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Study of the Movement of Soil Particles on the Surface of a Screw Tillage Working Body

Abstract. This study considers the interaction of soil particles with a screw tillage body, the working surface of which is made in the form of a deployed helicoid and substantially differs from the screw. Furthermore, the unfolded surface is characterised by manufacturability of the working body, since it is possible to calculate the geometric dimensions of a flat workpiece, which is formed into a finished product by simple bending with minimal plastic deformations. The purpose of this paper was to conduct theoretical and experimental studies of the movement of soil particles along the helical surface of the tillage working body, which is made in the form of a deployed helicoid. Mathematical modelling of the processes of movement of soil particles along the helical surface of a tillage working body was described based on general laws and principles of analytical and differential mathematics, theoretical and analytical mechanics. Experimental studies were carried out using a methodology with elements of mathematical statistics, mathematical methods of optimal planning of a multifactor experiment. The analysis of the results of experimental and theoretical studies was performed using applied computer programmes and systems. Experimental studies were conducted according to standard and independently developed methods.Results: a mathematical model of the movement of soil particles along the helical surface of the tillage body was developed, and it was established that when the angle of attack of the helical tillage working body increases, the lifting value of soil particles increases and the area of their dispersion by the helical surface increases. The value of the coefficient of friction does not substantially affect the shape of the trajectory of the soil particle. The quality of loosening the soil most depends on the angle of attack of the screw surface and the angular speed of rotation of the working body. The materials of this paper can be used by scientists for further research and practices in the selection of tillage units

Keywords: deployed helicoid, surface treatment, rectilinear formation, differential equations of motion, angular velocity, angle of attack, coefficient of friction, scattering area

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INTRODUCTION

For tillage, tools with disk working bodies are used. The profile of the treated soil and the size of the ridges depend on the size of the distance between the disks, the design parameters of the disks, and the angles of their installation. Tillage discs are set in such a way that the plane of placement of the blade and the direction of movement of the tillage unit form a given angle, i.e., the angle of attack. For better mixing of the soil and crop residue, the disk is also tilted from the vertical to the tilt angle, and therefore each disk must have its attachment to the harrow frame. If one uses a screw surface for tillage, it is also possible to provide surface tillage with a given depth and distance between the ridges of the tilled soil. However, the screw surface can now be fixed to the joint shaft. This simplifies the design of the working body.

Disk tillage tools, their designs, and calculation of their main parameters are covered in the studies [1-3].

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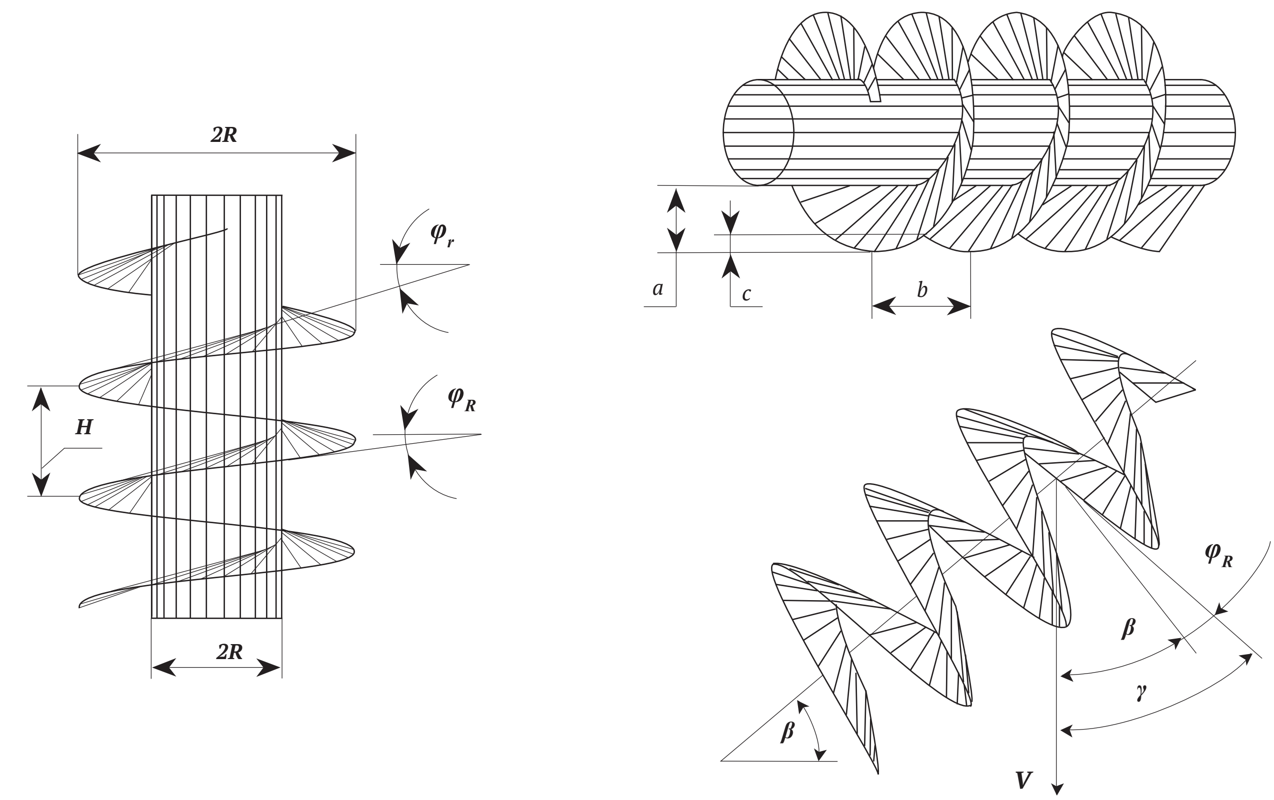
The study [4] thoroughly considers the design and calculation of disk tillage harrows. The study [5] considers the analytical expression of the model of installation of tillage disks for determining their geometric, structural, and technological parameters. In addition, other narrower studies investigated various possibilities for improving the quality of tillage with disc harrows [6-8]. The possibility of improving tillage units is considered in [9]. The studies [10; 11] investigated the motion of soil particles by the surface of disk tillage working bodies. The use of a helicoid for the calculation and manufacture of screw working elements is considered in the papers [12; 13]. The theory of design and construction of linear surfaces is covered in [14]. The study [15] justified the practical possibility of using a screw working body for tillage.

