UDC 631.358.44/45

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THEORY OF DEFLECTION OF TUBERS OF POTATO AT OPERATION OF SPIRAL SEPARATOR

The purpose. Heightening efficiency and quality of production process of separation of potato heap by improvement of construction of spiral separator of vibration type and theoretical justification of its rational parameters under condition of exclusion of damage of tubers of potato.**Methods.** Theoretical studies of the improved separator of potato heap were carried out with the use of basic provisions of higher mathematics, theoretical mechanics, and also creation of programs for PC and construction of graphical dependences and their analysis. **Results.** Equivalent scheme is created of interaction of tuber of potato with the surface of cantilever spiral springs on the basis of which motion characteristics of flight of a tuber before its impact with elastic surface of the mobile transporter. **Conclusions.** New mathematical model of flight of a tuber of potato from the surface of spiral separator and its impact with deflecting transporter is built. On the basis of the gained analytical dependences it is possible to study theoretically kinematic parameters of spiral separator of potato harvester with improved construction at its interaction with a tuber under condition of its non-damaging.

Key words: potato, tuber, spiral separator, removal of admixtures, equivalent scheme, equation of motion, deflection.

Formulation of the problem. Potato growing is one of the energy and material-intensive branches of agriculture, since it only exceeds the specific energy consumption for energy production per unit of grain by only 4 to 5 times in energy consumption. Therefore, with further development and improvement of the working bodies of potato harvesting machines and optimization of parameters, it is necessary to ensure a reduction of their material and energy intensity with a significant increase in the quality of the resulting products. At the same time, the specific energy consumption of the unit production of domestic potato harvesting machines is 1.6 ... 2.2 times higher than in Western Europe.

The analysis of technological schemes of potato harvesting equipment shows that the largest share of the mass of the whole machine falls on the separating working bodies, since with increasing their number and, consequently, the separation time of the potato pulp, an increase in the purity of the resulting product is achieved. This is explained by the fact that the purifying working bodies are the main link in ensuring the quality performance of the potato harvesting machine in general.

To improve the performance of potato harvesting machines, a design of a spiral separator of potato tuber, which is protected by the Ukrainian patent [1], was developed. The separator consists of three consecutive actuating screw helix, which are made in the form of console spiral springs, fixed in the mats. Experimental investigations of the cleaner [2] on the example of work in the technological scheme of a single-row potato digger showed the effectiveness of its application on potato harvesting machines. However, it has been found that a certain proportion of tubers and soil lumps, with dimensional-mass characteristics similar to tubers, flies through the following helix of the separator, which leads to deterioration of the quality of cleaning. In addition, there is a complexity in increasing the efficiency of the separator due to the limited values of angular velocities of the spirals.

To eliminate the flow of tubers through the separator, an improved design of the spiral separator is proposed, which is characterized by the fact that over the spirals is installed at a certain angle to the line formed by the centers of the axes of the spirals of the separator, a deflecting rubber smooth conveyor. At the same time, the bulb, which is torn off from the surface of the spiral, hits the conveyor and returns to the separating surface.

Analysis of recent publications. Separators of potato heap should not only provide reliable and qualitative performance of the process, but also constantly self-cleaning in the process of work. It is known that the systems of separating working bodies used on serial potato harvesters do not always provide a high degree of separation of soil impurities [3]. It happens, most often, as a result of intensive sticking of surfaces of separating working bodies with wet soil.

A lot of researchers and designers worked on the problem of creating efficient and reliable in the work of potato heap separators when it was assembled, as well as on stationary potato-cleaner points [4-8]. However, despite the large number of technological processes of cleaning the potato heap at harvesting, there is relatively little research on the optimization of spiral separators.

Purpose. Increasing efficiency and quality of potato heap separation process by improving design of vibratory type spiral separator and theoretically substantiating its rational parameters, with the exception of potato tubers damage.

Methods. Theoretical studies of improved potato heap separator were carried out using the main provisions of higher mathematics, theoretical mechanics, as well as compiling programs for numerical calculations on a PC and constructing graphical dependencies and analyzing them.

Results. The theoretical substantiation of the parameters of the improved spiral separator can be accomplished by constructing a mathematical model of the interaction of a potato tuber which is pushed out from the surface of the spiral separator upward and interacts with the rubber surface of the deflection of a smooth belt conveyor.

