THE IMPACT OF SOIL PHYSICAL AND MECHANICAL PROPERTIES ON DRAFT RESISTANCE OF PLOUGHS

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INTRODUCTION

It is known from our previous investigation [1] that the draft resistance of ploughs depends on such soil properties as its hardness, density, friction and adhesion. However, there were no analytical correlations that would enable to determine the draft resistance of the share-mouldboard surface and the plough body as a whole, depending on their properties.

The purpose of the investigation is to estimate forces acting upon the surfaces of the plough body and the impact of physical and mechanical properties of soil on its draft resistance.

OBJECT AND METHODS OF RESEARCH

The object of the research is the draft resistance of the plough body depending on its design parameters, as well as physical and mechanical properties of soil. On the basis of previous investigations [1], a computer algorithm has been worked out for the simulation of the forces exerted by soil upon operating (lifting and supporting) surfaces of the plough body, and draft resistance caused by these forces.

According to our previous investigations [1], draft resistance R_x of the plough body is determined by share cutting resistance R_{Px} , the resistance caused by weight R_{Gx} of the strip lifted, by inertia forces R_{Jx} , by soil adhesion R_{Ax} and by weight R_{Qx} of the plough body itself (including part of weight of the plough). However, the latter is not dependent on plough parameters.

$$R_x = \sum R_{ix} = R_{Px} + R_{Gx} + R_{Jx} + R_{Ax} + R_{Qx}, \tag{1}$$

Vertical reaction R_z and lateral reaction R_y of the operating part are defined by corresponding partial reactions:

$$R_z = \Sigma R_{iz}; \qquad R_y = \Sigma R_{iy}, \tag{2; 3}$$

Total draft resistance R_x of the operating part is composed of the resistance of working surface R'_x and the resistance of supporting (lower and lateral) surfaces R''_x :

$$R_{x} = R'_{x} + R''_{x} = \sum R'_{ix} + f_{0} \left(\sum R_{iz} + \sum R_{iy} + p_{Axy} S_{xy} + p_{Axz} S_{xz} \right),$$
(4)

where:

 f_0 – is the coefficient of soil friction along working and supporting surfaces of operating part;

 p_{Axy} and p_{Axz} – specific adhesion force, respectively, to lower and lateral supporting surfaces of the operating part;

 S_{xy} and S_{xz} – the surface area, respectively, of the lower and the lateral supporting surfaces of the operating part.

Friction resistance F_x is a constituent part of these reactions and their components, and by analogy we can write that

$$F'_{x} = \sum F'_{ix} = F'_{Px} + F'_{Gx} + F'_{Jx} + F'_{Ax} + F'_{Qx} = R'_{x} - R'_{xo}, \qquad (5)$$

$$F_x'' = f_0(R_z + R_y + p_{Axy}S_{xy} + p_{Axz}S_{xz}) = R_x'',$$
(6)

$$F_x = F_x' + F_x'', \tag{7}$$

Friction resistance is defined as the difference between total resistance (general value of the partial resistance) and resistance R_{xo} in operation without friction ($f_0 = 0$).

$$F_{ix} = R_{ix} - R_{ixo}; F_x = R_x - R_{xo},$$
(8; 9)

Ratio λ_F of friction resistance in partial and total resistance (reaction) is determined from their correlation:

$$\lambda_{F_{ix}} = F_{ix} R_{ix}^{-1}, \quad \lambda_{F_x} = F_x R_x^{-1}, \quad (10; 11)$$

Further we discuss the impact of friction on each partial resistance of the plough body.

RESULTS AND DISCUSSION

Cutting resistance R'_{Px} is proportional to soil hardness ρ_0 and the share edge surface area ω :

$$R'_{Px} = k_p \rho_0 \,\omega = k_p \rho_0 \,ib, \tag{12}$$

where:

 k_p – the coefficient involving the impact of the frontal surface shape of the ploughshare edge;

i and b – thickness and width of the edge.

It is evident from the formula (12) that the friction of soil along the edge does not influence cutting resistance of the edge.

At a sharp ploughshare (the rear bevel is absent) $R_{Pz} = 0$.