But presently, the process of tilling the soil with a screw working body remains unexplored, namely the study of the interaction of soil particles with a screw tillage body, the working surface of which is made in the form of an expanding helicoid, which are discussed in this paper.

The purpose of this study was to conduct theoretical and experimental studies of the movement of soil particles along the helical surface of the tillage working body, which is made in the form of a deployed helicoid.

MATERIALS AND METHODS

A screw working body that can be used for surface tillage is proposed in the form of a helicoid. The working turns of the surface of the screw organ are obtained by bending and then stretching the sweep ring along the axis. The surface obtained by this method differs from the screw. In a helical conoid, the rectilinear components of the helical surface are perpendicular to the axis, while in a spiral helicoid, they form an angle with the axis (Fig. 1a). The design parameters of the helical surface are the radius of the inner edge *r*, the radius of the outer (cutting) edge *R*, the pitch of the helical surface *H*, the angle of inclination of the generators. The inner and outer edges of the surface describe helical lines that have angles φR and φr. The presence of an angle of inclination of the generators contributes to the immersion of the helical surface into the soil if the axis of the helicoid is placed horizontally and at an angle β to the direction perpendicular to the direction of movement of the unit (Fig. 1b).



a) b)

Figure 1. Surface of the working body for tillage: a) structural parameters of the surface; b) projections of the screw surface

Figure 1b presents the helical surface without a shaft, and the angle of attack γ is shown at one of the points of the cutting edge:

$$\gamma=\beta+\varphi_R, \tag{1}$$

The cultivation depth $a=R-r$, the height of the ridges on the bottom of the soil *c*, the value of the distance *b* between the ridges are determined by the design parameters of the helical surface and the angle of attack γ. The consequence of the operation of such a screw body is similar to the result of the operation of a disk tillage working body. When each disk harrow needs to be installed on a separate rack with the necessary angles of attack and roll for the disk to enter the soil, then the shape of the helical working surface ensures its entry into the soil with simpler structural manufacturing.

The helical surface equations have the following form:

$$X = h\alpha - u\sin\phi\,;\quad Y = p\sin\alpha - u\cos\phi\cos\alpha\,;\quad Z = p\cos\alpha + u\cos\phi\sin\alpha, \tag{2}$$

where *α, u* are the variable parameters of the helical surface, *α* is the angle of rotation of the surface point around the axis, which is placed on the cylindrical surface of radius *p*; *u* is the value of the generator from the point on the helical line to the point on the helical surface; *h* is a screw parameter; *H* is the pitch of the surface *H=2πh*; *φ* is the angle of inclination of the generating element, while:

$$\cos\phi = \frac{p}{\sqrt{p^2 + h^2}} \tag{3}$$

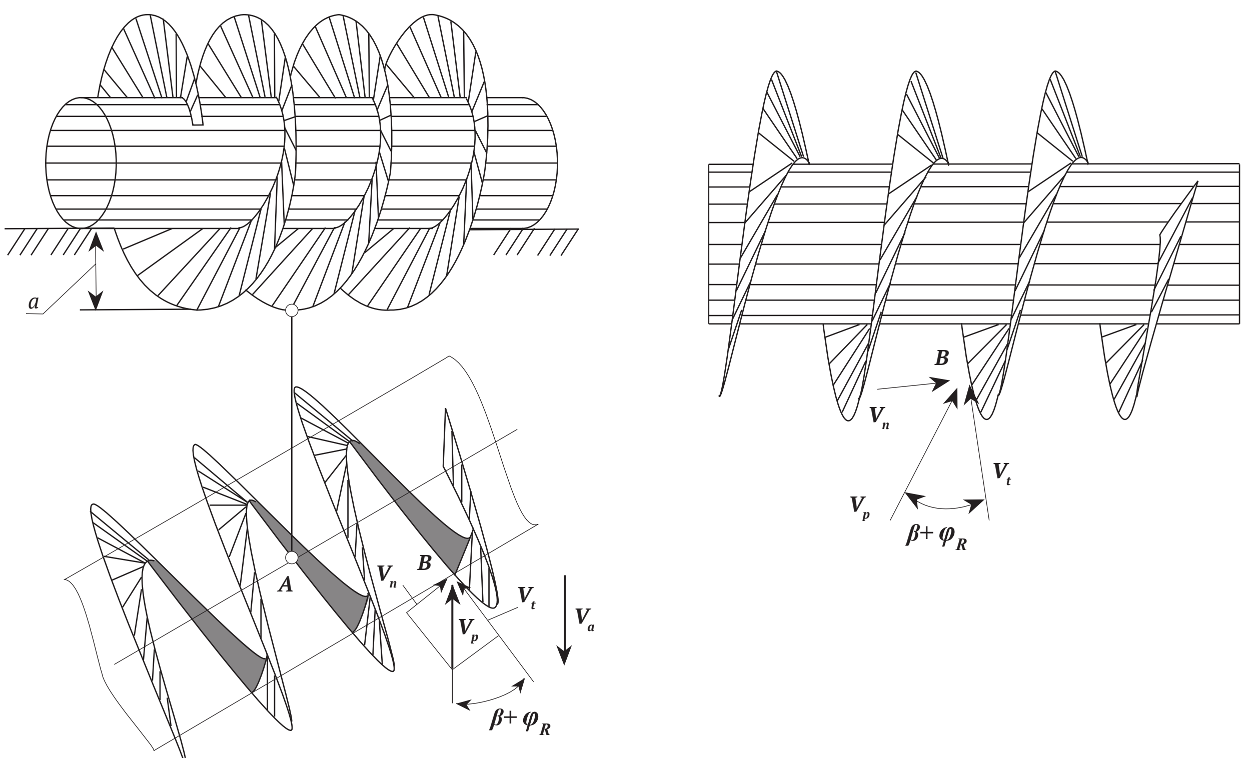
Based on this dependence, the Equation (2) is written as follows:

$$X = (A\alpha - u)\sin\phi\,;\quad Y = (A\sin\alpha - u\cos\alpha)\cos\phi\,;\quad Z = (A\cos\alpha + u\sin\alpha)\cos\phi, \tag{4}$$

where the constant $A = \sqrt{p^2 + h^2}$.

