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Interact of the tractor driving wheels with the soil by considering the rheological properties of soils

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ABSTRACT

The work offers a mathematical model of interaction of the tractor driving wheels with the soil. A rheological model is used as a law of shear deformation of soils as the principal law of linear deformation. Calculation formulae of tangential force and traction coefficient of the driving wheels are deduced. A numerical example and graphs are used to demonstrate that the theoretical results are quite close to the experimental data. Dependence of the traction coefficient of the deformable wheel with the ground allows analyzing the impact of rheological indicators of grounds and geometric and regime parameter of a wheel rolling and using a more grounded approach to the analysis of the problematic issues of dynamics of wheeled tractors. As it can be seen from formulae the tangential traction force and traction coefficient of an elastic wheel necessary to overcome the forces of friction, shear and ground cutting depend on normal load mg, acting on the wheel, wheel parameters rheological properties of the ground and movement regime.

1. Introduction

Many works are dedicated to the analytical study of the tractor driving wheels with the soil. Accordingly, there are several approaches to the study of the given question, which in the work [1] are divided into four groups. Group one incorporates the works, establishing the empirical dependence between the wheel parameters and the soil. The formulae deduced in this way are true only for the conditions of concrete experiments. Group two incorporates the works, in which the elastic wheel is replaced by a rigid wheel, but with a great radius, and the study results may be applied to the contact surface of the tire with the soil and drafting a design model for a concrete combination of a tire type and kind of soil. In these works the typical peculiarities of the interacting elements (the tire and the soil) are taken into account, but the general analytical solution applicable for all types of tires and soils is difficult to gain. The works in group four are based on the study of the general regularities of the deformability of soils and tires, with more generalized results gained on their basis.

The solution to the new questions of the indicators of the traction dynamics, maneuverability and possibility of the existing and newly designed tractors and other wheeled power machines needs a further development of the theory of interaction of the tractor driving wheels with the soil by using the fourth approach, particularly by considering the rheological properties of the soils.

2. Basic part

When considering the interaction of an elastic driving wheel with the soil, an assumption implying that under a steady-state regime, a tangential force F_k of the wheel traction equals to the sum of the soil tangential reactions directed towards the movement (Fig. 1).

In order to draft an equivalent design model, we proceed from the consideration that during the interaction of a driving wheel with the soil, there act the traction forces between the support surface of the tire and soil, in particular, the forces arising at cutting the ground brick with the side edges of the lugs. The work [2] proves that for loose grounds the value of shear and cutting forces increases and is frequently a determining one. As a driving wheel moves, its lugs shift and cut the ground in the direction opposite to their movement. The support of the lugs in the ground, shift and cutting of bricks, constrained between them are possible only if the traction forces are thoroughly used, i.e. in case of a wheel ship.

It is considered [2] that in case of steady motion of a wheel

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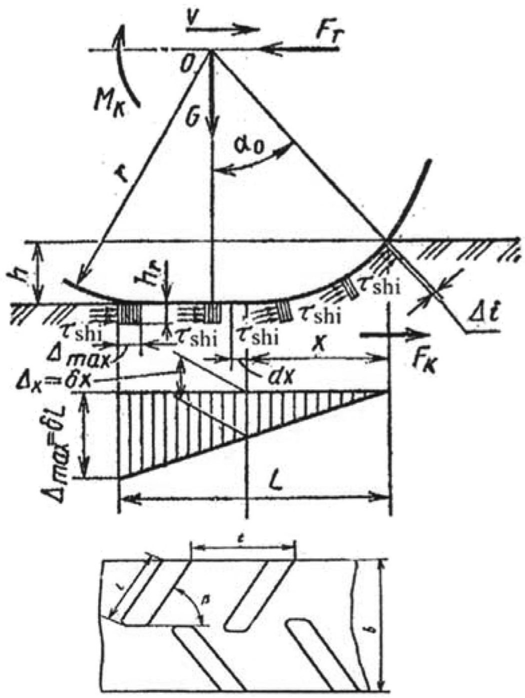

Fig. 1. Diagram of the interaction of a driving wheel with the soil.

($V = const$), a shift and cut of ground bricks take place basically in the periods of the egress of the last lug of the wheel support surface out of the ground (Fig. 1), and at this moment the load is distributed over the remained lugs, which are geared. All lugs move and cut the ground by equal values Δ_i, while the first lug shifts the ground by Δ_i, the second lug shifts the ground by $2\Delta_i$, the third lug shifts the ground by $3\Delta_i$ And so on. As the first lug passes all stages of gearing from the ingress into the ground to the egress from the ground, the maximum shift and cutting of the ground at the egress from the gearing $\Delta_{\max} = n\Delta_i$ (here n is the number of lugs in the gearing of the support surface with the ground).

It is proved [2] that the distribution of deformation of shear and cutting of ground bricks in contact with the support surface of a wheel with the ground may be presented as a triangle, and its maximum value may be presented as the product of the slipping coefficient δ and length of the support surface of a wheel L, i.e. $\Delta_{\max} = \delta L$.

