On the problem of interaction of the tillage working body with the soil

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Abstract. The article is devoted to the main soil treatment with disk working bodies. The article has a research character, which is expressed in the fact that the theoretical analysis of the interaction with the soil, as well as excerpts from the works of leading scientists on the subject under study, which provide optimal soil treatment and their shortcomings and ways to solve these problems are indicated. Equations obtained allow us to determine the movement of a particle on the surface of the disk's blade at the moment of its operation. The disk shape is theoretically justified. In conclusion, the main results achieved so far are presented.

Mechanical impact of working bodies on the soil is accompanied by resistance, the value of which depends on many factors. Many researchers having determined the relationship between the physical and mechanical properties of the soil and its quality processing parameters give various forms of calculations using various formulas. They are aimed at determining the traction resistance when plowing with different tillage units. Also, leading scientists identify a number of factors that affect the quality of plowing and the energy process of tillage itself:

- physical-mechanical (hardness, stickiness, humidity, signal ratio, etc.)
- technical (type of tillage unit design, condition, adjustment and etc.)
- technological (way of treatment, depth of tillage, velocity of treatment and etc.)

Also it is generally accepted that the traction resistance of a soil-processing unit consists of useful and harmful resistances of its working organs. The value of useful resistances depends on the size and geometric shapes of the plowshares and plow housings, the depth of processing, as well as on the friction properties of the materials used in the manufacture of working bodies. Harmful resistance depends on the amount of friction between the working bodies on the soil, plant residues, the degree of the wear of blades of the working bodies, the load on the support wheels of the engine and the trolley of the working bodies, as well as their rolling resistance [1].

Flat disks both with passive and active drive are used as the main and additional working bodies in disk huskers, plows, tuber harvesters and other machines.

If the passive disk moves on the surface of the soil without immersion depth, then we can say that $\lambda = 1$. In this case, the disk rolls without sliding or skidding, the instantaneous center of speed is located at the point of contact of the disk with the soil surface. At $\lambda > 1$, the disk moves with skidding and the instantaneous center of speeds is located on a straight

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line connecting the center of the disk with the point of contact of its blade with the soil surface. As λ increases, the instantaneous center of velocity approaches the center of the disk and coincides with it, λ = ∞. If the disk moves slipping, then λ < 1 and the instantaneous center of velocities is below the point of contact of the disk blade with the soil surface, and at λ = 0-outside the disk [2].

In the process of immersion of the disk into the soil, its resistance increases. This suggests that the kinematic parameter λ will decrease with increasing depth. However, this is not true. The results of the experiment show that the immersion of the freely rotating disk λ increases. This hidden pattern is determined by the friction forces acting on the blade and the side surfaces of the disk [3].

If the disk to be forced to rotate without taking this phenomenon, the rotation mode may be such that the disk will tend to rotate the shaft itself, and overloads will occur as a result of the circulation of intermediate power in the transmission.

Assuming that the side surface of the disk interacting with particles of the soil does not move them relative to the monolith, the equation of particle motion relative to the disk can be written as:

$$x = (R\cos\alpha_i - v_n t) \cdot \cos\omega t + R\sin\omega t$$

$$z = (R\cos\alpha_i - v_n t) \cdot \sin\omega t - R\sin\alpha\cos\omega t$$

where λ_i = arc sin $[(R-h_i)/R]$ – a corner characterized by the location of the particle in depth h_i.

Relative velocity of the particle

$$\upsilon_r = \upsilon_n + \sqrt{1 + \lambda^2 - 2\lambda(\sin\alpha_i + \omega t\cos\alpha_i) + \omega^2 t^2}; \tag{1}$$

Relative acceleration

$$\omega_r = \frac{d_{or}}{dt} = \frac{\omega(\omega t - \lambda\cos\alpha_i)}{\upsilon_n\sqrt{1 + \lambda^2 - 2\lambda(\sin\alpha + \omega t\cos\alpha_i) + \omega^2 t^2}}. \tag{2}$$

