

UDC 631.312:514.18

DOI: 10.31548/machinery/3.2024.09

Tetiana Kresan

PhD in Technical Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
<https://orcid.org/0000-0002-8280-9502>

Ali Kadhim Ahmed

PhD in Technical Sciences, Lecturer
College of Agriculture University of Diyala
32001, 1 Bagdad Str., Baqubah, Iraq
<https://orcid.org/0000-0002-6625-8325>

Serhii Pylypaka

Doctor of Technical Sciences, Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
<https://orcid.org/0000-0002-1496-4615>

Tetiana Volina*

PhD in Technical Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
<https://orcid.org/0000-0001-8610-2208>

Taras Voloshko

Senior Lecturer
Sumy National Agrarian University
40000, 160 Herasim Kondratiev Str., Sumy, Ukraine
<https://orcid.org/0000-0003-2605-8836>

Construction of the working surfaces of the tillage screw body from the compartments of the developable helicoid

Abstract. Improvement of the screw working bodies for surface tillage is important for increasing the efficiency and quality of agricultural work. The purpose of the work was to calculate the design of the screw a working body for the surface cultivation of the soil from the compartment of the developable helicoid, which would perform the technological process with minimal resistance to plunging in the soil. The surface theory, analytical, and differential geometry were used to design the working body. It is shown in the paper that through a given spiral line, which is the cutting edge of the surface (blade), it is possible to draw developable helicoids with different inclinations of rectilinear generators. Designing the surface for the best plunging into the soil is important. It is established that the proposed working body is an alternative to the existing disc-type tools. It has been proven that for a long time, spherical discs for surface cultivation of the soil were fixed on a common shaft, which was installed on the unit with a certain angle between its axis and the direction of movement

Article's History: Received: 12.04.2024; Revised: 28.06.2024; Accepted: 15.08.2024.

Suggested Citation:

Kresan, T., Ahmed, A.K., Pylypaka, S., Volina, T., & Voloshko, T. (2024). Construction of the working surfaces of the tillage screw body from the compartments of the developable helicoid. *Machinery & Energetics*, 15(3), 9-21. doi: 10.31548/machinery/3.2024.09.

*Corresponding author



Copyright © The Author(s). This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (<https://creativecommons.org/licenses/by/4.0/>)

of the unit, which contributed to the plunging of the discs in the soil. It is confirmed that the disc-type tillage implements were improved, but this complicated the design of the unit since each disc received an individual axis of rotation. Studies have shown that this made it possible to additionally set the roll angle, that is, the deviation of the plane of the disc blade from the vertical direction, which improved the plunging of the disc in the soil and ensured more effective turning and mixing of plant residues. The proposed screw working body combines the simplicity of the design of the common shaft and the presence of the angle of attack and roll, which confirms its effectiveness in comparison with existing analogs. The necessary calculations were made, and the surfaces of the right and left courses were constructed with the designation of the necessary structural parameters. The application of the obtained results can simplify the design of the soil processing unit

Keywords: attack angle; sharpening angle; surface step; screw parameter; ridges; soil profile

INTRODUCTION

Improvement of the tillage screw body can significantly increase the efficiency and quality of surface tillage. Traditional disc tools have their limitations, while screw-type working bodies, in particular developable helicoids, offer an alternative that allows for a more uniform finish with characteristic crests and troughs. The developable helicoid has a shape that contributes to easier plunging in the soil, which reduces resistance and facilitates work. In addition, the precise calculation of the flat workpiece for the manufacture of coils ensures high accuracy and efficiency in the production of these tools. All these factors contribute to increasing the productivity and quality of agricultural work, which is key to ensuring stable and efficient agricultural production.

The influence of operational factors of agricultural machinery on its technical condition was studied in detail by L. Semenenko *et al.* (2021). The authors established that in 90% of cases, increasing the durability and wear resistance of the working bodies of tillage machines is implemented by technological methods. S. Mudarisov *et al.* (2019) noted that there is a global trend toward the formation of a new agricultural strategy, the basis of which is the implementation of modern innovative soil cultivation technologies using the latest combined units. K. Aikins *et al.* (2020) applied the discrete element method to the design and optimization of tillage implements. The dependence of the soil tillage efficiency on the geometric and structural characteristics of the working bodies and their setting was established. The approach proposed by the authors makes it possible to improve existing soil cultivation technologies, including by reducing the energy intensity of the process, which corresponds to modern principles of sustainable agriculture.

Existing methods of processing the surface of the field before sowing, as noted by E. Zykin *et al.* (2022), are implemented by various agricultural machines, which are equipped with working bodies in the form of rotating spherical disks. But the problem of high-quality soil cultivation by such working bodies that meet the quality criteria remains unsolved.

R. Abdrakhmanov *et al.* (2023) give a detailed analysis of the structures of the disk working organs. The authors note that the main disadvantage of all structures is slippage when interacting with the soil, which significantly reduces the quality of soil cultivation. To eliminate this shortcoming, the authors propose a new design of the tillage disc.

V. Zubko *et al.* (2021) claim that field cultivation allows to solve important agrotechnical tasks: destruction of weeds, pests, and pathogens of plant diseases; preservation and increase of moisture reserves in the soil; activation of microorganisms; application of plant residues and mineral fertilizers to the soil; ensuring the necessary conditions for high-quality subsequent tillage of the soil. The analysis of the received data made it possible to determine the parameters of the movement speed of the soil tillage unit of the existing design, the depth of cultivation, and the direction of movement on the field, which allows performing disk tillage in compliance with agrotechnical requirements.

The relative movement of particles on the inner rough surface of the concave tillage disk, which rotates around its axis under the action of the soil reaction force, is considered T. Volina *et al.* (2021). The expediency of equipping such a disk with vertical radially mounted vanes has been investigated. As noted by M. Amantayev *et al.* (2018) and E. Zykin *et al.* (2020), the factors that significantly affect the quality of disk tillage are the shape and size of the disks, their placement on the frame and orientation in the soil, the weight of the machine.

Spherical tillage discs for surface tillage have been used for a long time. If earlier they were mounted on a common shaft in the form of a battery, now each disk has its own rotation node and individual attachment of the axis of rotation to the frame (Rashidov *et al.*, 2022). This allows setting not only the angle of attack but also the angle of inclination concerning the vertical plane. This contributes to a better movement of the soil along the surface of the disc and improves its mixing, but complicates the construction of the unit. The use of a screw surface can combine the fulfillment of the agrotechnical requirements of soil cultivation, the characteristic of units with individual fastening of discs, and the simplicity of design characteristic of battery-type implements (Hevko *et al.*, 2021). Therefore, screw working bodies are an alternative to disc tools.

The work of S. Pylypaka *et al.* (2021) is the closest to the conducted research. It considers the design of a screw working body when using which the profile of the treated soil has ridges and depressions, as well as when working with the disk working bodies. In this article, theoretical calculations were performed, the helical surface of the working body was constructed, and on their basis, the profile

of the treated soil was obtained concerning structural and technological parameters. It left out of consideration the important issue of plunging the working body into the soil. This issue has been studied for disc working bodies and consists of the fact that when the tillage disc is buried in the soil, it is necessary to eliminate the contact of its rear surface with the soil environment. Otherwise, the disk will try to roll to the surface, that is, its plunging will be unsatisfactory. The same applies to screw working bodies. To prevent such a possibility, there were conducted research in this article. The purpose of the work was to calculate the helical working surface of the working body for surface cultivation of the soil with the available back angle to reduce the resistance of plunging in the soil.

