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Contents

Study of the Interaction of a Transport Vehicle with an Open Road

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Abstract. One of the ways to reduce the harmful effects of undercarriage of traction and transport vehicles on the ground and to improve their traction characteristics is the use of rubber-track propulsion. Experimental research have shown that the rubber-track propulsion provides a more even distribution of the specific pressures created by the traction-transport machine and reduces the peak loads on the ground compared to the metal track. When the caterpillar propulsion interacts with the ground, the force of gravity of the machine is transmitted to the ground through the propulsive support branch. The values of these reactions and the patterns of their distribution over the support surface reflect the physical essence of the processes of interaction between the propulsion unit and the ground. The article presents the results of the research of the distribution of normal pressure along the length of the support surface of the rubber track. The uniform distribution of pressure affects the permeability of the traction vehicle.

Keywords: Rubber-track propulsion · Interaction modeling · Traction-transport machine

1 Introduction

For operation in various conditions, transport vehicles of various types and designs with different technical characteristics have been created. The type and purpose of the machine determines the design of its running system.

One of the urgent tasks in the transport industry has always been the issue of increasing the efficiency of their use, a large role in the solution of which belongs to the improvement of running systems of machines.

Practice shows that with insufficiently high traction and coupling qualities of transport vehicles, a decrease in its productivity, an increase in fuel consumption and a deterioration in other operational properties of the machine are recorded. Currently, one of the ways to reduce the harmful effects of the running systems of towing vehicles on the ground and improve their towing qualities is the use of a rubber caterpillar [1]. Experimental studies [2, 3] showed that the rubber-tracked mover, in comparison with the metal caterpillar, provides a more uniform distribution of specific pressures created by

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the towing vehicle and reduces peak loads on the ground. Therefore, studies on the interaction of the running system of a transport vehicle with the road surface are relevant.

2 Improving the Traction Characteristics

When a track mover interacts with the ground, the gravity of the vehicle is transmitted to the ground through the bearing strand of the mover [4, 5]. From the ground the reaction forces effect on the mover. The values of these reactions and the laws of their distribution on the bearing surface reflect the physical essence of the processes of interaction between the mover and the ground. It is precisely these laws that determine the interaction parameters of the tracks with the bearing surface, as well as the performance indicators of the tracked vehicles [6].

Mathematical models that reveal the mechanism of interaction between a belt mover with the base and the nature of the distribution of specific pressures are developed for a metal belt mover and do not take into account such a feature of rubber tracks as their deformability.

To identify the patterns of pressure distribution, the scheme proposed by Professor V. V. Katsygin [7] is adopted, and a part of the rubber track mover, consisting of two lower track wheels and a rubber track is respected. The action of the tension spring of the directive wheel is replaced by the sprung first roller (see Fig. 1). It is assumed that the tracked vehicle moves uniformly along the horizontal surface of the track.

Let the load G_1 that equals to the gravity of the vehicle applied to the selected part of the mover effect the portion of the track AB. It is assumed that the caterpillar is a flexible belt and its speed is zero. The position of the tape depends on its tension and ground stress. In turn, ground stresses depend on the degree of precipitation of various sections of the belt [8, 9].

In Fig. 1 the coordinate axes is drawn so that the abscissa axis is horizontal (at the level of the path surface before the mover deforms ground), and the ordinate axis passes vertically down through the middle of the AB section.

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

- for ground:

$$p = kh_1, \tag{1}$$

where p – specific pressure, k – volumetric crumpling coefficient of ground, but h_1 – settlement of ground;

- for rubber track:

$$p = c_z h_2, \tag{2}$$

where c_z – normal stiffness of rubber track, but h_2 – normal deformation of elements of rubber track.

