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Development of the information model of the soil cutting process spatially oriented knife of dynamic action

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Abstract. The results of the construction of an information model of the process of soil cutting with straight-furrow oriented knives of dynamic action are given. Bulldozer equipment and its main tasks are considered. A working hypothesis of the movement of the scraper and the vertically oriented knife has been formed. The working hypothesis is based on the fact that the movement of the spatially oriented knife will be carried out longitudinally - translationally, perpendicular to the trajectory of the movement of the working body. The dynamic movement of the knife will be carried out with the help of a self-oscillating hydraulic vibrator, the development of such a solution was implemented at the Department of Construction Machinery of KNUCA, the prerequisites were the work of the team, in particular, prof. Smirnov V.M. regarding the structure of the working body and prof. Baladinsky V.M. regarding the regularities of creating dynamic movements of cutting elements of earthmoving machines. And also, based on the works of Khmara L.A., candidate in connection with the intensification of the mechanization of earthworks in construction. Their vector movement and determination of the angles of application of the main cutting force to the corresponding angle α are presented. After constructing the movement vectors of the working body and the spatially oriented knife, a method of calculating the direction of the cutting force and the deflection angle α was developed. Using vector sums and speed ratios ranging from 10:1, where the spatially oriented knife moves ten times faster than the blade, to 1:10, where the spatially oriented knife moves ten times slower. A graph of the determination of the angle α is plotted depending on the ratio of the blade feeding speeds and the displacement of the spatially oriented knife. The speed ratio is calculated and entered in the speed ratio table according to the angle α and the bulldozer's gear ratio.

Key words: oblique cutting, spatially oriented, excavator blade, vector, speed ratio.

INTRODUCTION

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.

The cutting forces of soils with a simple blocked cut are shown (Fig. 1).

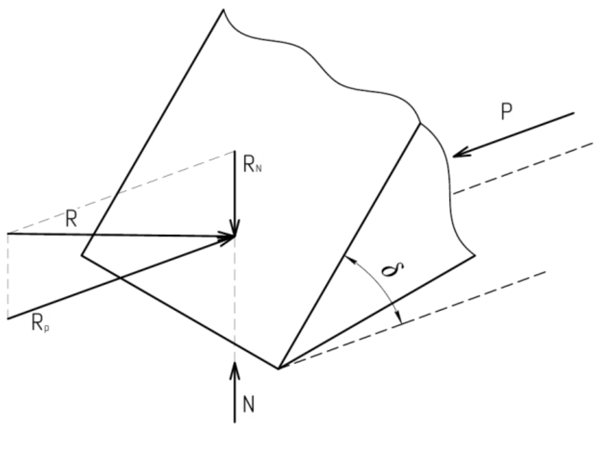

Fig. 1. P – frontal cutting force; N is the normal cutting force

The cutting forces of soils during oblique cutting are shown (Fig. 2).

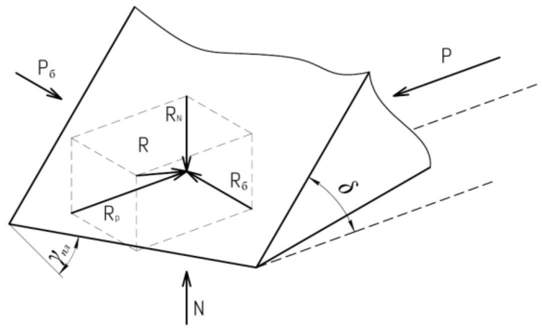

Fig. 2. P – frontal cutting force; N is the normal cutting force. Pb is the orthogonal cutting force

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.

RESEARCH ANALYSIS

A bulldozer is a universal earthmoving and transport machine, equipped with a curved shaft mounted on a frame, and designed to perform various construction works.

Most often, a bulldozer is used for preparatory work: for demolishing old buildings, uprooting tree stumps, clearing bushes, clearing construction sites of construction debris, etc.

Bulldozers perform significant volumes of work in reclamation construction during the construction of irrigation and drainage canals, backfilling of dams and embankment of paved roads, capital and operational planning of reclaimed lands, construction of ponds, development of pits for pumping stations [6].