The surface of the screw working body, which is set at an angle of attack *γ* relative to the movement of the unit shall be presented as follows (Fig. 2a). Part of the helical surface at the boundaries of the processing depth a is located in the soil. The lowest point *A* of the helical surface (cutting edge) contacts the soil at the bottom of the furrow. Point *B* of the edge contacts the soil at the level of the field surface. When the working body moves with speed V_p, then also with the same speed , the soil hits the helical surface. This speed is divided into two mutually perpendicular components: $V_t=V_p\cos(\beta+\varphi_R)$ and $V_n=V_n\sin(\beta+\varphi_R)$. The value of the angle of attack $\gamma=\beta+\varphi_R$, for the helical surface is variable and depends on the depth of the location of the point of the edge of the helical surface in the soil. This is caused by a variable angle value *φR*. The limits of the change of the angle *φR* are insignificant (Fig. 1a), and therefore its value is taken as a constant value and equal at the lowest point of the edge:

$$\varphi_R = arctg\left(\frac{h}{R}\right) = arctg\left(\frac{A\sin\varphi}{R}\right) \tag{5}$$



a) **b)**

Figure 2. Diagram of determining the particle speed

For calculations, the helicoid will not be turned to the angle *β*, but it will be assumed that the soil reaches it with the value of the velocity V_p when *β*=0 (Fig. 2b). This option allows describing the helical surface without turning it by the angle *β*, by replacing the rotation of the helicoid with the rotation of the speed vector of the harrow. That is, the helicoid is turned together with the vectors (Fig. 2a) back by the angle (*–β*). This allows using the parametric equations (3) of the helicoid without complications by rotating them by the angle *β*.

With the value of the transverse speed V_n, the soil particle enters the helical surface, and its angular speed of rotation depends on the value of the speed V_t. If the cutting edge of the helical surface rolls without sliding along the bottom of the furrow in the direction of movement of the tool, then with a certain assumption (the cutting edge of the working body is a helical line), $V_t=R\omega$ is written, where *ω* is the angular speed of rotation of the helical working body. Hence, *ω* is found as follows:

$$\omega=V_p\cos\left(\frac{\beta+\varphi_R)}{R}=V_R\cos\frac{\left[\beta+\mathrm{arctg}\left(\frac{A\sin\varphi}{R)}\right]}{R} \tag{6}$$

The magnitude of the velocity V_n and the angular velocity of rotation of the helicoid ω are considered upon solving the differential equations of particle motion by numerical methods.

If the surface variables u and α are set to depend on the amount of time the particle slides over the surface of the helicoid, then the equations of the trajectory of the particle will have the following form: $u=u(t)$ and $\alpha=\alpha(t)$.

Then Equations (3) transform into the equation of lines placed on the helical surface. For the difference between the equations of the surface and the equations of the line on it, uppercase letters were used in the expressions of the helical surface ("*X*", "*Y*", "*Z*"), and lowercase letters were used in the expressions of the line ("*x*", "*y*", "*z*"). When $u=u(t)$ and $\alpha=\alpha(t)$, equations (3) will record the trajectory of the material particle on the helical surface. At $u=const$, a helical line will be described on the surface of the helicoid. The radius *R* of its location is found as follows:

$$R^2 = \sqrt{Y^2 + Z^2} = (A^2 + u)^2 \cos^2 \phi \quad (5)$$

The value *u* with a known radius *R* is found as follows:

$$u = \frac{\sqrt{R^2 - A^2 \cos^2 \phi}}{\cos \phi} = \frac{\sqrt{R^2 - (p^2 + h^2)\cos^2 \phi}}{\cos \phi} \quad (6)$$

The following design parameters of the helicoid were adopted: $R=0.25$ m, $r=0.15$ m, $a=0.1$ m, $p=0.0721$, $h=0.0416$, $\varphi=30^0$. Next, the value *u* is found: $u=0.276$. If the value *r* is substituted instead of *R*, then $u=0.152$. Thus, the independent variable changes within $u=0.152...0.276$. Angle α changes within the limits of $\alpha=0...2\pi$.

According to the differentiation method (3), the projections of the particle sliding velocity along the helical surface are obtained as follows:

$$\begin{aligned} x' &= (A\alpha' - u')\sin\phi; \\ y' &= [\alpha'(u \sin\alpha + A\cos\alpha) - u'\cos\alpha]\cos\phi; \\ z' &= [\alpha'(u\cos\alpha - A\sin\alpha) + u'\sin\alpha]\cos\phi. \end{aligned} \quad (7)$$

The value of the relative velocity is obtained from (8):

$$V_r = \sqrt{x'^2 + y'^2 + z'^2} = \sqrt{(A\alpha' - u')^2 + u^2\alpha'^2 \cos^2\phi} \quad (8)$$

When the helical surface is in contact with the soil, it rotates with an angular velocity ω according to (4), and its value depends on the speed of movement of the unit $V_a=V_p$. During time *t*, the helical surface (3) will rotate through a certain angle $\psi=\omega\cdot t$. Parametric equations of a helicoid that record its position after turning an angle $\psi=\omega\cdot t$ (9):

$$\begin{aligned} X &= (A\alpha - u)\sin\phi; \\ Y &= (A\sin\alpha - u\cos\alpha)\cos\phi\cos\psi - (A\cos\alpha + u\sin\alpha)\cos\phi\sin\psi; \\ Z &= (A\sin\alpha - u\cos\alpha)\cos\phi\sin\psi + (A\cos\alpha + u\sin\alpha)\cos\phi\cos\psi. \end{aligned} \quad (9)$$

Having substituted the value $\psi=\omega\cdot t$ into (9) and simplified, the equation of a certain line on a helical surface, which is the absolute trajectory of motion, is as follows (10):

$$\begin{aligned} x &= [A\alpha - u]\sin\phi; \\ y &= -[A\sin(\omega t - \alpha) + u\cos(\omega t - \alpha)]\cos\phi; \\ z &= [A\cos(\omega t - \alpha) - u\sin(\omega t - \alpha)]\cos\phi. \end{aligned} \quad (10)$$

The differential equation of motion of a particle along a helical surface is written in the form of $m\bar{w}=\bar{F}$, which is written in projections on the coordinate axis, and therefore a system of equations is obtained.