MATERIALS AND METHODS

Research methods were based on the theory of surfaces of differential geometry. According to it, only helical ruled surfaces are classified according to the position of the rectilinear generator in relation to the axis of the surface (intersecting or oblique, what is the angle between them). The paper examined the compartment of the developable helicoid (torso-helicoid) as the surface that is most suitable both in terms of structural parameters and the technolo-

gy of manufacturing turns. They were obtained by bending and stretching the sweep in the form of a flat ring along the axis of the cylindrical shaft. The developable helicoid is formed by a set of rectilinear generators tangent to the helical line, which for the formed surface is called the turning edge. Based on the method of formation, the parametrization of the surface with a vertical axis has the form:

$$\begin{aligned} X &= p \cos \alpha \mp u \frac{p}{\sqrt{p^2+h^2}} \sin \alpha; Y = p \sin \alpha \pm u \frac{p}{\sqrt{p^2+h^2}} \cos \alpha; \\ Z &= h\alpha \pm u \frac{p}{\sqrt{p^2+h^2}}, \end{aligned} \quad (1)$$

where α, u are variable parameters of the surface, α is the angle of rotation of the point around the axis of the surface during its movement to the current point on the helical line, which is located on the cylinder of radius p ; u is the length of the rectilinear generator from the current point on the helical line to the point on the surface; h is a constant value (screw parameter) through which the step H of the surface is determined: $H = 2 \pi h$. The helical parameter h is a constant value and does not depend on the radius r of an arbitrary helical line on the surface. In Figures 1a, 1b, frontal projections of the surface of the developable helicoid were constructed according to equations (1) for the upper and lower sign, respectively.

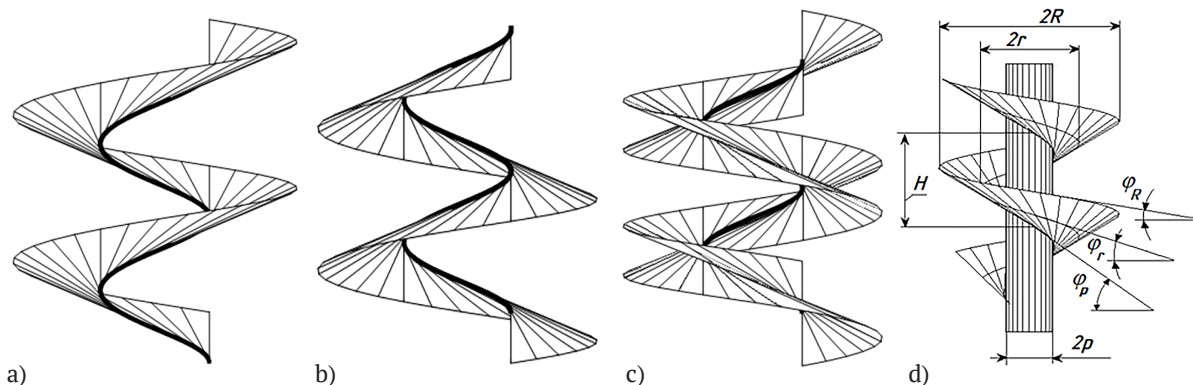


Figure 1. Developable helicoids formed by a set of rectilinear generators tangent to the helical line

Note: a, b) based on the right helical line with the upper and lower arrangement of rectilinear generators; c) based on the left helical line with the arrangement of straight-line generators extended in opposite directions from the helical line; d) surface with design parameters; R is the radius of the cylinder on which the helical line is located – the edge of the surface; r is the radius of the cylinder on which an arbitrary helical line is located; H is the pitch of the surface; p is the radius of the cylinder, on which the helical line is located – the turning point of the surface; $\varphi_R, \varphi_r,$ and φ_p are the elevation angle of the helical line, which is the edge of the surface, an arbitrary helical surface line and the turning edge

Source: developed by the authors based on equations (1), (2)

The left part of the equations (1) of the surface of the helicoid is the parametrization of the helical line (reverse edge) located on the cylinder of radius p . The right parts in front of the variable u are the projections of the unit base vector of the generator. They are obtained by differentiation of the left parts followed by their normalization to a unit vector. The upper sign corresponds to the count of the generator from the point on the spiral line up (Fig. 1a), and the lower one – down (Fig. 1b). As the angle α in equations (1) increases, a helical line is formed as a trajectory of a point in two movements: translational along the OZ

axis upwards and rotational around the counterclockwise axis (right-hand helical line). If the direction of rotation is changed to the opposite, then the helical line will be left-handed. The parametrization of the surface based on it had the form:

$$\begin{aligned} X &= p \cos \alpha \mp u \frac{p}{\sqrt{p^2+h^2}} \sin \alpha; Y = -p \sin \alpha \mp u \frac{p}{\sqrt{p^2+h^2}} \cos \alpha; \\ Z &= h\alpha \pm u \frac{h}{\sqrt{p^2+h^2}}. \end{aligned} \quad (2)$$

The two surfaces corresponding to the upper and lower signs in equations (2) are shown in Figure 1c. Since the

rectilinear generators going up and down from the point of contact have a common direction, two surface cavities are formed. Despite the similarity of the surfaces for the right and left helical lines, there is a difference between them: the visible side of one surface is invisible for the other and vice versa.

The helical line (edge of return) is given by two constant values: the radius p of the cylinder on which the edge of return is located, and the step $H=2\pi h$. Through p and h , the angle φ_p of the rise of the turning edge is determined:

$$\operatorname{tg}\varphi_p = \frac{h}{p}. \quad (3)$$

A section of the helicoid was cut out by coaxial cylinders at a certain distance from the return edge. The lines of intersection of these cylinders with the helicoid were also helical lines of the same pitch H but with a different angle of elevation. It was determined by the formula (3) when substituting the radius of the corresponding cylinder into the denominator. As the radius of the cylinder increases, the angle of elevation of the helical line decreases (Fig. 1d), but the angle of inclination of the generating helicoid remains constant and equal to the angle of elevation of the return edge.

In equations (1), (2), the guiding curve was a spiral line on a cylinder of radius p , which is a turning edge for the surface. The surface of the helicoid torso passed through other helical lines, including those with the radius of the

cylinder R (Fig. 1d). Taking the helical line, which is the outer edge of the compartment, as a base curve, the parametrization of the surface has changed slightly. The index “ R ” was used to indicate the right spiral line in the equations, and the index “ L ” was used for the left one:

$$\begin{aligned} X_R &= R \cos\alpha + ul; X_L = R \cos\alpha + ul; \\ Y_R &= R \sin\alpha + um; Y_L = -R \sin\alpha - um; \\ Z_R &= h\alpha + un; Z_L = h\alpha + un, \end{aligned} \quad (4)$$

where $l=l(\alpha)$, $m=m(\alpha)$, $n=n(\alpha)$ are direction cosines of the rectilinear generating surface. They had to be such as to ensure the contact of rectilinear generators with the edge of the turn.

The set of rectilinear generators, drawn through a given helical line at an angle φ_p , had to be tangent to the turning edge – a helical line on a cylinder of radius p (Fig. 1d). This means that on the horizontal projection, these generators were tangent to the circle of radius p . This approach of surface formation was applied in the work of S. Pylypaka *et al.* (2021). This research is its continuation.

RESULTS

Figure 2a shows a horizontal projection on which helical lines are depicted by circles of radii R and p . At the current value of the angle α , point A is taken on the given spiral line through which straight lines tangent to the circle of radius p are drawn. There are two such lines (Fig. 2a).

