizontal component renders resistance to the movement F_f. This component is balanced by the tangential tractive force F_k [14].

When the vehicle moves, a tread remains on the deformable surface of the path, and its depth depends on the physical and mechanical properties of the ground as well as the type and design of the propulsor. Ultimately, the physical picture of the interaction of the propulsor with the ground determines the traction properties of the traction vehicle.

Below is a schematic diagram of a traction vehicle with a triangular track propulsor (Figure 1). The figure shows the following physical quantities: F_f is the force of resistance to movement; F_k is the tangential tractive force; M_k is the torque; G is the vehicle weight; v is the movement speed.

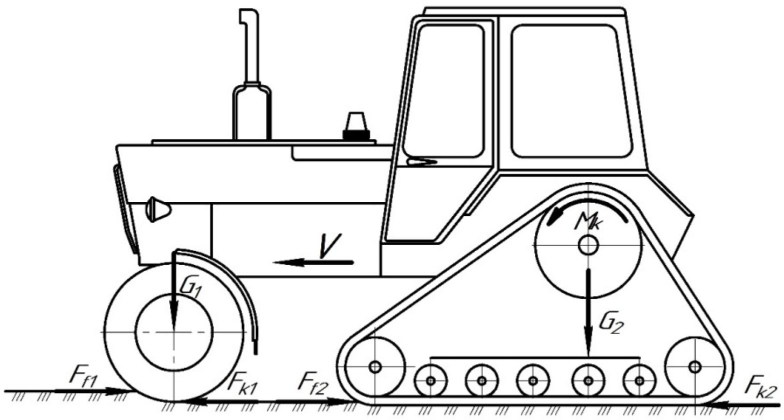

Fig. 1. Schematic diagram of a traction vehicle with a triangular caterpillar propulsor

In order to improve the traction properties and reduce the normal ground pressure in the design of the proposed traction vehicle, instead of the rear drive wheels, a triangular track propulsor is installed [4, 5]. Due to the large contact surface area of the track propulsor with the ground, in comparison with the wheeled one, the track propulsor has higher traction properties under the same operating conditions.

The tangential tractive force in this case is determined by the equation:

$$F_k = F_{k1} + F_{k2}, \tag{1}$$

Thus, the tangential tractive force of the traction vehicle is equal to the sum of the tangential tractive forces developed by the driving wheels and the track propulsor.

2.2 Determination of tangential tractive force of wheel

The tangential tractive force developed by a single wheel is the sum of the horizontal ground reactions [15]:

$$F_{k1} = \sum_{i=1}^{i=n} T_{gr}, \tag{2}$$

When the drive wheel interacts with the ground:

- friction force between the tire bearing surface and the ground act;
- forces arising when the tire lugs thrust into the ground act;
- forces arising from the shearing of ground bricks by the side faces of the lugs act.

When the drive wheel moves, its lugs move and cut the ground in the direction opposite to the movement. The thrust of the lugs to the ground and the shift and shear of the ground bricks placed between them are possible only with the full use of friction forces.

It follows that the grip of the bearing surface of the wheel with the ground occurs due to the friction forces that arise between the tire and the ground, and the shift and shear forces of the ground bricks placed between the lugs.

Studies [16] showed that the distribution of shift strain and shear of ground bricks in contact with the bearing surface of the wheel with the ground can be drawn as a triangle (Figure 2).