The value of the absolute acceleration of the particle is obtained by differentiating the expressions of the absolute trajectory (10) over time *t*. The value of the vector of the absolute velocity of a particle has the following form:

$$\begin{aligned} x' &= (A\alpha' - u')\sin\phi; \\ y' &= -[(u' + A(\omega - \alpha'))\cos(\omega t - \alpha) - u(\omega - \alpha')\sin(\omega t - \alpha)]\cos\phi; \\ z' &= -[(u' + A(\omega - \alpha'))\sin(\omega t - \alpha) + u(\omega - \alpha')\cos(\omega t - \alpha)]\cos\phi. \end{aligned} \quad (11)$$

Having differentiated the Equation (11), the vector of the total acceleration of the particle projected on the coordinate axis is obtained:

$$\begin{aligned} x'' &= (A\alpha'' - u'')\sin\phi; \\ y'' &= (A\alpha'' - u'' + u(\omega - \alpha')^2)\cos(\omega t - \alpha)\cos\phi + \\ &+ (A(\omega - \alpha')^2 + 2u'(\omega - \alpha') - u\alpha'')\sin(\omega t - \alpha)\cos\phi; \\ z'' &= (A\alpha'' - u'' + u(\omega - \alpha')^2)\sin(\omega t - \alpha)\cos\phi - \\ &- (A(\omega - \alpha')^2 + 2u'(\omega - \alpha') - u\alpha'')\cos(\omega t - \alpha)\cos\phi. \end{aligned} \quad (12)$$

Projections of the guide unit vector of the force weight will be as follows:

$$\{0;\ 0;\ -1\} \quad (13)$$

The reaction of the surface, which is directed along the normal to it, is determined by the partial derivatives of Equations (3):

$$\begin{aligned} \frac{\partial X}{\partial u} &= -\sin\phi; \frac{\partial X}{\partial \alpha} = A\sin\phi; \\ \frac{\partial Y}{\partial u} &= -\cos\phi\cos\alpha; \frac{\partial Y}{\partial \alpha} = (u\sin\alpha + A\cos\alpha)\cos\phi; \\ \frac{\partial Z}{\partial u} &= \cos\phi\sin\alpha; \frac{\partial Z}{\partial \alpha} = (u\cos\alpha - A\sin\alpha). \end{aligned} \quad (14)$$

After multiplying the vectors (14) and reducing the resulting vector to unity, the value of the projections of the normal vector to the surface will have the following form:

$$\{-\cos\phi; \sin\phi\cos\alpha; -\sin\phi\sin\alpha\}. \quad (15)$$

To match the directions of the unit vector (15) and the direction of action of other forces acting on the soil particle at the moment of time *t*, it must also be rotated by the angle $\psi=\omega\cdot$ similarly to the rotation of the surface (9):

$$\{-\cos\phi; \sin\phi\cos(\omega t-\alpha); \sin\phi\sin(\omega t-\alpha)\}. \quad (16)$$

The force of friction is directed in the direction opposite to the relative sliding speed of the particle V_r. The value of the projections of the unit vector is determined by the ratio of the terms of the velocity (7) to its value modulo (8) with its subsequent rotation through the angle $\varphi=\omega t$:

$$\left\{\begin{array}{l} \frac{(A\alpha'-u')}{\sqrt{(A\alpha'-u')^2+u^2\alpha'^2\cos^2\phi}}\sin\phi\,; \\ -\frac{u\alpha'\sin(\omega t-\alpha)+(u'-A\alpha')\cos(\omega t-\alpha)}{\sqrt{(A\alpha'-u')^2+u^2\alpha'^2\cos^2\phi}}\cos\phi\,; \\ \frac{u\alpha'\cos(\omega t-\alpha)-(u'-A\alpha')\sin(\omega t-\alpha)}{\sqrt{(A\alpha'-u')^2+u^2\alpha'^2\cos^2\phi}}\cos\phi \end{array}\right\}. \quad (17)$$

Next, the equation of motion of a particle $m\bar{w}=\bar{F}$ in projections is expanded onto the axes of the coordinate system, assuming that the friction force is directed opposite to vector (17):

$$\begin{gathered} mx'' = -N\cos\phi - fN\frac{(A\alpha'-u')}{\sqrt{(A\alpha'-u')^2+u^2\alpha'^2\cos^2\phi}}\sin\phi\,; \\ my'' = N\sin\phi\cos\alpha - fN\frac{u\alpha'\sin(\omega t-\alpha)+(u'-A\alpha')\cos(\omega t-\alpha)}{\sqrt{(A\alpha'-u')^2+u^2\alpha'^2\cos^2\phi}}\cos\phi\,; \\ mz'' = -mg + N\sin\phi\sin(\omega t-\alpha) - \\ -fN\frac{u\alpha'\cos(\omega t-\alpha)-(u'-A\alpha')\sin(\omega t-\alpha)}{\sqrt{(A\alpha'-u')^2+u^2\alpha'^2\cos^2\phi}}\cos\phi. \end{gathered} \quad (18)$$

