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# Analytical study of the soil sifting process through the surface of the potato heap cleaner

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**The purpose.** Justification of rational structural and kinematic parameters of the spiral cleaner of new construction, developed to improve the quality of potato tubers cleaning. **Methods.** Used methods of theoretical mechanics, higher mathematics and the theory of agricultural machinery. Conducted numerical calculations for the developed program in the system «Matlab». **Results.** Cleaning potato tubers from soil and plant impurities is an urgent problem in the technological process of potato production. We have developed a new spiral potato peeler, which is able to actively clean itself from sticky soil and effectively capture and remove lumps of soil of various sizes and shapes, as well as plant impurities. For substantiation of rational constructive and kinematic parameters of the cleaner the corresponding theoretical researches are carried out. The differential equation of reduction of soil lump mass at any moment of time taking into account structural and kinematic parameters of the cleaner is obtained. The solution of the differential equation on the PC has allowed to define the rational constructive and kinematic parameters of the spiral cleaner, providing improvement of quality of tuber cleaning. **Conclusions.** Calculations carried out on the PC showed that with the increase in the angular velocity of rotation of the spiral, the decrease of the soil lump mass increases also at the change of the angular velocity in the range from 10 to 30 rad·s – 1 the sieving time is shortened by 0.07 s to 0.025 s, which means in three times. Changing the amplitude *A* of the oscillating motion of the helix end and angle g lifting of the screw line does not lead to a significant reduction in sieving time and does not significantly affect the final mass of the lump of soil on the surface of the cleaning spiral.

***Key words:** potato heap, harvesting, soil lumps, impurities, cleaning spiral, parameters, differential equations, numerical calculations.*
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**Formulation of the problem.** An important operation in the potato harvesting process is the removal of soil impurities and plant residues from the potato heap and the removal of sticky soil from the tubers themselves. At the same time, the main requirements for these technological operations are not damage to potato tubers and the absence of losses. However, it should be noted that cleaning potato tubers from soil impurities and plant residues is still a rather complicated technical task.

In addition, numerous studies show that the existing potato harvesters with different types of cleaning devices (bar elevators, vibrating screens, slides, various separators of drum and rotary types) have a number of drawbacks associated with sticking of cleaning devices with soil and plant residues, because often during the harvest of potatoes the soil has high humidity and plasticity. In addition, there is significant damage to the tubers and, consequently, increased crop losses.

We have developed a new spiral potato heap cleaner, which is able to actively cleanse itself of stuck soil, as well as effectively capture and remove lumps of soil of various sizes and shapes, including plant residues. For the mentioned potato heap cleaner the patent of Ukraine for invention was received [1].

**Purpose of research** – Improving the quality of potato tubers cleaning by substantiating rational structural and kinematic parameters of the new construction spiral potato peeler.

**Research methods.** The research was conducted using the principles of theoretical mechanics, higher mathematics, as well as methods of programming for numerical calculations on a PC.

**Research results.** To carry out a theoretical study of the movement and sifting of soil lumps on the working surface of the spiral potato peeler, created by cleaning spirals, we will develop an equivalent scheme (Fig. 1), which shows only two adjacent cleaning spirals (this is enough for us), although in our proposed construction there are three (maybe more).