Figure 1,a and 1,v show that the shape of the relative trajectory of the particle changes depending on λ. The friction force F_t acting on the disk from the particle coincides in the direction with the vector of its relative velocity [4, 5].
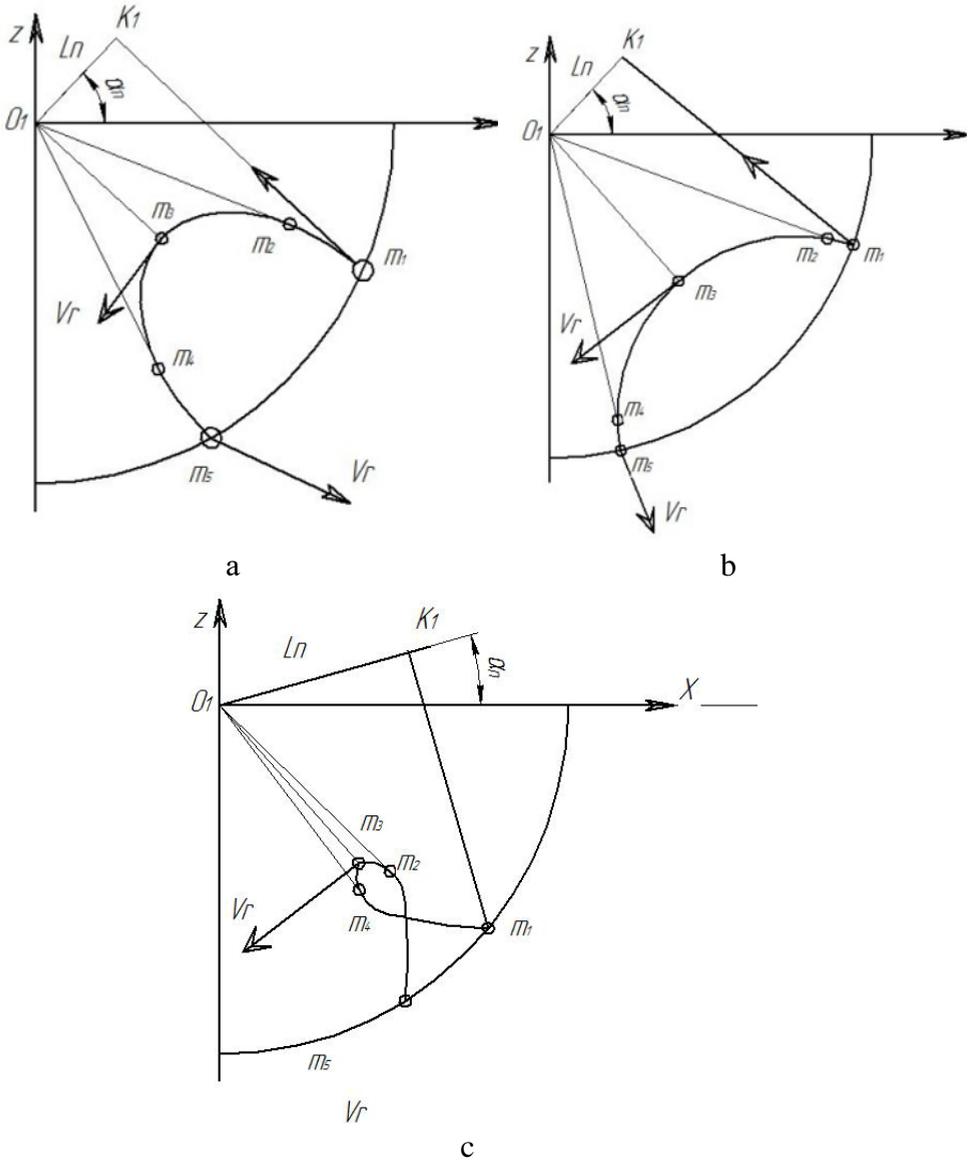
a

b

c

Fig. 1. Relative trajectory of the particle along the side flat disk surfaces at different values

The equation of the tangent to the relative path

$$\frac{z_n - z}{z} = \frac{x_r - x}{x}. \quad \text{or} \quad A_{xn} - B_{zn} - C = 0,$$

where

$$A = (\omega R \sin \alpha_i - \upsilon_n)\sin \omega t + \omega(R\cos\alpha_i - \upsilon_n \, \text{t})\cos\omega t; \qquad (3)$$

$$B = (\omega R \sin \alpha_i - \upsilon_n)\cos \omega t - \omega(R\cos\alpha_i - \upsilon_n \, \text{t})\sin\omega t; \qquad (4)$$

$$C = R(\omega R \sin \alpha_i - \upsilon_n)\sin \alpha_i + \omega(R\cos\alpha_i - \upsilon_n \, \text{t})^2. \qquad (5)$$

The moment of friction of the particle relative to the axis of rotation of the disk is characterized by a polar distance [6].

$$l_n = |C| t \sqrt{A^2 + B^2}.$$

Substituting the necessary data into this expression, and converting it, we get

$$l_n = \frac{\omega(R\cos\alpha_i - \upsilon_n t)^2 + R(\omega R \sin\alpha_i - \upsilon_n)\sin\alpha_i}{\sqrt{(\omega R \sin\alpha_i - \upsilon_n)^2 + \omega^2(R\cos\alpha_i - \upsilon_n t)^2}} \tag{6}$$

Assuming $t = 0$, we get the polar distance $l_п$ for the friction force acting on the blade of the disk

$$l_л = R(\lambda - \sin\alpha_i \sqrt{1 + \lambda^2 - 2\lambda\sin\alpha_i} \tag{7}$$

Figure 1 shows that on the sections of the curve $m_1 m_2$ and $m_3 m_5$, the direction of the velocity υ_r, and, consequently, the friction forces are opposite to the direction of rotation of the disk, and on the section $m_1 m_2 m_3$ they coincide with the direction of its rotation [7].

