UDC 621.878.23-182.38

DEVELOPMENT OF A PARAMETRIC MODEL OF THE SPATIALLY ORIENTED KNIFE ON THE BULLDOZER BLADE

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DOI: 10.32347/2410-2547.2023.111.263-275

The paper considers the results of the study of resistances arising during the operation of a bulldozer in the soil environment and processes in the drawing prism. What affects the stability and productivity of the bulldozer during excavation works. The geological map of the "Ukrainian crystalline shield" was studied, where the most common soils on the territory of Ukraine were found. Using the proposed hypothesis of the movement of spatially oriented knives on a bulldozer blade, it was shown that when excavating soil at different speed ratios, there is a deviation of the cutting force application vector by an angle (α), which in turn affects the geometric interaction of the spatially oriented knife with the working environment. Changing the geometric interaction of the spatially oriented knife with the soil affects the cutting force, which led to the creation of a parametric model of the interaction of spatially oriented knives with the working environment. The model was developed for different knife configurations and different ratios of the bulldozer speed to the spatially oriented knife movement speed. The total, normal, and orthogonal cutting forces for the working, subcritical, and critical depths of soil cutting were calculated, according to changes in the parametric model of the spatially oriented knife. A comparative calculation of the cutting force by a bulldozer without and with spatially oriented knives was carried out.

Key words: oblique cutting, spatially oriented, bulldozer, cutting resistance, cutting force, blade.

1. Introduction

During the operation of the earthmoving machine, its executive mechanism interacts with the soil, destroying and separating it from the massif.

The main characteristics of the digging process are geometric, kinematic, force and energy parameters, as well as indicators that determine the physical features of soil destruction, and the properties of the soil as an object of interaction, the design of the working body and the conditions of interaction of the working body with the soil.

The peculiarity of the digging process is that its power and energy indicators depend on kinematic conditions and on geometric parameters - thickness, width and area of the section, as well as on the angles of orientation of the working body in space.

Most calculations of knives and teeth of earthmoving equipment are based on the fact that its parameters do not change during the interaction of the working body with the soil.

Changes in parameters during the multi-vector action of parts of the working body have not been studied much. Therefore, the issue of creating a methodology for determining the parameters of a spatially oriented knife of dynamic action is particularly relevant.

2. Research analysis

The Ukrainian shield is covered with a small layer of Paleogene-Neogene sedimentary rocks, represented by limestones, sands, clays, siltstones, ferruginous quartzites, etc. Indigenous igneous rocks of the Archaean - Proterozoic - gneisses, granites, quartzites, diorites, etc. are exposed in river valleys.

On the slope of the shield, there is a stronger layering of sedimentary rocks, but Neogene Miocene and Pliocene deposits - clays, siltstones, sands - come to the surface.

Anthropogenic deposits are represented by Pleistocene deluvial loams and loess.

Therefore, the main soils with which the bulldozer works are soils located in the Ukrainian Crystalline Shield.

Cutting is the main method of mechanical soil development. The main geometric conditions are proposed to be the position of the edge of the cutting wedge relative to the direction of cutting and the surface of the massif, the contours of the cutting edge, the contours and number of working surfaces of the cutting edge, the number of the so-called side cut surface and the so-called blocked cut surfaces.

Based on these characteristics, the varieties of the process are distinguished and a classification of types of cutting is created [1].

Nominal traction force of the bulldozer

$$T_B = U_{fr} G_{fr},$$

where U_{fr} - coefficient of grafting of the base machine (Table 1) with bulldozer and ripper equipment, corresponding to permissible skidding and traction efficiency; G_{fr} - towing weight of the bulldozer in working condition.

Table 1

The value of the coefficient U_{fr} friction between the wheels and the road surface

Covering material	Pneumatic wheel		Caterpillar
	Low pressure	High pressure	
Concrete	0,9	0,8	0,45
Clay, loam, earth (dry and dense)	0,05 – 0,58	0,45 – 0,5	0,9
Clay, loam, earth (wet)	0,4 – 0,49	0,35 – 0,43	–
Loose earth	0,4 – 0,5	0,35 – 0,45	0,6
Loose sand	0,2 – 0,35	0,18 – 0,3	0,3
Ore quarry road	0,6 – 0,7	0,55 – 0,63	–
Gravel road	0,36	0,3	–
Trampled snow, ice	0,2 – 0,12	0,15; 0,1	0,12

Average static pressure of the bulldozer

$$q_p = G_B / 2L_{\sup} b,$$

where G_B - is the operating weight of the machine; $L_{\sup}$ - is the length of the track bearing surface, taking into account the ground clamps; b - is the width of the tracks.

The total resistance on the bulldozer blade W (kN) when digging and moving soil on a horizontal surface is determined by the sum of the resistance to cutting W_1; movement of the dragging prism W_2; movement of soil up the blade W_3; movement of the bulldozer horizontally or on a slope (rise) W_4 and friction of the bulldozer blade on the soil W_5 and is calculated from the ratio:

$$W = \sum_i W_i = W_1 + W_2 + W_3 + W_4 + W_5,$$

W_1 – cutting resistance of the working environment, (kN):

$$W_1 = K_1 B_o h \cdot 10^3,$$

K_1 – the specific cutting resistance (K_1 = 0,06; 0,09; 0,12; 0,15 – for sand, sandy loam, loam and clay, respectively) (MPa); B_o – the length of the blade, (m); h – the thickness of the layer to be cut (m), W_2 – resistance to soil prism dragging ahead of the blade, (kN):

