THE INFLUENCE OF GEOMETRICAL AND PHYSICAL PARAMETERS OF CUT-OFF LAYER ON TRACTION RESISTANCE

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ABSTRACT

The results of theoretical researches on the studying of influence of the soil layer geometrical and physical parameters on the traction resistance of the soil-cultivating tool working body were given. The transfer of layer on the smallest distance and its lifting on small height is carried out at non-moldboard plowing. It indicates the expediency of geometrical characteristics change of the layer section on the traction resistance. The obtained dependence allows solving an actual problem of decrease in energy consumption at the main soil processing.

Keywords: traction resistance; soil layer; kinetic energy; generalized coordinate.

INTRODUCTION

The main criteria for effective use of working parts of the agricultural cultivation machines are their cultivation quality and traction resistance. Presented in the paper research results showed that change f form and sizes of cut-off layer have a certain impact on the trajectory of its movement in the ZOX plane. The trajectory of the movement of layer points maximally approximate to the screw lines of the circular cylinder that simplifies their descriptions. But, because the distance of layer transfer and the lifting height change, it is necessary to estimate the feasibility of changing its cross-sections to the traction resistance (Blednykh 1983; Nuralin 2011; Nuralin 2013; Oleynikov 1983; Stübenbock1981; Targ 1970)

MATERIALS AND METHODS

For the determination of traction resistance of working body and the soil-cultivating machine as a whole, the Goryachkin (1965) rational formula is often used:

$$R_T = G \times f + a \times b \times k + a \times b \times \varepsilon \times \upsilon^2 \tag{1}$$

where G·f - an effort like the friction force; a·b·к - an effort of deformation and destruction of soil layer; a·b·ε·υ^2 – an effort necessary for the transfer of kinetic energy reservoir to the destroyed parts of layer, sufficient for their rejection aside.

Coefficients К and ε do not reflect the influence of layer section form, and their definition is represented to be difficult because of the necessity of carrying out a large number of tests in various conditions. Therefore, it is necessary to consider this question analytically, using Lagrange equation of the second-order. The system "soil layer - working body" can be considered holonomic with some assumptions.

Proceeding from the dynamics of interaction of soil layer with the working body (Fig.1), the traction resistance of the case can be presented by the law

$$R_{t.res} = \left(P^{fr}_{turn} + P^{fr}_{wall} + P^{fr}_{bot}\right) + \left(P^{plo}_{cut} + P^{fields}_{cut}\right) + P_{crum} \qquad (2)$$

where P^{fr}_{turn} - layer friction force on the working body surface;

P^{fr}_{wall} and P^{fr}_{bot} - case friction forces on the wall and furrow bottom respectively;

P^{plo}_{cut} and $P^{field.s}_{cut}$ - efforts of ploughshare to the layer cutting by the field sawn-off in the vertical and horizontal planes; P_{crum} - effort spent for the layer crumbling.