Bulldozers are used when performing the following types of construction work: clearing the territory of the vegetative layer of the soil, remnants of stumps, roots, planning the territory by cutting unevenness, filling depressions and removing excess soil; construction of embankment and pits during construction; development of wide trenches and pits; construction of dams; soil development on mountain slopes; backfilling of trenches; transportation of aggregates to receiving devices at warehouses of non-metallic building materials, etc[6].

The lowered blade cuts small mounds with a knife and fills small depressions with the cut soil, thereby leveling the soil surface.

Large-scale planning works related to cutting humps, filling ravines, large trenches, pits, canals, etc., are usually performed by the joint work of scrapers and bulldozers [10].

For the planning of soil dumps made by excavators or dump trucks, conveyors, etc., it is most expedient to use bulldozers with side dump extenders, which increase the width of the grip and thereby significantly increase the productivity of bulldozers on loose soils.

Blade is an attached equipment for bulldozers, motor graders, loaders, tractors and cars, which is used for soil development, snow removal and other works (Fig. 3) [11].

For the most part, the blade is a welded metal structure with a box section. Knives are attached along the lower edge of the blade. On both sides of the blade, side plates are welded, designed to prevent scattering of the transported material. With the help of a blade truck, the machine can move large volumes of cargo in one work cycle (over short distances), but, unlike buckets, blade are not suitable for loading soil onto vehicles.

Fig. 3. Wheeled bulldozer with blade equipment

Excavator knives are a special cutting pad that is attached to the working equipment of earthmoving and other machines [1].

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. 4).

The dynamic movement of the knife will be performed using a self-oscillating hydraulic vibrator [4] (Fig. 5).

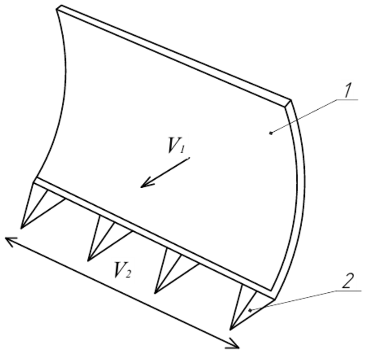

Fig. 4. Schematic representation of the trajectories of the working body: *1* – dozer blade; V_1 – the trajectory of the bulldozer movement; *2* – spatially oriented knife of dynamic action; V_2 – the trajectory of the spatially oriented knife of dynamic action

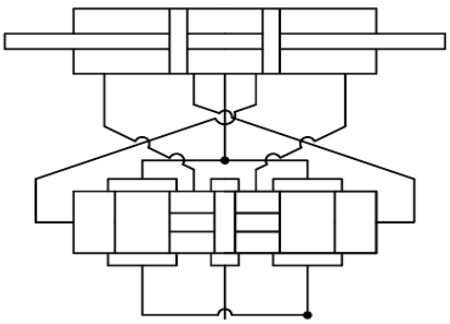

Fig. 5. Self-oscillating hydraulic vibrator

The development of such a solution was implemented at the Department of Construction Machinery of KNUCA, the prerequisites were the work of the team, in particular, Prof. Smirnov V.M. [3] regarding the structure of the working body and prof. Baladinsky V.M. [2] in relation to the regularities of creating dynamic movements of cutting elements of earthmoving machines. And also, according to the works of Khmara L.A., Ph.D. in relation to the intensification of the mechanization of earthworks in construction [5].

In our opinion, this movement of the working body and the spatially oriented knife of dynamic action should create two cutting forces that are parallel to the trajectories of movement. When developing soils, these forces will be combined into a total cutting force (Fig. 6) [12]. Therefore, the cutting forces that occur when interacting with the soil, and the nature of the chip formation and, in general, the energy intensity of digging and for the most productive cutting of the soil will depend on the geometric parameters such as the angle of rotation in the plan, no more than 30-45°, with a spatially oriented knife of dynamic action [13].