Under the impact of the lugs, there arise shear stresses τ_{shi}, which increase at the beginning and reach their maximum value $\tau_{\max}$ at shifting the ground by Δ_0, then they decrease and reach a constant value τ_{cut} at full cutting of the ground brick.

The ground deformation at distance x from the start of gearing equals to $\Delta_{\max} = \delta x$ (Fig. 1).

The tangential traction force necessary to overcome the ground shift is as follows:

$$F_{Kcut} = \int_0^L \tau x dA - \int_0^L b\tau x dx, \tag{1}$$

here dA is an elementary area of the support surface of a wheel, equaling to $dA = bdx$; b is the width of the wheel lug; $b = 2l \sin\beta$ (here l is the length of the side edge of a lug; β is the angle characterizing the position of a lug on the wheel (Fig. 1); at $\beta = 90^0$, $b = 2l$); dx is the length of the elementary area.

In a general case, τ_x depends on normal pressure P_x of the ground deformation, its physical-mechanical properties and wheel parameters, i.e. $\tau_x = f(P_x \Delta_x)$. In order to establish the given dependence, different empirical and semi-empirical formulae are used, including the functional dependence given by V.V. Katsigin [3]. In the given work, by using the methodology [2] of deducing a design equation of the tangential traction force, a more general approach is assumed. In particular, a rheological model of generalized elastic-viscous body as a law of deformation of soils is used [4,5,6].

$$\tau + T_r \frac{d\tau}{dt} = G_\infty \gamma + G_0 T_r \frac{d\gamma}{dt} \tag{2}$$

where $T_r = \frac{r}{G_0 + G_1}$ is the time of relaxation, sec;

$G_\infty = \frac{G_1 \cdot G_0}{G_1 + G_0}$ Is a longitudinal modulus of shear elasticity, N/m^2;
G_0 Is an instantaneous modulus of shear elasticity, N/m^2;
γ is a relative shear resistance;
t is the time, sec.

The essence of the longitudinal and instantaneous shear modules is as follows. At very slow processes of deformation, equation (2) with the speeds of $\frac{d\tau}{dt}$ and $\frac{d\gamma}{dt}$ can be neglected in relation to the values of τ and γ, and then we arrive at a common Hooke's law with a longitudinal shear modulus $G_\infty \gamma = \tau$, and on the contrary – in case of very rapid processes of deformation, the speeds of deformation and stresses are very great and the deformations and stresses may be neglected in comparison with them. At the same time, we arrive at Hooke's Law again, but it is differentiated in time and has an instantaneous modulus of shear $G_0 \frac{d\gamma}{dt} = \frac{d\tau}{dt}$.

We used the dependence [2] to deduce the formulae of the tangential force of wheel traction at the ground shift and traction coefficient. In order to reduce the derivation, as it is commonly accepted, let us change the support surface with a big curvature radius (within the limits of the contact with the ground) by a horizontal surface (Fig. 1) with the length of contact L. At the same time, let us assume that the shear reactions are parallel to the given plane and the wheel moves in the steady-state regime.

Let us determine the relative shear deformation and speed of the distribution of shift deformations, included in the original equation (2). If under the impact of lugs the soil is shifted by value Δ the relative shear resistance will be $\gamma = \frac{\Delta}{H_0}$ (where H_0 Is the depth of deformation, m).

Fig. 1 shows that at distance x, the shear resistance is $\Delta x = \delta x$ (with δ as a slipping coefficient).

Then, at distance x, we will have $\gamma = \frac{\delta x}{H_0}$. Let us express x by an actual speed $x = \upsilon_d t = \upsilon_T (1 - \delta) t$.

Then we have $\gamma = \frac{\delta \upsilon_d t}{H_0}$; $\frac{d\gamma}{dt} = \frac{\delta \upsilon}{H_0}$. Based on the foregoing, the original equation (2) will be as follows:

$$\tau + T_r \frac{d\tau}{dt} = G_0 T_r \frac{\delta \upsilon_d}{H_0} + G_\infty \frac{\delta \upsilon_d t}{H_0}. \tag{3}$$

And its solution will be as follows:

$$\tau = G_\infty \frac{\delta \upsilon_d t}{H_0} + \tau_0 e^{-\frac{t}{T_r}} + T_r (G_0 - G_\infty) \frac{\delta \upsilon_d}{H_0} - T_r (G_0 - G_\infty) \frac{\delta \upsilon_d}{H_0} e^{-\frac{t}{T_r}}, \tag{4}$$

where τ_0 Is the value of the initial tangential stress.

After the exchange $t = \frac{x}{\upsilon_d}$, solution (4) will be as follows:

$$\tau = G_\infty \frac{\delta x}{H_0} + \tau_0 e^{-\frac{x}{T_r \upsilon_d}} + T_r (G_0 - G_\infty) \frac{\delta \upsilon_d}{H_0} - T_r (G_0 - G_\infty) \frac{\delta \upsilon_d}{H_0} e^{-\frac{x}{T_r \upsilon_d}}. \tag{5}$$