$$W_2 = gQ_v \gamma \mu_2,$$

W_3 – resistance to soil movement up the blade, (kN):

$$W_3 = gQ_v \gamma \mu_1 \cos^2 \delta_o,$$

Friction resistance of the bulldozer blade against the soil W_4 (kN):

$$W_4 = gK_e m_e \mu_1,$$

Q_v – the volume of the dragging prism; μ_1 – the coefficient of soil friction on the surface of the blade (μ_2 = 0,7…0,8; 0,6…0,7; 0,5…0,6; 0,1…0.4 respectively, for soils I, II, III, IV categories); γ – soil density, t/m^3; μ_2 – coefficient of soil friction on soil (μ_1 = 0,49…0,65; 0,25…0,53; 0,18…0,47; 0,11…0,40 respectively, for soils I, II, III, IV categories); δ_o – slope of the bulldozer working path; g – acceleration of free fall, м/с^2; K_e – coefficient that takes into account the part of the equipment weight involved in friction against the soil, K_e = 0,5…0,8; m_e – mass of bulldozer equipment, t.

Resistance to movement of the bulldozer W_5, (kN):

$$W_5 = gG\omega_o,$$

where g – the free fall acceleration, m/s^2; G – the bulldozer weight, t; ω_o – the specific resistance to movement of the bulldozer (ω_o = 0,2; 0,18; 0,16; 0,14 for sand, sandy loam, loam and clay, respectively).

Volume of the dragging prism:

$$Q_v = 0,5K_v B_o H_o^2.$$

The values of the dragging prism coefficient Kv depending on the ratio of the blade height H_o to its length B_o and the type of soil are shown in table 2:

Table 2

Ratio. H_o/B_o	0,15	0,3	0,35	0,4	0,45
Cohesive soils of I and II categories	1,45	1,25	1,18	1,1	1,05
Incoherent soils	0,87	0,835	0,8	0,77	0,67

When working with a dozer with a pivoting blade and setting it at an angle, the total resistance will be less than when working with a fixed blade.

The coefficient of friction between soil and steel μ_1 depends on the type and condition of the soil, as well as the condition of the steel surface, and is 0,25…1,0 decreasing with increasing humidity and the degree of soil structure disruption. There is a connection between the coefficients μ_1 and μ_2 which is determined by the attitude $\mu_1 \approx 0,75\ \mu_2$, where μ_2 – is the coefficient of internal friction of the soil, μ_2= 0,58…1,1.

The coefficient of digging resistance K_1 for soft and dense soil, the relative density of which can be characterised by the number of blows C of the density meter, is recommended to be determined from the ratio:

$$K_1 = 0,16 + 0,1C.$$

All soil groups are divided into eight categories, including non-frozen (categories I - IV) and frozen (categories V - VIII) soils. Soils of categories I - IV are developed with conventional earthmoving equipment. Soils of categories V - VIII are more durable and, in case of a large frost depth, are excavated after preliminary mechanical or explosive loosening.

For dense and semi-rocky soils, as well as for hard coal and hard frozen rocks, the digging resistance coefficient K_1 should be determined taking into account the specific structural and strength characteristics of the soil in the massif. The position of the centre of pressure, the point at which all soil reactions on the bulldozer track are applied, is determined for the various cases that may occur in the operating conditions. The offset of the centre of pressure must not result in the front or rear edge of the track or wheels of the machine coming off the bearing surface.

The bulldozer is acted upon by a system of external forces: vertical rock reaction at the dump R_o; soil cutting resistance W_1; vertical reactions R_A and R_B at the tipping edges; grafting force with the surface $F_{fr} = Q_{fr}U$; weight of the base machine G_B. Internal forces also act in the system: S – force on the hydraulic cylinder; N_R and P_R – vertical and horizontal reactions in the pins O_1 of the pushing frame, respectively. Ψ – is the stability coefficient of edges A and B, respectively

$$\psi_A = (G_B l_2)/(W_1 r + 2Sl_2),$$

$$\psi_B = (G_B l_1)/(2Sl_2 - 2P_o r) = (G_B l_1)/(2Sl_2 - W_1 r).$$

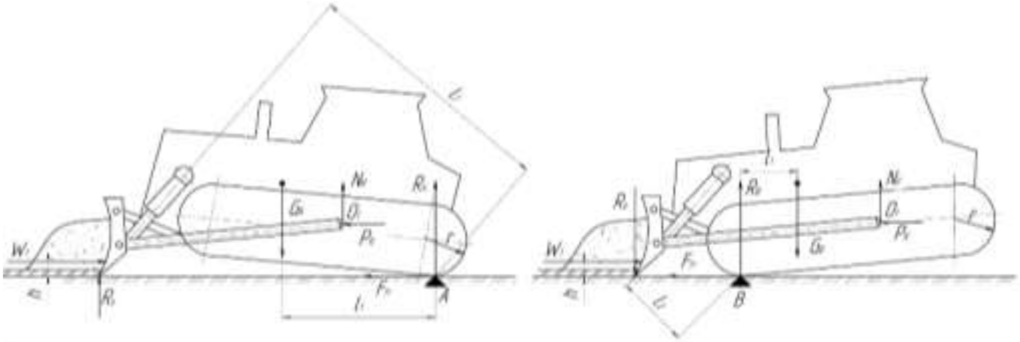


Fig. 1. Diagram of the forces acting on a bulldozer when calculating for overturning

During the operation of the earthmoving machine with oblique cutting, the interaction of the knife with the soil has a spatial character, which is manifested in the formation of a non-symmetric slot of a trapezoidal cross section. In order to quantify the influence of the spatial process, it is proposed to consider the force P as a component of parts corresponding to the nature of soil resistance in different parts of the area of destruction in front of the knife. Thus, the force P of oblique cutting of soil is defined as the sum of three components P_f - the force of overcoming the resistance of the soil by the front edge of the knife, P_s - the force to overcome the resistance of the soil to destruction in the lateral expansions of the slot, and $P_{s.c}$ - the force of overcoming the resistance of the soil cut by the side edges of the knife.