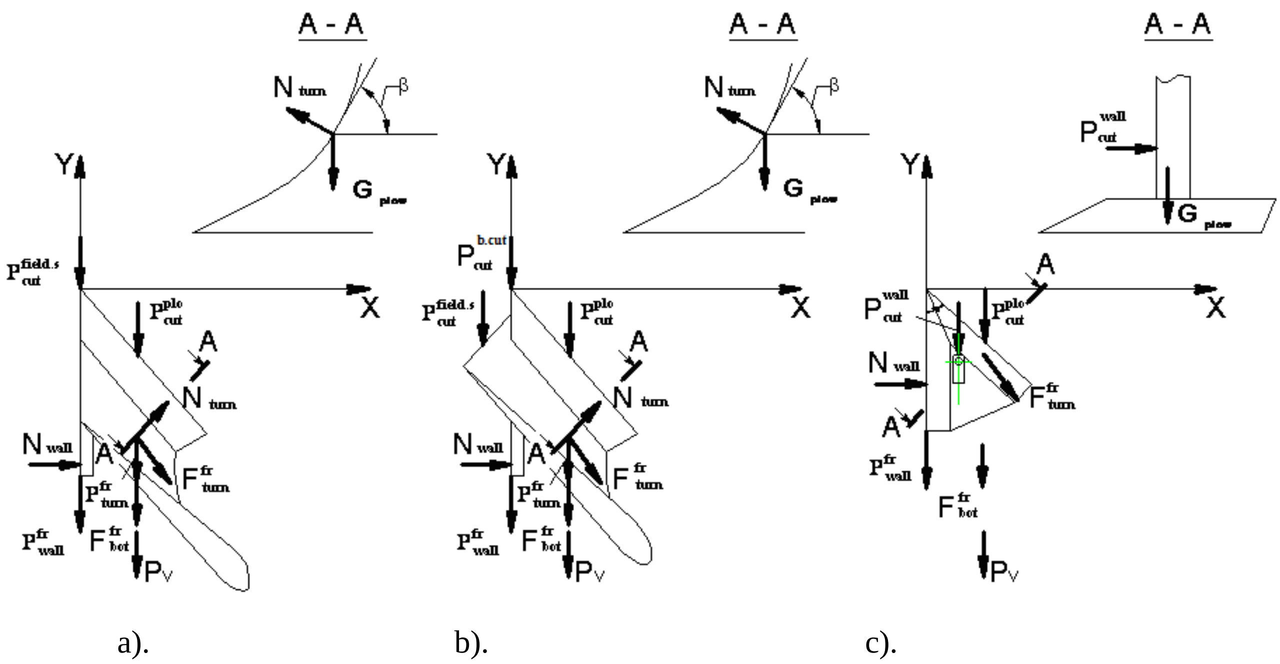


Figure 1. The schemes of external forces existing on the plow cases

a.- cultural; b.- rhomboid; c.- moldboardless.

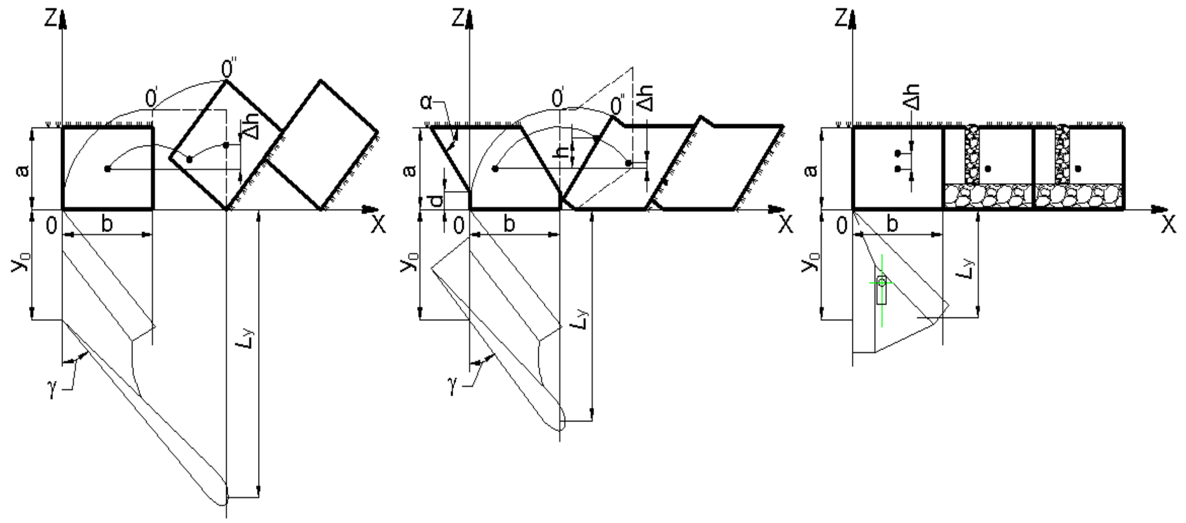
Technological process of plowing occurs by cutting soil layer in the horizontal and vertical planes by the ploughshare blade and field case edge. Further, the soil entering on the ploughshare angularly to the horizon, has the deformation depending on its state, crumbles on separate fractions and forms a layer. In the process of its movement on a plowshare-dump surface, it turns towards two edges cd^1 and ce^1 (Fig. 2) without deformation.

Kinematic turn of the layer occurs towards the movement line with some angle φ and the lift of its masses center for the height Δh.

For the rectangular layer:

$$\varphi = \pi/2 + \mathrm{arctg}\, a/b\,, \tag{3}$$

$$\Delta h = 0{,}5\left(\sqrt{a^2 + b^2} - a\right) \tag{4}$$



a) b). c).