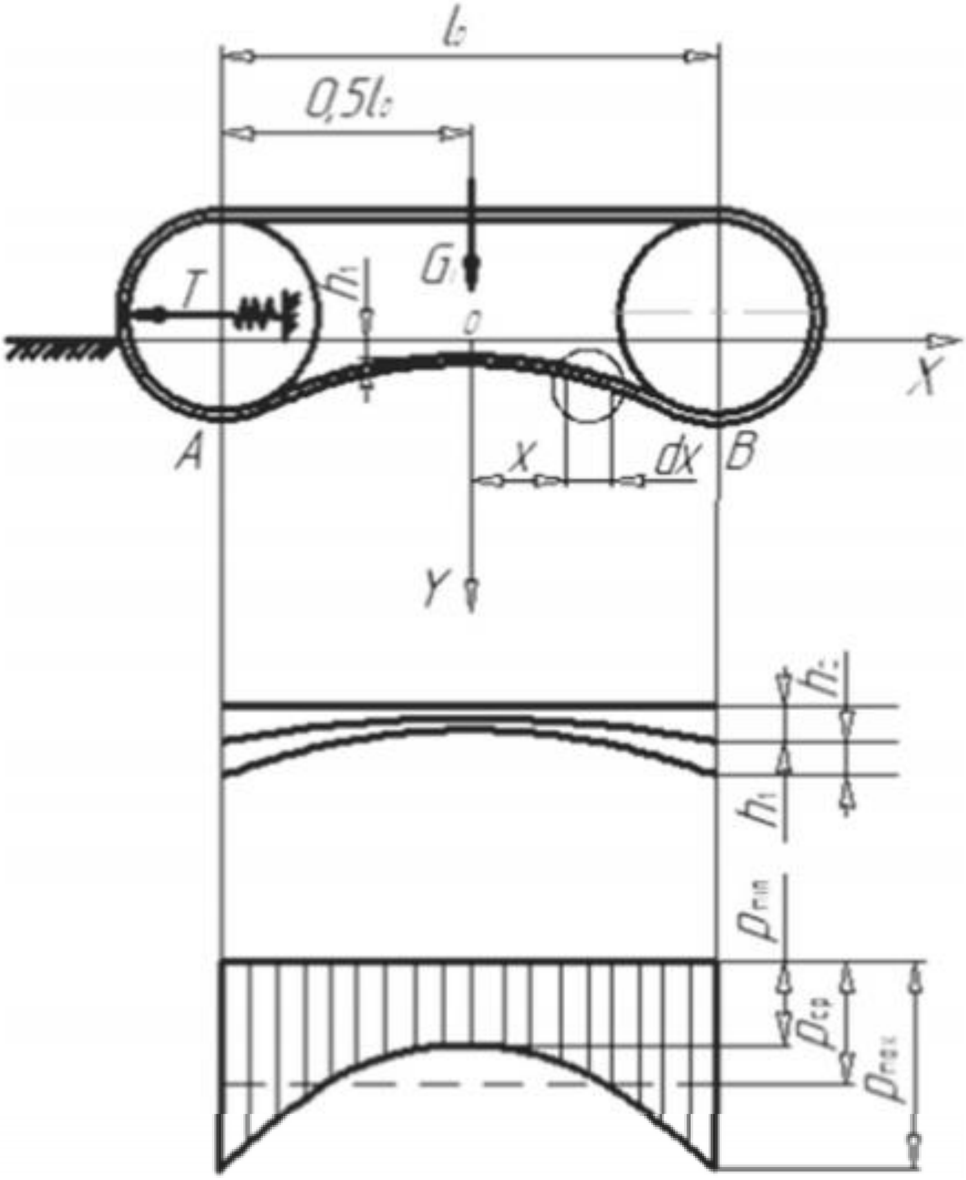

Fig. 1. Scheme to the conclusion of the law of pressure distribution along the length of the bearing strand of the rubber belt track.

In the joint solution of Eqs. (1) and (2) it is assumed that $y = h_1 + h_2$. As a result:

$$p = k_{st} y, \tag{3}$$

where k_{st} – specific stiffness coefficient, but y – joint deformation of ground elements of rubber track.

The specific stiffness coefficient depends on the volumetric crumpling coefficient of ground normal stiffness of elements of rubber track:

$$k_{st} = \frac{kc_z}{k + c_z}. \tag{4}$$

Using the obtained linear dependence (3) the law of distribution of normal pressure along the length of the bearing surface of the rubber track is determined.

Let us consider the equilibrium of an elementary strip spaced at a distance x from the origin of the coordinate system (the width b is equal to the width of the track, and the length is dx). This strip is in equilibrium under the action of the tension forces of the belt F and dF, as well as the forces of the ground dN_x:

$$dN_x = p_x b dx,$$

where p_x – pressure on bdx.

The indicated forces on the axes OX and OY (see Fig. 2) are shown. The sum of the projections of these forces on the axis is zero, i.e.

$$F\cos\theta + d(F\cos\theta) - F\cos\theta = 0.$$

or

$$d(F\cos\theta) = 0 \tag{5}$$

$$F\sin\theta + d(F\sin\theta) - F\sin\theta - p_x b dx = 0,$$

or

$$dF(\sin\theta) - p_x b dx = 0. \tag{6}$$

From Eq. (5) it follows that $F\cos\theta = \text{const}$, that is, the horizontal component of the belt tension is constant and equal to half the force of the tension spring $\frac{T}{2}$. The value $F = \frac{T}{2\cos\theta}$ in Eq. (6) is substituted. After reducing dx:

$$\frac{T}{2}\frac{d(tg\theta)}{dx} - p_x b = 0.$$

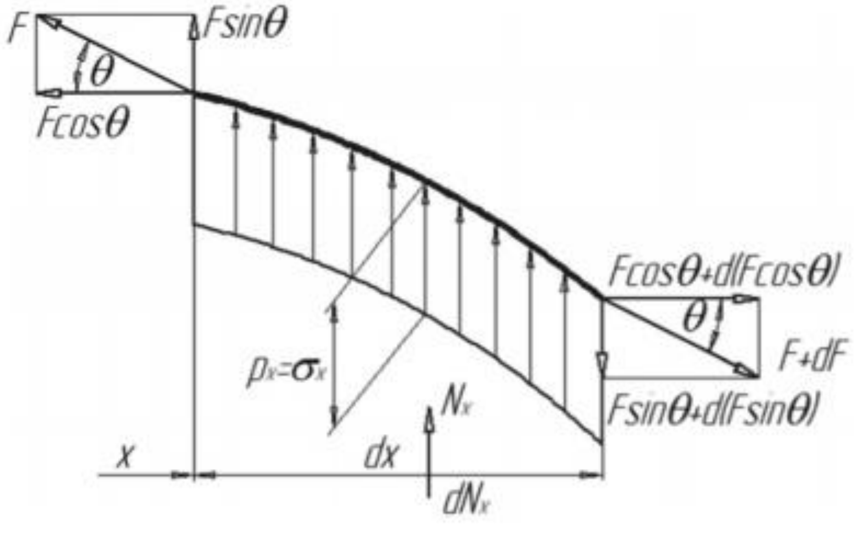

Fig. 2. Equilibrium of an elementary strip of a belt track.

where G_i – part of the mass of the vehicle falling on the considered section of the rubber track, b – rubber track width and l_0 – distance between rollers.

Substituting the value x in Eq. (9) the expression for determining the maximum and minimum pressure is obtained:

$$p_{\max} = \frac{G_i k_{st} e^{\frac{l_0}{2}\sqrt{\frac{2k_{st}b}{T}}}}{2\sqrt{\frac{k_{st}bT}{2}}\left(e^{\frac{l_0}{2}\sqrt{\frac{2k_{st}b}{T}}} - 1\right)}, \tag{11}$$

$$p_{\min} = \frac{k_{st} G_i}{2\sqrt{\frac{k_{st}bT}{2}}\left(e^{\frac{l_0}{2}\sqrt{\frac{2k_{st}b}{T}}} - 1\right)}. \tag{12}$$

Substituting the values $p_{\max}$, $p_{\min}$ and p_{av} in formula (10):

$$\xi_p = \frac{l_0}{2}\sqrt{\frac{2k_{st}b}{T}}, \tag{13}$$

where T – tension force of the rubber track.

From this formula it follows that the pressure unevenness increases if the distance between the rollers and the width of the track are increased, and, conversely, decreases with increasing track tension [10].

Substituting the value k_{st} in the previous formulas:

$$\xi_p = \frac{l_0}{2}\sqrt{\frac{2kc_z b}{T(k + c_z)}}, \tag{14}$$

$$p_{\max} = \frac{G_i k c_z e^{\xi_p}}{2(k + c_z)\sqrt{\frac{2kc_z bT}{2(k + c_z)}}\left(e^{\xi_p} - 1\right)}, \tag{15}$$

$$p_{\min} = \frac{G_i k c_z}{2(k + c_z)\sqrt{\frac{2kc_z bT}{2(k + c_z)}}\left(e^{\xi_p} - 1\right)}. \tag{16}$$

These expressions characterize the law of distribution of normal pressure along the length of the bearing surface of a rubber track. The uniformity of the pressure distribution affects the cross-country capacity of the towing vehicle. The pressure distribution along the length of the bearing surface of the rubber track belt is of no small importance to the normal stiffness of the rubber track belt.

To determine the normal stiffness of a rubber track, an arbitrary track element ΔL limited to two sections 1–1 and 2–2 (see Fig. 3) is considered. Under the influence of the part of the mass of the vehicle G_i falling on the considered section, the rubber track is deformed by the value Δh.

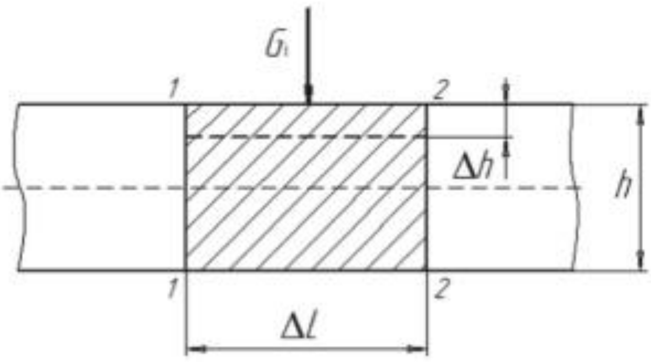

Fig. 3. Scheme for determining the normal stiffness of the track.