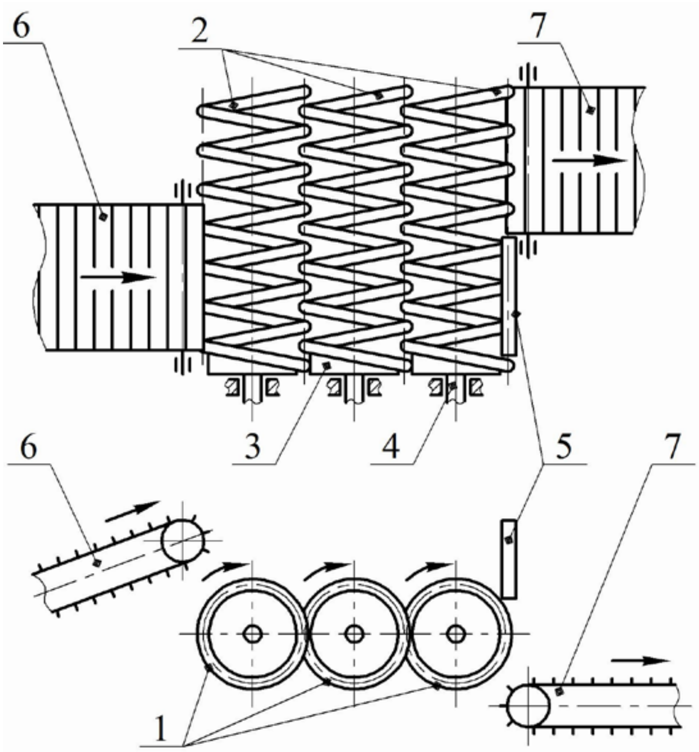

Fig. 1. – Constructive scheme of a spiral separator of potato tuber:
1 - screw rollers; 2 - Console spiral springs; 3 - the hamster; 4 - drive shaft; 5 - protective shield; 6 -terminer delivering a heap; 7 - conveyor, which removes potatoes

First of all, we construct an equivalent circuit for pushing, subsequent flight and deviation of the potato tuber with the work of the spiral separator of an improved design [1].