The difference between P_f with a rectangular cut and P_f with an oblique cut is proposed to be taken into account by the coefficient φ_f, which depends on the ratio h/b and the angle γ_{pl} of the rotation of the knife in the plan

The forces P_s and $P_{s.c}$ depend, in addition to the properties of the soil, only on the thickness of the section and the angle of rotation of the knife in the plan. The influence of the angle of rotation of the knife in the plane on the change of these forces is taken into account by the coefficients φ_s and $\varphi_{s.c}$ [2].

The ratio h/b between the thickness and the width of the section, when the thickness of the section increases, the dimensions of the side extensions increase proportionally, while when the width changes, they remain constant. After the thickness of the section reaches the so-called critical depth of cutting, the increase in the lateral expansion of the slot stops and the intensive growth of the zones of the lateral section of the soil by the edges of the knife begins. The soil in front of the knife beyond the critical cutting depth is pressed into the massif on the sides of the knife and is not separated from the massif. Therefore, the critical cutting depth corresponds to the minimum energy intensity [4].

The peculiarity of the digging process is that its power and energy indicators depend on kinematic conditions and on geometric parameters - thickness, width and area of the section, as well as on the angles of orientation of the working body in space [3].

3. The aim of the research

Creation of a methodology for calculating the parameterization of soil cutting with a spatially oriented knife of dynamic action depending on the application of the cutting force α.

4. Research results

The working hypothesis is based on the fact that the movement of a spatially oriented knife will be carried out longitudinally - a translational movement, perpendicular to the trajectory of the movement of the working body. What is schematically depicted in (Fig. 2), which should ensure undercutting of the soil and its easy removal from the development zone. Thereby reducing the supports that arise during the operation of the bulldozer and increasing its productivity, as well as expanding the area of use.

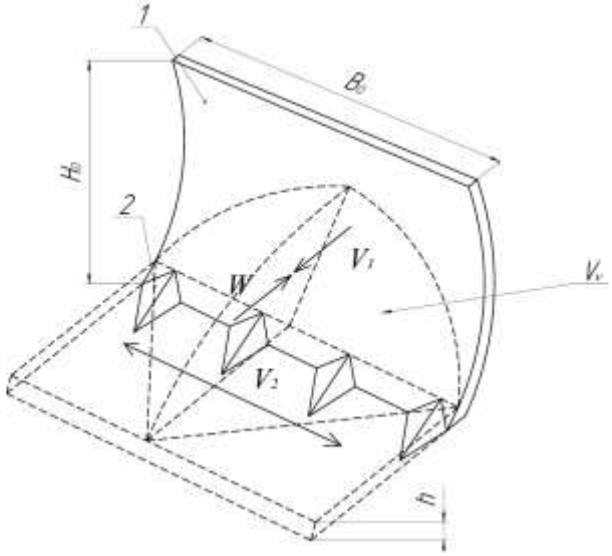
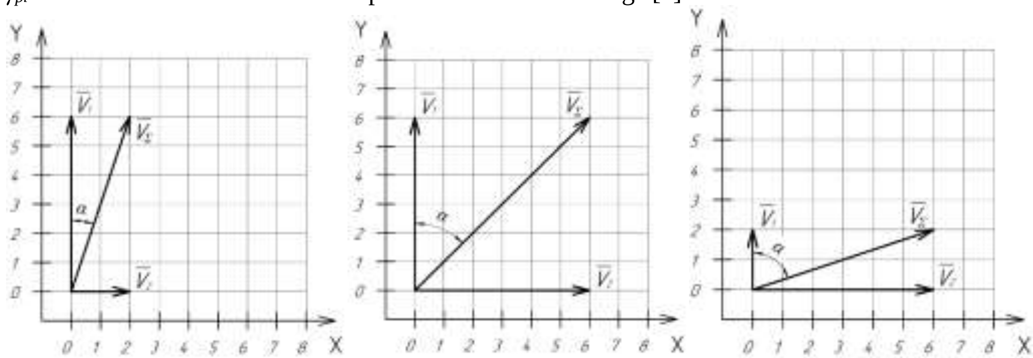


Fig. 2. Schematic representation of the trajectories of the working body:
1) Bulldozer blade; 2) spatially oriented knife of dynamic action; $\overline{V_1}$ – the trajectory of the bulldozer movement; $\overline{V_2}$ – the trajectory of the spatially oriented knife of dynamic action; B_o – blade wight; H_o – blade hight; h – the thickness of the layer to be cut; Q_v – volume of the dragging prism; β – cutting angle of the blade; A – centre of mass of the dragging prism

When the blade is fed into the spatially oriented knife, the vector $\overline{V_1}$ appears, depending on the ratio, it has its coordinates on the *Y* axis, when the knife is moved, the vector $\overline{V_2}$ appears, which in turn has its coordinates on the *X* axis. To determine the displacement vector, we sum the vectors according to the parallelogram rule, since the vectors have a common origin (Fig. 3).

Using the data obtained during the vector calculation, we apply the vector indicating the direction of the cutting force to the spatially oriented knife of dynamic action, taking into account the angle α, the indicator of the direction of application of the cutting force, we can find the change in the angle γ_{pl} of the rotation of the knife in the plan and the wide *b* change [4].



