IJDIAS International Journal of Discoveries and Innovations in Applied Sciences

| e-ISSN: 2792-3983 | www.openaccessjournals.eu | Volume: 1 Issue: 5

Study of the Movement of Soil Particles along the Working Surface of a Spherical Disc

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ABSTRACT:

Spherical discs are widely used as working parts of disc plows, stubble plows and harrows. However, their interaction with soil is still insufficiently studied [1; 6; 7; 8]. In the process of work, soil particles rise along the working surface of the disk, move along it and are thrown to the side.

Consider the movement of soil particles along the working surface of the disk. To do this, replace the spherical disc with a conical disc with the same angle « » at the top.

Introduction

Soil particles on the surface of the disc perform a complex movement: a portable rotational movement together with the disc and a relative movement along the disc. As a result, the particles arriving at the surface of the disk will begin to move along a certain trajectory «S_a» in absolute and along some trajectory «S_r» in relative motion (Fig. 1). The absolute speed of movement of soil particles on the surface of the disk is the geometric sum of the transport speed V_e and relative V_r [2;3;5].

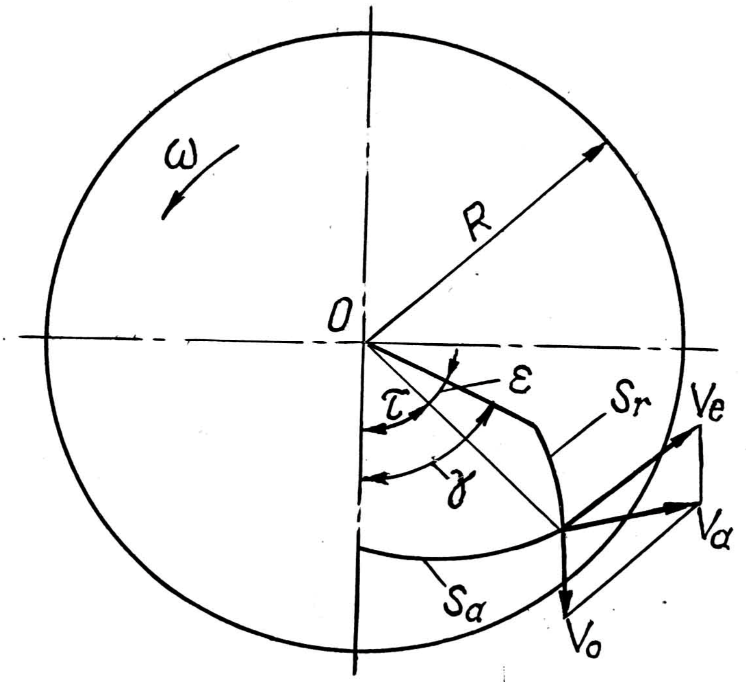

Fig. 1. Scheme of particle motion on the disk surface

Main part

The position of soil particles on the disk surface at any time is determined by two parameters: the angular displacement of soil particles in absolute motion «τ» and radius vector «r». We will take them as generalized coordinates.
The following forces act on a soil particle located at some point A on the disk surface (Fig. 2):

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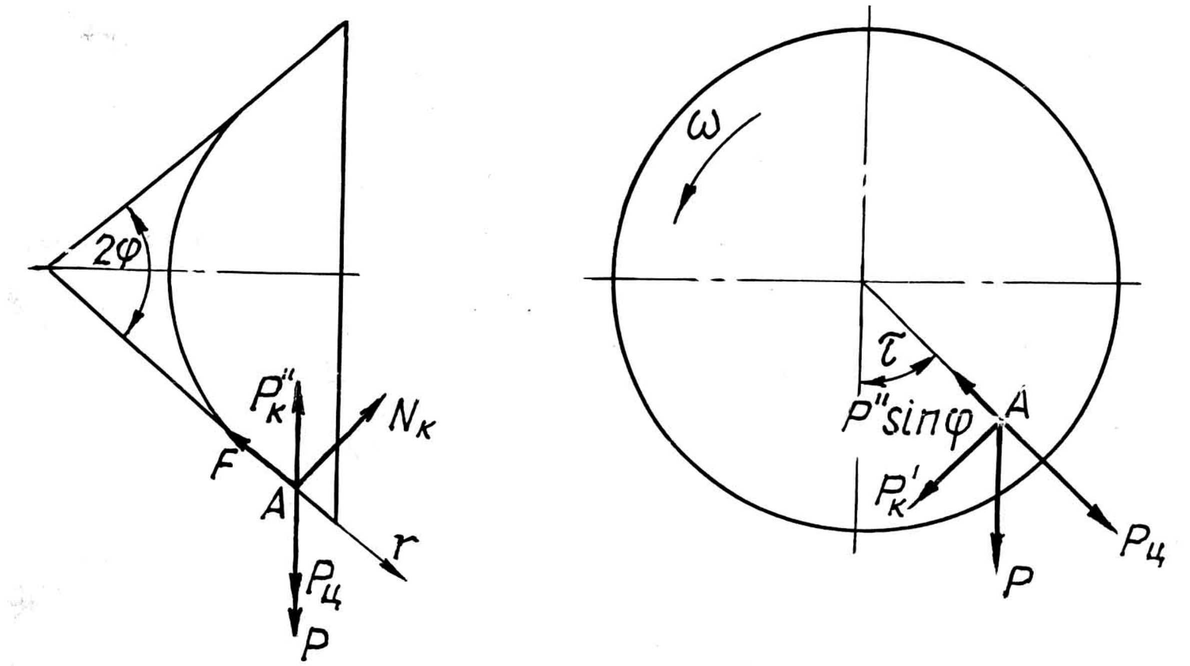