The equation (18) is solved with respect to other derivatives of the unknown coordinates, as well as the reaction force of the surface. After performing the simplifications, the result is as follows:

$$\begin{gathered} \alpha'' = \frac{(2u'+A(\omega-\alpha'))(\omega-\alpha')\cos\phi-g\cos(wt-\alpha)}{u\cos\phi} - f\alpha'\sin\phi\frac{u(\omega-\alpha')^2\cos\phi+g\sin(wt-\alpha)}{\sqrt{(A\alpha'-u')^2+u^2\alpha'^2\cos^2\phi}}; \\ u'' = g\cos\phi\sin(wt-\alpha) - fu'\sin\phi\frac{u(\omega-\alpha')^2\cos\phi+g\sin(wt-\alpha)}{\sqrt{(A\alpha'-u')^2+u^2\alpha'^2\cos^2\phi}} + \\ +\frac{2Au'(\omega-\alpha')\cos\phi - Ag\cos(wt-\alpha)+(\omega-\alpha')^2(A^2+u^2\cos^2\phi)\cos\phi}{u\cos\phi}; \\ N = m\sin\phi\,[u(\omega-\alpha')^2\cos\phi+g\sin(wt-\alpha)]. \end{gathered} \quad (19)$$

The first two equations (19) are solved according to numerous methods in the *Simulink* environment of the *MatLab* system [16]. It was assumed that the helical surface, the design parameters of which are given earlier, moves with a speed of V_a=*9 km/h* ($V_a=V_p$=*2.5 m/s*). The angle of attack β=*40*°, the coefficient of friction *f=0.3* [17]. Having performed the calculations, it was found that: V_t=*1.62 m/s*; V_n=*1.9 m/s*, ω=*6.5* s^{-1}.

Considering at what point on the cutting edge the particle enters the helical surface, the initial integration conditions are chosen. This point is given by initial coordinates u_o and α_o. For the version under study, the value u_o=*0.276 m*. To find the value of αo, equation (3) must be solved:

$$\alpha_0 = -\text{Arccos}\frac{Az+u\sqrt{(A^2+u^2)\cos^2\phi-z^2}}{(A^2+u^2)\cos^2\phi} \quad (20)$$

The value *z=-0.15 m* corresponds to the surface of the field, and the value *z=-0.25 m* corresponds to the bottom of the furrow. After substituting these values into Equation (20), the values α_o=*-0.94* and α_o=*-1.83* are obtained.

The initial values u_o' and α_o' can be used to find the direction of entry of the soil particle on the helical surface.

It was established that the soil particle is captured by the helical surface, then moves along it, and therefore the angular velocity of sliding decreases due to friction [18].

The derivative of the coordinate u_o' denotes the linear velocity of the soil particle by the surface along the generatrix u and depends on the velocity V_n, equal to *1.9 m/s*. However, the direction of the velocity V_n differs from the direction of the generating helical surface. In addition, when the helical surface rotates, the speed of movement of the particle along the axis of rotation occurs. The soil particle enters the surface at a speed V_n and, additionally, the surface of the helicoid "runs into" the particle due to rotation. Therefore, $u_o'=V_n$=*-1.9 m/s* is taken as the initial value of the parameter u_o'. Figure 3 shows the trajectories of soil particle movement based on the results of integration of differential equations (19).

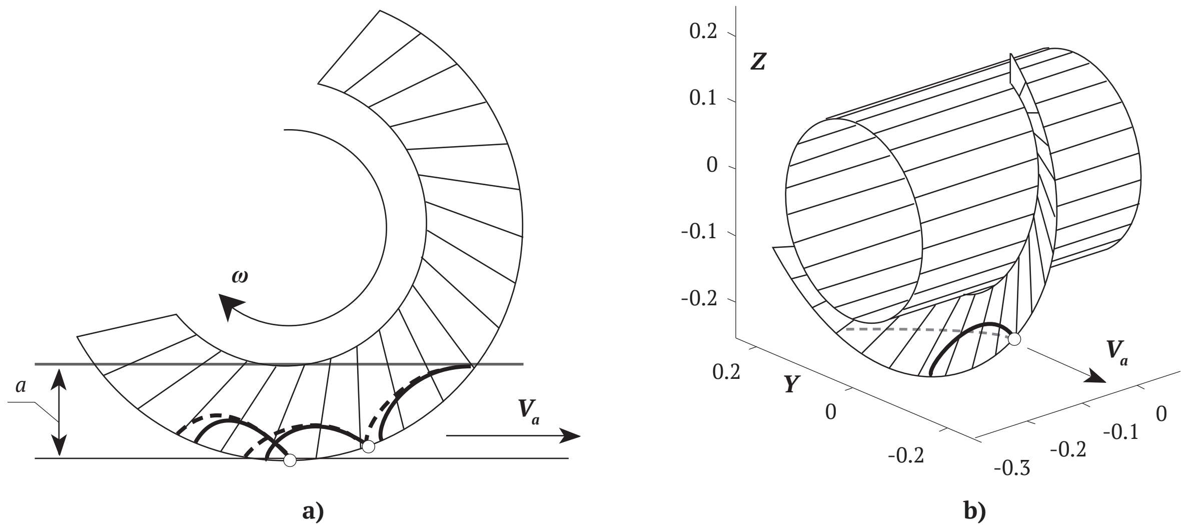


Figure 3. Relative and absolute trajectories of particle movement: a) helical surface; b) speed u_o'=-2.5 m/s

In Figure 3a, the helical surface is shown so that its axis is projected at a point. Soil particles are plotted along the spiral surface in three places: on the field surface, at an intermediate point, and at the bottom of the furrow. A solid line shows the movement of a soil particle without its interaction with other particles. However, in the real process, other soil particles act on the particle and force it to move along the helical surface. If the force of action of the particles balances the friction force, *f =0* is taken as the coefficient of friction. The dashed line shows the trajectories of soil particles at *f*=*0*. Figure 3a shows that the difference between the trajectories is insignificant.

Despite the position of the place where the soil particle enters the helical surface, the particle slides along it and approaches the shaft. If the speed of the unit is increased, this approximation increases. For example, in Figure 3b, the particle velocity was increased from *1.9 m/s* to *2.5 m/s*. Accordingly, the trajectory of the particle's movement is closer to the cylindrical shaft. As a result, the soil particles at the beginning of their movement, when sliding on the helical surface, approach the shaft. When the helical surface is immersed in the ground, the particles below press on the upper particles and the shaft gets in the way of the movement of the soil particles. Soil sticking will occur at the junction of the helical surface with the shaft. To avoid this, the shaft must be made latticed, as shown in Figure 4.

