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# PECULIARITIES OF METHODOLOGICAL APPROACH TO CHANGING PARAMETERS OF TECHNICAL CONDITION OF PNEUMATIC TIRES OF SELF-PROPELLED AGRICULTURAL MACHINES

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*Ruzhylo A.Z.* ***Peculiarities of methodological approach to changing parameters of technical condition of pneumatic tires of self-propelled agricultural machines.***

***Abstract.*** *The author has developed the peculiarities of the methodological approach to changing the parameters of the technical condition of pneumatic tires of self-propelled agricultural machines. The obtained analytical dependencies make it possible to establish changes in the depth of the rut, especially in over moistened soils, under the influence of the machine driver.*

***Key words:*** *tire, parameter, machine, condition.*

*Ружило А.З.* ***Особливості методологічного підходу зміни параметрів технічного стану пневматичних шин самохідних сільськогосподарських машин.***

***Анотація.*** *Автором сформовані особливості методологічного підходу зміни параметрів технічного стану пневматичних шин самохідних сільськогосподарських машин. Отримані аналітичні залежності дають змогу встановити зміни глибини колії, особливо в перезволожених ґрунтах, під впливом рушія машини.*

***Ключові слова:*** *шина, параметр, машина, стан.*

## Introduction

The analysis of the works showed that currently mathematical models using the rheological foundations of soil mechanics are quite complex, related to its indicators determined in laboratory conditions, in this connection it is necessary to develop simplified mathematical models of the influence of the mover on the soil [1].

## Analysis of recent researches

Wheeled machines are a promising basis for self-propelled agricultural machines because, in comparison with tracked machines [2], they have high productivity due to higher transport speeds [3]. For the widespread introduction of new machines into the practice of logging [4], it is necessary to have the possibility of their year-round use [5], since the seasonality of the operation of the equipment significantly extends its payback period and makes its purchase unprofitable [6]. In order to increase the efficiency of the operation of wheeled machines on overmoistened soils in the warm season [7], the leading firms of equipment manufacturers produce monotracks [8]. Wheels with tracks have more traction with the soil, putting less pressure on it [9]. The advantage of using caterpillars when working on soft and marshy soils is especially clear. Until now, methods and models have not been developed that allow predicting changes in the depth of the rut, especially in overmoistened soils, under the influence of the wheel-track engine of the machine [10].

## The aim and objectives of research

The aim of the research is the formation of a methodological approach to changing the parameters of the technical condition of pneumatic tires of self-propelled agricultural machines.

## Research results

Rutting by a wheel with a hard rim. The study was carried out under the following assumptions: the wheel rim is a rigid cylinder that does not deform under load; repeated movements of the wheel take place along the same track; the recovery time of deformations significantly exceeds the time between machine passes.

In Fig. 1 shows a schematic diagram of the formation of shrinkage during the n-fold passage of the machine wheel along the same track. The length of the horizontal projection of the contact of the wheel with the ground after n-fold passage can be determined based on the expression:

$$a_n = \left[2R \cdot (h_n - h_{n-1})\right]^{1/2} \quad (1)$$

in turn, shrinkage corresponds to:

$$x = h_n - \frac{\xi^2}{2 \cdot R} \quad (2)$$

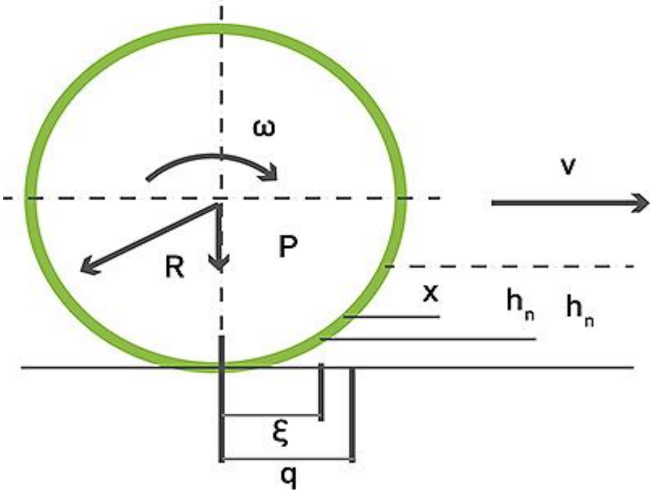


Fig. 1. Schematic diagram of the formation of soil shrinkage after n-fold passage along the track: R – wheel radius, v – machine speed, P – force, $h_n$ – sediment after n-fold passage, ξ – distance from the point of contact of the wheel with the soil surface.