Consequently, there are zones on the side surface of the disk in which the direction of friction forces is opposite to the direction of rotation of the disk around its axis and zones where they coincide. The same zones exist on the blade. These zones are separated by particles whose $l_п = 0$ and $l_л = 0$. $l_л = 0$, $ll = 0$, we find the depth:

$$h_i = R(1 - \lambda)$$

When $\lambda = 1$, we get $h_i = 0$, that is, the boundary is the lowest point of the disk blade. There is no such boundary for all $\lambda > 1$ on the blade, and the soil reactions create a moment directed against the rotation of the disk relative to its axis. At $\lambda = 0$, the reaction of the soil to the blade in the depth range $h_i = 0 - R$ creates a moment that coincides with the direction of rotation of the disk relative to its axis.

The points of the side surface where $l_п = 0$ (points m_2 and m_4 see Figure 1) are on the borders of these zones [8].

To get the equation of the boundary separating the zones, substitute the formula $t_п = 0$.

$$\omega(R\cos\alpha_i - \upsilon_n t)^2 + R(\omega R\sin\alpha_i - \upsilon_n)\sin\alpha_i = 0 \tag{8}$$

If in this equation we take the value R of the variable, start counting the time of the movement of the particle not from the moment of touching the blade, but from the moment of hitting the point m_2 (figure 1), i.e., take the replacement $R = R_i$ and $t = t_1 = 0$, and solve it with respect to R_i, we get

$$Om_2 = R_i = \frac{R}{\lambda}\sin\alpha_i = p\sin\alpha_i. \tag{9}$$

Where p is the radius of the fictitious circle equal to the distance of the OP from the center of the disk to the instantaneous center of velocities
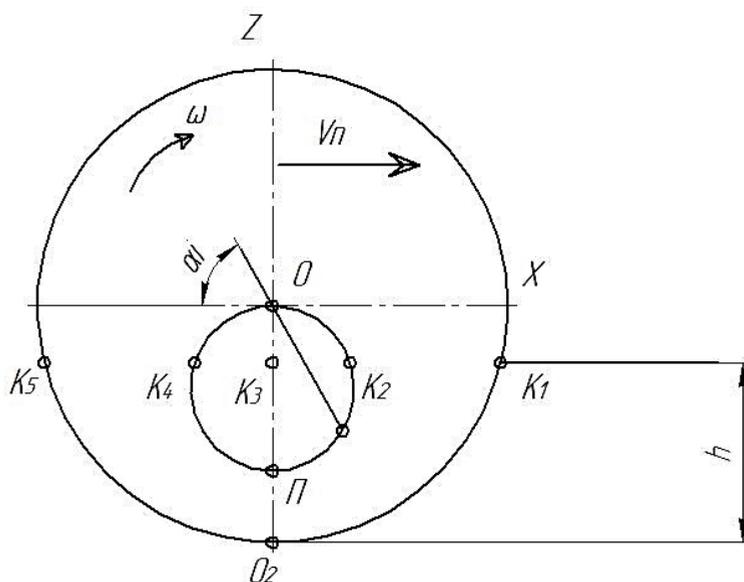
Fig. 2. Diagram of zones of the lateral surface of the disk

Expression (9) is the polar equation of the circle. Moreover, the pole of the system corresponding to this equation coincides with the center of the disk, and the polar axis – with the *x* axis [9] Figure 2-.

If the disk is immersed into the common soil or into the soil with plant remains at a depth of *h*, then inside the zone $K_2m_2\,\Pi K_4$ the forces of friction influence it inside the zone $K_2m_2\,\Pi K_4$, the moment direction which relatively to the point *O* coincides with the direction of rotation of the disk around its axis, and in the area $K_1O_2K_5K_4\Pi K_2$ – opposite to the direction of rotation of the disk. The part of the $K_3\Pi K_4$ area divides these zones [10].

Thus, if the passive disk moves on the surface of the soil without immersion, then we can say that $\lambda = 1$. In this case, the disk rolls without sliding or skidding, the instantaneous center of speed is located at the point of contact of the disk with the soil surface. At $\lambda > 1$, the disk moves with skidding and the instantaneous center of speeds is located on a straight line connecting the center of the disk with the point of contact of its blade with the soil surface. As λ increases, the instantaneous center of velocity approaches the center of the disk and coincides with it, $\lambda = \infty$. If the disk moves with a slip, then $\lambda < 1$ and the instantaneous center of velocities is below the point of contact of the disk blade with the surface of the soil, and at $\lambda = 0$ – outside the disk.

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