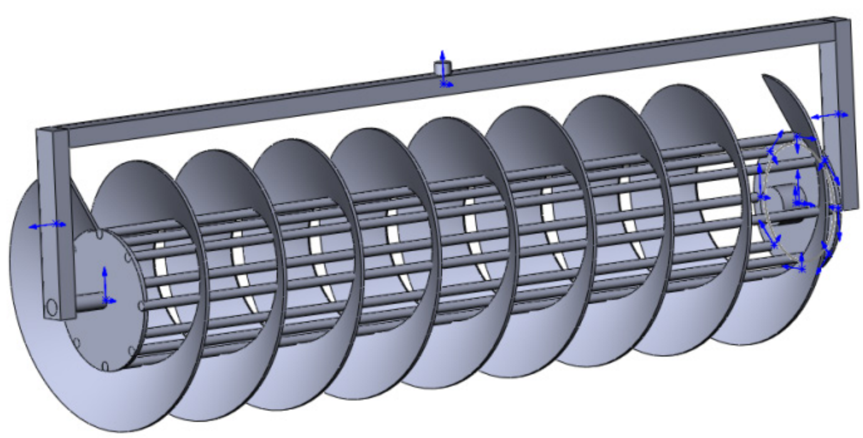
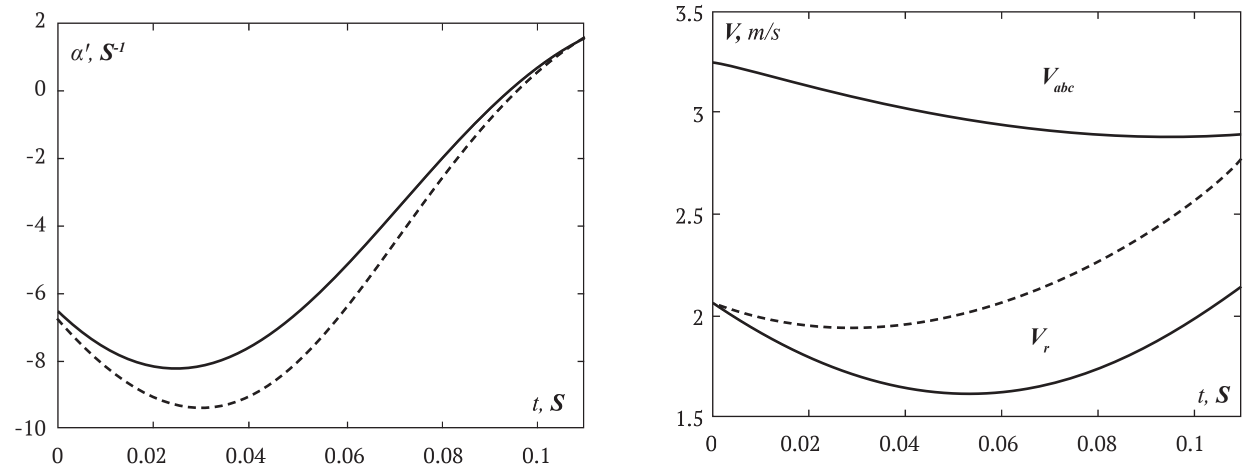


Figure 4. Grid shaft helicoid

Furthermore, the grid shaft additionally performs the function of a roller.

Figure 5 shows the kinematic characteristics of the movement of a soil particle that enters the helical surface at the field level (Fig. 3a). Solid lines show the dependence for *f*=*0.3*, and dashed lines for *f*=*0*.



a) b)

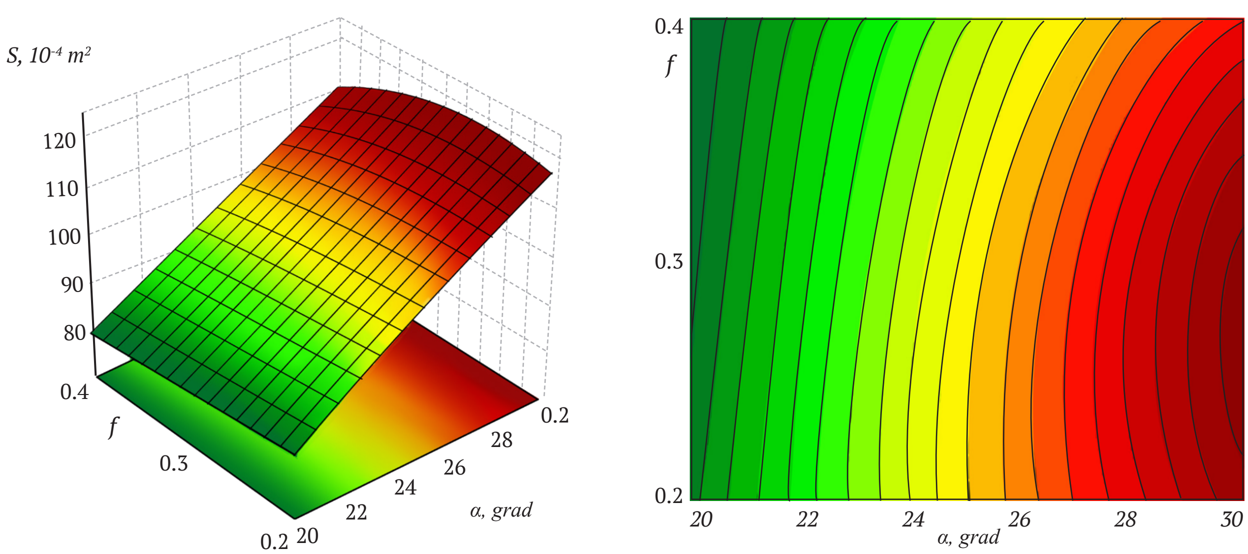
Figure 5. Graphs of changes in particle movement velocities at *f=0.3* (solid) and *f=0* (dashed) lines: a) angular velocity; b) relative and absolute speeds

An inherent feature of the movement of a soil particle is that at the beginning of the movement, the velocities decrease, and then gradually increase. The graphic dependences reflect the time interval (*t=0.11 s*) from the beginning of the particle's arrival on the helical surface until it leaves it.