Rice. 2. Scheme of forces acting on a soil particle

P=mg – gravity,

$P_ц = m(\dot{\tau})^2 r \sin\varphi$ - centrifugal force of inertia caused by transferable rotary motion at angular velocity «ω»;

$P_k' = 2m\dot{r}\dot{\tau}\sin\varphi$ - Coriolis force resulting from the rotational motion of a disk at angular velocity «ω» and relative motion along the radius vector;

$P_k'' = 2mr\dot{\varepsilon}\omega$ - the Coriolis force from the r component of the total relative velocity;

$F = fN_k$ – friction force;

$N_k = mg\cos\tau\cos\varphi + P_ц\cos\varphi - P_k''\cos\varphi$ - normal disc response or

$$N_k = mg\cos\tau\cos\varphi + mr(\dot{\tau})^2\sin\varphi\cos\varphi - 2mr\dot{\varepsilon}\omega\cos\varphi, \qquad (1)$$

where ε - angular displacement of a particle in relative motion;
f – coefficient of friction of soil against disc material.
Using the d'Alembert principle, we compose the equation for the relative motion of a particle along the surface of the disk:

$$m\ddot{r} = mg\cos\tau\cos\varphi + mr(\dot{\tau})^2\sin^2\varphi - 2mr\dot{\varepsilon}\omega\sin\varphi - fN_k\cos\psi, \qquad (2)$$

$$m\ddot{\varepsilon} = mg\sin\tau - 2m\dot{r}\dot{\tau}\sin\varphi - fN_k\sin\psi, \qquad (3)$$

where $\cos\psi = \dot{r} / \sqrt{(\dot{r})^2 + (\dot{r})^2}$ и $\sin\psi = r\dot{\varepsilon} / \sqrt{(\dot{r})^2 + (r\dot{\varepsilon})^2}$.

Taking into account that $\tau = \gamma - \varepsilon$ (где $\gamma = \omega t$ - angular displacement of the disk), we have

$\dot{\tau} = \omega - \dot{\varepsilon}$ и $\ddot{\tau} = -\ddot{\varepsilon}$.

Taking this into account, and expression (1), the differential equation of the relative motion of the particle will have the form

$$\ddot{r} = g\cos(\gamma - \varepsilon)\sin\varphi + r(\omega - \dot{\varepsilon})^2\sin^2\varphi - 2r\dot{\varepsilon}\omega\sin\varphi -$$

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$$-f\left[g\cos(\gamma-\varepsilon)\cos\varphi+r(\omega-\dot\varepsilon)^2\sin\varphi\cos\varphi-2r\dot\varepsilon\omega\cos\varphi\right]\cdot$$

$$\cdot\ \dot r\Big/\sqrt{(\dot r)^2+(r\dot\varepsilon)^2} \qquad (4)$$

$$r\ddot\varepsilon=g\sin(\gamma-\varepsilon)-2\dot r(\omega-\dot\varepsilon)\sin\varphi-f\left[g\cos(\gamma-\varepsilon)\cos\varphi+r(\omega-\dot\varepsilon)^2\sin\varphi\cos\varphi-2r\dot\varepsilon\omega\cos\varphi\right]\cdot$$

$$.\ r\dot\varepsilon\Big/\sqrt{(\dot r)^2+(r\dot\varepsilon)^2} \qquad (5)$$

Equations (4) and (5) are a generalized system of differential equations for the relative displacement of particles over a rough disk surface. It is a system of nonlinear nonhomogeneous differential equations of the second order, the solution of which in ordinary functions is not possible. The system of equations (4) and (5) can be solved by numerical methods, for example, by the Runge-Kutta method [4].