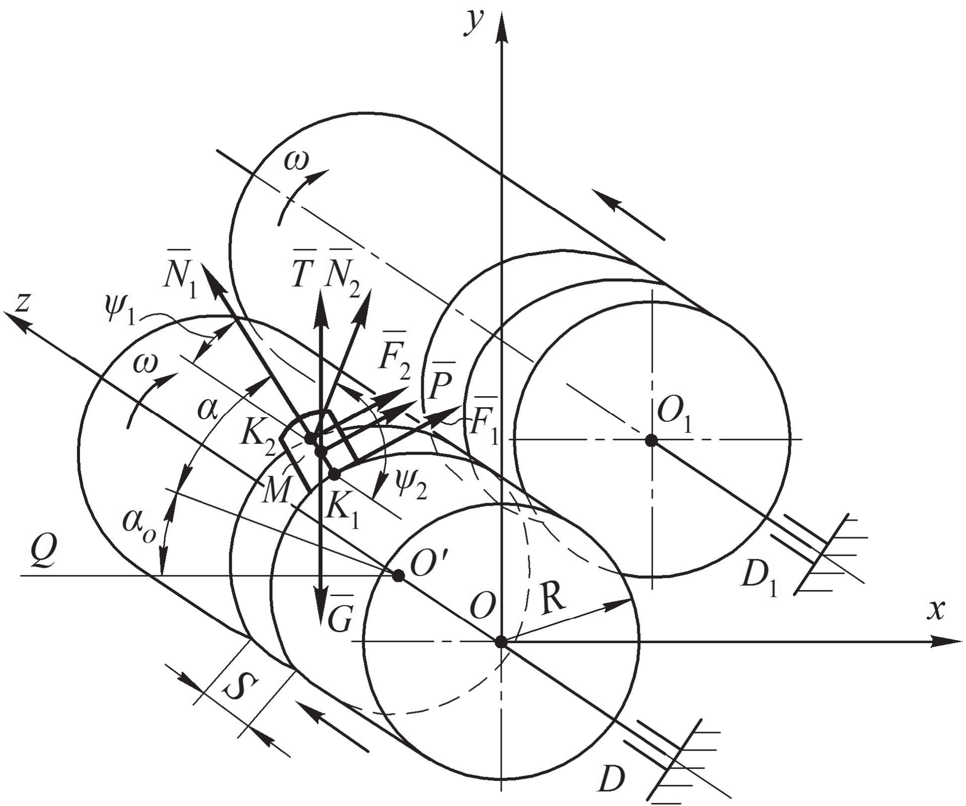


***Fig. 1. Equivalent soil sieving scheme, on the surface of the potato peeler***

It is shown (Fig. 1) on the equivalent scheme of a spiral of a spiral console are established by the ends in points D and $D_1$, which axes are parallel, other ends are located freely and can make oscillatory movements at work of a separator under the influence of the variable loading arising owing to receipt on the specified spirals of a potato heap. At the same time, the spirals rotate around their axes at the same angular velocities $\omega$ in one direction, which is shown by the arrows on the diagram. Cleaning spirals are made in the form of cylinders with radius *R*, their coils are directed in one direction (also shown by arrows in the diagram) and have a screw line pitchiї *S*. The angle of rise of the screw line is $\gamma$. These spirals are installed with some overlap.

Consider the most likely case where a lump of soil (indicated in the diagram through *M*) of any shape falls into the cavities between the two adjacent coils of the helix and comes into contact with them at points $K_1$ and $K_2$ (Fig. 1). In this case, a lump of soil will be considered a body of a variable mass and the positions of the body dynamics of a variable mass will be applied to describe its motion. In order to draw up the differential equations of motion of the soil lump as a body of variable mass, let us choose the absolute spatial Cartesian coordinate system *xOyz* as shown in Figure 1. Except for the coordinates $x$, $y$ and $z$ in the absolute coordinate system *xOyz*, which determine the position of the lump *M* on the coils of the helix, additional parameters have been entered, namely the angle $\alpha_0$ and $\alpha$, that determine the position of the body *M* in the cross section of the spiral itself.. At the same time, $\alpha_0$ – an angle that shows the starting position of the points $K_1$ and $K_2$ lump contact *M* with the neighboring spirals. It should be added that the dots $K_1$ and $K_2$ are respectively in the cross sections of the helix, one spiral from the other at a distance of a pitch *S* screw line. Agle $\alpha_0 + \alpha$ shows the position of the touch points $K_1$ and $K_2$ at any time *t* in the specified cross-sections, respectively. Corner countdown $\alpha_0$ and $\alpha$ move in the direction of rotation of the helix (clockwise). It is obvious that at *t* = 0, $\alpha = 0$.

We also accept that the current body weight *M* is a function of time *t*, I mean $m = m(t)$, its initial value will be equal to $m_0$. The equivalent diagram (Fig. 1) shows the directions and points of application of all forces acting on the body *M* of the variable mass when it moves along the coils of the spiral:

– $\bar{G}$ – force of body weight M variable mass;

– $\bar{N}_1$, $\bar{N}_2$ – normal reactions of neighboring spiral turns, at the points $K_1$ and $K_2$ in accordance;

– $\bar{F}_1$, $\bar{F}_2$ – friction forces at points $K_1$ and $K_2$;

– $\bar{T}$ – the force of the acceleration of the oscillating motion of the helix, which arises due to the bending of the longitudinal axis of the helix, is formed by the weight of the potato heep.