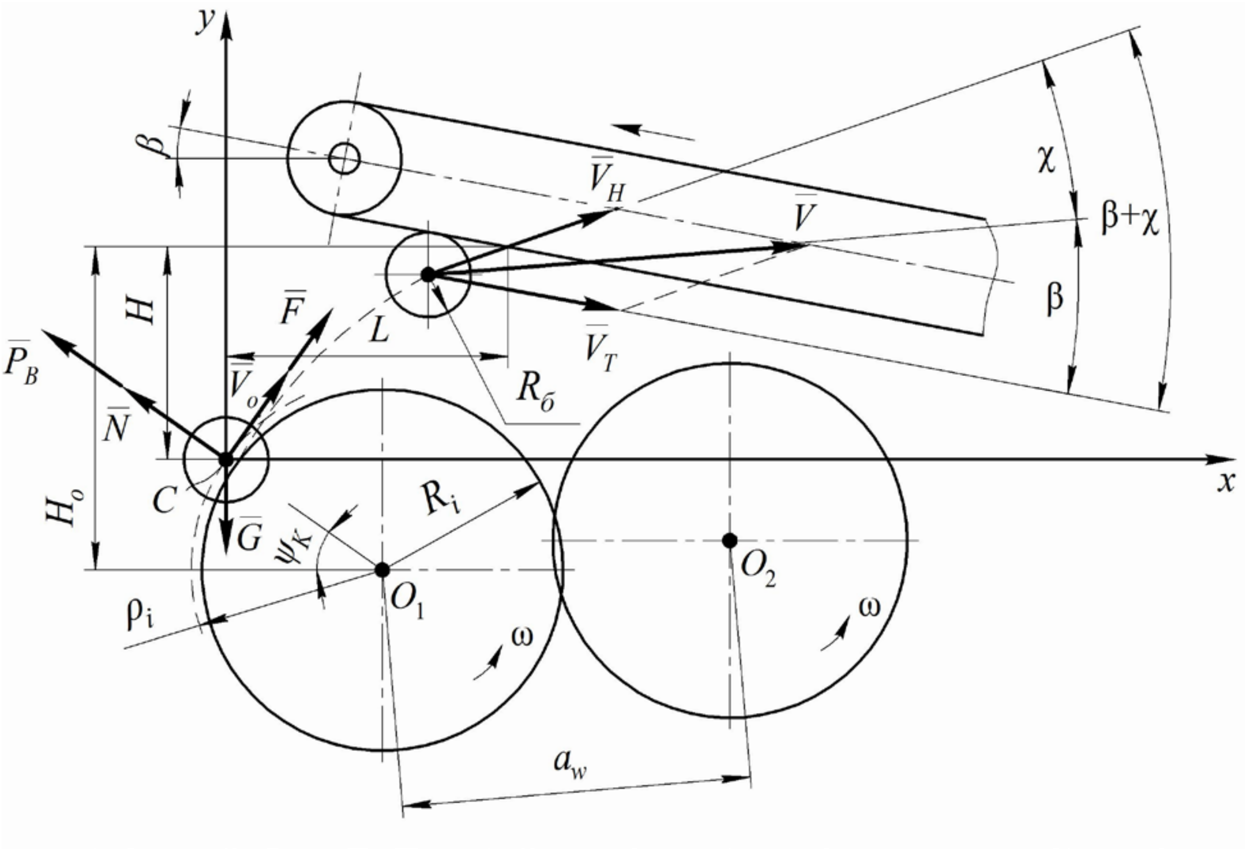

Fig. 2. – The equivalent scheme of the flight of the tuber in a spiral separator

To simplify analytical calculations, the body of potato tubers is approximated by a bullet. Consider the movement of a potato tuber with a shape close to the ball of the radius fixed $R_б$ on the surface of a spiral separator with an external radius R_i, step drill S and diameter d_n spiral rod. Spirals are installed in series with the inter-center distance a_w and some overlap. The rotation of the spirals around its own axis is in the direction of the clockwise with angular velocity ω. Assume that in motion the spiral is a smooth cylindrical surface

The position of the tuber on the surface of the helix will be determined by some radial ρ_i and angular parameters ψ_i. Interaction of a tuber with a surface of a spiral is possible in two variants: when moving on the surface of a winding with a contact at one point and when moving in a space between interchaines [2]. Therefore, the radial parameter will be:

- when moving in the interchain space:

$$\rho_i = \left(R_i - \frac{d_n}{2} \right) + \frac{1}{2}\sqrt{\left(d_n - 2R_б\right)^2 - S^2}\,, \qquad (1)$$

– when moving on the outer surface of the spiral

$$\rho_i = R_i + R_б\,. \qquad (2)$$

Having reached a certain value of the angle parameter ψ_k, the bulb is torn off from the surface of the spiral. This is possible provided that the normal reaction of the spiral cavity will be $N \geq 0$. To do this, consider the effect of forces on a mass of bulbs with a center at the point C: $\overline{G}$ - gravity; $\overline{N}$ - force of the normal reaction of the spiral, which is directed along the normal to the trajectory of the relative motion of the body through a spiral; $\overline{F}$ - the force of friction of slipping the body along the surface of the spiral; $\overline{P_b}$ - centrifugal force of inertia, which is directed along the normal to the trajectory of motion. We will design all the forces on the normal axis of the coordinate system with the beginning of the reference in the center of the tuber S. We have:

$$ma_n = N + P_b - G\,sin\,\psi_k\,. \qquad (3)$$

Since motion occurs only in the direction of the tangent axis, then $a_n = 0$, and hence

$$N + P_b - G\sin\psi_k = 0\,. \qquad (4)$$

Then, from the condition of separation, we find the value of the angle parameter ψ_k, which separates the bulb from the surface of the spiral:

$$\sin\psi_k \geq \frac{P_b}{G}\,. \qquad (5)$$

Because $G = mg$, $P_b = m\omega^2\rho_i$, then

$$\psi_k \geq \arcsin\frac{\omega^2\rho_i}{g}\,. \qquad (6)$$

Determine the point of contact (impact) of the tuber with the conveyor and the speed that it reaches at this point. For this we assume that the tuber, detached from the surface of the spiral at an angular position ψ_k, has a velocity $V_o = \omega\rho_i$.