Figure 2. Schemes of layer turns by different plow cases

a.- classic; b.- rhombic; c.- mouldboardless.

For the rhombic section soil layer:

$$\varphi = \pi - \alpha\,, \tag{5}$$

$$\Delta h = \left(a \cdot b \cdot \sin\alpha + d^2 \cdot \cos\alpha - a^2\right)/\,2a \tag{6}$$

We will define the ratios between longitudinal and cross movements of the layer points on the example of the point *O*. From the moment of the layer element introduction on the plowshare-dump surface and to the leave from it, this point passes the distance L_x in the plane *ZOX*:

For the rectangular section:

$$L_x = \pi b/2 + \left(\pi\sqrt{a^2 + b^2}\right)/180^0\, \mathrm{arctg}(a/b)\,, \tag{7}$$

For the rhombic section:

$$L_x = \pi \cdot b/2. \tag{8}$$

During this time, the point *O* will pass the way equal to L_y (fig.2) along the axis *Y*. The value L_y can be defined from the ratio:

For the rectangular section:

$$L_x = y_0 + (b + a)/tg\gamma , \tag{9}$$

For the rhombic section:

$$L_x = y_0 + b/tg\gamma . \tag{10}$$

The dependence between the two functions is equal to the dependence of their derivatives, we have $\upsilon_x = \upsilon_y L_x / L_y = \upsilon_{plow} L_x / L_y$. Indicating $L_x / L_y = n_y$, we will get:

$$\upsilon_x = \upsilon_{plow} n_y , \tag{11}$$

where υ_{pliow} - the speed of plow movement.

Angular speed of layer at the turn end is equal to:

$$\omega = \upsilon_{plow} n_y / r_{rot} , \tag{12}$$

The radius of layer rotation r_{rot} for different forms will be defined as:

For the rectangular:

$$r_{rot} = \sqrt{a^2 + b^2} , \tag{13}$$

For the rhombic

$$r_{rot} = \sqrt{a^2 + d^2} . \tag{14}$$

The moment of layer section inertia concerning the rotation pole e^1 taking into account Sht-ebner's (Targ 1970) theory is equal to:

For the rectangular:

$$I_{d^1} = m\left(a^2 + b^2\right)/3; \tag{15}$$

For the rhombic:

$$\begin{aligned} I_{d^1} = m(a-d)^2 \Big[& b^2 \sin^2\alpha + b(a-d)\sin 2\alpha + (a-d)^2 + d\big\{a^2 \sin^2\alpha + \\ & + (a-d)^2 \cos^2\alpha\big\} + a^2 d \sin^2\alpha \big\{b^2 + (a-d)^2\big\}\Big] / 3a^2 \sin^2\alpha \end{aligned} \tag{16}$$

The layer weight which is on a dump surface is equal to

$$G_{plow} = \gamma_{п} ab \int_0^{t_p} \upsilon dt \tag{17}$$

where γ_{soil} – soil density.

We will determine the case friction force on the furrow bottom:

$$P_{bot}^{fr} = \left(G_{plow} + G_{case}\right) f_{fr} = \left(G_{case} + \gamma_{soil} ab \int_0^{t_p} \upsilon dt \right) f_{fr} \ , \tag{18}$$

where G_{case} -the case weight considering the part of the whole tool weight; f_{fr} - a friction coefficient.

The frictional force on the working body surface was calculated with the help of the layer weight and the angle ε (Fig.1):

$$F_{turn}^{fr} = f_{fr} G_{plow} \cos\varepsilon \tag{19}$$

Then friction force projection on the working body surface on the axis Y is equal to

$$P_{turn}^{fr} = f_{fr} G_{plow} \cos\varepsilon \cdot \cos\theta \cdot \cos\gamma \tag{20}$$

where θ - tangential inclination angle to the surface in the plane ZOУ; γ - angle of generatix setting to the furrow wall.

