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Traction Resistance At The Tillage Wedge.

Vasilenko VV*, and Vasilenko SV.

Voronezh Agrarian University, 1, Michurin Av., Voronezh, 394087, Russia.

ABSTRACT

Most tillage bodies work on the principle of a wedge, so the analysis of its interaction with the soil allows you to choose the rational values of the design parameters of these tools. The most energy-consuming is plowing the soil with plows, so it is very important to justify the angle of lifting of the ploughshare, in which the traction resistance of the working body will be minimal. The developed analytical dependence of the traction resistance of a rectilinear dihedral wedge predicts the existence of a minimum of resistance at an optimal angle of ascent. Laboratory experiments were carried out with four wedges, which had different lifting angles. These experiments confirmed the analytical dependence. It turned out that for the size of the wedge, comparable to the size of the plow working body, the lifting angle should be equal to 16-18°, while the serial models of plows are made with a lifting angle of about 30°. Reducing the traction resistance of the plow with the optimal value of the angle of lifting of the ploughshares and the use of spontaneous vibration of the working bodies on the spring racks led to an increase in the performance of the unit with an experienced plow by 18%.

Keywords: wedge lifting angle, traction resistance, soil friction angle, soil density, experimental plow.

Corresponding author

INTRODUCTION

The vast majority of tillage working bodies works on the principle of dihedral or trihedral wedge. The founder of the theory of agricultural machines academician VP Goryachkin believed that such tools include, above all, plows and cultivators [1]. Since soil treatment is a very energy-intensive field operation, the study of the interaction of the wedge with the soil is an urgent task. The purpose of the study is to justify the optimal shape of the wedge, which can reduce the pulling resistance of the tool. The authors of the studies note that the most important influence on the drag force of the wedge is its angle of elevation [2, 3, 4]. In these publications, it is argued that as the angle of rise increases, the strength of resistance increases. The rational value of this angle is 25°. The minimum energy consumption can be achieved at a working depth of 150 mm, a speed of 1 m/s, and a low lifting angle. The authors of these publications believe that the traction resistance of the working bodies increases linearly with increasing lift angle. The source [5] States that with an increase in the front angle of the tool more than 90° traction resistance becomes greater than at sharp angles. Tillage tools have front and rear angles of inclination to the soil surface. Tools with these two sharp angles have a lower resistance force [6]. In-depth studies of the wedge-soil interaction forces are given in [7, 8]. They argue that the strength of the wedge resistance increases with increasing lift angle more intensively than the linear dependence. In the graphs, this force increases curvilinearly and smoothly at elevation angles from zero to 40°. The authors recommend to use for plough moldboards increasing angle of rise, which is better to grind the soil and reduces the length of the path of sliding the soil on the moldboard. The aim of our study is to establish the dependence of the traction resistance of a flat wedge on its lifting angle, provided that the soil layer must be raised to a predetermined height.

CALCULATION METHOD AND MATERIALS

The strength of the traction resistance of the wedge is determined by analyzing the acting forces between the wedge and the soil, taking into account the geometric dimensions of the wedge, the coefficients of external and internal friction of the soil, the density of the soil, its time resistance to shear and time resistance to rupture. The obtained analytical dependences were tested in experiments at the laboratory facility. The technical effectiveness of the implementation of the results of the calculation of the lifting angle is tested in the experimental four-body plow. Let's say you want to raise the soil layer to a height h wedge-shaped tool with a minimal pulling force, P, by varying the angle α (figure 1). The ABC wedge is affected by the gravity G of the soil layer, the friction force F of this layer on the working surface BC, the strength S of the resistance to the shear of the soil on the plane of chipping CD, the force F_1 of internal friction on this plane and the normal force N_2 as the resistance to fracture of the layer on the site CD. On the surface side of the AC forces are not taken into account, as the wedge moves on the support wheels. As for the normal forces N and N_1, they are a consequence of the interaction of these active forces and serve to determine F and F_1. We will take into account the entire length of the formation lying on the surface BC, and the point of application of force N_2 will be placed in the middle of this surface.