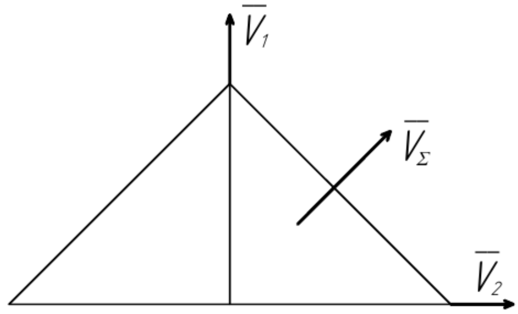

Fig. 6. $\overline{V}_1$ – vector of cutting force parallel to the trajectory of the working body; $\overline{V}_2$ – vector of cutting force with a spatially oriented knife of dynamic action; $\overline{V}_\Sigma$ – is the vector of total cutting force

PURPOSE OF THE ARTICLE

Creation of a technique for calculating the vector of the direction of the soil cutting force with a spatially oriented knife of dynamic action. Depending on the speed ratio of the working body and the spatially oriented knife. Also, the determination of the angle α, which affects the interaction of the knife with the soil.

RESEARCH RESULTS

Depending on the speed of movement of the knife, the direction of force application changes and the angle of interaction of the spatially oriented knife with the soil changes, when the speed of movement of the knife and its feed speed are equalized (at 45˚) then it starts to work as a knife of rectangular cutting, since the trajectory of movement is perpendicular its side face is calculated as for blocked cutting.

If the speed is less than the feed speed, it affects the destruction zone because it can be calculated using the formula for oblique cutting with a double-edged knife, and if the speed of the knife is greater than the feed speed, then the calculation is carried out as for oblique blocked cutting, since the second edge of the knife does not participate in cutting the soil.

At the beginning of the work, we will examine the ratio of feed and movement speeds of

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3:1; 1:1; 1:3. 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. The length of the vector $\overline{V}_\Sigma$ will show at what speed the knife moves, and the angle α between $\overline{V}_\Sigma$ and the vector of displacement of the knife $\overline{V}_1$ will indicate the change in the interaction of the spatially oriented knife with the soil, since the spatially oriented knife has an angle of rotation in the plan but its complex movement will affect this angle depending on the speed ratio.

Next, we build vectors according to speed ratios 3:1 (Fig. 7), 1:1 (Fig. 8), 1:3 (Fig. 9). The angle α between the vectors is determined by the formula (1.1) [7,8,9]

$$\alpha = \arccos\left(\frac{\Sigma V_x V_x + \Sigma V_y V_y}{\sqrt{\Sigma V_x^2 + \Sigma V_y^2} \cdot \sqrt{V_x^2 + V_y^2}}\right) \quad 1.1$$

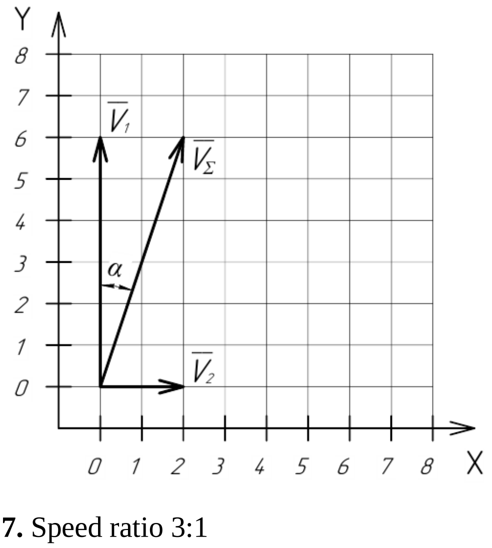

Fig. 7. Speed ratio 3:1

The calculation of the angle α at a ratio of 3:1 will be:

$$\alpha = \arccos\left(\frac{6 \cdot 6}{\sqrt{2^2 + 6^2} \cdot \sqrt{6^2}}\right) = 18°$$