The case friction force on the wall of furrow can be determined with the help of wall reaction to the case

$$P_{wall}^{fr} = N_{wall} f_{fr} = f_{fr} G_{plow} \cos\varepsilon \cdot \cos^2\theta \cdot \cos^2\gamma \tag{21}$$

The total friction force affecting the case:

$$P_{case}^{fr} = f_{fr} \left[G_{case} + G_{plow} \left(1 + \cos\varepsilon \cdot \cos\theta \cdot \cos\gamma + \cos\varepsilon \cdot \cos^2\theta \cdot \cos^2\gamma \right) \right] \tag{22}$$

Cutting force P_{cut}^{pou} and $P_{cut}^{field.s}$, being the dissipative forces, depend on the cutting length, movement speed, mechanical structure and soil condition, degree of ploughshares blunting and field edge, etc. The determination of these forces for each case demands carrying out a large number of experiments and can be an independent object of research. In our case, we will accept that these forces are proportional to the length of the cutting line and speed of plow movement:

$$P_{cut} = P_{cut}^{plo} + P_{cut}^{field.s} = \kappa_{cut} \upsilon_{plow} L \, , \tag{23}$$

where L = b + a - for rectangular layer; L = [b + d + (a - d)/sinα] - for rhombic layer.

The force spent for crumbling, is a dissipative force. It is known that crumbling at other factors being equal increases with the speed increase. Then force on crumbling can be written down as:

$$P_{crum} = \kappa_{crum} \upsilon_{plow} n_y \tag{24}$$

Having united the expressions (23) and (24) for the dissipative forces, we have

$$P_{diss} = \upsilon_{plow}(\kappa_{crum} n_y + \kappa_{cut} L) \tag{25}$$

For drafting Lagrange equation of the second-order for the considered system, working body - soil, we choose case movement q_i as the generalized coordinate, in the line of Y. Then the generalized speed is equal to $\dot{q}_i = \dot{y} = \upsilon_{plow}$.

Kinetic energy of the system is equal to the sum of energies for the movement, lifting and turn:

$$T_{\sum} = T_z + T_x + T_{turn} \tag{26}$$

At the determination of lifting energy, by analogy to the formula (11) we will express the speed on the axis *Z* with the help of plow speed and dependence $\Delta h/L_y$, which we will designate as n_z. Then kinetic energy of the layer at the turn end will be equal to

$$T_{\sum} = \frac{1}{2}\left[m \cdot \upsilon_{plow}^2 (n_y^2 + n_z^2) + I_{d^1}\omega^2\right] \tag{27}$$

The system potential energy will be defined from the formula:

$$\Pi = m \cdot g \cdot \Delta h \tag{28}$$

Lagrange's kinetic potential is equal to:

$$L = T_{\sum} - \Pi = k_M y(t)\left(\upsilon_{plow}^2(t) k_T - 2g \cdot \Delta h\right), \tag{29}$$

where, $k_M = \frac{1}{2g} \cdot \gamma_{soil} \cdot a \cdot b \cdot \cos\theta \cdot \cos\gamma$, $k_T = n_z^2 + n_y^2\left(1 + \rho_{d^1}^2 / r_{turn}^2\right)$, $y(t) = \int_0^t \upsilon_{plow}(t)dt$.

We find a private derivative from L with the help of the generalized speed:

$$\frac{\partial L}{\partial \upsilon_{plow}} = 2k_M k_T y(t)\upsilon_{plow}(t) \tag{30}$$

Then we will calculate the derivative of the formula (30) with the help of time:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \upsilon_{plow}}\right) = 2k_M k_T\left[\upsilon_{plow}^2(t) + y(t)W(t)\right], \tag{31}$$

where $W(t) = \frac{d\upsilon_{plow}(t)}{dt}$ - acceleration.

The derivative of Lagrange's kinetic potential on the generalized coordinate it is equal to

$$\frac{\partial L}{\partial y} = k_M\left[\upsilon^2_{plow}(t)\cdot k_T - 2g\cdot\Delta h\right] \tag{32}$$

The generalized force is equal to the projection of all forces influencing the system, generalized coordinate:

$$Q = \left(R_T - P^{fr}_{case}\right) + Q_{diss} \tag{33}$$

The power of viscous friction is proportional to $\upsilon_{plow}(t)$, that the function of dispersion or dissipative has to be scalar positive function:

$$P_{diss} = \sum_{i=1}^{n} \frac{\alpha_i \cdot \upsilon_i^2}{2}, \tag{34}$$

and the corresponding generalized force will be equal to:

$$Q_{diss} = -\frac{\partial P_{diss}}{\partial \upsilon_{plow}} = -\left(k_{crum} n_y + k_{cut} L\right) \tag{35}$$