Rotation of the disc occurs due to its rolling on the soil. Therefore, soil particles located on the surface of the disk are propped up by the soil flow and practically do not move tangentially to the circular arc of the disk of the trajectory. Because of this, we assume that soil particles in relative motion move only in the radial direction, i.e.

$\tau=\gamma$ и $\dot\tau=\omega$. In this case, the equation of the relative motion of a soil particle along the disk will have the following form:

$$\ddot r=g\cos\omega t\sin\varphi+r\omega^2\sin^2\varphi-f\left[g\cos\omega t\cos\varphi+r\omega^2\sin\varphi\cos\varphi\right] \qquad (6)$$

or

$$\ddot r-r\left[\omega^2\sin\varphi(\sin\varphi-f\cos\varphi)\right]=g\cos\omega t(\sin\varphi-f\cos\varphi). \qquad (7)$$

Introducing the notation

$$\omega^2\sin\varphi(\sin\varphi-f\cos\varphi)=k^2$$

and

$$g(\sin\varphi-f\cos\varphi)=A,$$

we have

$$\ddot r-k^2r=A\cos\omega t. \qquad (8)$$

Solving this equation and taking into account that $f=tg\varphi_T=\sin\varphi_T\big/\cos\varphi_T$ and

$\omega=V_m\cos\alpha/R$ (1) (where φ_T - the angle of friction of the soil against the disc material, V_m- forward speed of the disc, R – radius of the disk) we get

$$r=0{,}5\left[r_0+\frac{R^2g\sin(\varphi-\varphi_T)}{(V_M\cos\alpha)^2(\cos\varphi_T+\sin(\varphi-\varphi_T))}\right]*$$

$$*\left[e^{\frac{V_M\cos\alpha}{R}\sqrt{\frac{\sin\varphi\sin(\varphi-\varphi_T)}{\cos\varphi_T}}t}+e^{-\frac{V_M\cos\alpha}{R}\sqrt{\frac{\sin\varphi\sin(\varphi-\varphi_T)}{\cos\varphi_T}}t}\right]-$$

$$-\frac{R^2g\sin(\varphi-\varphi_T)}{(V_M\cos\alpha)^2(\cos\varphi_T+\sin\varphi\sin(\varphi-\varphi_T))}\cos\left(\frac{V_M\cos\alpha}{R}\right)t \qquad (9)$$

Using equation (9), you can determine the relative speed of movement of soil particles along the disk, the moment, angle and speed of their descent from the disk.

The relative speed is determined from the equation

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$$V_r = \dot{r} = \frac{0,5V_M \cos\alpha}{R}\left[r_0 + \frac{R^2 g \sin(\varphi-\varphi_T)}{(V_M \cos\alpha)^2(\cos\varphi_T + \sin\varphi \sin(\varphi-\varphi_T))}\right]*$$