RESULTS AND DISCUSSION

The analysis of helical linear surfaces (helicoids) showed that the surface of the expanding helicoid can also be used as an alternative to disk working bodies, since it can also provide surface tillage with a given depth and distance between the ridges of the tilled soil.

To determine the quality of soil loosening, a multifactorial experiment was conducted to determine the area of soil scattering by a screw working body [19]. In the conducted experimental studies on the determination of the area of dispersion of soil particles by the turn of a helical surface, the variable parameters were as follows: the angle of attack of the helical surface α=20°-30°, the angular speed of rotation of the helical surface ω=0–10 s^{-1} and soil moisture, which is determined by the coefficient of friction *f*=0.2...0.4. After processing the numerical values, a regression equation was obtained, which determines the area of dispersion of particles *S* according to the change of the above parameters:



a) b)

Figure 6. The dependence of the change in the dispersion area of particles *S* on the angle of attack of the helical surface *α* and the coefficient of soil friction *f*

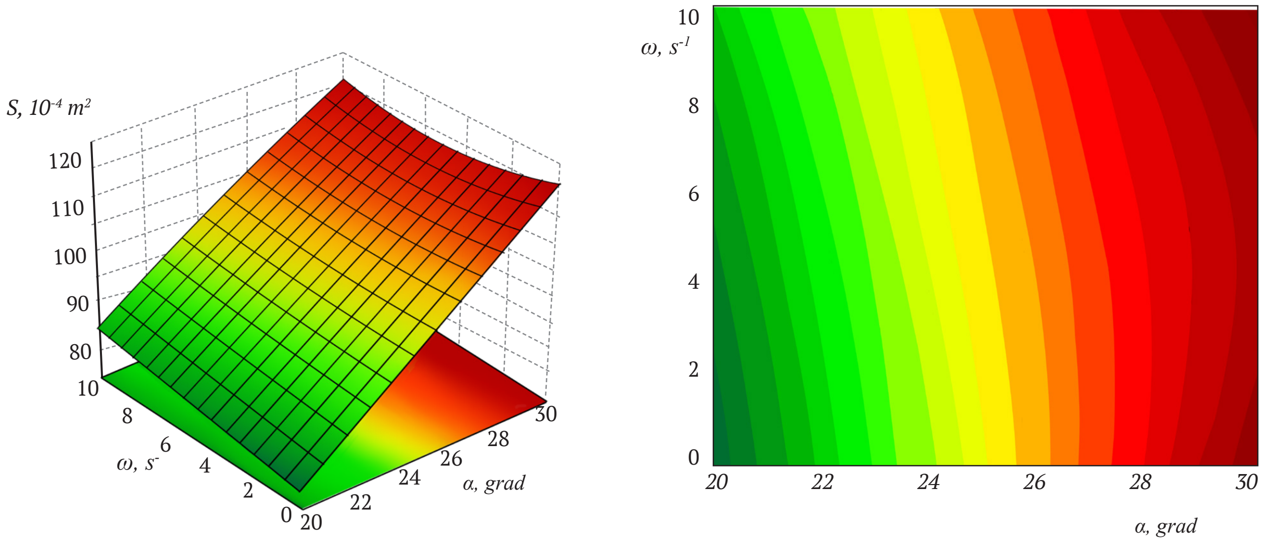


Figure 7. Dependence of the change in the particle dispersion area *S* on the angle of attack of the helical surface *α* and the angular speed of rotation of the helical surface *ω*

$$S=9.97+3.46\cdot\alpha+1.76\cdot\omega-4.64\cdot\alpha\cdot f \quad (21)$$

Having analysed the regression Equation (21), the response surfaces and their two-dimensional cross-sections were constructed, which are presented in Figures 6, 7, and 8 [20].

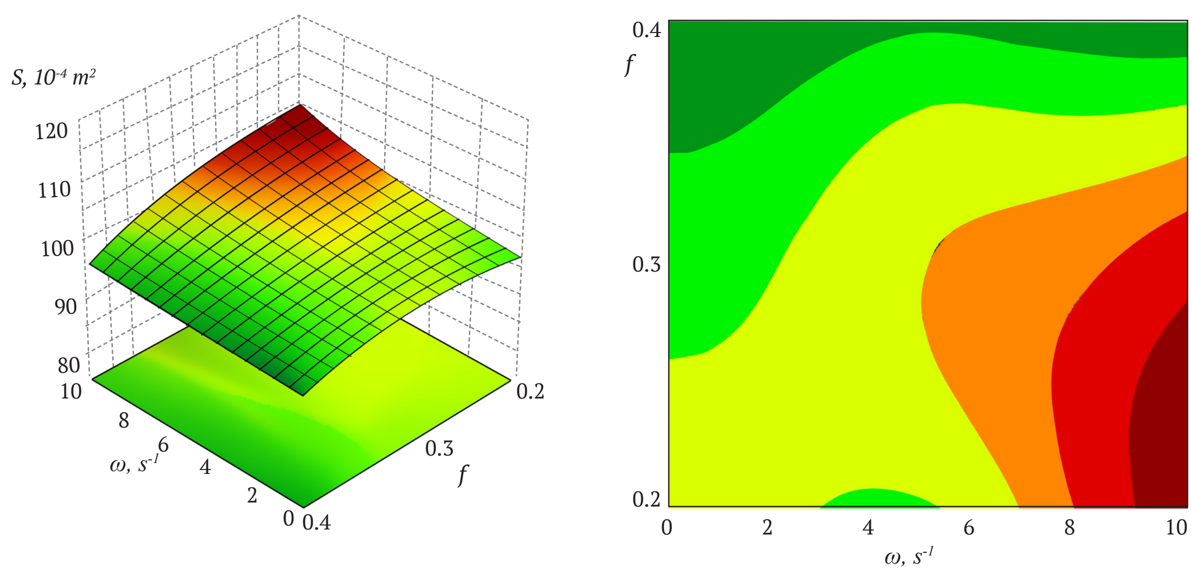


Figure 8. The dependence of the change in the particle dispersion area *S* on the angular velocity of rotation of the helical surface *ω* and the soil friction coefficient *f*