(a) (b) (c)

Fig. 3. Determination of the vector of the direction of the cutting forces and the angle α:
(a) – deviation of the angle α in the vector display of the ratio of the speeds of movement of the bulldozer blade faster than the movement of the spatially oriented knife;
(b) – the deviation of the angle α in the vector mapping of the ratio of the speeds of movement of the bulldozer blade is the same as the movement of the spatially oriented knife;
(c) – the deviation of the angle α in the vector display of the ratio of the speeds of movement of the bulldozer blade is less than the movement of the spatially oriented knife

The angle of deviation of the total cutting force a was determined at the ratio of the bulldozer speed to the speed of movement of the spatially oriented knife in the range from 10:1 to 1:10 (Fig. 4).

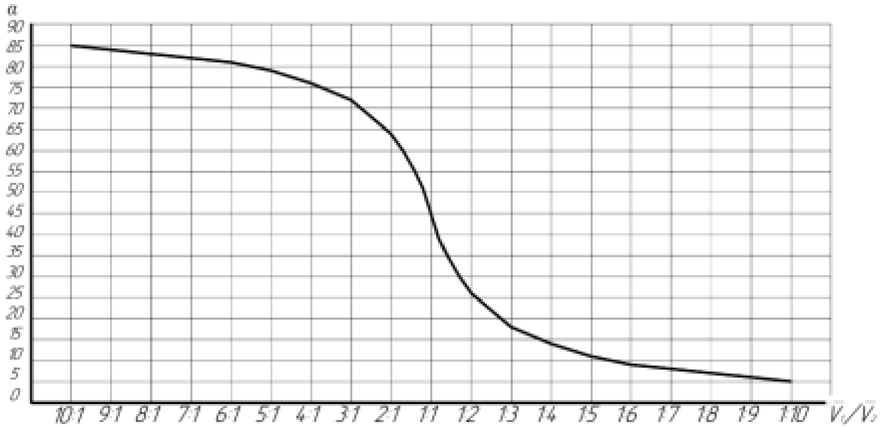


Fig. 4. The graph of the dependence of the angle α on the ratio of the traction speed of the working machine $\overline{V}_1$ to the speed of movement of the spatially oriented knife $\overline{V}_2$

Due to the use of a dihedral knife, we get two angles $\gamma_{pl.y}$ and $\gamma_{pl.x}$ of rotation in the plan, which correspond to each of the faces, and a change in the cutting width *b*. These parameters affect the cutting width *b* therefore, the definition of the cutting width is derived according to the movement vector and is calculated according to the equations (b_{com}), which are given below. The critical cutting depth for most soils at normal knife cutting angles, the ratio *h/b* of the cutting depth *h* to the knife width *b* is in the range from 1 to 3.

Nine main dependences of the parameterization of the knife on the angle α were deduced:

1. When $\gamma_{pl.y} > \alpha < \gamma_{pl.x}$ is presented in (Fig. 5) then the turning angles in the plan will be:

$$\gamma_{pl.v.1} = \gamma_{pl.y} - \alpha,$$

$$\gamma_{pl.v.2} = \gamma_{pl.y} + \alpha.$$

Vector notch width:

$$b_I = A \cdot \cos(\gamma_{pl.v.1}),\ b_{II} = B \cdot \cos(\gamma_{pl.v.2}).$$

Common notch width: $b_{com} = b_I + b_{II}$.

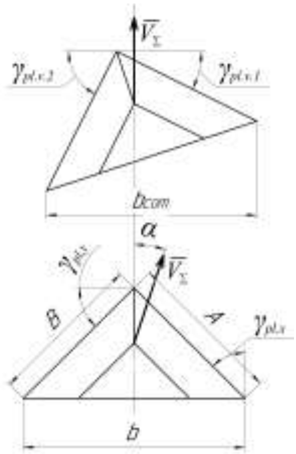


Fig. 5. Parameterization of spatial oriented knife when $\gamma_{pl.y} > \alpha < \gamma_{pl.x}$

2. When $\gamma_{pl.y} = \alpha = \gamma_{pl.x}$ is presented in (Fig. 6) then the turning angles in the plan will be:

$$\gamma_{pl.v.1} = \gamma_{pl.y} - \alpha\ (0^\circ),$$

$$\gamma_{pl.v.2} = \gamma_{pl.y} + \alpha\ (90^\circ).$$

Common notch width: $b_{com} = b_I = A$.

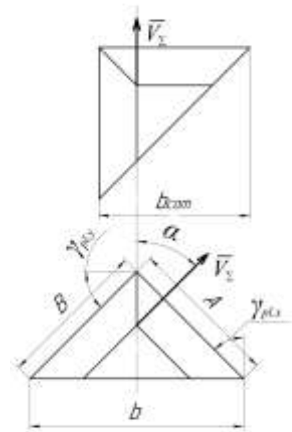


Fig. 6. Parameterization of spatial oriented knife when $\gamma_{pl.y} = \alpha = \gamma_{pl.x}$

3. When $\gamma_{pl.y} < \alpha > \gamma_{pl.x}$ is presented in (Fig. 7) then the turning angles in the plan will be:

$$\gamma_{pl.v.1} = \alpha - \gamma_{pl.y},\ \gamma_{pl.v.2} = \alpha + \gamma_{pl.y}\ \ (> 90^\circ).$$