On the basis of the above scheme of forces and application of the theorem about change of quantity of movement of a material point in the differential form the system of differential equations of movement of a body *M* of variable weight (breast of soil) on a working spiral of a cleaner of a potato heap of the following kind is received:

$$\left.\begin{aligned}
&m\ddot{x} = -N_1 \cdot \sin\psi_1 \cdot \cos(\alpha_0 + \omega t) - N_2 \cdot \sin\psi_2 \cdot \cos(\alpha_0 + \omega t) + \\
&+ fN_1 \cos\gamma \cdot \sin(\alpha_0 + \omega t) + fN_2 \cos\gamma \cdot \sin(\alpha_0 + \omega t) - \\
&- m \cdot \omega^2 \cdot A \cdot \sin(\alpha_0 + \omega t) \cdot \cos(\alpha_0 + \omega t) - \dot{x}\frac{dm}{dt}, \\
&m\ddot{y} = N_1 \cdot \sin\psi_1 \cdot \sin(\alpha_0 + \omega t) + N_2 \cdot \sin\psi_2 \cdot \sin(\alpha_0 + \omega t) + \\
&+ fN_1 \cos\gamma \cdot \cos(\alpha_0 + \omega t) + fN_2 \cos\gamma \cdot \cos(\alpha_0 + \omega t) + \\
&+ m \cdot \omega^2 \cdot A \cdot \sin^2(\alpha_0 + \omega t) - \dot{y}\frac{dm}{dt} - mg, \\
&m\ddot{z} = N_1 \cos\psi_1 - N_2 \cos\psi_2 - fN_1 \sin\gamma - fN_2 \sin\gamma - \dot{z}\frac{dm}{dt}.
\end{aligned}\right\} \quad (1)$$

In the resulting equation system:

$\omega t = \alpha$ – spiral angle of rotation at any time $t$;

$\dot{x}\frac{dm}{dt}$, $\dot{y}\frac{dm}{dt}$, $\dot{z}\frac{dm}{dt}$ – reactive force projections $\bar{P}$, which is due to the weight loss of the *M* body, on the axis of coordinates *Ox*, *Oy* and *Oz* respectively. These forces are shown in the equivalent diagram (Fig. 1);

*A* – the amplitude of the oscillation of the bent spiral axis;

$\psi_1$, $\psi_2$ – angles of inclination of normal reactions $\bar{N}_1$ and $\bar{N}_2$ to the axis *Oz* in accordance;

*f* – the coefficient of friction of the body *M* on the surface of the helix.

Further, from the system of equations (1) we determine the rate of mass reduction *m* lump of soil M at the current time *t*, that is the value $\frac{dm}{dt}$, $kg \cdot s^{-1}$.

Taking into account that the movement of lumps of soil *m* is carried out with the help of the coil of the spiral, the equation of which in the parametric form looks like [7], namely:

$$\left.\begin{aligned}
&x = R \cdot \cos(\alpha_0 + \omega t), \\
&y = R \cdot \sin(\alpha_0 + \omega t), \\
&z = \frac{S}{2\pi} \cdot (\alpha_0 + \omega t),
\end{aligned}\right\} \quad (2)$$

the final differential equation of mass change, taking into account the above, will have the following form:

$$\begin{aligned}
&\frac{dm}{dt} = \frac{2\pi(N_1 \cos\psi_1 - N_2 \cos\psi_2)}{S\omega} + \\
&+ \frac{\pi R \tan\gamma}{S} \cdot \left\{ m\omega\left[\frac{1}{\tan(\alpha_0 + \omega t)} + \tan(\alpha_0 + \omega t)\right] + \right. \\
&+ \frac{m\omega A}{R}\left[\frac{\sin^2(\alpha_0 + \omega t)}{\cos(\alpha_0 + \omega t)} - \cos(\alpha_0 + \omega t)\right] - \\
&- \frac{mg}{\omega R \cos(\alpha_0 + \omega t)} + (N_1 \sin\psi_1 + N_2 \sin\psi_2) \times \\
&\left. \times \frac{1}{\omega R}\left[\tan(\alpha_0 + \omega t) - \frac{1}{\tan(\alpha_0 + \omega t)}\right]\right\}.
\end{aligned} \quad (3)$$

The differential equation (3) is an equation that reflects the reduction of the mass of the breast of soil *M* with the passage of time *t*, which occurs under the influence of applied external forces, is shown in the equivalent scheme (Fig. 1), taking into account structural and kinematic parameters of the new spiral potato heap cleaner.

To perform the numerical calculation on the PC of the obtained differential equation (3) it is necessary to set the initial conditions: at $t = 0$: $m = m_0$, $\alpha_0 = \frac{\pi}{4}$.

The main parameters of the spiral potato heap cleaner for numerical calculation are as follows: $m_0$ = 0,2 kg; *R* = 0,15 m; *S* = 0,035 m; $\gamma$ = 20°; $\omega$ = 10, 20, 30 $rad \cdot s^{-1}$; *A* = 0,005 m.