According to known dependencies [5,9,10 4], the range and altitude will be determined from the following expressions:

$$L = V_o t \cos\psi_k ,$$
$$H = V_o t \sin\psi_k - \frac{gt^2}{2}. \qquad (7)$$

Excluding from the dependencies (7) the time parameter t and combining them, we obtain an expression that describes the trajectory of the movement of the potato tuber center as the dependence of the altitude from range:

$$H(L) = L\, tg\psi_k - \frac{gL^2}{2V_o^2 \cos^2\psi_k}. \qquad (8)$$

At the same time, the bulb will have a speed at the point of height H:

$$V_H = \sqrt{V_o^2 - 2gH} =$$
$$= \sqrt{V_o^2 - 2g\left(L\, tg\psi_k - \frac{gL^2}{2V_0^2 \cos^2\psi_k}\right)}. \qquad (9)$$

If, through the center of the tuber C, a coordinate system with a horizontal axis x and a vertical axis y is made, and in the expression (8) the parameters L and H the current coordinates are replaced x and y, accordingly, then the flight law of the tuber in this coordinate system will take the following form:

$$y(x) = x\, tg\psi_k - \frac{gx^2}{2V_o^2 \cos\psi_k}. \qquad (10)$$

In the design of an improved spiral separator at a height H_o from the center of the first spiral, a conveyor is installed at an angle β to the horizon with a slope towards the transport of technological mass. Its surface (lower working part) will be described in the same coordinate system by the following equation:

$$y(x) = H_o - (\rho_i + R_á)\sin\psi_k - x\, tg\beta . \qquad (11)$$

It is obvious that the point of contact of the bulb with the deflecting conveyer is the point of intersection of the trajectory (10) of the flight of the tuber with the surface of the conveyor (the plane described by expression (11)), and therefore the coordinates of the point of the contact in the coordinate system xCy can be determined from the solution of the system of equations (10) - (11). Since the left-hand sides of these equations will be equal in this case, then equating the right-hand sides of these equations after some transformations, we obtain the following square equation for a relatively unknown coordinate x:

$$\begin{aligned}&\frac{gx^2}{2V_o^2\cos^2\psi_k}-\left(tg\beta+tg\psi_k\right)x+\\&+\left[H_o-\left(\rho_i+R_б\right)\sin\psi_k\right]=0.\end{aligned} \tag{12}$$

Solving the obtained equation we find the value of the flight range of the tuber prior to the interaction with the conveyer:

$$\begin{aligned}x=\frac{V_o^2\,cos^2\psi_k}{g}\cdot\Bigg\{&\left(tg\beta+tg\psi_k\right)+\\&+\sqrt{\left(tg\beta+tg\psi_k\right)^2-\frac{2g\left[H_o-\left(\rho_i+R_б\right)sin\psi_k\right]}{V_o^2\,cos^2\psi_k}}\Bigg\}.\end{aligned} \tag{13}$$

The height of the flight of the center of the tuber and its velocity at the point of contact will be determined by the substitution of the solution (13) in formulas (11) and (9), respectively.

The velocity V_H at the point of contact will be directed at an angle χ to the horizon whose tangent is defined as the derivative of the function (10) for the variable x:

$$tg\chi=\frac{dy}{dx}=tg\,\psi_k-\frac{gx}{V_o^2\cos^2\psi_k}. \tag{14}$$

The resulting potato tuber velocity $\overline{V}$ at impact will be equal to the vector velocity of the bulb at the point of contact $\overline{V}_H$ and the speed of the conveyor $\overline{V}_T$:

$$\overline{V}=\overline{V}_H+\overline{V}_T, \tag{15}$$

or

$$V = \sqrt{V_H^2 + V_T^2 - 2V_H V_T \cos\left(V_H \hat{,} V_T\right)}, \tag{16}$$