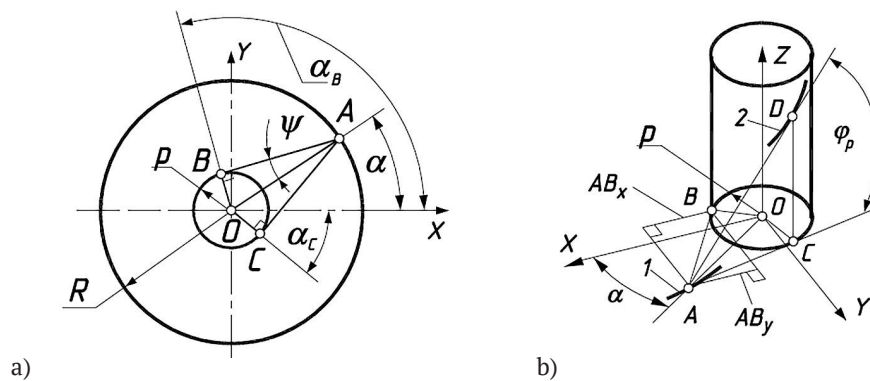


Figure 2. Graphical illustrations for determining the direction of rectilinear generators of a helicoid that pass through a given helical line

Note: a) horizontal projection of a given helical line with rectilinear generators of a helicoid; b) axonometric image of fragments of a given helical line and generating helicoid with its reverse edge; R is the radius of the cylinder on which the helical line is located – the edge of the surface; p is the radius of the cylinder, on which the helical line is located – the turning point of the surface; α is the current value of the angle, which is an independent variable; α_B and α_C are values of the angles α for the corresponding points; φ_p – the angle of elevation of the return rib; AB_x and AB_y are projections of segment AB ; ψ is the angle between the radial direction and segment AB ; A, B, C, D, O are points; 1 – a fragment of a helical line – the edge of the surface; 2 – a fragment of the reverse rib

Source: developed by the authors based on conducted research

To find their direction, it was necessary to know the coordinates of points A, B , and C . They were recorded through the current value of the corresponding angle: $A \{R\cos\alpha, R\sin\alpha\}$, $B \{p\cos\alpha_B, p\sin\alpha_B\}$, $C \{p\cos\alpha_C, p\sin\alpha_C\}$. The angle ψ has a constant value: $\psi = \operatorname{Arccos}(p/R)$. Using

the connections between the angles of right triangles, expressions for the required angles could be found: $\alpha_B = \alpha - \operatorname{Arccos}(p/R) + \pi/2$, $\alpha_C = \alpha + \operatorname{Arccos}(p/R) - \pi/2$. After that, the coordinates of points B and C could be written as a function of the current value of the angle α : $B \{p\cos(\operatorname{Arccos}(p/R) + \alpha)$,

$p \sin(\arccos(p/R) + \alpha)$, $C \{p \sin(\arcsin(p/R) + \alpha), -p \cos(\arcsin(p/R) + \alpha)\}$. Having the coordinates of points A, B, and C, the lengths of the segments AB and AC can be found as the distance between the coordinates of their endpoints. The projections of these segments on the axis OX and OY are the projections AB_x, AB_y and AC_x, AC_y (Fig. 2b shows the projections for the segment AB):

$$\begin{aligned} AB_x &= \frac{1}{R} \left[(R^2 - p^2) \cos \alpha + p \sqrt{R^2 - p^2} \sin \alpha \right]; \\ AB_y &= \frac{1}{R} \left[(R^2 - p^2) \sin \alpha - p \sqrt{R^2 - p^2} \cos \alpha \right]; \\ AC_x &= \frac{1}{R} \left[(R^2 - p^2) \cos \alpha - p \sqrt{R^2 - p^2} \sin \alpha \right]; \\ AC_y &= \frac{1}{R} \left[(R^2 - p^2) \sin \alpha + p \sqrt{R^2 - p^2} \cos \alpha \right]. \end{aligned} \quad (5)$$

Segments AB and AC are equal, and their length can be found by their projections:

$$AB = AC = \sqrt{AB_x^2 + AB_y^2} = \sqrt{AC_x^2 + AC_y^2} = \sqrt{R^2 - p^2}. \quad (6)$$

In Figure 2b the axonometry shows fragments of the given helical line (marked with the number 1) and the edges of the helicoid return (marked with the number 2), through points A and D of which the generating surface passes. The angle of inclination φ_p of the rectilinear generator (segment AD) can be determined from the right triangle ACD:

$$\operatorname{tg} \varphi_p = \frac{CD}{AC} = \frac{CD}{\sqrt{R^2 - p^2}}. \quad (7)$$

From expression (7), the length of the segment CD can be found, which is also the projection of the base vector of the rectilinear generating helicoid onto the axis OZ, i.e. $CD = CD_z$. According to the known projections of the segment AD $\{AC_x, AC_y, CD_z\}$, one can find the projections l, m, n of the unit base vector of the rectilinear generating helicoid, parallel to the segment AD (Fig. 2b):

$$\begin{aligned} l &= \frac{\cos \varphi_p}{R} \left(\mp p \sin \alpha - \sqrt{R^2 - p^2} \cos \alpha \right); \\ m &= \frac{\cos \varphi_p}{R} \left(\pm p \cos \alpha - \sqrt{R^2 - p^2} \sin \alpha \right); \\ n &= \pm \sin \varphi_p. \end{aligned} \quad (8)$$

The two signs in expressions (8) correspond to the two opposite directions of the rectilinear generator, the count of which starts from a point on the given helical line. It should be borne in mind that the radius p and the angle φ_p are connected by the dependence (3), namely: $p = h \operatorname{ctg} \varphi_p$. Taking this into account, the direction cosines (8) will be finally written:

$$\begin{aligned} l &= \frac{\cos \varphi_p}{R} \left(\mp h \operatorname{ctg} \varphi_p \sin \alpha - \sqrt{R^2 - h^2 \operatorname{ctg}^2 \varphi_p} \cos \alpha \right); \\ m &= \frac{\cos \varphi_p}{R} \left(\pm h \operatorname{ctg} \varphi_p \cos \alpha - \sqrt{R^2 - h^2 \operatorname{ctg}^2 \varphi_p} \sin \alpha \right); \\ n &= \pm \sin \varphi_p. \end{aligned} \quad (9)$$

The expressions of the direction cosines (9) include three constant values: R and h , which specify the base spiral line and the angle φ_p of the slope of the rectilinear generators. It can be changed within certain limits, which means that a set of developable helicoids can be drawn through a given helical line. The maximum value of the radius p can be equal to the radius r of the limiting shaft (the case when the internal helical line is the turning edge), and the minimum value can be greater than zero. For the case when $p = r$ from dependence (3): $\varphi_p = \operatorname{Arctg}(h/r)$. Thus, $\operatorname{Arctg}(h/r) \leq \varphi_p < 90^\circ$.

Figure 3 shows the frontal projections of the surfaces constructed according to equations (4) taking into account (9). Through the helical line of right-hand movement (Fig. 3a, 3b, 3c), surfaces with different set angles of inclination of the generators pass. Figure 3d is the same, but the helical line is a left-hand line.