Common notch width:

$$b_{com} = b_I = A \cdot \cos(\gamma_{pl.v.1}).$$

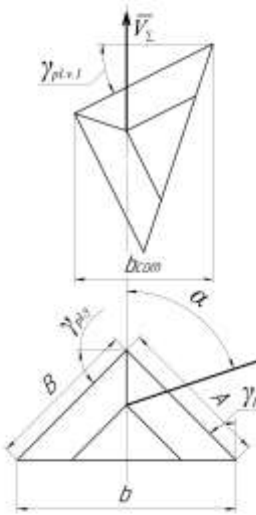


Fig. 7. Parameterization of spatial oriented knife when $\gamma_{pl.y} < \alpha > \gamma_{pl.x}$

4. When $\gamma_{pl.y} = \alpha > \gamma_{pl.x}$ is presented in (Fig. 8) then the turning angles in the plan will be:

$$\gamma_{pl.v.1} = \gamma_{pl.y} - \alpha\ (0^\circ),\ \gamma_{pl.v.2} = \gamma_{pl.y} + \alpha.$$

Vector notch width:

$$b_I = A,\ b_{II} = B \cdot \cos(\gamma_{pl.v.2}).$$

Common notch width: $b_{com} = b_I + b_{II}$.

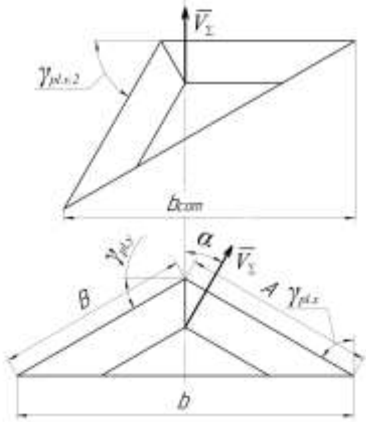


Fig. 8. Parameterization of spatial oriented knife when $\gamma_{pl.y} = \alpha > \gamma_{pl.x}$

5. When $\gamma_{pl.y} < \alpha < \gamma_{pl.x}$ is presented in (Fig. 9) then the turning angles in the plan will be:

$$\gamma_{pl.v.1} = \gamma_{pl.x} - \alpha,\ \gamma_{pl.v.2} = \gamma_{pl.y} + \alpha.$$

Vector notch width:

$$b_I = A \cdot \cos(\gamma_{pl.v.1}),\ b_{II} = B \cdot \cos(\gamma_{pl.v.2}).$$

Common notch width: $b_{com} = b_I + b_{II}$.

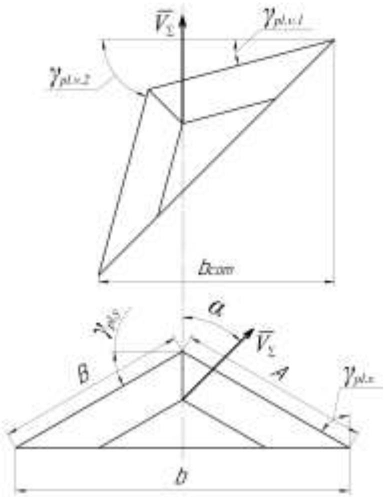


Fig. 9. Parameterization of spatial oriented knife when $\gamma_{pl.y} < \alpha < \gamma_{pl.x}$

6. When $\gamma_{pl.y} < \alpha = \gamma_{pl.x}$ is presented in (Fig. 10) then the turning angles in the plan will be:

$$\gamma_{pl.v.1} = \alpha - \gamma_{pl.y},\ \gamma_{pl.v.2} = \alpha + \gamma_{pl.y}\ \ (90^\circ).$$

Common notch width:

$$b_{com} = b_I = A \cdot \cos(\gamma_{pl.v.1}).$$

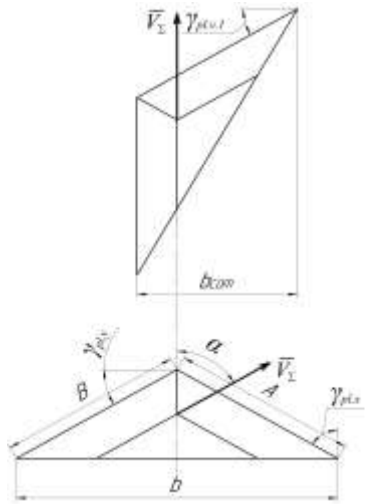


Fig. 10. Parameterization of spatial oriented knife when $\gamma_{pl.y} < \alpha = \gamma_{pl.x}$

7. When $\gamma_{pl.y} > \alpha > \gamma_{pl.x}$ is presented in (Fig. 11) then the turning angles in the plan will be:

$$\gamma_{pl.v.1} = \gamma_{pl.y} - \alpha,$$

$$\gamma_{pl.v.2} = \gamma_{pl.y} + \alpha \quad (> 90^{\circ}).$$

Vector notch width:

$$b_{com} = b_I = A \cdot \cos(\gamma_{pl.v.1}).$$

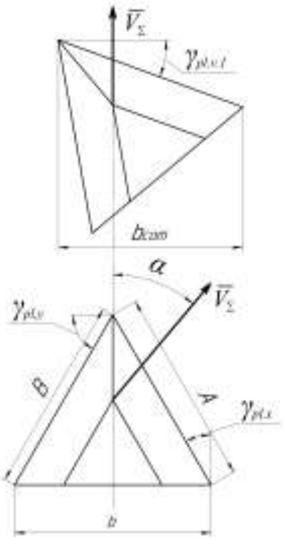


Fig. 11. Parameterization of spatial oriented knife when $\gamma_{pl.y} > \alpha > \gamma_{pl.x}$

