Investigation the process of soil seeding during cleaning of rootbull fruits by spiral type cleaner

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Abstract. Cleaning of root crop bodies from impurities during their digging from the soil is a complex and energy-consuming technological process. Therefore, the development of new types of cleaners of root crop pile from impurities, in particular spiral type cleaners, allowing to intensify this process and improve the quality of cleaning is a step to successfully overcome this problem. The paper presents a study of the technological process of sifting soil particles during the cleaning of the heap of root crops with a spiral-type cleaner. In particular, a calculated mathematical model was constructed, which reflects the movement along the spiral of the body cleaner (soil particles) of variable mass. Using the differential equation of volume change, the differential equation of mass change, i.e. the mass that is sifted through the coils of the spiral cleaner was compiled. Based on the theoretical study, it was found that many factors influence the intensity of soil sifting on the spiral separator – the initial mass of particles, the design dimensions of the cleaner, frictional properties of the surface, angular parameters of body placement on the spiral surface and angular velocity of the spiral roller rotation, and the intensity of these parameters has been studied. Using PC, graphical dependences of the intensity of soil sieving on the angle of rotation of the cleaning spiral when changing the angular velocity of the spiral were constructed.

KEYWORDS*: ROOT CROPS, SPIRAL CLEANER, INTENSITY OF SOIL SIFTING.*

1. Introduction

During the technological process of digging root crops, it is necessary to immediately remove as much soil and other plant impurities from the heap. Purification of the bodies of root crops from impurities is further done by sifting the soil during movements on the cleaning surfaces of the cleaners. However, in the process of mechanized harvesting of root crops after digging up the heap, a significant part of soil impurities is still fed to the working bodies for further cleaning of the bodies of root crops, ie separation with their subsequent transportation. It was found that the content of tubers in the excavated layer is only 3-5%, and the other 95-97% are impurities in the form of fine soil and its lumps, stones, uterine tubers and plant remains [1]. In addition, the high content of impurities in the excavated root of tubers (such as sticky soil) leads to significant losses during storage. Purity of root crops can be achieved by using effective separating working bodies. Many scientists in Ukraine and abroad have worked on the problem of creating effective and reliable potato separators [2-5]. Thus, the effectiveness of the use of heaters of root crops from any impurities can be achieved by using drive cleaning spirals with free cantilever ends, ie spiral separators. However, such spiral separators require theoretical and experimental research in order to improve the quality of their work.

In order to ensure the best intensity of sieving the soil when cleaning the heap on a spiral separator, it is necessary to study the dynamics of the separation process. To do this, consider the movement of the soil heap, ie the body of variable mass on the surface of the spiral roller and determine the influence of factors that most affect the change in mass, ie sifting the soil when cleaning the heap of root crops from impurities.

2. Materials and Methods

To solve this problem, it is necessary to build a mathematical model of the movement of soil particles of variable mass on the surface of the turn of the cleaning spiral in order to study the effect of structural and kinematic parameters on the percentage of sifted soil. To do this, we must first consider the basic tenets of the theory of motion of a variable mass and then build an equivalent scheme. If in the spatial Cartesian coordinate system *xOyz* we will consider a unit volume of a certain size: with length along the axis Ox, width along the axis Oz, height along the axis Oy, then change this volume dW will pass on length, width and height, and at its general change it is necessary to consider action of the separate parameter. To do this, we use the differential equation of change in volume, which has such a general form:

$$dW = \frac{\partial W}{\partial x}dx + \frac{\partial W}{\partial y}dy + \frac{\partial W}{\partial z}dz\ , \tag{1}$$

where W – unit volume of mass; dW – change in unit volume; $\frac{\partial W}{\partial x}$; $\frac{\partial W}{\partial z}$; $\frac{\partial W}{\partial y}$ – gradients of change of unit volume on the corresponding coordinates.