$$P = G \cdot tg\alpha + F \cdot \cos\alpha + S \cdot \cos(90^\circ - \alpha - \varphi) + F_1 \cdot \cos(90^\circ - \alpha - \varphi) + N_2 \cdot \sin\alpha, \qquad (1)$$

where *P* is the thrust force required to move the wedge and equal to its traction resistance, *N*;

G – the gravity of the formation lying on the wedge, N;

α – angle of rise;

F – the friction force of the formation on the working surface of the wedge, N;

S – force shear resistance of the soil at the plane of shear by CD, N;

φ – angle of soil friction on the wedge;

F_1 – the force of internal soil friction on the soil on the plane of chipping CD, N;

N_2 – the strength of the fracture resistance of the formation over the area CD, N.

In the analysis of equation (1), we take into account the relationship of the acting forces:

$$F = f \cdot N; \quad N = G \cdot \cos\alpha + N_2 + (S + F_1)\cos\varphi; \qquad (2)$$

$$F_1 = f_1 \cdot N_1; \quad N_1 = 0.5 \cdot G \cdot \cos(90^\circ - \alpha - \varphi) + S \cdot \cos(90^\circ - \alpha - \varphi) \cdot \sin(90^\circ - \alpha - \varphi), \qquad (3)$$

where *f* is the coefficient of external soil friction on the wedge;

f_1 is the coefficient of internal friction of the soil on the soil;
φ, φ_1 – angle of external and internal friction of the soil, are taken up, respectively, 28° and 60°.

The numerical values of the acting forces can be determined by their dependence on the parameters of the soil layer:

$$G = m \cdot g = \frac{h \cdot a \cdot b \cdot \rho \cdot g}{\sin \alpha} \; ; \quad (4)$$

$$S = \frac{\tau_в \cdot a \cdot b}{\sin(90^\circ - \alpha - \varphi)} \; ; \quad (5)$$

$$N_2 = \frac{2 \cdot M_{из}}{l} = \frac{2 \cdot M_{из} \cdot \sin \alpha}{h} \; , \quad (6)$$

where *a* and *b* are the dimensions of the formation cross-section, 0.30 and 0.45 m, respectively, are accepted;
m – mass of the formation lying on the working surface of the wedge, kg;
l – length of the working surface of the wedge, m;
h – the height of the rise of the soil on the wedge, taken *h* = 0.30 m;
ρ – density of the soil, ρ = 1200 kg/m^3 is accepted;
$\tau_в$ – temporary resistance of soil to shear is taken, $\tau_в$ =10 kPa;
$M_{из}$ – bending moment, which breaks off the formation and separates it from the plane CD, Nm.

As for the moment of $M_{из}$, it is possible to determine this moment according to the moment of resistance *W* of the layer to the bend and the time resistance $\sigma_в$ to the break:

$$M_{из} = W \cdot \sigma_в = \sigma_в \cdot \frac{b}{6} \cdot \left(\frac{a}{\sin(90^\circ - \alpha - \varphi)} \right)^2 . \quad (7)$$

Temporary soil resistance to rupture is taken $\sigma_в$ = 5 kPa. When all these values are substituted into equation (1) and its solution, the dependence presented graphically in figure 2 is obtained.

RESULTS

The test of analytical dependence (1) was undertaken in the laboratory at a specially manufactured facility (figure 3).

The pulling force was determined for four metal wedges with lifting angles of 10, 15, 22 and 30°. All wedges were 0.20 m high and 0.15 m wide. In each experiment, the minimum load was selected, which promoted the wedge in the soil channel without acceleration on the test site with a length of 1.6 m. The effort of moving an empty cart without a wedge was subtracted from each result obtained to obtain only the wedge resistance. After each experiment, the soil was leveled and rolled with a special roller. The results of the experiments confirmed the nature of the theoretical dependence of the drag force of the wedge on the lifting angle (figure 4).

