

Operational parameters and modes of rotary working body for harrowing crops

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Abstract. A rotary working body with evenly spaced needles along perimeter is a flat disk (rotating in longitudinal-vertical plane). The technological process of interaction with soil is that when rolling rotary disk in soil layer, needle is introduced into it, crushing and shifting soil in direction of rotation. The degree of soil loosening of freely rotating needle disk on axis in longitudinal-vertical plane depends on several parameters: diameter of a disk, number and shape of needles, speed of progressive motion, soil properties. There was made an analytical research of needle working bodies in terms of influence of sizes of disk and needles on process of their interaction with soil.

1 Materials and methods of research

Technological process of multifunctional unit, which combines several operations performed in one pass through field, implies the presence of appropriate set of agricultural machines in the design. The purpose of harrowing crops is to give the desired structure to upper part of arable layer of soil, to activate its biological and chemical processes, to level surface of field, to destroy soil crust, young growth and seedlings of weeds. This unit should be equipped with working bodies for loosening soil to predetermined depth and machine for fertilizing. Rotary working bodies for soil loosening without drive (passive), need additional theoretical studies, as they have a relatively small history of their development. In this regard, it is an urgent task to study operational parameters and modes of rotary working body for harrowing crops [1].

2 Results of research

A research of optimal shape of needles of tillage needle-shaped disks.

To ensure minimum energy consumption during operation of needle-shaped disks, you need to use disks with curved needles, tangent to profile of needle in point A in moment of needle's entry into soil should coincide with velocity vector V_{abc} (Fig. 1).

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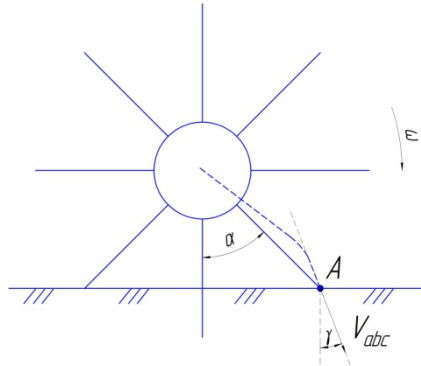


Fig. 1. Scheme of needle-shaped disk operation

When rolling needle-shaped disk without slippage, trajectory of needle movement of needle *A* will be cycloid [2]. The moment of needle entering into soil is characterized by angle α (Fig. 2). The absolute velocity of V_{abc} of needle point *A* will be equal to vector sum of progressive velocity of movement of disk V and rotational velocity U relative to axis of rotation of needle-shaped disk [3]:

$$\vec{V}_{abc} = \vec{V} + \vec{U} \tag{1}$$

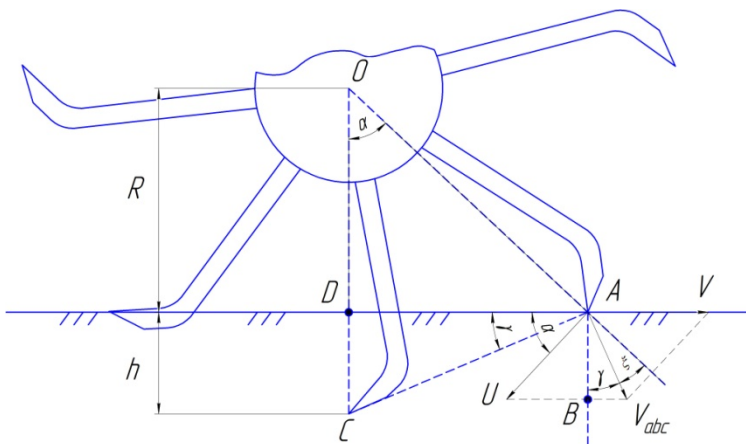


Fig. 2. Calculation scheme to evaluation of angle of needle's entry into soil

Using the cosine theorem, we find the value of absolute velocity:

$$V_{abc} = \sqrt{V^2 + U^2 + 2 \cdot V \cdot U \cdot \cos(\pi - \alpha)} \tag{2}$$

Assuming that instantaneous center of rotation is located at point *C* [4], we obtain:

$$V = U \tag{3}$$

Figure 2 shows that

$$\cos \alpha = \frac{R}{R + h} \tag{4}$$

with regard to trigonometric transformations.

$$\cos(\pi - \alpha) = -\cos \alpha = -\frac{R}{R+h} \tag{5}$$

As a result, from the expression (2) we obtain:

$$V_{abc} = \sqrt{V^2 + V^2 + 2 \cdot V \cdot V \cdot \frac{R}{R+h}} = \sqrt{2} \cdot V \cdot \sqrt{1 - \frac{R}{R+h}} \tag{6}$$

In the result we obtain from the expression (2):

From triangle $AB \bar{V}_{abc}$ segment AB is equal $AB = V_{abc} \cdot \cos \gamma$.

From triangle $AB \bar{U}$ segment AB is equal $AB = U \cdot \sin \alpha$, then

$$V_{abc} \cdot \cos \gamma = U \cdot \sin \alpha.$$

$$\cos \gamma = \frac{U}{V_{abc}} \cdot \sin \alpha \tag{7}$$

With regard to expressions (3), (4) and (6) and taking that $\sin \alpha = \sqrt{1 - \cos^2 \alpha}$, the formula (7) will be as follows:

$$\cos \gamma = \frac{U}{V_{abc}} \cdot \sin \alpha = \frac{\sqrt{1 - \left(\frac{R}{R+h}\right)^2}}{\sqrt{2} \cdot \sqrt{1 - \frac{R}{R+h}}} = \frac{\sqrt{1 - \psi^2}}{\sqrt{2} \cdot \sqrt{1 - \psi}} \tag{8}$$