Considering the fact that $m = \gamma_m \cdot W$, where m – mass of the heap;
γ_m – the density of the tuber layer, and accordingly $dm = \gamma_m dW$, then expression (1) will take the following form:

$$dm = \frac{\partial m}{\partial x}dx + \frac{\partial m}{\partial y}dy + \frac{\partial m}{\partial z}dz\ . \tag{2}$$

Analytical expression (2) is a differential equation of change in body weight relative to its geometric parameters (dimensions). Knowing the variable coordinate compared to the initial position and substituting them in this equation, we can theoretically study this change in mass.

Further studies of the process of mass change will be carried out using an extended version of the known formula for sifting grain mass on a keyboard straw shaker. For our case, this equation can be represented as follows:

$$m = m_o(1 - e^{-\lambda L})\ , \tag{3}$$

where L – mass movement during separation; m_o – the initial mass of the separating heap; e – natural logarithm index; λ – the coefficient of separation of the studied working body, which depends on the parameters and modes of operation, as well as on the properties of the soil (moisture, fractional composition, etc.).

If in our case the mass movement is relative to the three coordinate axes, then $L = \sqrt{x^2 + y^2 + z^2}$. Then, taking into account this, expression (3) takes the following form:

$$m = m_o\left(1 - e^{-\lambda\sqrt{x^2+y^2+z^2}}\right). \tag{4}$$

Next, we determine the partial derivatives of mass by the coordinates included in expression (2). They will be equal:

$$\left.\begin{aligned} \frac{\partial m}{\partial x} &= \frac{m_o \cdot \lambda \cdot x \cdot e^{-\lambda\sqrt{x^2+y^2+z^2}}}{\sqrt{x^2+y^2+z^2}}, \\ \frac{\partial m}{\partial y} &= \frac{m_o \cdot \lambda \cdot y \cdot e^{-\lambda\sqrt{x^2+y^2+z^2}}}{\sqrt{x^2+y^2+z^2}}, \\ \frac{\partial m}{\partial z} &= \frac{m_o \cdot \lambda \cdot z \cdot e^{-\lambda\sqrt{x^2+y^2+z^2}}}{\sqrt{x^2+y^2+z^2}}. \end{aligned}\right\} \tag{5}$$

Substitute the obtained expressions (5) into the differential equation of mass change (2). Then it follows that:

$$dm = m_o \lambda \sqrt{x^2 + y^2 + z^2} \cdot e^{-\lambda\sqrt{x^2+y^2+z^2}}. \qquad (6)$$

If the left and right parts of the last expression (6) are divided into m_o, then we obtain an analytical expression to determine the percentage of soil sifted by the separator (in fractions):

$$P = \lambda \sqrt{x^2 + y^2 + z^2} \cdot e^{-\lambda\sqrt{x^2+y^2+z^2}}. \qquad (7)$$

The obtained expression (7), if we substitute in it the corresponding values of the parameters allows us to study the effect of the coordinate change on the percentage of the sieved soil. Determination of the separation coefficient λ we carry out by numerical method by experiment [6, 7]. For this purpose we choose two points at a distance L_1 and L_2 relative to the point of supply and the percentage of sifted soil in them is, respectively P_1 and P_2. Then the expression by which we determine the separation coefficient λ, will take the following form:

$$\lambda = \frac{\ln \dfrac{P_1 \cdot L_2}{P_2 \cdot L_1}}{L_2 - L_1}. \qquad (8)$$

If we substitute in expression (8) the values of the corresponding points we obtain the separation coefficient, which we substitute in expression (7).

Using PC, construct the percentage surface of the sieved soil according to (7), provided that the separation coefficient $\lambda = 1.1$ (the separation coefficient must be greater than 1.0) (Fig. 1) when changing coordinates x, z from 0 to 0.5 m, and the coordinate y will not be taken into account, assuming that the sieving along this coordinate is not significant and can be neglected.