8. When $\gamma_{pl.y} > \alpha = \gamma_{pl.x}$ is presented in (Fig. 12) then the turning angles in the plan will be:

$$\gamma_{pl.v.1} = \gamma_{pl.y} - \alpha,$$

$$\gamma_{pl.v.2} = \gamma_{pl.y} + \alpha \quad (90^{\circ}).$$

Vector notch width:

$$b_{com} = b_I = A \cdot \cos(\gamma_{pl.v.1}).$$

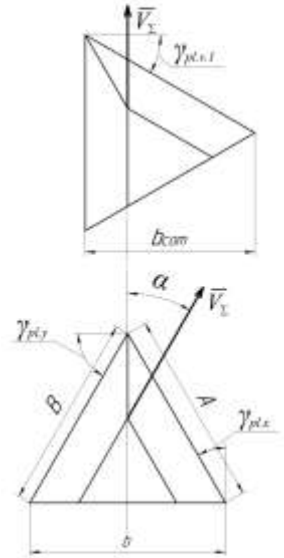


Fig. 12. Parameterization of spatial oriented knife when $\gamma_{pl.y} > \alpha = \gamma_{pl.x}$

9. When $\gamma_{pl.y} = \alpha > \gamma_{pl.x}$ is presented in (Fig. 13) then the turning angles in the plan will be:

$$\gamma_{pl.v.1} = \gamma_{pl.y} - \alpha \quad (0^{\circ}),$$

$$\gamma_{pl.v.2} = \gamma_{pl.y} + \alpha \quad (> 90^{\circ}).$$

Vector notch width:

$$b_{com} = b_I = A.$$

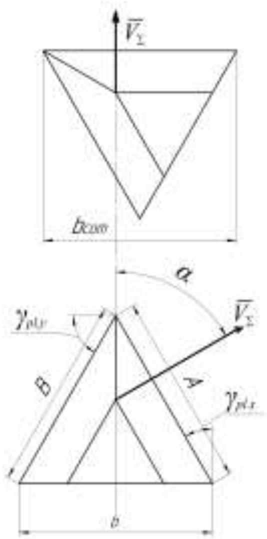


Fig. 13. Parameterization of spatial oriented knife when $\gamma_{pl.y} = \alpha > \gamma_{pl.x}$

Having determined the parameters of the interaction of the knife with the working environment, the change in the cutting width b_{com} and the change in the angle of rotation in the $\gamma_{pl.v.1}$ we can calculate the full cutting force.

Calculation of the total cutting force:

$$P = \varphi(\delta)\varphi_f m_f b_{com} h + \varphi_s m_s h^2 + \varphi_{s.c} m_{s.c} h.$$

Normal cutting force:

$$N = P\left(\frac{\cos\gamma_{pl.v.1} - \tan\mu\sin\delta\sqrt{\cos^2\gamma_{pl.v.1} + \tan^2\delta}}{\tan\delta\cos\gamma_{pl.v.1} + \tan\mu\cos\delta\sqrt{\cos^2\gamma_{pl.v.1} + \tan^2\delta}}\right).$$

Orthogonal cutting force:

$$P_o = P\left(\frac{\tan\delta\sin\gamma_{pl.v.1}}{\tan\delta\cos\gamma_{pl.v.1} + \tan\mu\cos\delta\sqrt{\cos^2\gamma_{pl.v.1} + \tan^2\delta}}\right).$$

Where b will be equal to b_{com}, h – is the width of the knife and the depth (thickness) of the cut; m_f – the strength coefficient characterizing the specific resistances in the frontal part of the notch (MPa); m_s – strength factor characterizing specific resistances in lateral extensions (MPa); $m_{s.c}$ – the strength coefficient characterizing the specific resistance along the lines of the side section (кN/м); $\varphi(\delta)$ – coefficient that takes into account the influence of the cutting angle δ; φ_f – the coefficient that takes into account the effect of the angle $\gamma_{pl.v.1}$ of the blade turning in the plane, according to the force P_f; φ_s – the coefficient that takes into account the effect of the angle $\gamma_{pl.v.1}$ of the blade turning in the plane, according to the force P_s; $\varphi_{s.c}$ – the coefficient that takes into account the effect of the angle $\gamma_{pl.v.1}$ of the blade turning in the plane, according to the force $P_{s.c}$; μ – angle of soil friction on steel.

The calculation for clay loam was carried out and three main cutting forces were determined, namely, the total cutting force, the normal cutting force and the orthogonal cutting force, the calculation results are presented in the form (Tabl. 3) and graphs on (Fig. 15, Fig. 16, Fig. 17).

Table 3

Cutting forces of clay loam at a depth of 10, 20, 35 cm

α	Clay loam								
	h, cm								
	10			20			35		
	P, kN	N, kN	P_o, kN	P, kN	N, kN	P_o, kN	P, kN	N, kN	P_o, kN
0°	3,86	1,66	0,00	7,62	3,28	0,00	13,04	5,62	0,00
10°	3,94	1,67	0,59	7,79	3,30	1,12	13,52	5,74	1,75
20°	3,96	1,58	1,28	7,97	3,18	2,51	14,20	5,70	4,22
30°	3,90	1,36	2,03	8,11	2,83	4,20	15,10	5,30	7,66
40°	3,96	1,40	3,63	8,53	2,99	7,91	16,65	5,81	15,62
45°	2,79	1,42	0,00	6,11	3,11	0,00	12,05	6,14	0,00
50°	2,75	1,40	0,18	5,88	2,99	0,39	11,42	5,81	0,75
60°	2,59	1,30	0,52	5,39	2,71	1,09	10,12	5,09	2,04
70°	2,39	1,17	0,83	4,86	2,38	1,69	8,80	4,31	3,06
80°	2,19	1,03	1,13	4,35	2,04	2,24	7,69	3,60	3,95
90°	1,93	0,83	1,38	3,81	1,64	2,73	6,52	2,81	4,66