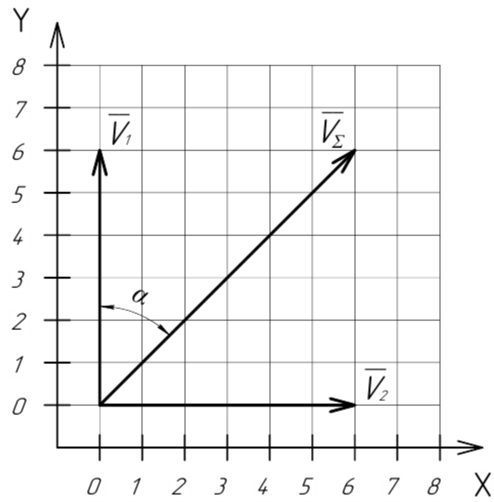

Fig. 8. Speed ratio 1:1

The calculation of the angle α at a ratio of 1:1 will be:

$$\alpha = \arccos\left(\frac{6 \cdot 6}{\sqrt{6^2 + 6^2} \cdot \sqrt{6^2}}\right) = 45°$$

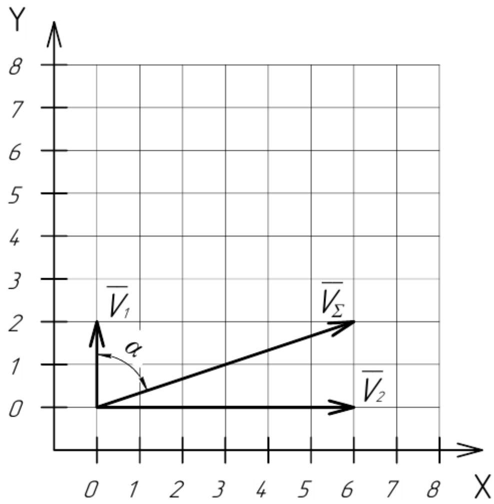

Fig. 9. Speed ratio 1:3

The calculation of the angle α at a ratio of 1:3 will be:

$$\alpha = \arccos\left(\frac{6 \cdot 2}{\sqrt{6^2 + 2^2} \cdot \sqrt{6^2}}\right) = 72°$$

Calculations were made in the ratio from 10:1 to 1:10, based on the calculation results, a graph of the angle α was drawn (Fig. 10)

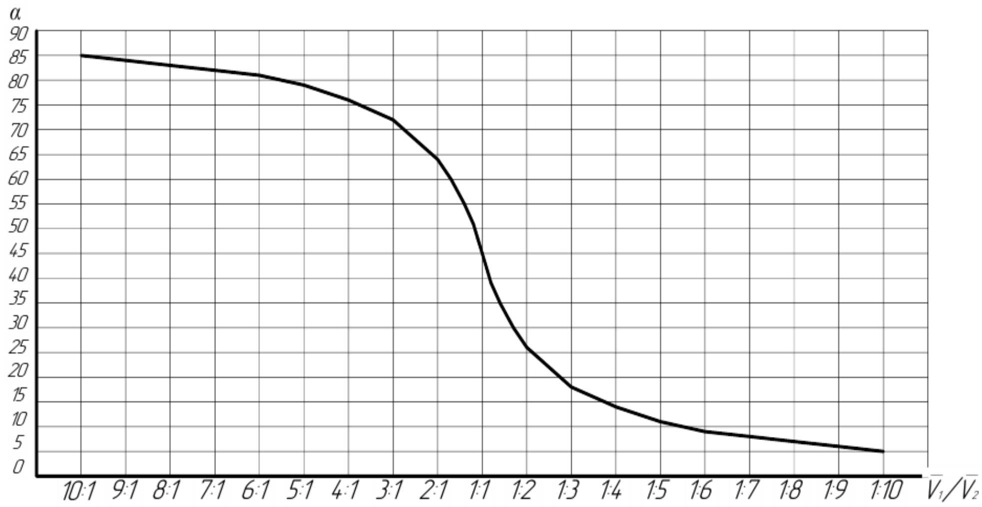

Fig. 10. Graph of the angle *α* depending on the ratio of the speed of movement of the spatially oriented knife to the thrust speed of the blade

Average working speeds of analogue bulldozers [2], respectively:

I – first gear 1.5 *km/h* - 0.41 *m/s;*
II – second gear 3 *km/h* - 0.83 *m/s*;
III – third gear 6 *km/h* - 1.6 *m/s*;
IV – fourth gear 9 *km/h* - 2.5 *m/s*.