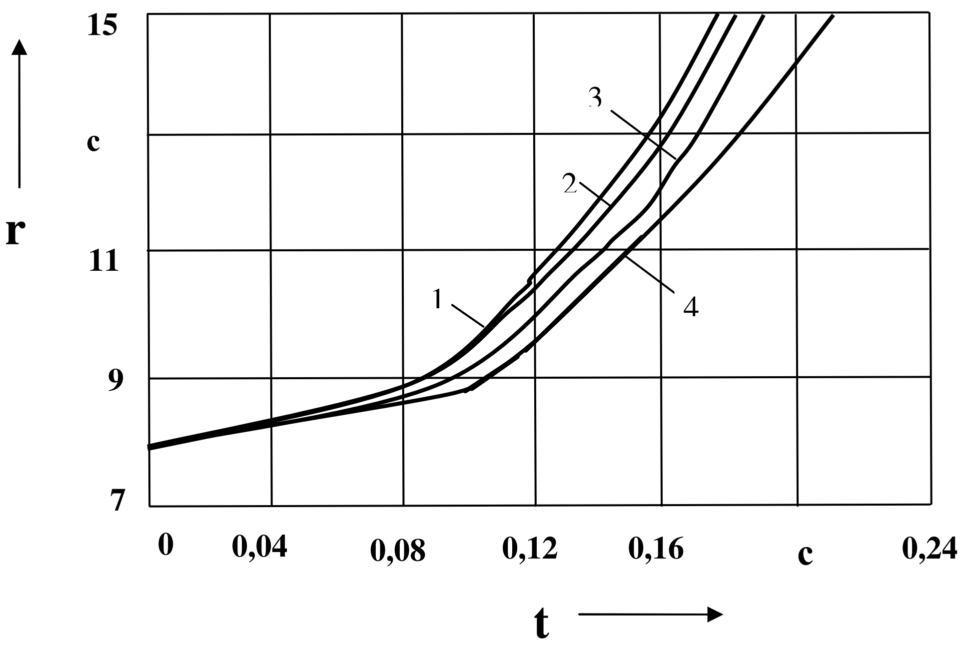
$$*\left[e^{\frac{V_M \cos\alpha}{R}\sqrt{\frac{\sin\varphi\sin(\varphi-\varphi_T)}{\cos\varphi_T}}t} - e^{-\frac{V_M \cos\alpha}{R}\sqrt{\frac{\sin\varphi\sin(\varphi-\varphi_T)}{\cos\varphi_T}}t}\right]+$$

$$+\frac{Rg\sin(\varphi-\varphi_T)}{V_M\cos\alpha(\cos\varphi_T+\sin\varphi\sin(\varphi-\varphi_T))}\sin\left(\frac{V_M\cos\alpha}{R}\right)t. \quad (10)$$

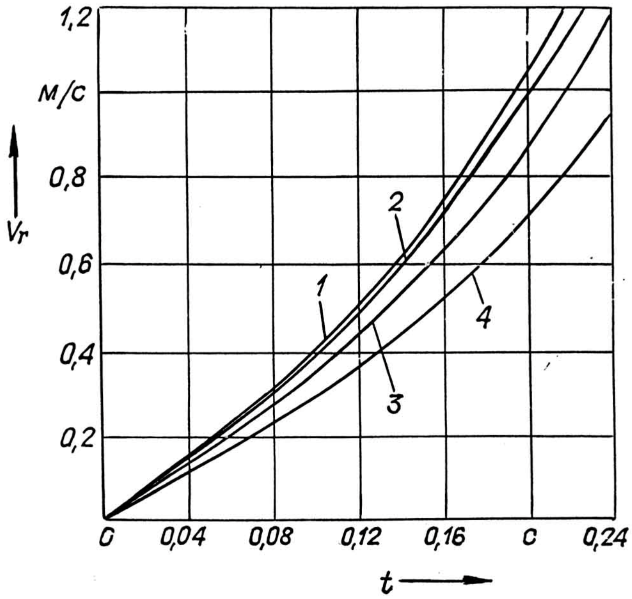
Equations (9) and (10) establish the relationship between all the parameters that determine the movement of particles along the disk working body.

From the analysis of (9) and (10) it follows that for the given operating conditions, the path and speed of movement of soil particles in relative motion mainly depends on the speed of movement of the unit and the angle of attack of the disk.

Using formulas (9) and (10) in Figs. 3 and 4, graphs of changes in the relative motion and relative velocity of soil particles are plotted for various values α and the following data $\varphi = 60$, r=7,5 см и V_M=1,5.



Rice. 3. The nature of the change in the relative motion of a soil particle along the disk at different values of the angle α : 1…4 – respectively at α =0^0, 10^0, 20^0 and 30^0



Rice. 4. The nature of the change in the relative speed of movement of a soil particle at different values of the angle α : 1…4 – respectively at α =0^0, 10^0, 20^0 and 30^0.

It follows from the analysis of the presented graphs that with an increase in the angle of attack of the disk, the movement of soil particles along the disk slows down.

From equation (9) after setting in it the final value of the radius of the vector $r = R/\sin\varphi$ we find the time during which the particle is on the disk.

During this period of time, the disc will rotate through an angle

$$\gamma_1 = \omega t_{1.}$$

Substituting t_1 in (10) we find the relative velocity of the particle at the moment of its descent from the disk.

Conclusion

Thus, the developed mathematical models that characterize the movement of soil particles along the working surface of the disc cultivator made it possible to establish that the intensity of its impact on the soil depends on the angle of attack of the disc, its diameter, and the speed of the unit.

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