The normal deformation of the rubber track using Hooke's law is finded:

$$\Delta h = \frac{G_i h}{ES}, \quad (17)$$

where h – track thickness, but E – modulus of elasticity of the track material. For rubber E = 10 MPa. S – area of an arbitrary part of a track, $S = b \cdot \Delta L$.

The coefficient of normal stiffness of a rubber track is determined by the formula

$$C_z = \frac{G_i}{S_{\prod} \cdot \Delta h} \quad (18)$$

where $S_{\prod}$ – cross sectional area of the track, $S_{\prod} = h \cdot b$.

Figures 4 and 5 show the curves constructed by the formulas (14)–(16) for rubber track mover on the clay loam with $k = 0.5 \cdot 10^6$ N/m^3; $l_0 = 0.4$ m; $b = 0.35$ m; $T = 10$ kN; $G_i = 40$ kN.

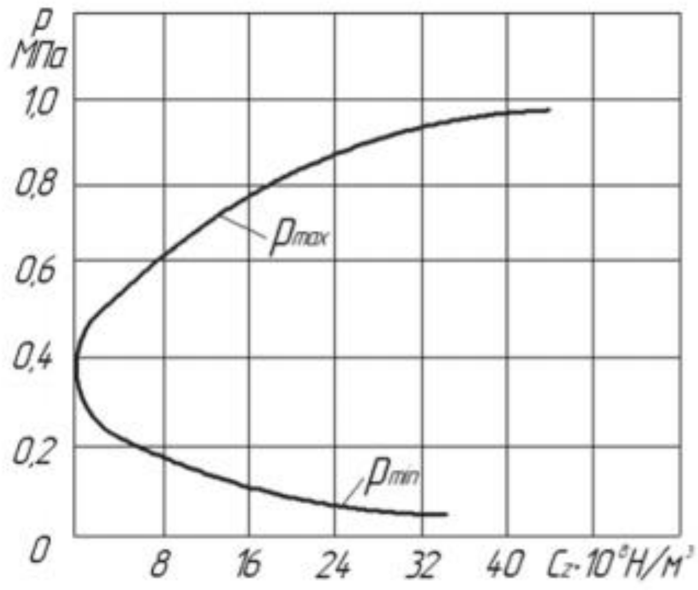

Fig. 4. The dependence of the specific pressures on the normal stiffness of the rubber tracks.

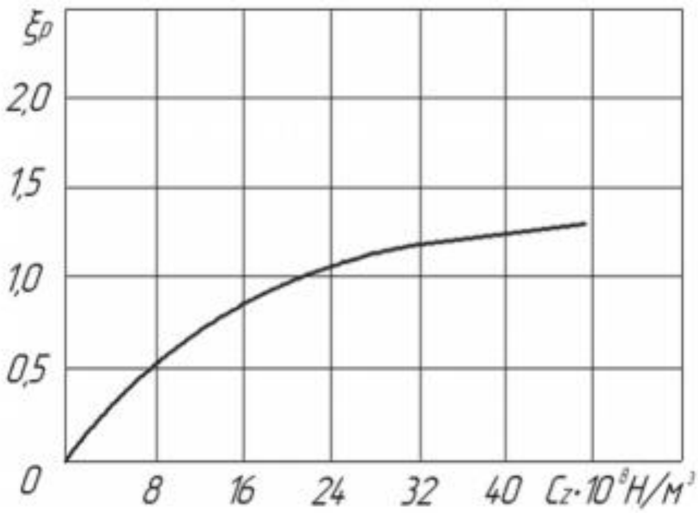

Fig. 5. Dependence of the coefficient of relative non-uniformity of the pressure distribution on the normal stiffness of the rubber track.

From the obtained dependences it follows that an increase in the normal stiffness of the elements of the rubber track causes an increase in the maximum specific pressure with an asymptotic approximation to its value for an absolutely rigid track.

The minimum specific pressure decreases, also asymptotically approaching its value for an absolutely rigid track. In accordance with this, there is an increase in the non-uniformity of the pressure distribution along the length of the rubber track.

3 Conclusion

As a result of the study, dependencies were obtained to determine the main structural parameters of the track running system, the nature of the distribution of normal pressure along the length of the supporting surface of the rubber track was determined. The obtained dependencies take into account such a feature of rubber tracks as their deformability. These studies allow to determine the optimal parameters of the running system of the transport machine at the design stage, which will ensure the preservation of the roadway and movement on concrete and asphalt surfaces.

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Содержание

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