де $\cos\left(V_H \hat{,} V_T\right)$ – direction cosine of the velocity vector of the bulb at the moment of contact $\overline{V}_H$ to the velocity vector of the conveyor V_T. According to the strike scheme (Fig. 1), it follows that:

$$\cos\left(V_H \hat{,} V_T\right) = -\cos(\beta + \chi). \tag{17}$$

Then

$$V = \sqrt{V_H^2 + V_T^2 + 2V_H V_T \cos(\beta + \chi)}. \tag{18}$$

To fulfill the condition of "no damage" to tubers, it is necessary that the resulting speed of the body after impact does not exceed the maximum permissible value, which according to [3, 11] we will accept 4...5 m·s^{-1}. Substituting expression (9) in expression (18) and taking into account the above-mentioned restriction on the velocity of the tuber after impact, we obtain a kinematic condition for its not damage during impact on the surface of the deflecting conveyor:

$$V = \sqrt{\omega^2 \rho_i^2 - 2g\left[L\,tg\psi_k - \frac{gL}{2\omega^2\rho_i^2 cos^2\psi_k}\right] + V_T^2 + \overline{\left. +2\sqrt{\omega^2\rho_i^2 - 2g\left[L\,tg\psi_k - \frac{gL}{2\omega^2\rho_i^2 cos^2\psi_k}\right]}V_T\, cos(\beta+\chi) \right)}} \le [V]. \tag{19}$$

The realization of the obtained dependence (20) with the help of applications for the PC allowed to determine the parameters of the improved design of the spiral separator without damage to the potato tubers, which leads to an increase in the efficiency of the spiral separator and reducing the damage to the tubers.

According to the developed program for PC in the environment Mathcad were made numerical calculations that gave the opportunity to build graphic dependencies (Fig. 3 – Fig. 5).

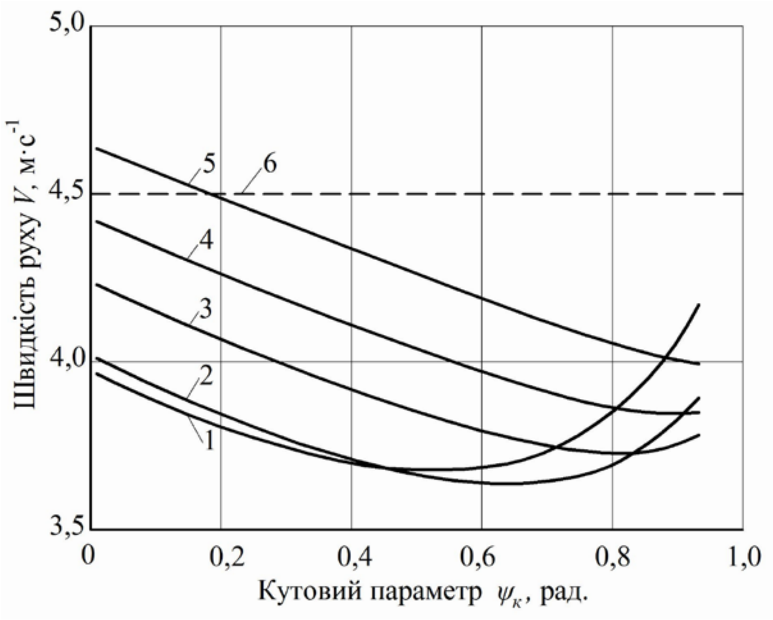

Fig. 3. – Dependence of the speed of the tuber on the angle parameter ψ_k at different values of the radial parameter ρ:
1 – ρ = 0.24 m; 2 – ρ = 0.27 m; 3 – ρ = 0.32 m; 4 – ρ = 0.35 m; 5 – ρ = 0.38 m; 6 – restriction of speed without bulb damage