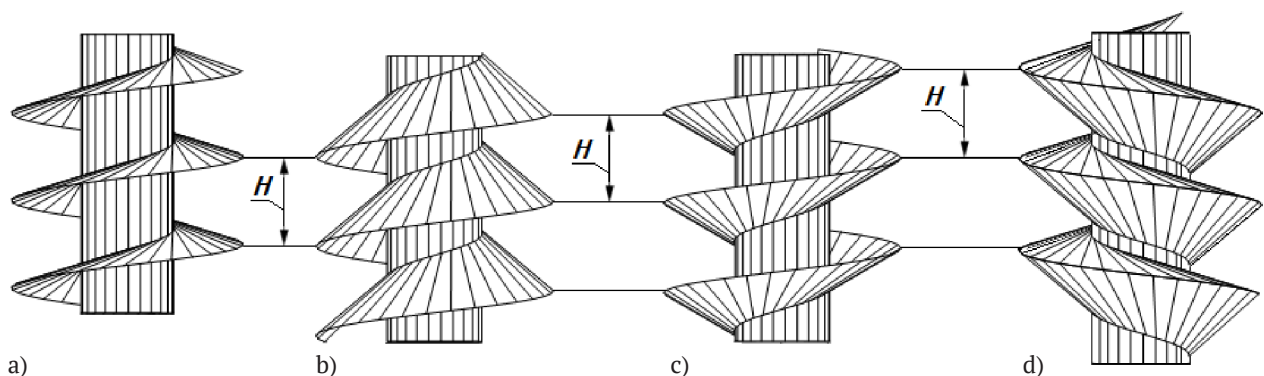


Figure 3. Helicoid torsos passing through a given helical line of the same right-hand and left-hand pitch

Note: a) right-hand course, rectilinear generators are directed downward, $\varphi_p = 17^\circ$; b) right-hand course, rectilinear generators are directed downward, $\varphi_p = 40^\circ$; c) right-hand course, rectilinear generators are directed upwards, $\varphi_p = 30^\circ$; d) left-hand course, rectilinear generators are directed down and up, $\varphi_p = 17^\circ$ and $\varphi_p = 40^\circ$ H – pitch of helical lines, which is the pitch of the surface

Source: developed by the authors based on conducted research

In Figure 3 compartments of helicoid torsos are limited by outer and inner helical

line can be obtained from equations (4) at $u = 0$. At another constant value of the length of the rectilinear generator

$u = const$, an internal helical line will be obtained for the value of the radius r . It is obvious that for all four compartments of surfaces (Fig. 3) the value of parameter u will be the same. On the horizontal projection, all four spiral lines

$$u = \frac{-R(l \cos \alpha + m \sin \alpha) + \sqrt{R^2(l \cos \alpha + m \sin \alpha)^2 - (l^2 + m^2)(R^2 - m^2)}}{l^2 + m^2} \quad (10)$$

Substitution from (8) of the expressions of the base vectors l and m in (10) and further simplifications make it possible to obtain a simple formula for finding u :

$$u = \frac{\sqrt{R^2 - p^2} - \sqrt{r^2 - p^2}}{\cos \phi_R} \quad (11)$$

The substitution in (11) of the dependence $p = h \operatorname{ctg} \phi_p$ gives the final result:

$$u = \frac{\sqrt{R^2 - h^2 \operatorname{ctg}^2 \phi_p} - \sqrt{r^2 - h^2 \operatorname{ctg}^2 \phi_p}}{\cos \phi_R} \quad (12)$$

When $r = R$ according to (12), $u = 0$ will be obtained. For other values of r , the value u will be obtained from the interval $r = p \dots R$, at which the spiral line will correspond to the value of the radius r . Disc working bodies are used for surface tillage. For the disk to plunge into the soil, it is placed at an angle of attack to the direction of movement of the unit. If the surface of the helicoid is placed so that its axis is horizontal, then under certain conditions it can also be considered as a tillage body. In Figure 4a, the projections show a developable helicoid with a cylindrical shaft, which

are projected by a circle of radius r , that is, it can be written: $X_R^2 + Y_R^2 = r^2$. By substituting the expressions X_R and Y_R or X_L and Y_L into this equation, a quadratic equation is obtained. Its solution concerning u gives the result:

lies on the surface of the soil. The points of contact of the external helical line with the soil surface are marked with circles. The shaft is not shown on the horizontal projection so that the angle ϕ_R at the points of contact can be marked. By analogy with the disk working body, this angle can be considered the angle of attack. If the surface of the helicoid is rolled across the field, its intensive plunging into the soil will obstruct the back side of the surface, which in Figure 4a is painted in light gray. To avoid this, the helicoid should be turned by the angle β , as shown in Figure 4b. If the angle β was equal to the angle ϕ_p of the slope of the generators, then the angle ε (Fig. 4b) would be equal to zero. However, to prevent the soil from being crushed by the back side of the working surface, this angle (or back angle) for disc working bodies, taking into account the angle of sharpening the blade, should be equal to $3^\circ - 5^\circ$ (Pylypaka *et al.*, 2021). In this study, a surface of zero thickness is considered, therefore it is assumed that $\varepsilon \geq 5^\circ$. It can be more accurately determined by taking into account the thickness of the surface of the helicoid and the sharpening angle of the cutting edge. Therefore, the angle of attack will be determined by the sum of two angles: $\beta = \phi_p + \varepsilon$.

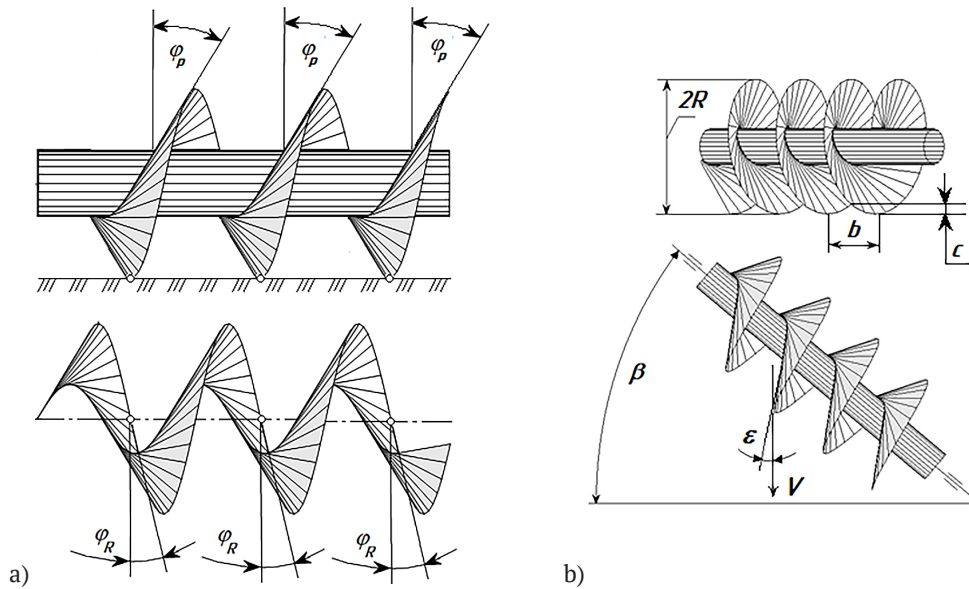


Figure 4. Developable helicoid with a horizontal axis of rotation

Note: a) the horizontal axis of the helicoid is perpendicular to the direction of rolling; b) the horizontal axis of the helicoid forms an angle of $90^\circ - \beta$ with the direction V of the aggregate movement; ϕ_R is the angle of elevation of the helical line, which is the edge of the surface; R is the radius of the cylinder on which the helical line is located – the edge of the surface; β is the angle between the axis of the helicoid and the direction perpendicular to the direction of movement of the unit; V – direction of movement of the unit; ε – rear angle; b is the distance between ridges; c is the height of the ridges

Source: developed by the authors based on research

With this orientation of the helicoid, the back side of the surface is not visible on the frontal projection, unlike the frontal projection in Figure 4a. This means that it will not interfere with the plunging of the surface into the soil. The surface was assumed to plunge into the soil until the cylindrical shaft touched the field surface. The profile at the border of treated and untreated soil (Fig. 4b) will be similar to the profile after passing the disk working bodies. If it is necessary to treat the soil to a depth of 0.1 m at $R=0.25$ m, the radius of the cylindrical shaft should be $r=0.15$ m.