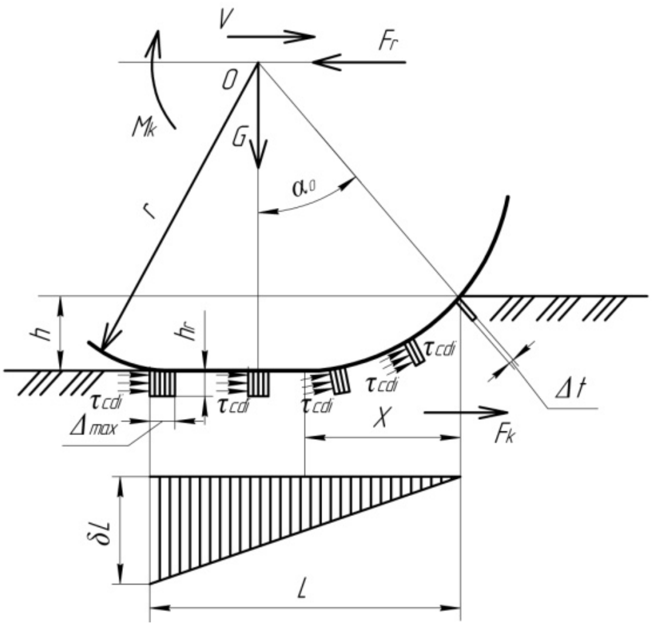

Fig. 2. Scheme of interaction of drive wheel with ground

The shear stresses τ_{sh} that occur in the ground when exposed to lugs, increase and reach a maximum, and after that they decrease and reach a constant value when the ground brick is completely cut. At the same time, the stress τ_{sl} that occurs when the ground brick is sheared by the side faces of the lug with the height h_{gr} can be considered as a first approximation independent of the deformation.

Thus, the tangential tractive force due to one lug changes according to the same law as the tangential reaction of the ground:

$$T_{gr} = \left[(c + q \cdot \mathrm{tg}\, p)B_{gr}l_{gr} + 2\left(c + \varepsilon_q q \cdot \mathrm{tg}\, p\right)\right]B_{gr}h_{gr}\mathrm{th}\frac{S}{K_\tau}, \tag{3}$$

Solving together equations (2) and (3), as well as integrating the resulting equation, we determine the tangential tractive force developed by the drive wheel [17]:

$$F_{k1} = \frac{1}{t_{gr}}\left[(c + q \cdot \mathrm{tg}\, p)B_{gr}l_{gr} + 2\left(c + \varepsilon_q q \cdot \mathrm{tg}\, p\right)\right]B_{gr}h_{gr} \cdot \frac{K_\tau}{\delta}\ln\left|\mathrm{ch}\frac{\delta l_{gr}}{K_\tau}\right|, \tag{4}$$

2.3 Determination of tangential tractive force of track propulsor

Next, we determine the tangential tractive force developed by the bearing surface of the track propulsor. It can be described by the following equation:

$$F_{k2} = 2\sum_{i=1}^{i=n} T_{tr}, \tag{5}$$

When the tracked vehicle moves, reactive forces act on the bearing surfaces of the tracks from the side of the ground. In this case, the lugs shift the soil in the direction opposite to the movement of the traction vehicle. The thrust of the lugs to the ground and the shift and shear of the ground bricks are possible only with the full use of friction forces.

With the steady movement of the tracked vehicle, the magnitude of the ground shift increases on each subsequent track. For each n^{th} track, the total amount of shift may be so significant that the ground brick will be cut off at the base.

Studies [18, 19, 20] show that the shear forces that arise in the ground when exposed to individual lugs, at the first moment increase due to friction and adhesion between the tracks and the ground [21], and then, after reaching a certain maximum, they begin to decrease. The decrease in shear forces depending on the deformation continues until the ground bricks are completely cut. Subsequently, the shear force does not change.

The tangential tractive force developed by the track link is equal to [8]:

$$T_{tr} = T_{tr\,\max} \cdot \mathrm{th}\frac{S}{K_\tau} = \left[(c + q \cdot \mathrm{tg}\, p)BL + 2\left(c + \varepsilon_q q \cdot \mathrm{tg}\, p\right)\right]\mathrm{th}\frac{S}{K_\tau}, \tag{6}$$

It should be noted that the value of the lug has an insignificant effect on the tangential tractive force, since the share of this force, realized due to the cutting of the ground, is small. The height of the lug affects the shear force in the sense that deeper ground layers are sheared as it gets increased.

Solving equations (5) and (6) together, we obtain:

$$F_{k2} = 2\left[(c + q \cdot \mathrm{tg}\, p)BL + 2\left(c + \varepsilon_q q \cdot \mathrm{tg}\, p\right)\right] \frac{K_\tau}{\delta} \ln\left|\mathrm{ch}\frac{\delta L}{K_\tau}\right|. \tag{7}$$

This equation is valid for a traction vehicle with a metal track propulsor and does not take into account such a feature of rubber tracks as their deformability.

