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Laboratory Study Results of Soil-Cutting Operating Elements

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Abstract. Studying the wear of soil-cutting working tools in the field conditions has certain difficulties associated with the impermanence of soil properties. The paper presents the results of a laboratory study of the power characteristics in the process of wearing of a soil-cutting wedge in an artificial abrasive soil medium. (*Research purpose*) To determine the nature of changes in cutting forces in vertical and horizontal planes depending on the conditions and a degree of wear of a soil-cutting wedge. (*Materials and methods*) For the experiment, use was made of quartz as an abrasive material, paraffin with additives of ceresin and petrolatum as binding components; cement was additionally introduced to change the granulometric composition of a soil model, and a cross-planer was used as a drive mechanism. (*Results and discussion*) It has been shown that the horizontal component, or traction resistance, increases linearly with increasing the depth of cutting. An increase in the soil-cutting velocity also leads to an increase in the traction resistance of the wedge, and its magnitude increases in a power-law dependence on the velocity. It has been established that the cutting angle affects not only the variation of the wedge traction resistance, but also the shearing pattern, which changes as it increases and changes from shear shavings into shift shavings, which contributes to the traction force growth. It has been found that an increase in traction resistance is affected by an increase in the hardness of abrasive material and a decrease in the distribution density of solid particles in its volume. As the width of the back chamfer and the angle of its inclination to the furrow bottom increased, the traction characteristics both in the vertical and horizontal planes increased as well, the back chamfer width having the greatest influence on the vertical component. As the blade worn out depending on the friction path, the vertical component of frictional forces increased sharply, while the horizontal component increased insignificantly. (*Conclusions*) The results of the conducted studies have shown that the wedge depth mainly depends on the back chamfer width. The traction resistance of the wedge is greatly influenced by physical and mechanical properties of an abrasive medium, cutting conditions and a degree of the blade blunting.

Keywords: abrasive model of soil, soil wedge, back chamfer, intensity of blade wear.

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Studying the wear of soil-cutting working tools in the field faces certain difficulties due to the variability of soil properties, its heterogeneity and changing weather conditions [1]. Because of the seasonality of fieldwork, studies often do not fit into one cycle (year), they have to be postponed for the next year, increasing the test time and accumulating errors in experimental results.

In the post-harvest period, the root and stubble residues remaining in the topsoil (plow layer) exert a great influence on the performance characteristics of soil-cutting elements [2]. Therefore, laboratory research methods are often the only possible ones.

The research purpose is to determine the nature of changes in cutting forces in the vertical and horizontal planes, depending on the conditions and the degree of wear of a soil-cutting wedge.

Materials and methods. The paper presents the results of a laboratory study of power characteristics in the wear of a soil-cutting wedge in an abrasive medium including solid particles most often found in soil (quartz particles of a size ranging from 0.05 to 0.5 mm) and paraffin with additional components to change the properties of the abrasive soil environment model. Another basic component of soil is clay particles, which make soil plastic and determine its rheological properties [3]. Under natural conditions, soil samples of the same granulometric composition can change their properties depending on humidity (weather conditions).

The substantiation of the use of technical paraffin with additives of ceresin and petrolatum as a binding abrasive particle instead of moistened clay was based with an analytical calculation of the similarity criteria by V.A. Venikov's method to ensure the compliance of the soil model based on the sand-paraffin mixture with the real soil conditions of different regions of the Russian Federation [4, 5].

Preliminary tests have shown that the creep variation curves of water-saturated chernozem samples with different preliminary compaction are similar to the samples when clay with water is replaced with technical paraffin with various additives of abrasive (quartz) and dust particles (cement, gypsum, etc.) in the soil environment. The use of paraffin as a binder allows obtaining a soil model that demonstrates stable properties for a long time. The choice of paraffin in the considered studies was based on the experimental data of G.N. Sineokov, who noted that in wedge cutting at an ambient temperature of 18-22°C, a mixture of paraffin with an abrasive is destroyed by shearing, like loamy soils [6]. The results of laboratory studies have shown the similarity of the wear pattern of blades in an artificial abrasive material consisting of quartz sand and paraffin with natural soil conditions. A back chamfer formed on the blade and inclined at a negative angle to the furrow bottom, and the forces of cutting resistance increased.