If one pulls the screw working body shown in Figure 4b in the direction V of the unit's movement, then it will be plunging into the soil. As a result of the interaction with the soil, a reaction force will arise, which will put pressure

on the working surface of the coil. The component of this force will try to move the working body to the side perpendicular to the direction of its movement. To balance this moment of force, it is advisable to make the unit in the form of two working bodies, as shown in Figure 5. The surface of the second working body should have a turning edge with the opposite direction of winding and the direction of rectilinear generators, as shown in Figure 5. The cylindrical shaft for the tool was chosen taking into account the specified depth and tillage of the soil. Also, with this option, the height of the ridges c and the distance b between the ridges could be reduced. (Fig. 5, frontal projection). For the ridges to be of the same height, the position of both helical working bodies must be correctly coordinated.

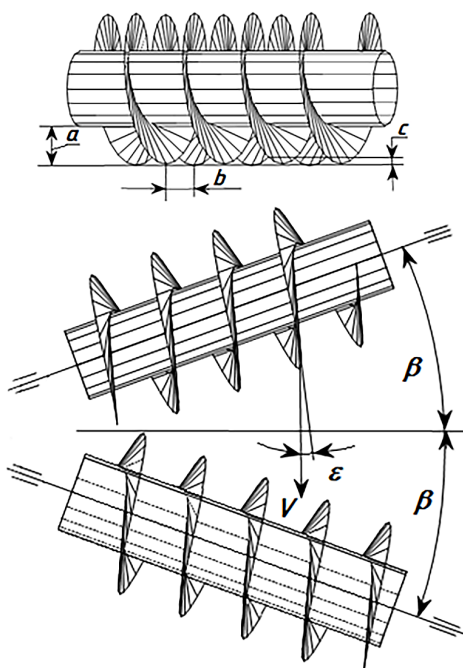


Figure 5. Soil tillage tool in projections, which consists of two screw working bodies

Note: horizontal and frontal projections; β is the angle between the axis of the helicoid and the direction perpendicular to the direction of movement of the unit; V – direction of movement of the unit; ε – rear angle; a – depth of processing; b is the distance between ridges; c is the height of the ridges

Source: developed by the authors based on research

Earlier it was said that the rotation angle β is determined from the expression: $\beta = \varphi_p + \varepsilon$. The angle ε should be as small as possible, but as noted, it cannot be less than 5° . The question arises about the value of the angle φ_p , since the compactness of the tillage tool depends on the value of the angle β . For this, the angle φ_p should also be taken as small as possible, but such that the surface plunges into the soil. It can be seen from formula (3) that the value of the angle φ_p depends on the pitch of the helical line (edge of the turn) and the radius p of the cylinder on which it is located. At a constant step, the angle φ_p can be changed by changing the radius p . The section of the surface located between two coaxial cylinders will have the same pitch as the turning edge, and the angle φ_p of the slope of the

generators will depend on the value of the radius p . Therefore, through the given helical line, which was considered the outer edge (blade) of the working helical surface, it is possible to draw a whole set of helicoids with a different angle φ_p of the inclination of the generators, which was considered in the previous subsection.

Based on the obtained results, it is possible to proceed with the construction of the working turns of the screw tillage body with different angle φ_p of the inclination of the rectilinear generating helicoid. For this, the original spiral line – the cutting edge of the working surface – must be specified. Let $R=0.25$ m. Step H was chosen taking into account the desired distance b between ridges. For one working surface at $\beta=0$, $H=b$. When the surface is rotated by

an angle β , the distance b will be slightly smaller than the step H , namely: $b = H \cos \beta = 2 \pi h \cos \beta$ (Fig. 6a). From here, the helical parameter h of the helical line could have been determined, but for this, the angle β needed to be known. Since it is the sum of two angles $\beta = \varphi_p + \varepsilon$, of which φ_p is still unknown, in the first approximation it was assumed that $H = b$. Considering that there will be two surfaces (Fig. 6), the step can be doubled, i.e. $H = 2b$. It was assumed that $b = 0.2$ m, then $h = 0.06$ m. The depth of tillage was assumed to be $a = 0.1$ m. Then the radius r of the internal helical line was determined as $r = Ra = 0.15$ m. The angle of inclination of the generating φ_r was taken as a minimum $-\varphi_p = \text{Arctg}$

$(h/r) = 22^\circ$. For this case $\beta = \varphi_p + \varepsilon = 27^\circ$. To construct the surface according to equations (4), it is necessary to know the limits of the change of the u parameter. It can be found from expression (12): $u = 0.21$ m. Therefore, the parameter u varies within $u = 0 \dots 0.21$, and the angle α depends on the number of turns (for one turn $\alpha = 0 \dots 360^\circ$). In Figure 6a, based on the given data, the working turns of the surface are constructed according to equations (4), in which one output screw line is right-hand, and the other is left-hand. The choice of the sign in expressions (9) – lower or upper – determined the desired reference direction of the rectilinear surface.

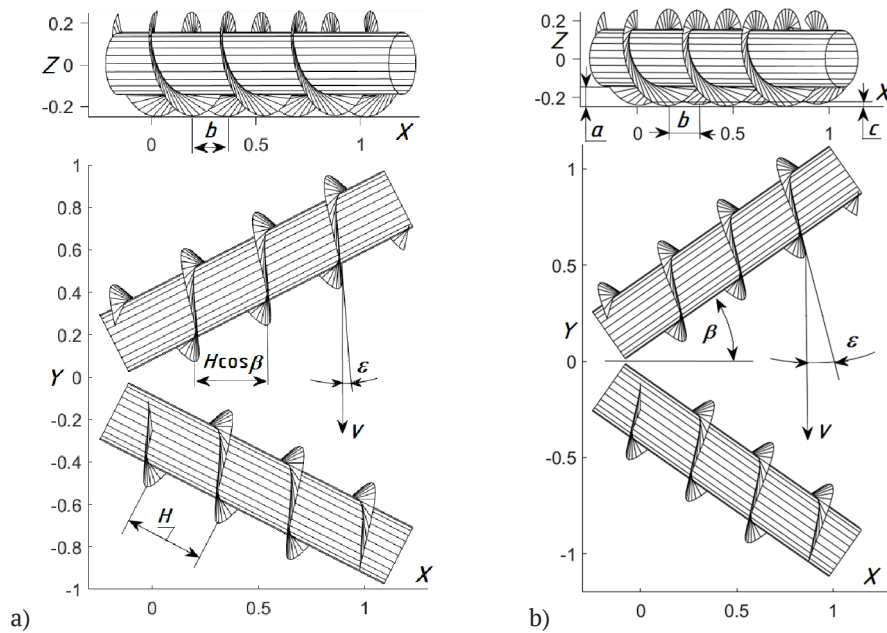


Figure 6. Working surfaces of helicoids passing through right-hand and left-hand helical lines with parameters $R=0.25$ m and $h=0.06$ m

Note: a) $\varphi_p = 22^\circ$; $\beta = 27^\circ$; $b = 0.17$ m; b) $\varphi_p = 22^\circ$; $\beta = 35^\circ$; $b = 0.14$ m; a – depth of processing; b is the distance between ridges; c – ridge height; β is the angle between the axis of the helicoid and the direction perpendicular to the direction of movement of the unit; V – direction of movement of the unit; ε – rear angle; H is the pitch of the surface

Source: developed by the authors based on research

Since the angle β is already known ($\beta = 27^\circ$), the refined value of the distance b between the ridges became known: $b = H/2 = 2 \pi h \cos \beta / 2 = 0.17$ m. The construction of the images took place according to the specified dimensions in scale; therefore, it is possible to estimate the lower profile of the treated soil from the frontal projection in Figure 6a. There are quite a lot of options for the received tillage tool. For example, simply increase the angle of attack β without changing other parameters. Figure 6b shows the diagram of the tillage unit for the angle of attack $\beta = 35^\circ$. At the same time, the distance between the ridges decreased to $b = 0.14$ m, but the height of the ridges did not change. The length of the unit has increased somewhat. The angle ε also increased from 5° to 13° , which is a positive consequence of the increase in the angle of attack. The fact is that the back side of the surface needs to be sharpened, as mentioned earlier. As a result, a narrow strip of the new surface

appeared. For a spherical disk, such a surface is a cone, for a helicoid – another helicoid. This is also the rear surface, which should not disturb the soil. To fulfill this condition, an angle margin ε is required. However, it is possible to increase the angle ε by increasing the angle β up to a certain limit. An excessive increase in the angle of attack β can lead to a decrease in the angular speed of rotation due to the drag of the helical surface. The unit can be adjusted. The range of changing the angle of attack β is quite wide – it can reach up to 40° in disc peelers.