Given that:

$$\frac{d\xi}{dt} = -v \quad (3)$$

The rate of formation of shrinkage is equal to:

$$\frac{dx}{dt} = -\frac{\xi v}{R} \tag{4}$$

The equation of the discrete nature of the formation of rut formation for viscoelastic soils with an n-fold pass takes the form:

$$p = C\left(h_n - \frac{\xi^2}{2R}\right) + \left[\mu_0 + \mu\left(h_n - \frac{\xi^2}{2R}\right)\right] \cdot \frac{\xi v}{R} \tag{5}$$

From the submission of force

$$P = \int pbd\xi\,, \qquad 0 \leq \xi \leq a, \tag{6}$$

the pressure value follows

$$p = \frac{P}{b \cdot a_n} \tag{7}$$

After integrating (6) over ξ, taking into account (7), the formula for calculating the track drop after the nth pass of wheeled logging machines with a rigid rim is obtained:

$$\frac{P}{b} = C \cdot h_n \cdot a_n - C\frac{a_n^3}{6R} + \left[\frac{1}{2}\mu_0 a_n^2 + \left(\frac{1}{2}h_n a_n^2 - \frac{a_n^4}{8R}\right)\right] \cdot \frac{v}{R}. \tag{8}$$

Expression (8) can be written in the form:

$$h_n = h_{n-1} + \frac{a^2}{2R}. \tag{9}$$

then (8) and (9) allow us to make successive calculations of track shrinkage after each pass, assuming:

$$h_0 = 0\,, \quad h_1 = \frac{a_1^2}{2R}, \quad h_2 = h_1 + \frac{a_2^2}{2R}, \quad h_3 = h_2 + \frac{a_3^2}{2R}.$$

With a linear viscoelastic soil rheological model, the rut formation equation (9) takes the form:

$$\frac{P}{b} = C \cdot h_n \cdot a_n - C\frac{a_n^3}{6R} + \frac{1}{2}\mu_0 a_n^2 \cdot \frac{v}{R} \tag{10}$$

Equation (10), taking into account (9), can be reduced to the form

$$B = C \cdot h_n \cdot (h_n - h_{n-1})^{1/2} - 3^{-1}C(h_n - h_{n-1})^{3/2} + A(h_n - h_{n-1}) \tag{11}$$

$$B = P\left[b(2R)^{1/2}\right]^{-1}, \ A = \mu_0 v R^{-1/2}$$

For viscous rheology, the C parameter is zero, therefore, from (11) the linear nature of the formation of shrinkage follows from the number of passes:

$$h_n = c \cdot n\,, \qquad c = \frac{B}{A}. \tag{12}$$

In the absence of a viscous component μ0 = 0 and (12) takes the form

$$B = C \cdot h_n \left(h_n - h_{n-1}\right)^{1/2} - 3^{-1} C \left(h_n - h_{n-1}\right)^{3/2} \tag{13}$$

Rutting for elastic soils. For elastic soils, the parameters characterizing the viscous properties are μ0 = μ = 0, so from (13) the equation for rutting follows in the form:

$$\frac{P}{b} = c \cdot h_{n-1} \cdot a + \frac{ca^3}{3R} \tag{14}$$

Taking into account (14), determining:

$$\Delta h_n = h_n - h_{n-1} \tag{15}$$

equation (15) takes the form:

$$\frac{P}{b} = c \cdot \left(2R\Delta h_n \left(h_n + \frac{2}{3}\Delta h_n\right)\right) \tag{16}$$

By introducing dimensionless variables un and $\delta_n$

$$\Delta h_n = \gamma \cdot u_n \tag{17}$$

$$h_{n-1} = \gamma \cdot \delta_{n-1} \tag{18}$$

$$\gamma = \left[\frac{P^2}{2b^2c^2R}\right]^{1/3} \tag{19}$$

$$\delta_n = \delta_{n-1} + u_n \tag{20}$$

equation (20) is reduced to the form:

$$u_n^{1/2}\left(\delta_{n-1} + \frac{2}{3}u_n\right) = 1 \tag{21}$$

When n = 1 and $\delta_0 = 0$, we get

$$\frac{2}{3}u_1^{3/2} = 1$$, and $$u_1 = \left(\frac{3}{2}\right)^{2/3} = 1{,}31$$

Then it becomes possible to determine $u_2$, $\delta_1$, etc. Type of dependence of the generalized depth hn·γ = δ n -1 from the number of passes is shown in Fig. 2.