Analysis of the surfaces shows that the dispersion area of particles *S* varies within 70*10⁻⁴…130*10⁻⁴ (m²) depending on the change in the angle of attack of the helical surface *α*, the angular speed of rotation of the helical surface *ω*, and the coefficient of friction *f*. It was established that an increase in the angle of attack of the helical surface *α* leads to an increase in the dispersion area of particles *S* by 1.81 times, and an increase in the angular speed of rotation of the helical surface *ω* to an increase in *S* by 1.36 times; within the limits of the change in the coefficient of friction *f*, the change in *S* is insignificant.

Experimental studies were carried out to determine the effect of soil moisture on the quality of its cultivation, i.e., on the dispersion value of soil particle dispersion. In experimental studies of the operation of the screw working body during soil cultivation, the absolute soil moisture W_a

varied in the range from 10% to 30% at a fixed value of the angle of attack of the screw surface α=20° and the angular speed of the screw working body ω=5 (s^{-1}).

The research results are presented in the form of a graphical dependence, which is presented in Figure 9. It was established that with an increase in the absolute humidity of the soil W_a in the range from 10% to 30%, the size of the scattering area of soil particles S decreases from $98*10^{-4}$ to $86*10^{-4}$ (m^2), i.e., by 1.14 times.

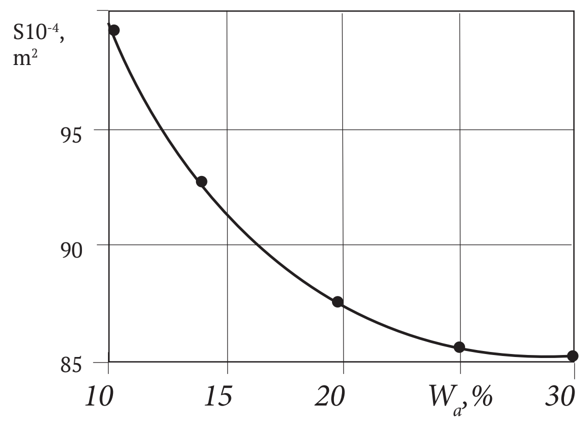


Figure 9. Dependence of the change in the dispersion area of particles S on absolute soil moisture W_a

The results of research on determining the quality of soil loosening and determining the area of soil scattering by a screw working body are similar to the results of the study [8], which presents the results of research on determining the quality of soil loosening by a disk working body [21; 22].

Thus, the screw working body works like disk tools. When the blade of the helical surface is in contact with the ground, the available angles of attack and roll are similar to the angles for disc tools. The developed tillage screw working body has an uncomplicated design and low metal consumption.

CONCLUSIONS

As a result of the conducted research, a mathematical model of the movement of soil particles through the helical working surface of the tillage body, which is an expanding helicoid, was developed.

As a result of solving differential equations by the method of numerical integration, it was found that an increase in the angle of attack of the screw working body leads to an increase in the height of the rise of particles and an increase in the area of their dispersal over the helical surface. The value of the coefficient of friction almost does not affect the trajectory of the movement of the particle.

To determine the quality of soil loosening, a multifactorial experiment was conducted to determine the area of scattering of soil particles. It was established that the quality of loosening the soil depends most on the angle of attack of the screw surface and the angular speed of rotation of the working body. The results of studies of the effect of soil moisture on the size of the particle scattering area are also given.

The perspective of this study is to establish the quality of loosening the soil and determine the area of scattering of soil particles depending on the angle of inclination of the rectilinear elements of the helical surface.

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Дослідження руху частинки ґрунту по поверхні гвинтового ґрунтообробного робочого органа

Анотація. В статті розглянуто взаємодію частинок ґрунту із гвинтовим ґрунтообробним органом, робоча поверхня якого виконана у вигляді розгортного гелікоїда і суттєво відрізняється від шнека. Крім того, для розгортної поверхні властива технологічність виготовлення робочого органу, оскільки можна розрахувати геометричні розміри плоскої заготовки, яка формується у готовий виріб простим згинанням із мінімальними пластичними деформаціями. Метою дослідження було проведення теоретичних та експериментальних досліджень руху частинок ґрунту по гвинтовій поверхні грунтообробного робочого органу, яка виконана у вигляді розгортного гелікоїда. Математичне моделювання процесів руху частинок ґрунту по гвинтовій поверхні грунтообробного робочого органу описано на базі загальних законів і принципів аналітичної та диференціальної математики, теоретичної та аналітичної механіки. Експериментальні дослідження були проведені із застосуванням методики з елементами математичної статистики, математичних методів оптимального планування багатофакторного експерименту. Аналіз результатів проведених експериментальних та теоретичних досліджень виконано із використанням прикладних комп’ютерних програм та систем. Експериментальні дослідження проводили відповідно до стандартних та самостійно розроблених методик. Результати: розроблено математичну модель руху частинки ґрунту гвинтовою поверхнею ґрунтообробного органу, та встановлено, що при збільшенні величини кута атаки гвинтового грунтообробного робочого органа величина підйому частинок ґрунту зростає і збільшується величина площі їх роззосередження гвинтовою поверхнею. Величина коефіцієнта тертя несуттєво впливає на форму траєкторії руху частинки ґрунту. Якість розпушування ґрунту найбільше залежить від кута атаки гвинтової поверхні та кутової швидкості обертання робочого органу. Матеріали статті можуть бути використані науковцями для подальших досліджень та практиками у виборі ґрунтообробних агрегатів

Ключові слова: розгортний гелікоїд, поверхневий обробіток, прямолінійна твірна, диференціальні рівняння руху, кутова швидкість, кут атаки, коефіцієнт тертя, площа розсіювання