If at an angle of inclination of the generators $\varphi_p = 22^\circ$, the plunging of the surface into the soil and its processing occurs normally, then it can be preserved while maintaining the angle of attack $\beta = 40^\circ$, while reducing the step H . Accordingly, the helical parameter h and the minimum value of the angle φ_p will decrease. However, the required value of $\varphi_p = 22^\circ$ was taken, not the minimum. At the same

time, the value of the angle ε will not change either. Therefore, the three parameters could be left unchanged, while step H could be reduced (the distance b between the ridges would also decrease). However, the decrease in step H led to a decrease in the space between the turns, which can interfere with the passage of soil lumps between them to the point of jamming the inter-turn space with the soil. In addition, jamming can be facilitated by the solid structure of the shaft, so it is necessary to make it lattice (Fig. 7). In this case, the shaft will perform an additional rolling function.

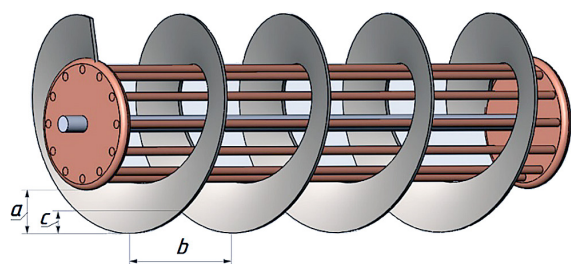


Figure 7. Lattice shape of the shaft

Note: an axonometric image; a – depth of processing; b – the distance between ridges; c is the height of the ridges

Source: developed by the authors based on conducted research

An increase in the angle φ_p leads to a decrease in the angle of elevation of the soil on the surface of the helicoid. According to agrotechnical requirements, it is necessary to ensure the mixing of the soil with harvest residues, which

cannot be done without raising the soil to a great height. This requirement can be provided by a decrease in the angle of elevation of the soil, that is an increase in the angle φ_p , which makes it easier for the cut strip of soil to rise along the surface of the helicoid. Of course, the increase in the angle φ_p also has its limit and its rational value can be found during the experiment.

Figure 8a shows the diagram of the tillage unit, which differs from the unit in Figure 6b by the fact that the angle φ_p is increased to 35° . As a result, the angle ε became equal to zero. In principle, such an option is possible if the edge is sharpened not from the outer (back) side of the surface, but from the inner (working) side, but this method of sharpening is not practiced in disc-working bodies. The angle β could be increased from 35° to 40° , then the angle $\varepsilon = 5^\circ$ would appear. Such a scheme of the unit is shown in Figure 8b. In addition, step H has also been increased. At the same time, the angle between the edge of the surface and the direction of entry V_p of the particle on the surface increases (Fig. 8b). This contributes to a better plunging of the surface into the soil. The best plunge would be if this angle were straight, that is, the particle entered the surface perpendicular to the blade (this applies to the lowest point of the blade, as it approaches the surface of the field, this angle will no longer be straight). For this, it is necessary to increase the angle β : $\beta = 90^\circ - \varphi_R = 90^\circ - \text{Arctg}(h/R)$. For example, for the unit, the scheme of which is shown in Figure 8b, the angle β should be 72° . It is obvious that at this value of the angle β , the rotation of the helicoid around its axis will become difficult or impossible.

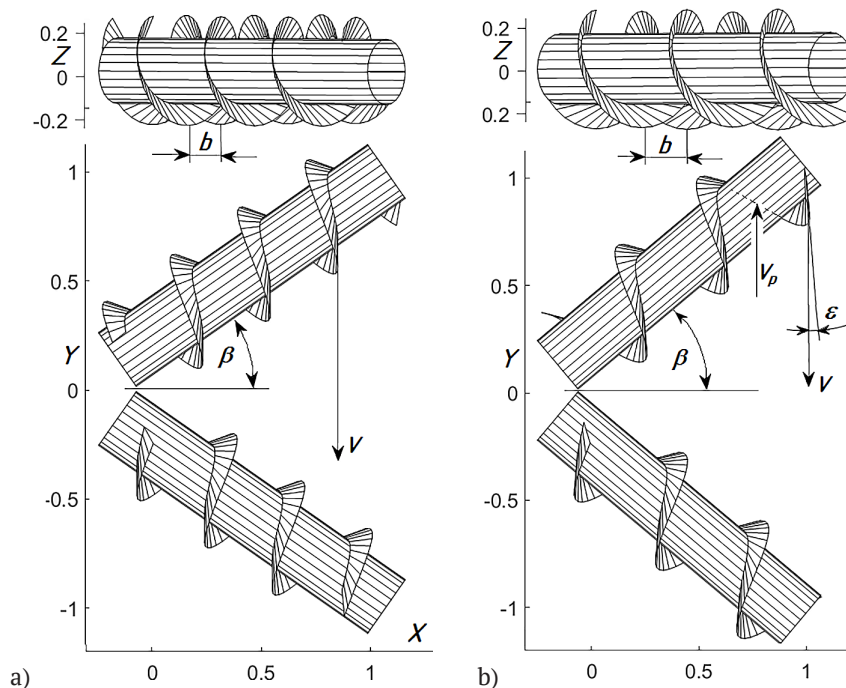


Figure 8. Working surfaces of helicoids of different steps

with the same angle $\varphi_p = 35^\circ$ of the inclination of rectilinear generators

Note: a) $h=0.06$ m; $\beta=35^\circ$; $\varepsilon=0$; $b=0.14$ m; b) $h=0.08$ m; $\beta=40^\circ$; $\varepsilon=5^\circ$; $b=0.19$ m

Source: developed by the authors based on conducted research

On all diagrams of the tillage unit (Fig. 6, 8), the height c of the ridges is practically the same, only the distance b between the ridges differs. In general, the shape of the profile of the cultivated soil is determined by the parameters h and R of the external helical line (cutting edge) and the angle β of its axis.

DISCUSSION

The experience of industrialized countries over the past century in the issue of weed control has shown that the main criteria for the decisions of manufacturers of tillage machines are simplicity and convenience (Syromyatnikov, 2017). It is important to develop new non-chemical methods of weed control due to the impact of herbicides on human health and increasing the resistance of weeds (Syromyatnikov, 2018). The European Union Commission encourages member states to develop low-pesticide agriculture (Busari *et al.*, 2015). The basis of this process is the improvement of weed control machines. In this sense, research on the improvement of working bodies for surface treatment corresponds to modern trends in the development of agricultural machines. The basis for the design of tillage working bodies is the availability of their simple analytical physical and mathematical models (Ghereș, 2014; Tesliuk *et al.*, 2019), the development of which scientists pay a lot of attention. Experimental studies play an important role in bringing the working bodies to the optimal form so that agrotechnological requirements are met during their work. However, analytical calculations play a big role, which is demonstrated in the proposed article on the provision of a back angle.