where $\psi = \frac{R}{R+h}$

This dependence can be obtained in another way. Assuming that instantaneous center of rotation is at point C [4], we find absolute angular velocity of needle-shaped disk:

$$\omega_{abc} = R + \frac{V}{h} \tag{9}$$

Absolute velocity of needle A's point is equal, respectively:

$$V_{abc} = \omega_{abc} \cdot AC, \tag{10}$$

From right triangle AOD we find:

$$AD = \sqrt{(R+h)^2 - R^2} \tag{11}$$

In consideration of rectangular triangle ADC, we obtain:

$$AC = \sqrt{(CD)^2 + (AD)^2} = \sqrt{h^2 + (R+h)^2 - R^2} \tag{12}$$

$$\cos \gamma = \frac{AD}{AC} = \frac{\sqrt{(R+h)^2 - R^2}}{\sqrt{h^2 + (R+h)^2 - R^2}} = \frac{\sqrt{1 - \left(\frac{R}{R+h}\right)^2}}{\sqrt{2} \cdot \sqrt{1 - \frac{R}{R+h}}} = \frac{\sqrt{1 - \psi^2}}{\sqrt{2} \cdot \sqrt{1 - \psi}} \tag{13}$$

Angle of entry of needle γ into soil depends on radius of disk and depth of treatment does not depend on speed of needle-shaped disk.

To build the needle profile at point A, it is necessary to draw tangent at the angle ξ (Fig. 3).

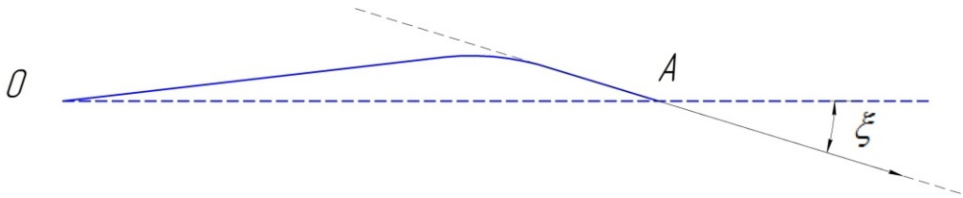


Fig. 3. Scheme of needle's profile design.

$$\xi = \alpha - \gamma = \arccos(\psi) - \arccos\left(\frac{\sqrt{1-\psi^2}}{\sqrt{2} \cdot \sqrt{1-\psi}}\right) \quad (14)$$

where $\psi = \frac{R}{R+h}$

Further design of needle profile is performed in form of logarithmic spiral in accordance with known technique [5].

Analyzing the graphical interpretation of dependence (14) (Fig. 4), it can be concluded that with decrease in depth of treatment (increase in the value of ψ), the angle ξ decreases, and at $h = 0$ the angle $\xi = 0$ (i.e., needles approach rectilinear form). With increasing the depth of treatment (decrease in ψ) the angle ξ increases.

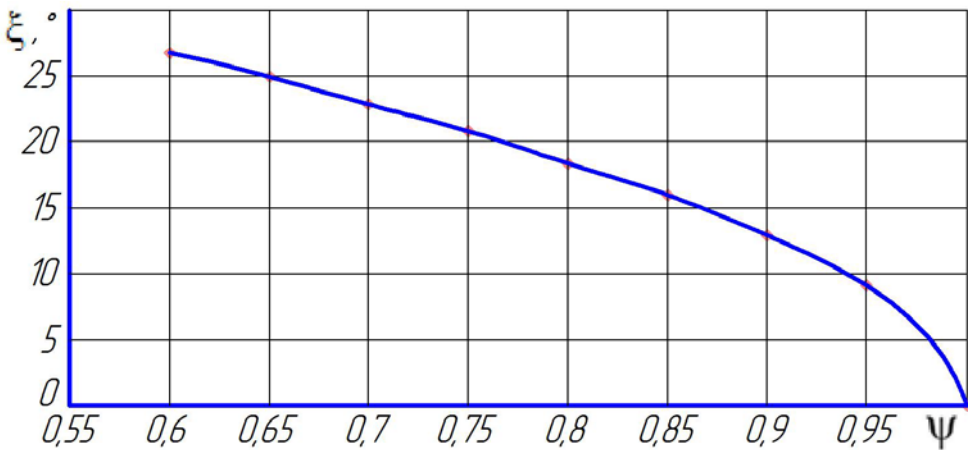


Fig. 4. Dependence of the angle ξ from ψ .

The calculation performed for standard needle-shaped disk with diameter of 550 mm shows that with increase in depth of treatment from 4 to 6 cm, the angle ξ increases from 11° to 13.5° (Fig. 5).

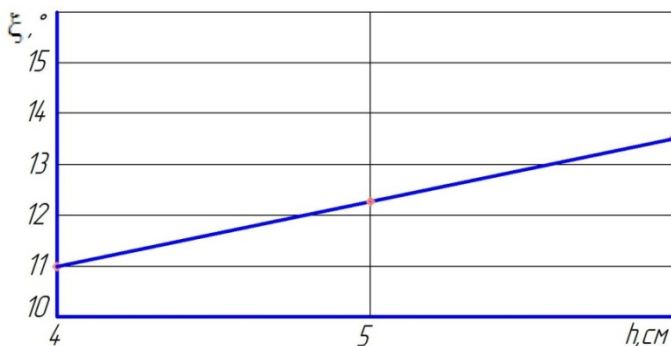


Fig. 5. Dependence of angle ξ on depth of treatment h for needle-shaped disk $\varnothing 550$ mm.

3 Conclusions

There were obtained theoretical dependences on justification of optimal angle of needle entry into soil on the basis of kinematic analysis of needle-shaped disk movement. With increase of treatment depth of 4 to 6 cm, the angle ξ increases from 11° to 13.5° .

References

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