This dependence has an optimal zone of resistance of the working body. For a wedge of height *h*=0.30 m and a width of *b*=0.45 m, the optimum angle is in the range 16 to 18°. Compared to the 30° lifting angle, the wedge resistance is reduced by 14%. For a wedge with smaller dimensions (*h*=0.20 m and *b*=0.15 m), the optimum angle is between 14-16°. The difference in the optimal angles for the two sizes of wedges can be explained by the scale factor. In both cases, a decrease in the lifting angle compared to the optimum leads to excessive lengthening of the wedge, the accumulation of more soil on it, and this is the cause of an increase in traction resistance. If the lifting angle is increased to 35-40°, then the area of the formation cleavage and the normal pressure on the working surface increase markedly. In the practice of modern plow construction, it is customary to choose the angle of lifting of the ploughshare about 30°, that is, there is still an opportunity to reduce the resistance of the working body of the plow due to its more rational geometry. Although a decrease in the lifting angle leads to an increase in the size and metal content of the plow body or tool of cultivator, the benefit of a lower resistance force indicates a desirable trend in the design of the shape of the working surfaces of tillage bodies. The lifting angle of the ploughshares in our experienced plows with a full turnover of soil layers [9] and upgraded models (figure 5) is 18°.

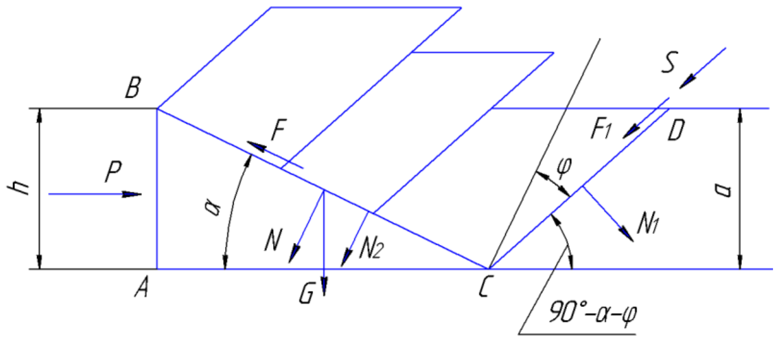


Figure 1 – Forces acting on the wedge

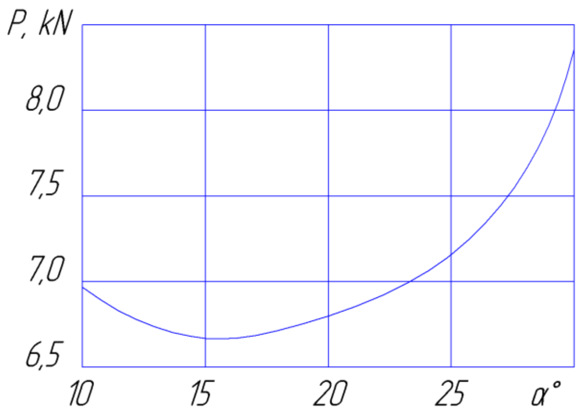
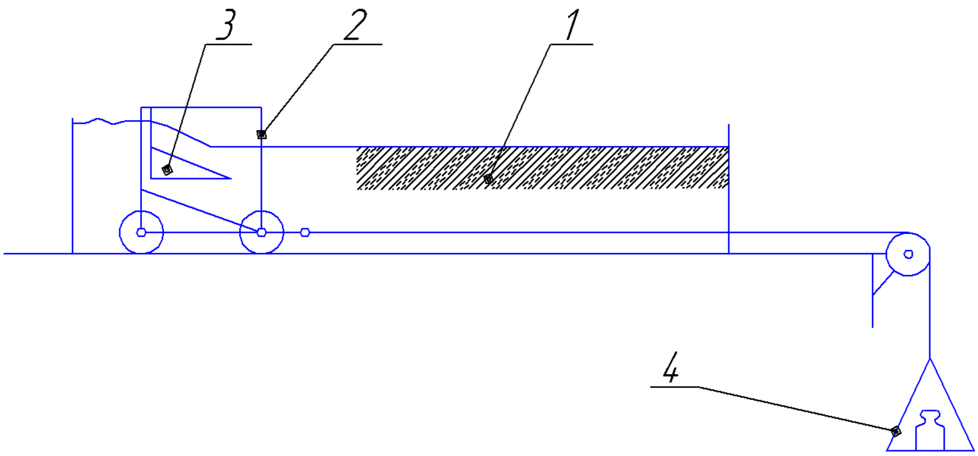