The paper presents the laboratory study results describing the action of cutting forces in vertical $P_в$ (buoyancy force) and horizontal $P_г$ (resistance to motion) planes (*Fig. 1*).

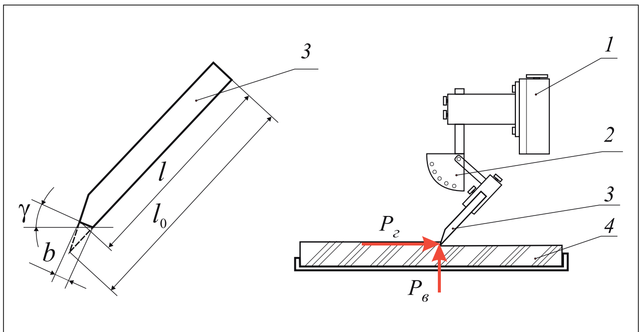

Fig. 1. Scheme of a fragment of a laboratory installation for determining the force characteristics with cutting forces in the vertical ($P_в$) and horizontal planes ($P_г$):
1 – a drive mechanism with a dynamometer; 2 – a device for sample setting; 3 – a prototype; 4 – an abrasive medium; b – the back chamfer width; γ – the inclination angle of the back chamfer to the furrow bottom; l – the length of the sample when it wears out; l_0 – the length of the new sample

Results and discussion. Experiments on the influence of the cutting conditions on the traction resistance of the soil-cutting wedge were carried out with samples of steel 45 having an angle of sharpening of $\theta = 30°$ and a thickness of the cutting edge of 0.2 mm. The relatively sharp blade and the absence of the back chamfer did not make a significant effect on the value of Pв and its values ranged around the zero mark. A cross-planer was used as a drive mechanism.

Fig. 2 shows the dependence of the traction resistance $P_г$ of the soil-cutting wedge on the depth *h* and the cutting speed *υ*.

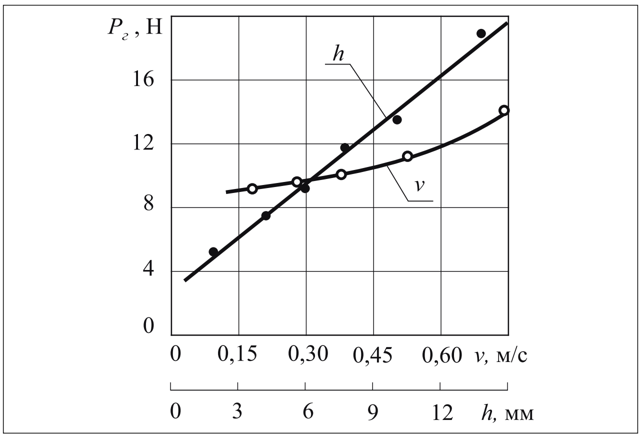

Fig. 2. Effect of depth and cutting speed on traction resistance

With increasing depth *h* of cutting, the value of $P_г$ continuously increases in a linear manner. This indicates an increasing force in the detachment of shavings, the dimensions of which increase in proportion to the depth.

Measurements of traction resistance in field conditions during testing on loamy soils (*Fig. 3*) have confirmed the linear dependence obtained under laboratory conditions within the limits of measuring the tillage depth from 16 to 28 cm during plowing.

Fig. 3. Measuring plow traction resistance in field conditions

An increase in the velocity *υ* also leads to an increase in the traction resistance of a soil-cutting wedge, with the value of $P_г$ increasing in a power-law dependence on *υ*, and the equation of the curve $P_г = f(υ)$ is described by an equation of the type $y = ab^x$, where *y* and *x* respectively denote $P_г$ and the velocity-dependent coefficient *υ*. This indicates that after reaching a certain velocity range, the sizes of the soil fragments of the formation begin to decrease rapidly (lumpiness). In this case, the forces of resistance of the soil medium to the wedge movement begin to increase rapidly, which inevitably leads to an increase in the pressure on the cutting edge of the blade and, correspondingly, its more intensive wear [7].

The influence of the cutting angle α on the traction resistance $P_г$ of the wedge blade is shown in *Fig. 4*.

The curve $P_г = f(a)$ can be divided into three characteristic regions. In section *I* a linear increase in $P_г$ is observed with increasing α. Section *II* is distinguished by a sharp increase in $P_г$ with a characteristic heel region. In section *III* the curve again becomes flat and further growth of $P_г$ is observed in a relationship close to linear.