Empirical generalization of the dependence presented in Fig. 2, there is a formula:

$$h_n \cdot \gamma^{-1} = n^{1/2} \tag{22}$$

$$h_n = h_1 n^{1/2} \tag{23}$$

Deformation of viscoplastic soils. For viscoplastic soils, according to (6), the deformability equation is obtained in the form:

$$p = p_т + (\mu_0 + \mu \cdot x)\frac{dx}{dt} \qquad (24)$$

after its integration, we get the relationship between the time of impact of the logging machine on the soil and the sediment in the form of a parabola:

$$t = \frac{x \cdot \mu_0}{p - p_т} + \frac{1}{2} \cdot \frac{\mu \cdot x^2}{p - p_т} \qquad (25)$$

from which it follows that at the beginning of the shrinkage formation process

$$t = \frac{x \cdot \mu_0}{p - p_т} \qquad (26)$$

which corresponds to the linear equation

$$p - p_т = \mu_0 \frac{dx}{dt} \qquad (27)$$

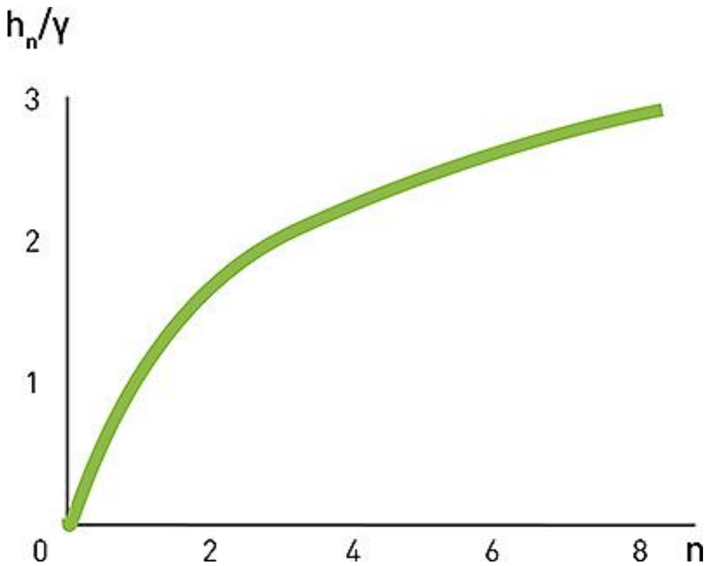


Fig. 2. Dependence of the generalized track depth on the number of passes

Thus, the parameter µ0 can be determined by the development of the initial process of precipitation formation, and µ by such information.

Rutting in viscoplastic soils. The study of the pattern of rutting for viscoplastic soils can be performed on the basis of the equation

$$p = p_т + \left[\mu_0 + \mu \cdot \left(h_n - \frac{\xi v}{2R}\right)\right]\frac{\xi v}{R} \qquad (28)$$

or after integration over ξ we obtain the equation

$$\frac{P}{b} = p_т + \left[\frac{1}{2}\mu_0 \cdot a_n^2 + \frac{1}{2}\mu \cdot h_n a_n^2 - \frac{\mu a_n^4}{8R}\right]\frac{v}{R} \qquad (29)$$

which, taking into account (25), takes the form of the equation:

$$\frac{P}{b} = p_т \cdot \left[2R \cdot (h_n - h_{n-1})\right]^{1/2} + \mu_0 \cdot v \cdot (h_n - h_{n-1}) + \frac{1}{2}\mu \cdot v \cdot (h_n - h_{n-1})^2 \qquad (30)$$

which allows to study the successive increase of precipitation during successive passage along the track of wheeled vehicles. When μ = 0, equation (44) takes the form of a quadratic equation with respect to the value:

$$(h_n - h_{n-1})^{1/2}$$

At high speeds (30) will change to

$$\frac{P}{b} = \mu_0 \cdot v \cdot (h_n - h_{n-1}) - \frac{1}{2}\mu \cdot v \cdot (h_n - h_{n-1})^2 \qquad (31)$$

and (31) takes the form of a quadratic equation with respect to

$$(h_n - h_{n-1})$$

Rutting by wheeled and tracked machines. In the analysis of soil deformation by wheeled-track machines, assumptions are made: the track is in the form of a thin strip, the stiffness of which when bending around an axis parallel to the movement is infinitely large; stiffness around another axis, perpendicular to the first and lying in the plane of the tape, is vanishingly small; the width of the tape is equal to the width of the wheel rim; the recovery time of the soil deformation after the passage of the logging machine is much longer than the time of the subsequent passage; the passage of the logging machine takes place along the same track.