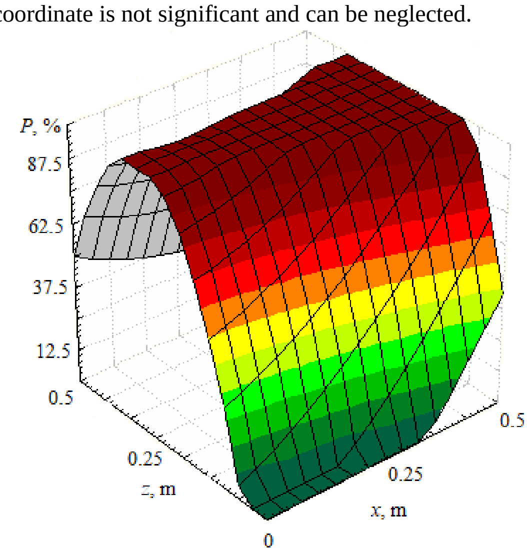

***Figure 1**. Dependence of the percentage of sifted soil (P) from longitudinal (x) and transverse (z) coordinates at the separation coefficient λ = 1.1*

The original analytical expression (8) does not take into account the dynamics of the motion process. To consider the separation in terms of dynamics, we use the differential equation of motion of a body of variable mass on the surface of the cleaning spiral (because a separate volume can be conditionally taken as a body) [7, 8].

We will construct further the equivalent scheme on which we will present the spiral separator in the form of the cylinder with radius R (Fig. 2). To build a mathematical model on an equivalent circuit, we select the elementary volume by mass m. The beginning of the movement on the surface of the cleaning spiral corresponds to the angular parameter ψ_0. The rotation of the cleaning spiral occurs in the direction indicated by the arrow. Body from position A_1 for some time t moves to position A_2. We will show in an equivalent diagram all the forces acting on the body during its motion.

Next, consider this motion of a body of variable mass and make a differential equation of its motion.

In the initial position, the location of the body will be determined by the angle – ψ_o. Its initial mass is equal to – m_o.

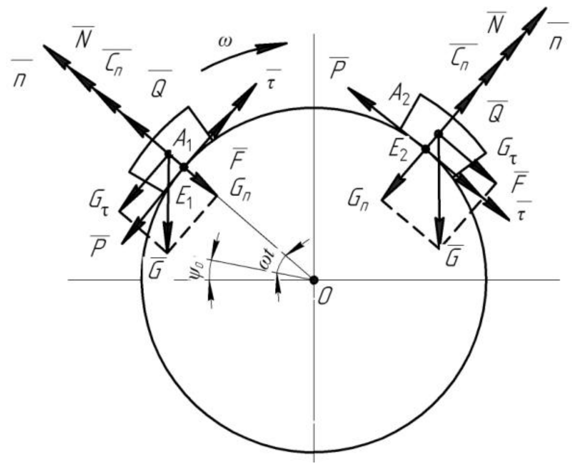

***Figure 2.** Equivalent scheme of motion of a body of variable mass on the surface of a spiral roller (cross section)*

When turning the mass of the cleaning spiral at an angle $\delta\psi$ the current mass value will be equal to:

$$m = m_o - \Delta m = m_o - q' \cdot t,$$

where q' – intensity of soil separation, t – turning time; Δm – change in mass.

The position of the body is determined by the angle $\omega t = \beta$. Define the forces that will act on the system under consideration:

$G = (m_0 - \Delta m) g$ – gravity of a body of variable mass; N – normal surface reaction; $F = Nf$ – the friction force of the mass on the surface of the separator, where f – the coefficient of friction of the sliding heap on the surface of the spiral; $P = \dot{x}\dfrac{d(\Delta m)}{dt}$ – force from the action of mass change; $C_n = (m_0 - \Delta m)\dot{\beta}^2 \cdot R$ – centrifugal force; $Q = (m_0 - \Delta m) \cdot \dot{\beta}^2 \cdot A \cdot \sin(\psi_0 + \varphi_{Ph} + \dot{\beta} t)$ – force from the acceleration of oscillating motion, where A – amplitude of oscillations; φ_{Ph} – phase shift.