Further, according to the program developed by us in the medium «Matlab», as a result of the numerical solution of the differential equation (3), the obtained graphical dependences (function diagrams $m = m(t)$ ), are presented in Fig. 2.

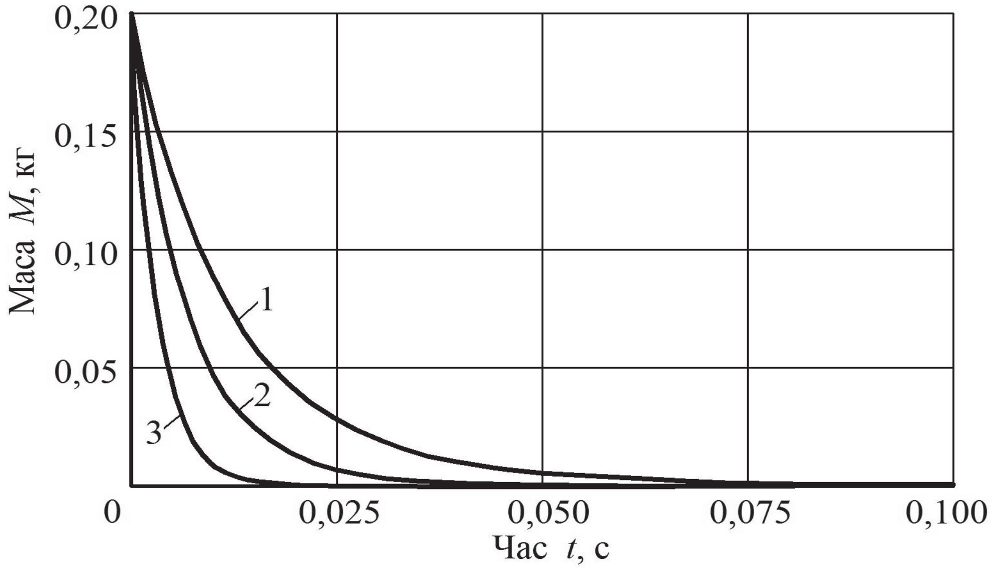


***Fig. 2. Dependence of sieved mass of lumps of soil as a function of time at:***

***1) ω = 10 rad·s$^{-1}$; 2) ω = 20 rad·s$^{-1}$; 3) ω = 30 rad·s$^{-1}$***

As can be seen from the graphical dependences of the angular velocity increase $\omega$ The rotation of the cleaning spirals has a significant effect on the loss of mass of the soil lumps they contain. For example, an increase in the angular velocity $\omega$ with 10 rad·s$^{-1}$ to 30 rad·s$^{-1}$ reduces the time *t* of lump sifting by almost three times. However, further increase of this kinematic parameter is limited by the conditions of not damaging potato tubers, which are cleaned with this spiral cleaner.

We also carried out numerical calculations of the specified differential equation (3) at change of other constructive parameters of the potato peeler of the developed construction. However, it has been shown in the calculations that with their changes, e.g. the radius of the *R*-spiral, the angle of $\gamma$ the lifting of the helical screw line and the amplitude *A* of the oscillating motion of the end of the helical spiral does not significantly reduce the time *t* of sifting through the mass of lumps of soil on the surface of the spiral potato heap cleaner.

**Conclusions**

*A mathematical model of the lump sifting process has been developed, which is delivered to the spiral separator together with a heap of potato tubers dug out from the ground, in case the lump (particle) of soil comes into contact with the spiral turns of the separator in two points.*

*A new differential equation is obtained, which allows to describe the process of decreasing the mass of soil lumps coming to the spiral surface of the separator as a function of the time that occurs when they move along the spiral.*

*Numerical calculations carried out on the PC with the use of the program «Matlab» showed that with the increase in the angular velocity of the spiral, the reduction of the mass of the soil breast significantly increases with the change in the angular velocity in the range from 10 to 30 rad·s$^{-1}$ screening time for lumps of soil is reduced from 0.07 s to 0.025 s, which means in three times.*

*Numerical calculations with the help of PC, which were carried out with changes in other constructive parameters of spiral potato heep peeler showed that in general the change in radius R of the spiral, the angle $\gamma$ the rise of the helical screw line and the amplitude A of the oscillating motion of the end of the helical spiral do not lead to a significant reduction in the sifting time and do not significantly affect the final weight of the soil breast on the surface of the cleaning spiral.*

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