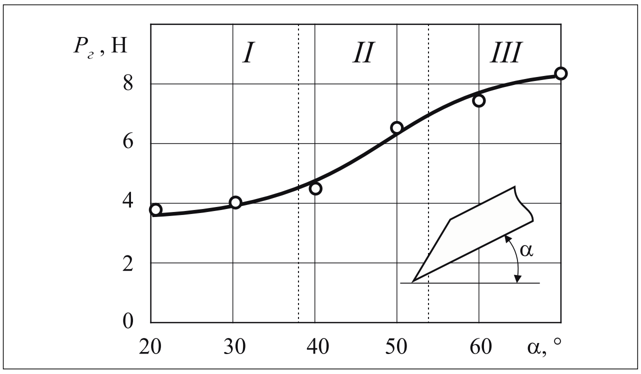

Fig. 4. Dependence of the traction resistance Pг on the angle α

Analyzing the dependence of $P_г = f(\alpha)$, we can conclude that as the angle α is increased to 40° in the section *I*, the values of $P_г$ are increased due to an increase in energy required to fracture the formation. With an increase in α, the size of shavings decreases, crumbling improves, accordingly, traction resistance increases, as well as in the case of cutting speed increasing. In section *II*, within the range of the cutting angle from 40 to 55°, there is an area of a densified core formation, where, as the blade moves forward, the friction of abrasive particles with the metal surface is accompanied by internal friction between the abrasive particles periodically appearing before the blade, which increases the cutting forces. In section *III*, when α is more than 55°, further growth of $P_г$ is observed. In this case, in addition to the densified core and increased energy of formation fracturing, a gradual change in the pattern of formation fracturing with the transition from shear shavings (*Fig. 5a*) to shift shavings has a significant effect on traction resistance (*Fig. 5b*).

The results of the conducted studies have shown that when the type of soil destruction changes from shear shavings to shift shavings, the energy of soil destruction increases due to the replacement of the fracture type as caused by the effect of normal tensile stresses on fracture under the action of shear stress tangent lines [8].

Fig. 6 shows the dependence of the cutting force $P_г$ on the hardness of the artificial soil *H* (curve *1*) and the distribution density in the amount of abrasive particles ρ (curve *2*).

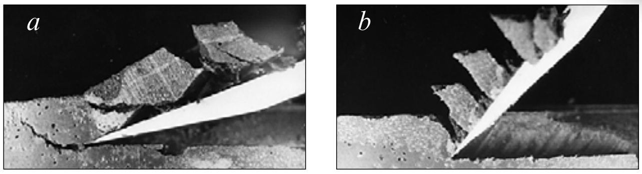

Fig. 5. Destruction of the formation with a transition from shear shavings (a) to shift shavings (b)

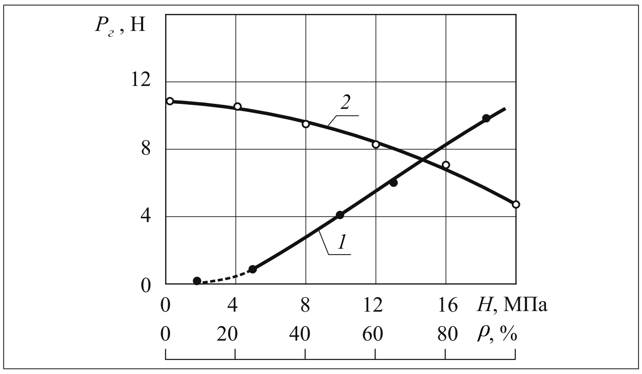

Fig. 6. The effect of hardness H and the distribution density of the abrasive particles ρ on the cutting force $P_г$

As can be seen from *Fig. 6*, the value of $P_г$ increases with increasing *H*, and the function $P_г = f(H)$ is close to linear and decreases with increasing ρ. The decrease in the value of $P_г$ in the second case is caused by a decrease in the values of the soil connectivity indicators τ and σ due to an increase in the amount of quartz solid particles larger in size than fine particles of pulverized cement added to the «artificial soil» in experiments.

Under operating conditions, similar indicators are obtained when processing heavy loamy soils with a high content of fine clay particles, where the traction resistance is much higher than on soils with a significant content of larger quartz particles, for example, sandy and sandy loamy soil types [9].