Tillage units are used for soil treatment. Working bodies in contact with the ground can be those that are rigidly attached to the frame (loosening paws, spring teeth) and those that rotate around an axis (rolls, disk working bodies). Tillage discs are used to grind and mix plant residues with soil. Previously, they were mounted on a common shaft, the axis of which made a certain angle to the direction of movement of the unit, that is the angle of attack. Under the action of the unit's weight, the discs plunged into the ground and rotated under the action of reaction forces from the side of the ground. Their common axis of rotation remained parallel to the field surface during operation. Recently, for better operation of discs, they are arranged so that the axis of rotation of the disc additionally makes a certain angle with the surface of the field, that is, the roll angle. This requires an individual rotation unit for each disk, which complicates the design. Research on improving the performance of discs and improving their shape is mainly conducted experimentally.

M. Klendii & O. Klendii (2016) developed an analytical model of a concave spherical disk placed in a three-dimensional coordinate system with a given direction of movement of the unit. The model includes the design parameters of the disk and the depth of tillage. In addition, the authors established a relationship between the angle of attack and the roll of the disc for a given value of the

rear angle at the level of the field surface. In this work, for the first time, calculations were made on how to combine the angles of attack and roll and at the same time ensure the presence of the rear angle. This is the similarity of the research conducted in this article. The difference is that instead of disc working bodies, a screw working body is offered, which is fundamentally different from the disc working body, but performs the same work. The profile of cultivated soil is also similar: it consists of ridges and depressions. It is also necessary to ensure the presence of a back angle to prevent the working body from rolling out onto the field surface, i.e. for better plunging in the soil. However, the calculations are fundamentally different because the working bodies have different shapes.

Disc coulters are widely used for crushing plant residues on the surface of the field. There are four main types of these discs: smooth, toothed, undulating, and wavy. R. Magalhaes *et al.* (2007) emphasize the problems in the operation of the existing designs of discs and the low efficiency of crushing plant residues. In the case of dry soil, they require a high vertical load to penetrate it. In the case of high soil moisture, the remains are pressed into the soil without crushing them. R. Magalhaes *et al.* (2007) proposed a new geometry of angled disc coulters, which allows crushing plant residues on the field surface in any soil condition, avoiding clogging and reducing traction force.

Analytical calculations also play a big role in this. S. Krivoshapko & M. Rynkovskaya (2017) considered in detail the types of helical ruled surfaces, including developable ones, for their practical application. The article does not talk about working bodies for soil cultivation, although the use of the surface of the developable helicoid as a drill for digging pits is shown. This article is designed to show the possibilities of designing helical surfaces and the features of their shape. It lists five types of helical ruled surfaces. It states that engineers know about straight and oblique helicoids, which are non-developable. One of the helicoids listed in this article is the developable one, which was considered in current study for the design of a screw tillage body.

The application of the developable helicoid as an alternative to tillage discs is considered by S. Pylypaka *et al.* (2021). It shows the use of the developable helicoid surface as the working surface of the tillage tool. At the same time, the profile of the treated soil will consist of ridges and depressions, similar to disk working bodies. The size of the distance between the ridges and the size of the depressions depend on the direction of the spiral line, which is the cutting edge of the working surface, that is, the blade. The profile is also affected by the angle of attack and the depth of plunging of the working surface into the soil. In this paper, it is stated that through a given spiral base line, which is the edge of the surface, it is possible to draw many developable helicoids, which will differ among themselves by the angle of inclination of the rectilinear generators concerning the surface axis. This angle affects the great effort of plunging into the ground of the working surface and

the quality of turning over the ground and mixing it with plant residues. Hence, it is assumed that this angle can play the role of roll angle for disc guns. In the work, a comparative analysis of two working organs – disk and screw – was carried out, and it was concluded that the screw organ can be an alternative to the disk. However, at the same time, an important issue was not considered – avoiding contact of the back side of the screw working surface with the soil environment. This issue is discussed in detail in the proposed article, the material of which develops and complements previously conducted research.

CONCLUSIONS

The soil tillage unit, equipped with screw working surfaces in the form of turns of a developable helicoid, is a promising solution for surface soil tillage, which can replace traditional disk tools. This alternative offers not only efficiency but also simplicity of construction, which allows the reduction of costs of production and maintenance of units. The analytical description of the design parameters of turns, developed in this paper, opens up opportunities for optimizing these parameters taking into account various agrotechnical requirements. It is important to note that the design of the unit allowed for variation in the parameters of the working bodies while maintaining key characteristics of soil cultivation, such as continuity of cultivation, the specified depth, the appropriate distance between the ridges, and minimal disturbance of the soil structure on the back side.

One of the key advantages of the screw working body is the ability to adjust the angle of attack and the angle of roll. In particular, changing the angle β to a value of 35° ensures the formation of the rear angle ε , which, even without taking

into account the thickness of the helicoid coil, is 13° . This is an important aspect, because the reduction of the angle ε due to the sharpening of the blade can reduce the efficiency of the plunging of the working body into the soil, but a positive angle provides sufficient plunging, which is critical for quality processing. Thus, the unit with screw working bodies provides not only a similar processing profile to disk tools, but also better control over processing parameters.

Prospects for further research are aimed at improving the design of the screw unit. One of the directions is the detailed consideration of the thickness of the helical working surface, which will improve processing efficiency, reduce energy consumption and increase the reliability of the working bodies. Another important direction is the study of the influence of various agrotechnical conditions, such as the type of soil, humidity and the speed of movement of the unit, on the operation of screw organs. This will make it possible to develop universal recommendations for the use of such units in various conditions, which will contribute to their wider implementation in agriculture.

Thus, the development and implementation of screw tillage units has a significant potential for increasing the efficiency and cost-effectiveness of surface tillage. This opens up new opportunities for improving agricultural technologies and reducing the impact on the environment, which are important factors in modern agriculture.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

- [1] Abdrakhmanov, R., Kononov, M., Kalimullin, M., Troyanovskaya, I., Sakhapov, R., & Razetdinov, I. (2023). Study of the kinematics of a disc-pin working body. *E3S Web of Conferences*, 443, article number 04004. doi: 10.1051/e3sconf/202344304004.
- [2] Aikins, K.A., Barr, J.B., Ucgul, M., Jensen, T.A., Antille, D.L., & Desbiolles, J.M.A. (2020). No-tillage furrow opener performance: A review of tool geometry, settings and interactions with soil and crop residue. *Soil Research*, 58(7), 603-621. doi: 10.1071/SR19153.
- [3] Amantayev, M., Gaifullin, G., Kravchenko, R., Kushnir, V., & Nurushev, S. (2018). Investigation of the furrow formation by the disc tillage tools. *Bulgarian Journal of Agricultural Science*, 24(4), 704-709.
- [4] Busari, M.A., Kukal, S.S., Kaur, A., Bhatt, R., & Dulazi, A.A. (2015). Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research*, 3(2), 119-129. doi: 10.1016/j.iswcr.2015.05.002.
- [5] Ghereş, M.I. (2014). Mathematical model for studying the influence of tillage tool geometry on energy consumption. *Inmateh – Agricultural Engineering*, 42(1), 5-12.
- [6] Hevko, I., Dovbush, T., Tson, O., Dovbush, A., & Stanko, A. (2021). Synthesis of screw working bodies with elastic surfaces and results of working body research. *Agricultural Machines*, 47, 63-72. doi: 10.36910/acm.vi47.649.
- [7] Klendii, M.B., & Klendii, O.M. (2016). Interrelation between incidence angle and roll angle of concave disks of soil tillage implements. *Inmateh-Agricultural Engineering*, 49(2), 13-20.
- [8] Krivoschapko, S.N., & Rynkovskaya, M. (2017). Five types of ruled helical surfaces for helical conveyers, support anchors and screws. *MATEC Web of Conferences*, 5, article number 06002. doi: 10.1051/mateconf/20179506002.
- [9] Magalhaes, P.S.G., Bianchini, A., & Braunbeck, O.A. (2007). Simulated and experimental analyses of a toothed rolling coulter for cutting crop residues. *Biosystems Engineering*, 96(2), 193-200. doi: 10.1016/j.biosystemseng.2006.10.014.
- [10] Mudarisov, S., Gabitov, I., Lobachevsky, Y., Mazitov, N., Rakhimov, R., Khamaletdinov, R., Rakhimov, I., Farkhutdinov, I., Mukhametdinov, A., & Gareev, R. (2019). Modeling the technological process of tillage. *Soil and Tillage Research*, 190, 70-77. doi: 10.1016/j.still.2018.12.004.