At an inclined ploughshare lateral reaction R_{Py} arises, its value being affected by the friction reaction.

$$R_{Py} = k_p \rho_0 \ ib \ ctg \ (\gamma + \varphi_0), \tag{13}$$

where:

 γ – the inclination angle of the edge towards the direction of movement (the wall of the furrow); φ_{o} – the angle of friction.

When friction is absent, $f_0 = 0$, $\varphi_0 = 0$

and

$$R_{Pvo} = k_p \rho_0 \ ib \ ctg \ \gamma, \tag{14}$$

The friction of soil along the ploughshare edge reduces the lateral pressure of the ploughshare (the pressure of the plough body against the wall of the furrow).

The resistance of the supporting surface

$$R''_{Px} = k_p \rho_0 \, ib \, f_0 \, ctg \, (\gamma + \varphi_0) = F''_{Px}, \tag{15}$$

Total cutting resistance

$$R_{Px} = k_p \rho_0 ib \left[1 + f_0 ctg \left(\gamma + \varphi_0\right)\right], \tag{16}$$

The lateral cutting resistance of the knife is determined by formulae, similar to those for the cutting resistance from below. Consequently, similar to the above formulae will also be the formulae defining the impact of friction on the total resistance of the knife.

Resistance caused by the weight of the lifted strip:

$$R_{Gx} \approx q \,\delta gk_{y} r \sin^{-1} \gamma *$$

$$* \left\{ \left[(\sin \gamma \cos \varepsilon_{1} + \cos^{2} \gamma \sin^{-1} \gamma) e^{f_{0} \sin \gamma (\varepsilon_{1} - \varepsilon_{2})} - (\sin \gamma \cos \varepsilon_{2} + \cos^{2} \gamma \sin^{-1} \gamma) \right] \cos \varepsilon_{1} + (\cos \varepsilon_{1} e^{f_{0} \sin \gamma (\varepsilon_{2} - \varepsilon_{1})} - \cos \varepsilon_{2}) (\cos \varepsilon_{1} - f_{0} \sin \varepsilon_{1} \sin \gamma)^{-1} * \right.$$

$$* \sin \varepsilon_{1} \left[\sin \varepsilon_{1} \sin \gamma + f_{0} (\sin^{2} \gamma \cos \varepsilon_{1} + \cos^{2} \gamma) \right] \right\}$$

$$(17)$$

$$R_{G_z} \approx q \,\delta g \, r \sin^{-1} \gamma \, (\varepsilon_2 - \varepsilon_1) \,, \tag{18}$$

$$R_{G_y} \approx q \delta g r \sin^{-1} \gamma (\varepsilon_2 - \varepsilon_1) (\varepsilon_1 + 0.52) \operatorname{ctg} \gamma$$
(19)

$$R''_{Gx} = f_0 \left(R_{Gz} + R_{Gy} \right) = F''_{Gx} \tag{20}$$

Resistance caused by inertia forces:

$$R'_{Jx} = q \, \delta v^2 k_y^{-1} \sin \gamma \left\{ \left(\sin \gamma \cos \varepsilon_1 + \cos^2 \gamma \sin^{-1} \gamma \right)^* \right. \\ \left. * e^{f_0 \sin \gamma (\varepsilon_1 - \varepsilon_2)} - \left(\sin \gamma \cos \varepsilon_2 + \cos^2 \gamma \sin^{-1} \gamma \right) + \right. \\ \left. + \left(\cos \varepsilon_1 - f_0 \sin \varepsilon_1 \sin \gamma \right)^{-1} e^{f_0 \sin \gamma (\varepsilon_2 - \varepsilon_1)} \right]$$
(21)