The vector equation of motion of a body of variable mass will look like this:

$$m\frac{d^2\bar{l}}{dt^2} = \bar{G} + \bar{N} + \bar{F} + \bar{P} + \bar{C}_n + \bar{Q}.$$

In projections on the tangent $\bar{\tau}$ and normal $\bar{n}$ we make differential equations of motion of this system. They look like this:

$$\left.\begin{aligned} &(m_0 - \Delta m)\ddot{\beta} \cdot \rho = F \cdot \cos\gamma - G \cdot \cos(\beta_0 + \beta) - P, \\ &0 = N + C_n - G \cdot \sin(\beta_0 + \beta) + Q. \end{aligned}\right\} \qquad (11)$$

From the second equation of system (11) we find the normal reaction of the surface – N. It will be equal:

$$N = G \cdot \sin(\beta_0 + \beta) - Q - C_n. \qquad (12)$$

Substituting in the first equation of the system (11) value N, as well as the value of other forces that make up the right part of it we get:

$$\begin{aligned} &(m_0 - \Delta m)\ddot{\beta} \cdot \rho = f\,(m_0 - \Delta m)\cos\gamma \times \\ &\times\left[g \cdot \sin(\beta_0 + \beta) - A \cdot \dot{\beta}^2 \cdot \sin(\beta_0 + \psi_{Ph} + \beta) - \rho \cdot \dot{\beta}^2\right] - \\ &-(m_0 - \Delta m) \cdot g \cdot \cos(\beta_0 + \beta) - \frac{d(\Delta m)}{dt}\dot{x}. \end{aligned} \qquad (13)$$

Considering that $\Delta m = q't$, and having carried out certain algebraic transformations we will write down the final expression which will express dependence of intensity of separation of a potato heap on constructive and kinematic parameters of a spiral separator:

$$q' = \frac{m_0\dot{\beta}\left\{\ddot{\beta} + f\cos\gamma\left[-g\sin\left(\beta_0+\beta\right) + A\dot{\beta}^2\sin\left(\beta_0+\psi_\Phi-\beta\right)+\rho\dot{\beta}^2\right] + g\cos\left(\beta_0+\beta\right)\right\}}{\beta\left\{\ddot{\beta} + f\cos\gamma\left[-g\sin\left(\beta_0+\beta\right) + A\dot{\beta}^2\sin\left(\beta_0+\psi_{Ph}-\beta\right)+\rho\dot{\beta}^2\right] + g\cos\left(\beta_0+\beta\right)\right\} + \rho\dot{\beta}^2\sin\left(\beta_0+\beta\right)+e\dot{\beta}^2\sin\beta}. \quad (14)$$

From the above expression (14) it follows that the sieving intensity on the spiral separator is influenced by many factors – initial mass, construction dimensions (radius of the spiral, angle of inclination of the helix), frictional surface properties, angular parameters of variable mass on the spiral surface and angular velocity rotational movement of the spiral cleaning roller.

3. Results and discussions

We will analyze the influence of these parameters on the intensity of separation by means of direct substitutions in expression (14) of the specific values of the quantities included in it. The values of such values (reflecting the parameters of the spiral separator of our design) are shown in table 1.

Tabel 1. *Constructive and kinematic parameters of the spiral separator, ensuring the efficiency of the screening process of soil*

Dimension	Dimensionality	Value
Coefficient of sliding friction f	–	0.5
Angle of rise of the helical line γ	deg	20
Eccentricity of fixing the spiral e	m	0.005
The initial mass of the heap m_0	kg	80
Amplitude of spiral oscillations A	m	0.01
The initial value of the angular parameter β_0	deg	45
Phase shift ψ_{Ph}	deg	0
Radial mass placement parameter ρ	m	0.15
Spiral rotation angle β	rad	0, 1.047, 2.094, 3.14, 4.187, 5.234, 6.28
The angular velocity of rotation of the spiral $\dot{\beta}$	rad·s^{-1}	0, 10, 20, 30, 40, 50
Acceleration of spiral rotation $\ddot{\beta}$	rad·s^{-2}	0

According to the accepted conditions, when solving expression (14), the intensity of separation Q (kg·s^{-1}) will take the values shown in the graphs of Fig. 3. To obtain the value of the specific intensity of sieving the soil is enough to divide this value by the area of the separator and multiply by coefficients that take into account the filling of the surface of the cleaning spiral, uniformity of mass and volume change along the length of the heap. The obtained graphical dependences indicate that in the second quadrant (on the rise of the mass on the surface of the spiral) the intensity of separation decreases. On the contrary, the growth of separation is investigated by lowering the mass.