- [11] Volina, T., Pylypaka, S., Rebrii, A., Pavlenko, O., & Kremets, Ya. (2021). Particle movement on concave coulter of the centrifugal distributor with radially installed vertical blades. In *Advanced Manufacturing Processes II* (pp. 237-246). Cham: Springer. doi: [10.1007/978-3-030-68014-5_24](https://doi.org/10.1007/978-3-030-68014-5_24).
- [12] Pylypaka, S., Klendii, M., Trokhaniak, V., Kresan, T., Hryshchenko, I., & Pastushenko, A. (2021). External rolling of a polygon on closed curvilinear profile. *Acta Polytechnica*, 61(1), 270-278. doi: [10.14311/AP.2021.61.0270](https://doi.org/10.14311/AP.2021.61.0270).
- [13] Rashidov, N.Sh., Maiviatov, F.M., Babajanov, L.K., & Xujakulov, A. (2022). Stepped plow with cutting disc for tillage of sloping fields. *IOP Conference Series: Earth and Environmental Science*, 1076, article number 012023. doi: [10.1088/1755-1315/1076/1/012023](https://doi.org/10.1088/1755-1315/1076/1/012023).
- [14] Semenenko, L., Tarasov, O., Vasylenko, S., Cherep, V., & Polishchuk, V. (2021). Mathematical models for assessing the reliability of agricultural machinery, taking into account the influence of military factors in the front-line territory. *Scientific Horizons*, 24(9), 55-62. doi: [10.48077/scihor.24\(9\).2021.55-62](https://doi.org/10.48077/scihor.24(9).2021.55-62).
- [15] Syromyatnikov, Y.N. (2017). Improvement of the effectiveness of the technical process of movement of soil in a cultivating separating ripper. *Agriculture*, 1, 48-55. doi: [10.7256/2453-8809.2017.1.22037](https://doi.org/10.7256/2453-8809.2017.1.22037).
- [16] Syromyatnikov, Y.N. (2018). Ways to reduce the specific pressure of wheeled thrusters on the soil. *Agriculture*, 4, 95-103. doi: [10.7256/2453-8809.2017.4.26797](https://doi.org/10.7256/2453-8809.2017.4.26797).
- [17] Tesliuk, H., Volik, B., Sokol, S., & Ponomarenko, N. (2019). Design of working bodies for tillage tools using the methods of bionics. *Eastern-European Journal of Enterprise Technologies*, 3(1(99)), 49-54. doi: [10.15587/1729-4061.2019.169156](https://doi.org/10.15587/1729-4061.2019.169156).
- [18] Zubko, V., Sokolik, S., Khvorost, T., & Melnyk, V. (2021). Factors affecting quality of tillage with disc harrow. In *20th International scientific conference engineering for rural development* (pp. 1193-1199). Jelgava, Latvia. doi: [10.22616/ERDev.2021.20.TF262](https://doi.org/10.22616/ERDev.2021.20.TF262).
- [19] Zykin, E., Kurdyumov, V., Lazutkina, S., & Albutov, S. (2020). The experimental determination of the diameter of a flat disk in a ridge seeder. *IOP Conference Series: Materials Science and Engineering*, 971, article number 052055. doi: [10.1088/1757-899X/971/5/052055](https://doi.org/10.1088/1757-899X/971/5/052055).
- [20] Zykin, E., Lazutkina, S., & Ovchinnikov, V. (2022). Theoretical substantiation of the curvature radius and diameter of spherical discs of a combined tillage unit. *AIP Conference Proceedings*, 2503, article number 030038. doi: [10.1063/5.0100000](https://doi.org/10.1063/5.0100000).

Тетяна Кресан

Кандидат технічних наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
<https://orcid.org/0000-0002-8280-9502>

Алі Ахмед

Кандидат технічних наук, викладач
Коледж сільського господарства університету Діяла
32001, вул. Багдадська, 1, м. Бакуба, Ірак
<https://orcid.org/0000-0002-6625-8325>

Сергій Пилипака

Доктор технічних наук, професор
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
<https://orcid.org/0000-0002-1496-4615>

Тетяна Воліна

Кандидат технічних наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
<https://orcid.org/0000-0001-8610-2208>

Тарас Волошко

Старший викладач
Сумський національний аграрний університет
40000, вул. Герасима Кондратьєва, 160, м. Суми, Україна
<https://orcid.org/0000-0003-2605-8836>

Конструювання робочих поверхонь ґрунтообробного гвинтового органу із відсіків розгортного гелікоїда

Анотація. Удосконалення гвинтових робочих органів для поверхневого обробітку ґрунту є важливим для підвищення ефективності та якості сільськогосподарських робіт. Метою роботи був розрахунок конструкції гвинтового робочого органу для поверхневого обробітку ґрунту із відсіку розгортного гелікоїда, який би виконував технологічний процес з мінімальним опором занурення у ґрунт. Для конструювання робочого органу застосовано методи теорії поверхонь, аналітичної та диференціальної геометрії. В роботі показано, що через задану гвинтову лінію, яка є ріжучою крайкою поверхні (лезом), можна проводити розгортні гелікоїди із різним нахилом прямолінійних твірних. Це важливо для конструювання поверхні для найкращого занурення у ґрунт. Встановлено, що запропонований робочий орган є альтернативою існуючих знарядь дискового типу. Доведено, що тривалий час сферичні диски для поверхневого обробітку ґрунту закріплювалися на спільному валу, який встановлювався на агрегаті з певним кутом між його віссю і напрямом руху агрегату, що сприяло зануренню дисків у ґрунт. Підтверджено, що ґрунтообробні знаряддя дискового типу були вдосконалені, але це ускладнило конструкцію агрегату, оскільки кожен диск отримав індивідуальну вісь обертання. Дослідження показали, що це дозволило додатково встановлювати кут крену, тобто відхилення площини леза диска від вертикального напрямку, що покращувало занурення диска в ґрунт і забезпечувало ефективніше перевертання та перемішування рослинних залишків. Запропонований гвинтовий робочий орган поєднує простоту конструкції спільного валу і наявність кута атаки та крену, що підтверджує його ефективність у порівнянні з існуючими аналогами. Зроблено необхідні розрахунки, побудовано поверхні правого і лівого ходу із позначенням необхідних конструктивних параметрів. Застосування отриманих результатів може спостити конструкцію ґрунтообробного агрегату

Ключові слова: кут атаки; кут заточки; крок поверхні; гвинтовий параметр; гребні; профіль ґрунту