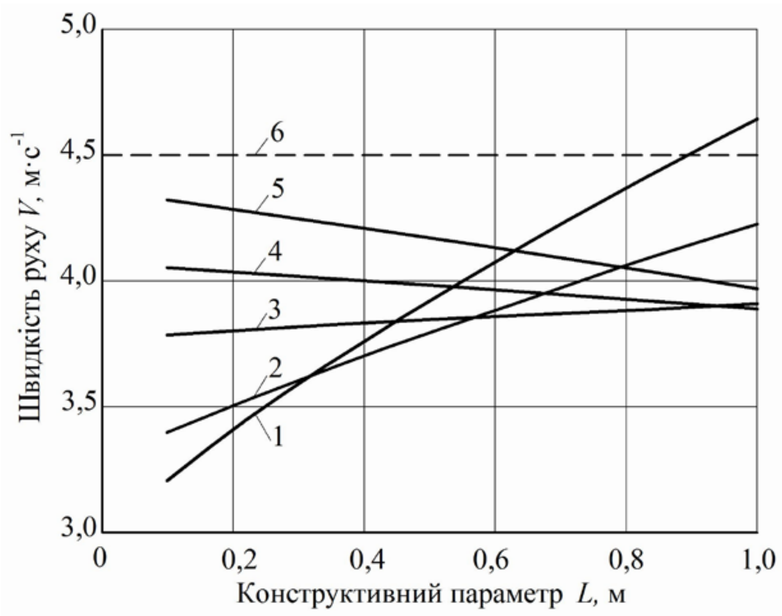

Fig. 4. – The dependence of the speed of the tuber on a constructive parameter L with different values of the radial parameter ρ:
1 – ρ = 0.24 m; 2 – ρ = 0.27 m; 3 – ρ = 0.32 m; 4 – ρ = 0.35 m; 5 – ρ = 0.38 m; 6 – restriction of speed without bulb damage

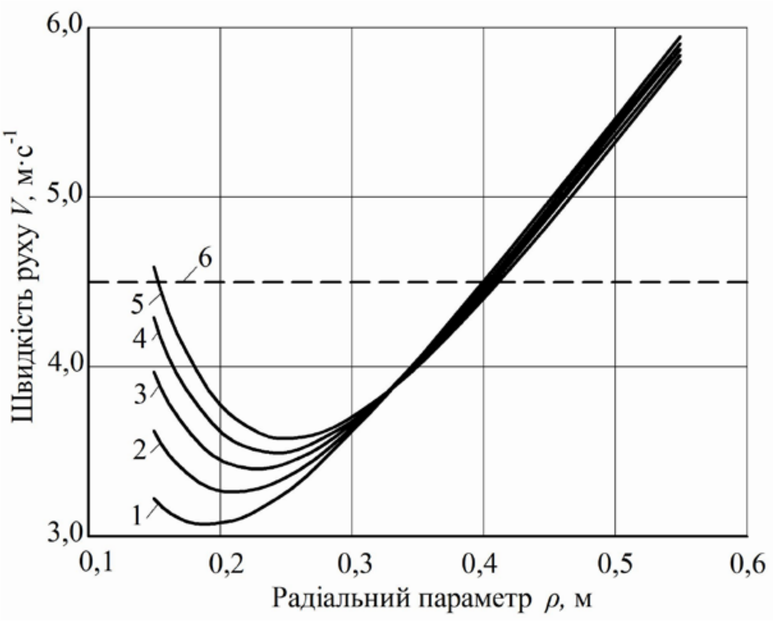

Fig. 5. – Dependence of the velocity of the tuber on the radial parameter ρ at different values of the constructive parameter L:
1 – L = 0.10 m; 2 – L = 0.15 m; 3 – L = 0.20 m; 4 – L = 0.25 m; 5 – L = 0.30 m; 6 – restriction of speed without bulb damage

As you can see from the charts of Fig. 3, the angular parameter ψ_k can be selected by the values of the radial parameter ρ= 0.24 m and ρ= 0.27 m, which equals 0.4...0.6 rad. Other sizes ρ are not desirable, provided that the size of the spiral cleaner increases. The curves shown in Fig. 4, indicate that the advantage should be given to lengths L which are 0,2 ... 0,5 m, based on the pre-adopted values ρ. Also, under the conditions of the pre-design parameters of the spiral cleaner (ψ_k and L) adopted, as shown in the curves in Fig. 5, the radial parameter ρ must have the above values.

Conclusions

1. A new calculated mathematical model of the flight of potato tubers from the surface of the spiral separator and its impact on the reflecting conveyor.

2. On the basis of the obtained analytical dependencies, the kinematic parameters of the spiral separator of the potato harvesting machine of the improved design were theoretically studied in its interaction with the bulb, provided that it is "non-damage".

3. The rational structural parameters of the spiral separator provided that the potato tubers are not damaged should be considered ρ = 0.26 m, ψ_k = 0.5 rad., and L – not more than 0,5 m.

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