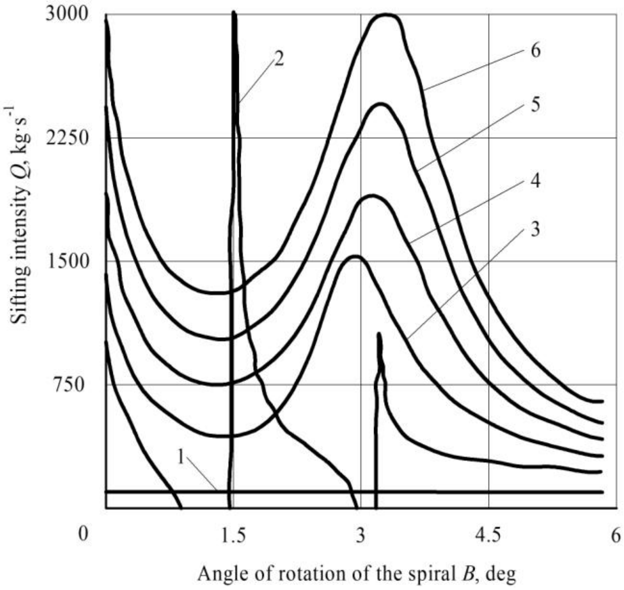

Figure 3. *Dependence of sieving intensity Q (kg·s^{-1}) from the angle of rotation of the spiral B (deg) at the angular velocity of the spiral:1 – 0 rad·s^{-1}; 2 – 10 rad·s^{-1}; 3 – 20 rad·s^{-1}; 4 – 30 rad·s^{-1}; 5 – 40 rad·s^{-1}; 6 – 50 rad·s^{-1}*

As the angular velocity of the rotational motion of the spiral increases, the intensity of separation also increases. At an angular parameter of about 3.3 rad, the intensity of separation of the soil heap increases from 0 kg·s^{-1} at angular velocity of rotational motion 0 rad·s^{-1} to 3000 kg·s^{-1} at an angular velocity equal to 50 rad·s^{-1}. With further rotation of the cleaning spirals together with the heap, the intensity of separation of soil impurities decreases. This is evidenced by the attenuating nature of the curves.

4. Conclusion

Based on the calculations and mathematical transformations performed on a PC using the developed program, an analytical expression for determining the percentage of sifted soil by the spiral separator was obtained, allowing us to study the effect of coordinate changes on the percentage of sifted soil.

Studies of soil sieving in the cleaning of the heap of root crops from impurities with a spiral-type cleaner have also been carried out. It is established that many factors influence the intensity of soil screening on the spiral separator – the initial mass, the constructive dimensions of the cleaner, the frictional properties of the surface, the angular parameters of body placement on the spiral surface and the angular speed of the spiral roller rotational motion, and the intensity of these design parameters has been studied.

A graphical dependence of soil screening intensity Q (kg·s^{-1}) on the cleaning spiral rotation angle B (deg) at angular velocity of spiral rotation from 0 to 50 rad·s^{-1} is plotted. The obtained graphical dependences indicate that in the second quadrant (on the rise of the mass on the surface of the spiral separator) the intensity of separation decreases. On the contrary, the growth of separation is investigated at lowering the ground mass.

As the angular velocity of the spiral rotational motion increases, the intensity of separation also increases. At an angular parameter of about 3.3 rad, the separation intensity increases from 0 kg·s^{-1} at angular velocity 0 rad·s^{-1} to 3000 kg·s^{-1} at angular velocity 50 rad·s^{-1}. When turning the spiral together with the heap, the intensity of separation decreases. This is evidenced by the attenuating nature of the curves.

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