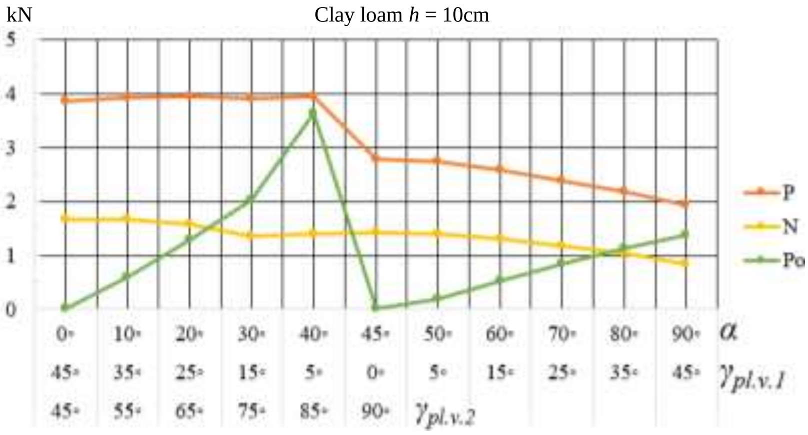


Fig. 15. Graph of soil cutting forces at a working cutting depth of 10 cm

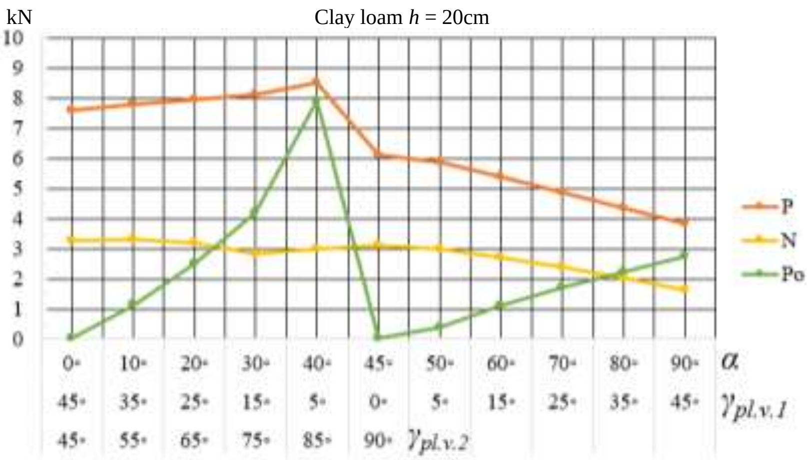


Fig. 16. Graph of soil cutting forces at a subcritical cutting depth of 20 cm

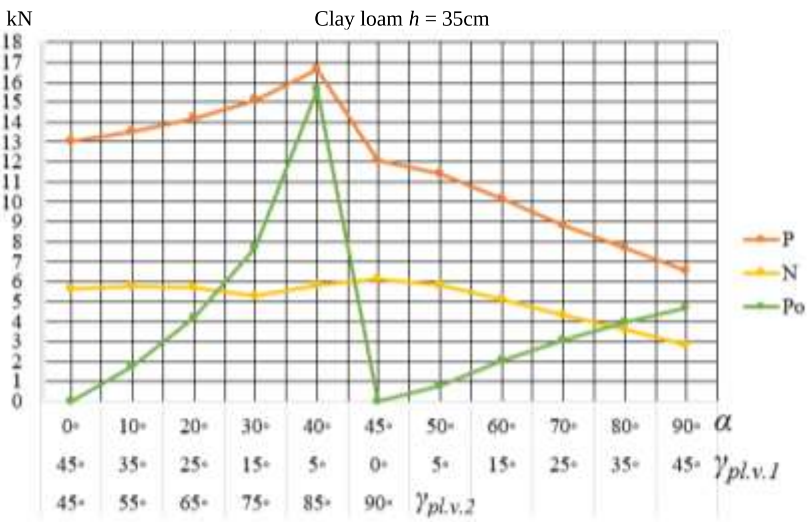


Fig. 17. Graph of soil cutting forces at a critical cutting depth of 35 cm

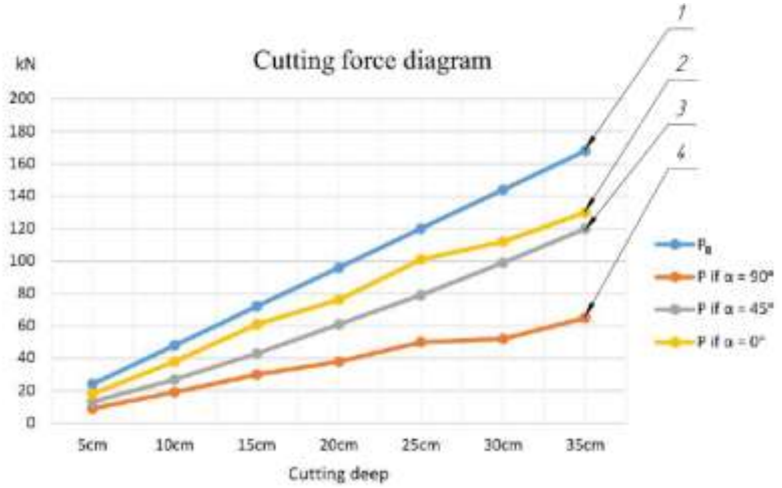


Fig. 18. Graph of soil cutting forces

P_B – soil cutting forces with a bulldozer without knives, and three cutting forces P, at different angles α, which show how much easier soil digging is when using spatially oriented knives.