At the next stage of the study, the influence of the parameters of the back chamfer of the wedge blade on the cutting forces was determined.

For the experiments, two batches of worn samples were prepared with an initial sharpening angle θ_0 of 30°. Samples of the first batch had the same angle of sharpening after wear, equal to 60° (the angle of inclination of the back chamfer to the furrow bottom γ was 10°), but different values of the back chamfer width *b* = 0.5; 1.0; 1.5; 2.0; 2.5; 3.0 mm. This made it possible to determine the effect of the width *b* of the back chamfer on the cutting forces in two planes (vertical $P_в$ and horizontal $P_г$), regardless of the angle of its inclination to the furrow bottom γ (*Fig. 7*).

The results of the study on the influence of the back chamfer width on the traction resistance of the soil-cutting wedge have shown that with increasing parameter *b*, the values of both $P_в$ and $P_г$ increase as well, and the intensity of growing the force $P_в$ considerably

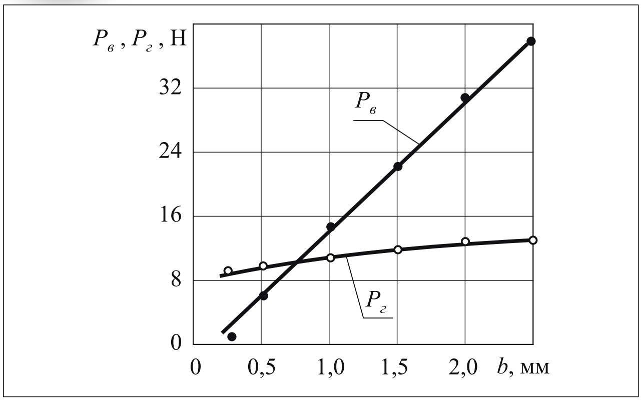

Fig. 7. Dependence of cutting forces $P_{\text{г}}$ and $P_{\text{в}}$ on the width b of the back chamfer

exceeds the increase in $P_{\text{г}}$. Hence it follows that the value of parameter *b* (at $\gamma = 10°$) has the greatest effect on the deeper penetration of the wedge blade, while the traction resistance with increasing parameter *b* varies to a much lesser extent.

The second batch of samples had equal back chamfer width *b* of 1.5 mm, but different wedge angles $\theta = 40$, 50, 60, 70 and 80°. The use of samples with the same value of parameter *b* for setting at one cutting angle $\alpha = 20°$ and a single constant angle of initial sharpening $\theta_0 = 30°$ made it possible to determine the pattern of changes in cutting forces as a function of the angle of the back chamfer inclination to the furrow bottom, the value of which was $\gamma = \theta - \theta_0 - \alpha$ (*Fig. 8a*).

Dependences of the cutting force components on the angle γ of the back chamfer inclination to the furrow bottom are shown in *Fig. 8b*.

With an increase in parameter γ, as well as *b*, an increase in the values of $P_{\text{в}}$ and $P_{\text{г}}$ is observed, however, there is no pronounced acceleration of growth of any of the parameters as compared with the other, that is, the angle γ plays the same role in changing the vertical and horizontal components of cutting forces, and its increase leads to a decrease in deeper penetration and an increase in traction resistance of the wedge.

In addition, an experiment was conducted to study the cutting forces in the dynamics of wedge blade wear. *Fig. 9* shows the dependence of the indicators $P_{\text{в}}$ and $P_{\text{г}}$ on the friction path *S*. The parameters *b* and γ were continuously varied.

As the blade wears out, depending on the path *S*, the vertical component of the cutting forces $P_{\text{в}}$ sharply increases, but the value of $P_{\text{г}}$ increases insignificantly. This indicates that the blade wear has the greatest impact on the penetration ability of the soil-cutting wedge, while its traction resistance varies insignificantly.