The speed of movement of a spatially oriented knife of dynamic action. In relation to the speed of the bulldozer's working movement in *m/s*.

Calculated depending on the angle *α*, which was determined by the vector sum method.

Table. Ratio of speeds according to angle *α* and speed gear

α	Speed ratio	I – first gear *m/s*	II – second gear *m/s*	III – third gear *m/s*	IV – fourth gear *m/s*
5°	1:10	0,041	0,083	0,16	0,25
6°	1:9	0,045	0,092	0,17	0,27
7°	1:8	0,051	0,1	0,2	0,31
8°	1:7	0,058	0,11	0,22	0,35
9°	1:6	0,068	0,13	0,26	0,41
12°	1:5	0,082	0,16	0,32	0,5
14°	1:4	0,1	0,2	0,4	0,62
18°	1:3	0,13	0,27	0,53	0,83
36°	1:2	0,2	0,41	0,8	1,25
45°	1:1	0,41	0,83	1,6	2,5
64°	2:1	0,82	1,66	3,2	5
72°	3:1	1,23	2,49	4,8	7,5
76°	4:1	1,64	3,32	6,4	10
78°	5:1	2,05	4,15	8	12,5
81°	6:1	2,46	4,98	9,6	15
82°	7:1	2,87	5,81	11,2	17,5
83°	8:1	3,28	6,64	12,8	20
84°	9:1	3,69	7,47	14,4	22,5
85°	10:1	4,1	8,3	16	25

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RESEARCH CONCLUSIONS

After constructing the vectors of movements of the working body and the spatially oriented knife, a method was developed for calculating the direction of the cutting force and the angle of deviation *α*. Using vector sums and speed ratios ranging from 10:1 when the spatially oriented knife moves ten times faster than the blade, to 1:10 when the spatially oriented knife moves ten times slower.

A graph of the angle α is constructed for ratios from 10:1 to 1:10.

There is also a table of ratios of speeds to average speeds of bulldozers.