In [22], a mathematical model that characterizes the law of distribution of normal pressure along the length of the bearing surface of a rubber track was developed. To identify the patterns of pressure distribution, a part of a rubber-track propulsor consisting of two road wheels and a rubber track was considered.

The deflection of the rubber track between the rollers, and hence the normal pressure acting on the rubber track between the rollers, are due to elastic deformations of the ground and elements of the rubber track and are determined by following linear laws:

– for ground:

$$q = k_z h_1, \tag{8}$$

– for rubber track:

$$q = c_z h_2, \tag{9}$$

When solving equations (8) and (9) together, we take $y = h_1 + h_2$. As a result, we get:

$$q = k_r y, \tag{10}$$

The coefficient of unit stiffness depends on the coefficient of volumetric bearing of ground and the normal stiffness of the elements of the rubber track:

$$k_r = \frac{k_z \cdot c_z}{k_z + c_z}. \tag{11}$$

Using the obtained linear dependence (11), we determine the tangential tractive force developed by the rubber-track propulsor:

$$F_{k2} = 2\left[(c + k_r y \cdot \mathrm{tg}\, p)BL + 2\left(c + \varepsilon_q k_r y \cdot \mathrm{tg}\, p\right)\right] \frac{K_\tau}{\delta} \ln\left|\mathrm{ch}\frac{\delta L}{K_\tau}\right|. \tag{12}$$

In the general case, the tangential tractive force developed by a wheeled traction vehicle with all-wheel half-track drive equals:

$$F_k = \frac{1}{t_{gr}}\left[(c + q \cdot \mathrm{tg}\, p)B_{gr} l_{gr} + 2\left(c + \varepsilon_q q \cdot \mathrm{tg}\, p\right)\right]B_{gr} h_{gr} \cdot \frac{K_\tau}{\delta} \ln\left|\mathrm{ch}\frac{\delta l_{gr}}{K_\tau}\right| +$$
$$+2\left[(c + k_r y \cdot \mathrm{tg}\, p)BL + 2\left(c + \varepsilon_q k_r y \cdot \mathrm{tg}\, p\right)\right] \frac{K_\tau}{\delta} \ln\left|\mathrm{ch}\frac{\delta L}{K_\tau}\right|. \tag{13}$$

Thus, the formula for determining the tangential tractive force takes into account the deformability of the rubber tracks of the propulsor, slipping, the geometric parameters of the propulsor, and the physical and mechanical properties of the soil.

2.4 The impact of a half-track propulsor on the operational properties of a wheeled traction vehicle

In order to determine the effect of the installation of a half-tracked propulsor proposed by the authors of this study on the tangential traction force of a wheeled traction vehicle, numerical modeling methods were used.

The indicators determining the operational properties of a traction velicle on a wheeled and tracked propulsors are shown in Table 1.

Table 1. Comparative performance indicators of a traction vehicle with wheeled and tracked propulsors

Indicator	Wheel propulsor		Track propulsor	
	stubble	field for sowing	stubble	field for sowing
q, MPa	0,18-0,22	0,1-0,15	0,04	0,04
φ_k	0,6-0,8	0,5-0,7	0,8-1,0	0,6-0,8
f_k	0,08-0,1	0,12-0,18	0,06-0,08	0,08-0,1
δ	0,08-0,2	01-0,22	0,01-0,03	0,01-0,03
η	0,72	0,62	0,9	0,85

To assess the effect of a half-tracked propulsors on the traction properties of a Class 2 wheeled traction vehicle, we draw the graph of the dependence of the slipping on the tangential traction force (Figure 1). The figure shows the results of a theoretical study of the effect of tangential traction force on the slipping of a wheeled traction vehicle with a different layout of the running system. Curves II, III and IV are based on the results of previous studies, and curve I is based on the results of the current study.

As can be seen from the graph, the slip curves $\delta = f(F_k)$ have a linear character up to 16 kN for a traction vehicle with a 4×2 chassis configuration, up to 19 kN for a traction vehicle with a 4×4 chassis configuration, and up to 22 kN for a traction vehicle on a half-track with metal tracks and up to 25 kN for a traction vehicle on a half-track with rubber tracks.