The results of the conducted studies have shown that the depth of the soil wedge mainly depends on the parameters of the back chamfer and, in particular, on its width. As a result of the conducted research, it can be noted that the composition selected as a substitute for natural soil

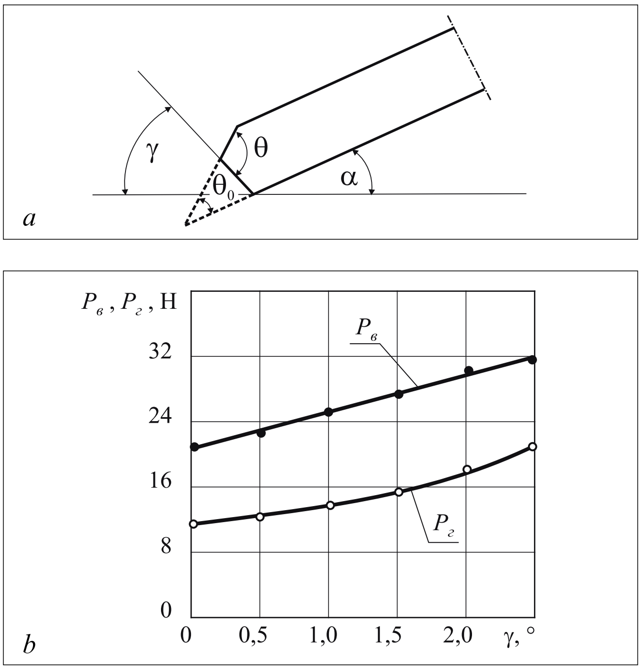

Fig. 8. Dependences of $P_{\text{в}}$ and $P_{\text{г}}$ on the inclination angle of the back chamfer γ

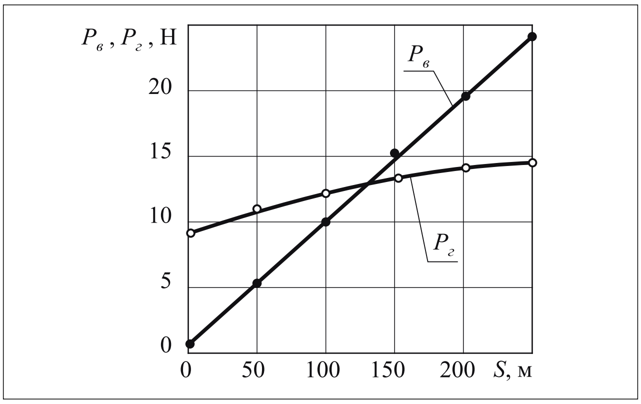

Fig. 9. Dynamics of changes in $P_{\text{в}}$ and $P_{\text{г}}$ in the course of the blade wearing

conditions, including abrasive particles of quartz sand and paraffin, adequately reflects the processes occurring in the natural soil environment when it interacts with the working tools of tillage machines. Thus, if we compare the data obtained in field studies on the wear of the blades of soil-cultivating tools with the results of laboratory studies, we can conclude that there is a direct relationship between the width of the back chamfer and the angle of its inclination to the furrow bottom. Laboratory tests allow reproducing more precisely and accurately certain factors, in particular, cutting conditions (speed, tillage depth, geometric parameters of the blade typical for tillage tools) and to determine their influence on the power characteristics of the blade itself and the single blade in the considered case, and not in combination with other components, for example, plow-bottom share surface. In this case, individual factors are superimposed, which leads to distortion of the results and an increase in errors in the experimental data. Similar phenomena occur in the study of the effect of physical and mechanical properties typical for natural soil conditions, taken according to individual criteria, which cannot be done under real soil conditions, which can be divided into components (hardness, cohesion of abrasive particles, the presence of additional inclusions, etc.) only in laboratory studies.

The traction resistance of the soil-cutting wedge is strongly influenced by physical and mechanical properties of soil (abrasive medium), cutting conditions (speed, depth, angle of the blade inclination to the furrow bottom) and the degree of the blade blunting (the sharpening angle).

Conclusions

1. The most acceptable material replacing the natural soil environment is an abrasive mixture with stable properties, regardless of the study duration, for example, artificial soil mass based on solid abrasive particles and paraffin.

2. The physical-and-mechanical properties of the abrasive medium (hardness, cohesion of abrasive particles, the presence of additional dust-like inclusions), cutting conditions (speed, depth, cutting angle) and the sharpness of a wedge blade (a degree of blunting) have the greatest impact on the traction resistance of the soil wedge.

3. The penetration ability of the soil wedge depends on the blade wear characterized by the formation of a back chamfer in the process of wear, that is inclined at a negative angle to the direction of travel, where the fundamental geometrical chamfer parameter acting on the wedge penetration is its width.

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Conflict of interest.
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