The sign "minus" in this case specifies that the dissipative forces are directed against the case movement. Then Lagrange equation of the second-order for this system is:

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \upsilon_{plow}}\right) - \frac{\partial L}{\partial y} = Q \tag{36}$$

Solving the equations (31) and (32) cooperatively, from the equation (36) we will get the differential equation 2nd order for the traction resistance:

$$R_T = 2A\ddot{y}y + A\dot{y}^2 + B\dot{y} + Cy + D, \tag{37}$$

where $A = k_T \cdot k_M$, $C = \gamma_{plow} a \cdot b \cdot f \cdot [1 + \cos\varepsilon \cdot \cos\theta \cdot \cos\gamma(1 + \cos\theta \cdot \cos\gamma)]$,

$B = k_{crum} \cdot n_y + k_{cut} \cdot L$, $D = G_{case} \cdot f + 2k_M \cdot g \cdot \Delta h$.

The resulted dependence describes the resistance of working body taking into account the unevenness of its movement. Considering the assumption about the uniformity of the plow movement accepted by us previously, the equation is as follows

$$R_T = A\dot{y}^2 + B\dot{y} + Cy + D \tag{38}$$

The obtained dependences were calculated and plotted the graphs of the change in energy expenditure per soil overturning of the formation for various working element (Fig. 3)

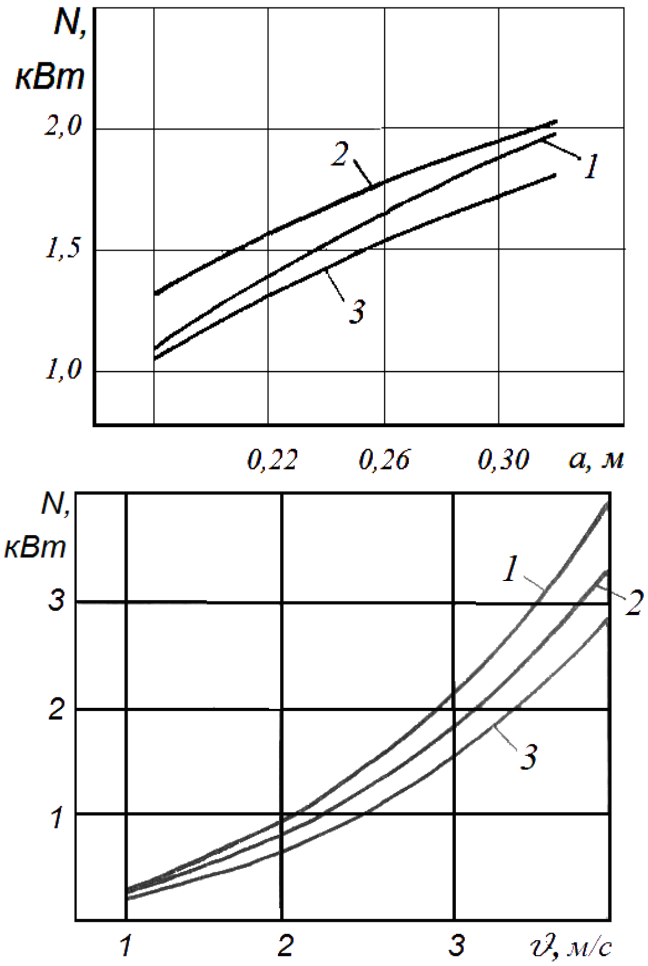


Figure 3. Change in the power consumed per soil overturning, depending on the depth of plowing (a) and the speed of the motion tool (b):

1. Rectangular layer; 2. Parallelogram layer; 3. "Rhombic" layer

CONCLUSIONS

The analysis of the received dependences shows that 30% of the general energy is required for a layer turn for the plowing. At small speeds of movement, the size of traction tool resistance does not depend on geometry and cut-off layer form. With the depth increase of plowing and movement speed, the costs of energy for lifting and layer turn sharply increase that leads to the increase in the traction resistance of working body. At non-moldboard plowing, the tool has the smallest traction resistance due to the turn lack and not big lifting of rectangular layer. Dump plowing on a layer turn with rectangular section demands expenses of energy 10 … 15% more than with rhombic.

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