The schematic diagram of the deformation of the soil under the wheeled and crawler drive of the logging machine after the nth number of passes is shown in Fig. 3.

The length of the projection of the area of contact of the track with the ground on the horizontal plane is equal to:

$$A = 1 + a_n = 1 + \left[2R \cdot (h_n - h_{n-1})\right]^{1/2} \qquad (32)$$

here, the horizontal projection of the wheel deformation is equal to:

$$a_n = \left[2R \cdot (h_n - h_{n-1})\right]^{1/2} \qquad (33)$$

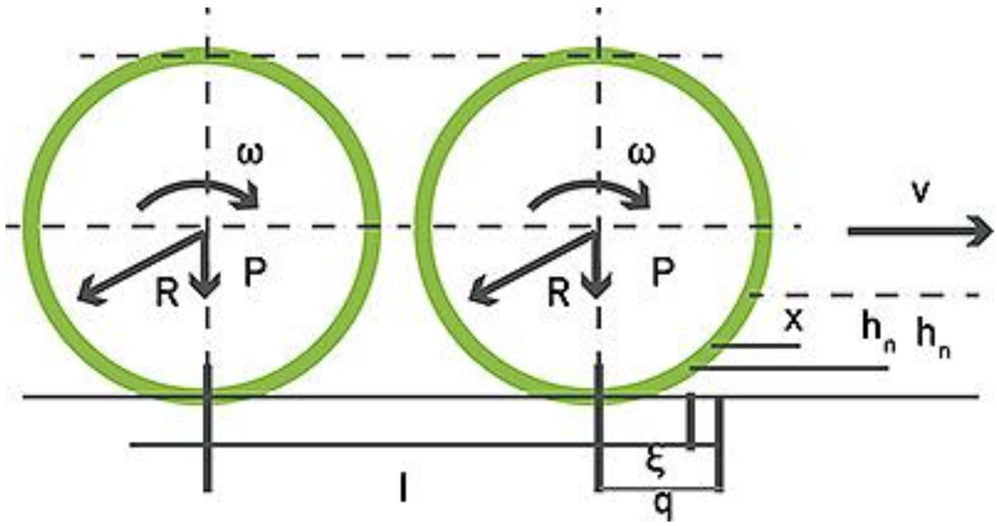


Fig. 3. The schematic diagram of the deformation of the soil under the wheeled and crawler drive of the logging machine after the nth number of passes

Soil shrinkage can be represented by the expression:

$$x = h_n - \frac{\xi^2}{2R} \tag{34}$$

After differentiating ξ in time, the representation is obtained:

$$\frac{d\xi}{dt} = -v \tag{35}$$

and the rate of shrinkage formation:

$$\frac{dx}{dt} = \frac{\xi \cdot v}{R} \tag{36}$$

The force of deformation, according to (46), is equal to:

$$P = b \cdot (p \cdot l + p \cdot a_n) = b \cdot p \cdot (1 + a_n) \tag{37}$$

where b is the width of the track.

For the viscoelastic model, the expression is obtained:

$$Pa_n = \int p d\xi = \int \left[ c\left(h_n - \frac{\xi^2}{2R}\right) + \mu\left(h_n - \frac{\xi^2}{2R}\right)\frac{\xi v}{R} \right] d\xi = Ch_n a_n - C\frac{a_n^3}{6R} + \mu h_n v \frac{a_n^2}{2R} - \mu v \frac{a_n^4}{8R^2} \tag{38}$$

Then (38) becomes:

$$P = b \cdot (1 + a_n) \cdot \left( Ch_n - C\frac{a_n^2}{6R} + \mu \cdot h_n \cdot v \frac{a_n^2}{2R} - \mu \cdot v \frac{a_n^3}{8R^2} \right) \tag{39}$$