Figure 2 – The effect of the lifting angle on the resistance of the wedge in the soil



1– hopper with soil channel; 2 – trolley; 3 – wedge; 4 – cargo

Figure 3 – Experimental laboratory setup

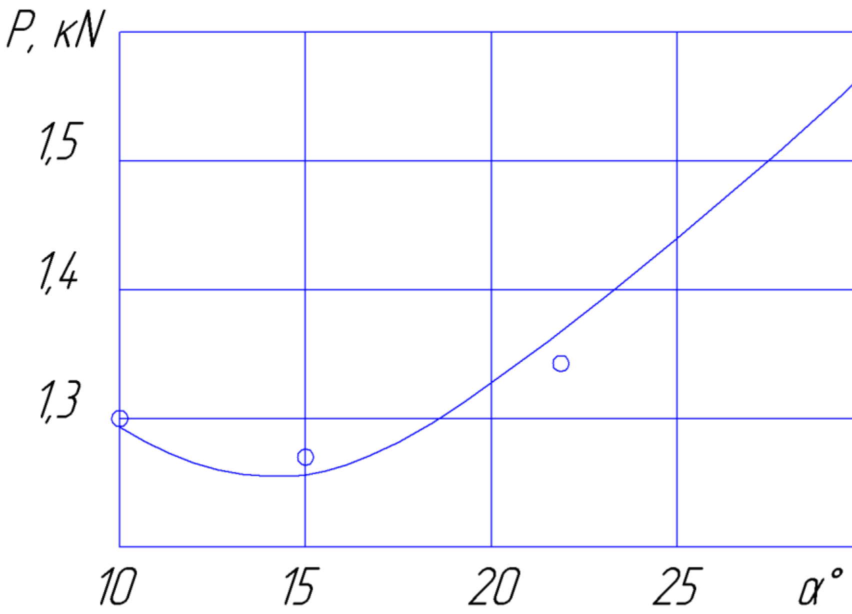


Figure 4 – Theoretical curve and experimental data of traction resistance of the wedge height of 0.25 m and a width of 0.15 m

Figure 5 – Pilot plough PPN-4-45 produced by Voronezh machine tool plant

Working bodies of these plows have a more stretched forth the form and require less tractive effort of the tractor. The arable unit, consisting of a tractor T-150K with a capacity of 110 kW and a four-body plow PPN-4-45 with a width of 1.8 m and a plowing depth of 0.30 m, showed a productivity of 1.65 ha / h. The same unit, but with a lifting angle of 30°, showed a performance of 1.35 ha / h, that is 18% less. A significant increase in the productivity of the unit is obtained through the use of a reduced lifting angle of the ploughshares and spring struts of the working bodies with spontaneous vibration.

CONCLUSION

The method of analytical study of the influence of the lifting angle on the traction resistance of the tillage wedge, based on the analysis of the interaction of the tool and the soil, showed reliable results, confirmed by laboratory experiments. In the analytical dependence of the traction resistance, there is a minimum that corresponds to the optimal lifting angle. The optimal angle of the ploughshare from the plough work of the buildings with a width of 0.45 m is in the range of 16-18°. The reduction of the plow traction resistance with the optimal value of the ploughshare angle and the use of spontaneous vibration of the working bodies on the spring struts led to an increase in the productivity of the unit with an experienced plow by 18%.

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