REFERENCES

1. **Vetrov Yu. A.** (1971) Rezanye hruntov zemleroinymy mashynamy [Cutting soil with earthmoving machines]. Moscow, Mashynostroenye publ. [Mechanical engineering], 357. - (*in Russian*).
2. **Baladins`kyi V. L.** (2001). Budivel`na tehnika: navchal`nyi posibnyk [Construction equipment: a study guide]. Kyiv, Lybid publ., 368. - (*in Ukrainian*).
3. **Smirnov V. M.** (2009). Osnovy teorii rizannia gruntiv prostorovo orietovanymy nozhamy zemleryinyh mashyn [Basics of the theory of cutting with spatially oriented blades of earthmoving machines]. Kyiv, MP Lesya publ., 260. - (*in Ukrainian*).
4. **Baladinsky V. L., Pelevin E. L., Rashkivsky V. P., Smirnov V. M., Solonko R. M.** (2003) Patent of Ukraine No.53190, class. E02F 3/04. - (*in Ukrainian*).
5. **Khmara L. A., Balonev V. Y.** (1988). Povysheniie proizvoditielnosti mashyn dlia zemlianykh rabot [Increasing the productivity of earthmoving machines]. Kyiv, Budivelnyk publ., 152.- (*in Russian*).
6. **Sheshko, E. E.** (2011). Hirnycho-transportni mashyny i obladnannia dlia vidkrytykh robit navchan [Mining transport machines and equipment for open works]. Dopomoha dlia studentiv vyshchykh uchbovykh zakladiv [Assistance for students of higher educational institutions]. Hirska knyha publ., 250. - (*in Ukrainian*).
7. **Mikhailenko V. M., Fedorenko N. D., Demchenko V. V.** (2003). Dyskretna matematyka. [Discrete Math]. Kyiv, Vydavnyctvo Yevrop. un-tu, 319. - (*in Ukrainian*).
8. **Kapitonova Yu. V., Kryvyi S. L., Letychevskyi O. A.** (2002). Osnovy dyskretnoi matematyky [Fundamentals of discrete mathematics]. Kyiv, Naukova dumka publ., 578. - (*in Ukrainian*).
9. **Naziiev M. I.** (1994). Liniina alhebra ta analitychna heometriia [Linear algebra and analytic geometry]. Kyiv, Lybid publ. - (*in Ukrainian*).
10. **Tkachuk M. M., Yakymchuk B. N., Kyrysha R. O.** (2015). Orhanizatsiia ta tekhnolohiia budivelnykh robit [Organization and technology of construction works]. Rivne, NUVHP, 250. - (*in Ukrainian*).
11. **Caterpillar** [Electronic resource]. Wheeled dozers: internet-resource equipment manufacturer. URL: https://www.cat.com/en_MX/products/new/equipment/dozers/wheel-dozers/18580971.html.
12. **Rashkivskyi V., & Fedyshyn B.** (2022). Analiz zasobiv rizannia gruntiv prostorovo-oriientovanymy nozhamy dynamichnoi dii zemleryinykh mashyn [Analysis of soil cutting tools with spatially oriented knives of dynamic action of earthmoving machines]. Girnychi, budivelni, dorozhni ta melioratyvni mashyny [Mining, constructional, road and melioration machines], No. 96, 28–34. - (*in Ukrainian*). https://doi.org/10.32347/gbdmm2020.96.0401
13. **Rashkivskyi V., Fedyshyn B.** (2021). Analiz kharakteru struzhkoutvorennia pry roboti prostorovo-oriientovanymy nozhamy dynamichnoi dii [Analysis of the nature of chip formation when working with spatially oriented knives of dynamic action]. Girnychi, budivelni, dorozhni ta melioratyvni mashyny [Mining, constructional, road and melioration machines], No.97, 57–61. - (*in Ukrainian*). https://doi.org/10.32347/gbdmm2021.97.0402

Розробка інформаційної моделі процесу різання ґрунту просторово орієнтованим ножем динамічної дії

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Анотація. Наведено результати побудови інформаційної моделі процесу різання ґрунтів просторово орієнтованими ножами динамічної дії. Розглянуто бульдозерне обладнання та його основні робочі завдання. Сформовано робочу гіпотезу переміщення відвалу та просторово орієнтованого ножа. Робоча гіпотеза базується на тому, що рух просторово орієнтованого ножа буде здійснюватися поздовжньо - поступальним рухом, який буде комбінований з перпендикулярним до траєкторії руху робочого органу. Динамічний рух ножа буде здійснюватися за допомогою автоколивального гідравлічного вібратора, розробка такого рішення була реалізована на кафедрі будівельних машин КНУБА, передумовами стала робота колективу, зокрема проф. Смирнова В.М. щодо будови робочого органу та проф. Баладінський В.М. щодо закономірностей створення динамічних рухів різальних елементів землерийних машин. А також, за працями Хмари Л.А., канд. у зв'язку з інтенсифікацією механізації земляних робіт у будівництві. Представлено їх векторний рух і визначення кутів прикладання основної сили різання на відповідний кут α. Після побудови векторів переміщень робочого органу та просторово орієнтованого ножа розроблено методику розрахунку напряму сили різання та кута відхилення α. Використання векторних сум і коефіцієнтів швидкості в діапазоні від 10:1, коли просторово орієнтований ніж рухається в десять разів швидше за відвал бульдозера, до 1:10, коли просторово орієнтований ніж рухається в десять разів повільніше. Побудовано графік визначення кута α в залежності від співвідношення швидкостей подачі відвалу та переміщення просторово орієнтованого ножа. Співвідношення швидкостей пораховано і занесено в таблицю співвідношення швидкостей відповідно до кута α та швидкісної передачі бульдозера.

Ключові слова: косокутне різання, просторово-орієнтований, відвал екскаватора, вектор, співвідношення швидкостей.