Soil cutting was calculated for a bulldozer with a blade size of B_o = 4m. The graph shows:

1) Soil cutting with the blade without spatially orientated blades, at a depth of 5 to 35 cm.

2) Soil cutting with a blade with spatially orientated blades, at a cutting depth of 5 to 35 cm and a cutting force angle of $\alpha = 0^o$.

3) Soil cutting with a blade with spatially orientated knives, at a cutting depth of 5 to 35 cm and a cutting angle of $\alpha = 45°$.

4) Cutting soil with a blade with spatially oriented knives, at a cutting depth of 5 to 35 cm and a cutting force angle of $\alpha = 90°$.

The graph (Fig. 18) clearly shows the effect of spatially oriented knives on the cutting force of soils, namely its decrease with an increase in the angle of application of the cutting force α.

5. Conclusions

Knowing that the cutting supports of the bulldozer strongly influence its stability and productivity, we used our working hypothesis when the spatially oriented knife moves perpendicular to the movement of the working machine, and depending on the speed ratio, its interaction with the working environment changes. Further affects the calculation of the cutting force.

Based on the ratio of the speeds of the bulldozer and the spatially oriented knife, a vector representation of the cutting forces and a general vector of the direction of the cutting force, which has a deviation from the axis of the bulldozer's motion by an angle, is created α.

Applying the obtained vectors to a spatially oriented knife of dynamic action, nine main correlations were found with respect to the angles of rotation in the plan and a method of their calculation was created.

With the help of the method, we find that the deviation to the angle α will affect the geometric interaction of the knife with the soil, namely, the angles of rotation change in plan $\gamma_{pl.v.1}$ and $\gamma_{pl.v.2}$, and the total width b_{com}.

The geological map of Ukraine was studied, with the help of which the most common soils were determined.

A calculation was made for the cutting forces for clay loam, which is shown in the graphs, where it can be seen that when using the theory of oblique cutting of dynamic action, the cutting forces decrease, which accordingly reduces the resistance of the bulldozer, increases its directional stability and productivity.

The calculation of the digging resistance for the bulldozer blade was carried out, comparing the cutting force without spatially oriented knives and with them.

The calculation of the cutting force of the bulldozer blade without and with spatially orientated blades showed us the effect of increasing the cutting angle α on the cutting force.

The graph (Fig. 18) clearly shows the effect of spatially oriented knives on the cutting force of soils, namely its decrease with an increase in the angle of application of the cutting force α.

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Стаття надійшла 20.09.2023

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РОЗРОБКА ПАРАМЕТРИЧНОЇ МОДЕЛІ ПРОСТОРОВО ОРІЄНТОВАНОГО НОЖА НА ВІДВАЛІ БУЛЬДОЗЕРА

У статті розглянуто результати дослідження опорів, які виникають під час роботи бульдозера в ґрунтовому середовищі та процеси в призмі волочіння. Що впливає на стійкість та продуктивність бульдозера при виконанні землерийних робіт. Досліджено геологічну карту «Українського кристалічного щита», де знайдено найпоширеніші ґрунти на території України. Використання запропонованої гіпотези руху просторово орієнтованих ножів на бульдозерному відвалі показало що при розробці ґрунту при різних співвідношеннях швидкостей, виникає відхилення вектору прикладання сили різання на кут α, що в свою чергу впливає геометричну взаємодію просторово орієнтованого ножа з робочим середовищем. Зміна геометричної взаємодії просторово орієнтованого ножа з ґрунтом впливає на силу різання, в наслідок чого було створено параметричну модель взаємодії просторово-орієнтованих ножів з робочим середовищем. Для різних конфігурацій ножів та різних співвідношень швидкості руху бульдозера та швидкості переміщення просторово орієнтованого ножа. Розраховано повну, силу по нормалі та ортогональну силу різання, для робочої, докритичної, та критичної глибини різання ґрунтів, відповідно до змін параметричної моделі просторово орієнтованого ножа. Та проведений порівняльний розрахунок сили різання бульдозером без просторово орієнтованих ножів та з ними.

Ключові слова: косокутне різання, просторово орієнтований, бульдозер, опір різанню, сила різання, відвал.

УДК 621.878.23-182.38
Рашківський В.П., Федишин Б.М. **Розробка параметричної моделі просторово орієнтованого ножа на відвалі бульдозера** // Опір матеріалів і теорія споруд: наук.-тех. збірн. – К.: КНУБА, 2023. – Вип. 111. – С. 263-275.
Стаття присвячена створенню параметричної моделі просторово орієнтованого ножа динамічної дії, для розрахунку повної сили різання, та впливу кута прикладання сили різання α.
Іл. 17. Табл. 3. Бібліог. 17 назв.

UDC 621.878.23-182.38
Rashkivskyi V.P., Fedyshyn B.M. **Development of a parametric model of the spatially oriented knife on the bulldozer blade** // Strength of Materials and Theory of Structures: Scientific-and-technical collected articles – Kyiv: KNUBA, 2023. – Issue 111. – P. 263-275.
The paper considers to the creation of a parametric model of a spatially oriented knife of dynamic action for calculating the total cutting force and the effect of the angle of application of the cutting force α.
Figs. 18. Tabs. 3. Refs. 17.

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