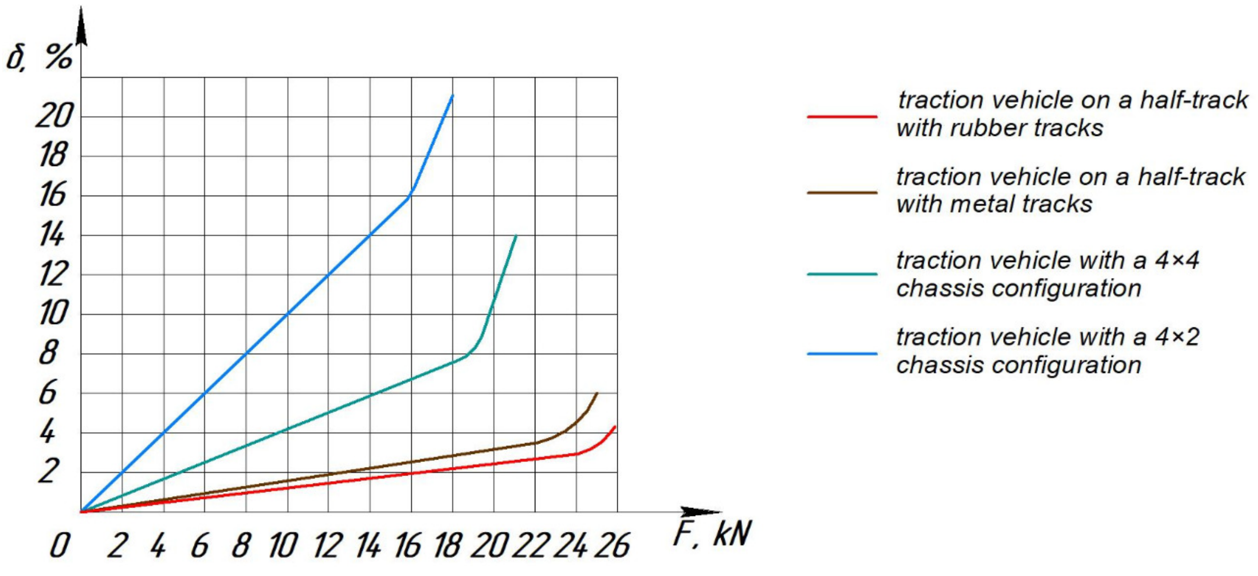

Fig. 3. Dependence of the slipping on the tangential traction force

The analysis showed that with increasing stress, the amount of slipping increases, but the intensity of growth of a half-tracked propulsor compared to a wheeled propulsor is much lower. Due to the larger contact surface area of the half-tracked propulsor with the ground compared to the wheeled propulsor, under the same operating conditions, the half-tracked propulsor has higher traction properties, working mainly when slipping.

Thus, a half-tracked propulsor with rubber tracks has higher traction and support properties compared to other types of described propulsor. It also meets modern environmental requirements: it significantly reduces the harmful effects on the soil, significantly improves the working conditions of the operator of the traction vehicle.

3 CONCLUSIONS

Based on a comparative analysis of wheeled and tracked vehicles when operating them in heavy road conditions, and especially in off-road conditions, one can conclude that the latter have an advantage in such important indicators as cross-country ability, performance, maneuverability, traction qualities, convenience and reliability of operation. The results of the research work are presented, within the framework of which the design of a half-tracked propulsor of a traction vehicle with rubber tracks has been developed. The general dynamics of a traction vehicle was examined and the effect of external forces on it during the movement of the vehicle was described, as well as the mechanism of the tangential traction force. The tangential thrust force of the proposed traction vehicle design is equal to the sum of the tangential thrust forces developed by the driving wheels and tracks. As a result of mathematical transformations, a linear dependence that determines the tangential thrust force developed by the rubber-track propulsor was obtained. Furthermore, an for determining the tangential thrust force equation was obtained, taking into account the deformability of the rubber tracks of the propulsor, slipping, geometric parameters of the propulsor and the mechanical properties of the soil. Comparison of this equation with the equation for determining the tangential tractive force developed by a 4×4 wheeled tractor showed that equipping a traction vehicle with a half-tracked propulsor will significantly increase the tractive and coupling properties of the vehicle.

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