It follows from (23):

$$h_n = h_{n-1} + \frac{a_n^2}{2 \cdot R} \tag{40}$$

and formula (40) will take the form

$$pa_n = Ch_{n-1}a_n + \frac{1}{3} \cdot \frac{Ca_n^3}{R} + \mu \cdot v \cdot \left( \frac{h_{n-1}a_n^2}{2R} + \frac{a_n^4}{8R^2} \right) \tag{41}$$

from which the expression for determining the pressure on the soil follows:

$$p = Ch_{n-1} + \frac{1}{3} \cdot \frac{Ca_n^2}{R} + \mu \cdot v \cdot \left( \frac{h_{n-1}a_n}{2R} + \frac{a_n^3}{8R^2} \right) \tag{42}$$

Based on (39) and (42), we obtain:

$$\frac{P}{b} = \left[ Ch_{n-1} + \frac{1}{3} \cdot \frac{Ca_n^2}{R} + \mu \cdot v \cdot \left( \frac{h_{n-1}a_n}{2R} + \frac{a_n^3}{8R^2} \right) \right] \cdot (1 + a_n) \tag{43}$$

When l = 0, which corresponds to the condition of movement of wheeled forestry machines with a hard disk, formula (43) turns into:

$$\frac{P}{b} = Ch_{n-1}a + \frac{1}{3} \cdot \frac{Ca^3}{R} + \mu \cdot v \cdot \left( \frac{h_{n-1}a^2}{2R} + \frac{a^4}{8R^2} \right) \tag{44}$$

In the case when the condition l >> is fulfilled, (44) takes the form

$$\frac{P}{bl} = Ch_{n-1} + \frac{1}{3} \cdot \frac{Ca_n^2}{R} + \mu \cdot v \cdot \left( \frac{h_{n-1} a_n}{2R} + \frac{a_n^3}{8R^2} \right)$$
(45)

The resulting formulas allow for the given soil rheology to consistently determine the sediment with known shrinkage from the previous pass. Assuming the initial condition h0 = 0, it is possible to determine the depth of the rut formed as a result of the next pass of the logging machine by successive solutions of the constructed equations. For the first pass, we get the shrinkage:

$$h_0 = 0, \; h_1 = \frac{a_1^2}{2 \cdot R}$$

and according to (59) we obtain the equation:

$$\frac{P}{bl} = \frac{1}{3} \cdot \frac{Ca_1^2}{R} + \frac{\mu \cdot v \cdot a_1^3}{8 \cdot R^2}$$
(46)

the solution of which allows you to determine the depth of the rut after the first pass. Further:

$$h_2 = h_1 + \frac{a_2^2}{2 \cdot R}, \qquad \ldots, \qquad h_3 = h_2 + \frac{a_3^2}{2 \cdot R}$$
(47)

At low speeds of movement of the machine (47) goes to:

$$\frac{P}{b \cdot l} = Ch_{n-1} + \frac{1}{3} \cdot \frac{Ca_n^2}{R}$$
(48)

therefore, for the depth of the rut after the first pass of the logging machine, we get the formula:

$$h_1 = \frac{a_1^2}{2 \cdot R} = \frac{3}{2} \cdot P \cdot (Cb \cdot l)^{-1}$$
(49)

We compare the formation of ruts in the soil by wheeled and tracked machines and wheeled machines. According to dynamic tests of soils, the rheological properties of which are described by equation (6) at $\mu_0 = 0$, the dependence of shrinkage on the number of blows of constant force has the form:

$$h_n = h_1 \cdot n^{1/2}$$
(50)

such a single parametric dependence allows you to determine all subsequent ones based on the depth of the first pass.

According to (61)-(63) we get:

$$\frac{P}{b \cdot lC} = \beta = h_{n-1} + \frac{3}{2}(h_n - h_{n-1})$$
(51)

Then

$$h_n = \frac{3\beta}{2} - \frac{h_{n-1}}{2}$$
(52)

After the first pass, the track depth is even $h_1=\{3\beta/2\}$ after the second $h_2=\{3\beta/4\}$, after the third $h_3=\{9\beta/8\}$, after the fourth $h_4=\{15\beta/16\}$. Note that the condition of low speed of the machine is equivalent to the condition μ = 0, which characterizes the soil as elastically deformable.

## Conclusions

1. The processing results showed that initially there was an intensive increase in the depth of the rut with an increase in the number of machine passes, caused by the destruction of the upper layer and compaction of the lower layer. In the future, the intensity of rutting or increases, a car with a wheel drive.
2. The obtained results provide a basis for using the results of mathematical modeling in forecasting the development of soil deformation processes under the influence of wheeled and wheeled and tracked agricultural machines.

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