 $\sin\varepsilon_1 \left[\sin\varepsilon_1 \sin\gamma + f_0 \left(\sin^2\gamma \cos\varepsilon_1 + \cos^2\gamma \right) \right] \right\}$

$$R_{Jz} = q \,\,\delta \,\,v^2 k_y^{-1} \sin \gamma \sin \varepsilon_2 \,\,e^{f_0 \sin \gamma \,(\varepsilon_2 - \varepsilon_1)} \tag{22}$$

$$R_{Jy} \approx q \,\,\delta \,\, v^2 k_y^{-1} \sin \gamma \cos \gamma \,(1 - \cos \varepsilon_2) \tag{23}$$

$$R''_{Jz} = f_0(R_{Jz} + R_{Jy}) = F''_{Jx}, \qquad (24)$$

Resistance caused by soil adhesion:

$$R'_{Ax} = p_A br \sin^{-1} \gamma (e^{f_0 \sin \gamma (\varepsilon_2 - \varepsilon_1)} - 1) *$$

$$* \{ \sin \gamma \cos \varepsilon_1 + \cos^2 \gamma \sin^{-1} \gamma + (\cos \varepsilon_1 - f_0 \sin \varepsilon_1 \sin \gamma)^{-1} *$$

$$* \sin \varepsilon_1 \left[\sin \varepsilon_1 \sin \gamma + f_0 (\sin^2 \gamma \cos \varepsilon_1 + \cos^2 \gamma) \right] \}$$
(25)

$$R_{Az} = 0 \tag{26}$$

$$R_{Ay} \approx 0 \tag{27}$$

$$R''_{Ax} = f_0 \left(p_{Axy} S_{xy} + p_{Axz} S_{xz} \right) = F''_{Ax}$$
(28)

Where:

q – area of cross section of the strip to be lifted;

 δ – soil density;

 k_v - soil compaction coefficient in front of the operating part;

 f_0 – coefficient of soil friction against the surface of the operating element;

v – movement speed of the plough body; p_A – specific force of soil adhesion to the operating surface;

b – surface width of a soil strip;

 ε_1 and ε_2 are correspondingly the initial and final angles of the lifting (share- mouldboard); g – acceleration caused by gravity (g = 9,81).

As an example, Figure 1 shows the draft resistance of the sharemould-board surface having the initial lifting angle $\varepsilon_1 = 30^\circ$ and the final lifting angle $\varepsilon_2 = 100^{\circ}$.



Fig. 1. Impact of the soil friction coefficient f_0 upon the draft resistance of the plough body share-mouldboard (lifting) surface at various inclination angles γ of the horizontal generatrices and speeds

It is evident that friction resistance constitutes a 36-52% of the total resistance of the lifting surface.

CONCLUSIONS

1. The derived analytical correlations allow to determine draft resistance of the share-mouldboard surface and the resistance of supporting surfaces of the plough body depending on the value of soil hardness, density, adhesion, friction coefficient, as well as on the parameters of the plough body and its working speed.

2. The impact of friction upon draft resistance of the plough is significant. It constitutes approximately one half of its total draft resistance including the resistance of the supporting surfaces (25-32%).

3. Increasing the angle of inclination between the horizontal generatix of the share mouldboard surface and the direction of travel of the plough, as well as higher working speed lead to a lower proportion of friction resistance in the total resistance of the plough.

4. The main ways of lowering friction resistance and the total draft resistance of the plough are the introduction of a more rational design of its body having optimum parameters, decreasing the values of reactions of supporting surfaces, the application of antifriction materials and the replacement of slipping surfaces by moving ones.

REFERENCES

1. Vilde A.:Dynamics of the soil tillage machine operating parts and their elements. In: Proceedings of the Latvia University of Agriculture, Vol.1 (295). Jelgava, Latvia, 36-44. 1999.

SUMMARY

By using analytical correlations derived as a result of theoretical research, a computer algorithm has been worked out for simulating the functions of the plough body and the forces exerted by soil upon the operating parts, as well as its draft resistance. These correlations allow to determine the draft resistance of the plough depending on the parameters of its body, as well as to evaluate the impact of the physical and mechanical properties of soil upon it. They considerably influence the draft resistance of the body and, respectively, the energy capacity of ploughing and fuel consumption. The greatest influence upon it is exerted by soil adhesion, which manifests itself particularly in wet clay soils at lower temperatures. The maximum plough resistance occurs in caked clay soils, the minimum – in sandy soils.