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# Theory of process of cleaning potato with spiral separator

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**The purpose.** To raise overall performance of spiral separator on the basis of development of the new theory of movement of a tuber of potato on its surface. That will enable to determine constructive and kinematic parameters of the developed construction of spiral separator of potato heap, ensure excellence of cleanout, and eliminate damage of tubers. **Methods.** Theoretical mechanics and higher mathematics. **Results.** The designed at the level of invention spiral separator ensures, by results of the lead experiments, necessary level of separation of ingredients of heap. That forms a foundation for the further determination of its most rational parameters and operating conditions. As a result of the carried out analytical research the equivalent scheme of interaction of a tuber of potato, approximated by a material corpuscle on a surface, organized by two console-mounted spirals (end-effectors of cleaner) is created. Spirals of separator are brought in gyrating driving and can simultaneously realize oscillating movements in longitudinal-vertical plane under action of varying load caused by continuous feed on cleanout of potato heap. Forces acting on it are affixed to a body of potato tuber. For the designed equivalent scheme the system is made which consists of three differential equations of movement of a body of potato tuber on the surface of the cavity, organized by two cantilever spirals. **Conclusions.** After necessary transformations and getting fixed parameters there is an opportunity to solve the gained set of equations on the PC and to probe effect of constructive and kinematic parameters of spiral separator of potato heap on speed of migration of a tuber. Kinematic and design parameters specified in such way will ensure improvement of quality of cleaning potato tubers from soil and vegetable admixtures.

***Key words:*** *potato, tuber, spiral separator, equivalent scheme, forces, differential equations, design parameters.*

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**Objective:** Improving of the efficiency of the spiral separator on the basis of the development of a new theory of potato tuber movement on its surface, which will give an opportunity to determine the constructive and kinematic parameters of the improved design of the spiral potato separator.

**Methods**: Theoretical mechanics, higher mathematics.

**Results**: Designed at the level of the invention, the spiral separator provides, based on the results of experimental researches, required level of separation of the components of a heap, which serves as the basis for further identification of its most rational parameters and operating modes. As a result of the conducted analytical research, an equivalent scheme of interaction of potato tubers, an approximated material particle located on the surface formed by two cantilevered spirals (working organs of the cleanser), was constructed. Separator spirals are rotated and can simultaneously perform oscillatory movements in a longitudinal-vertical plane under the action of an alternating load due to the continuous supply of potato heap. On the body of the potato tubers, accordingly, forces are active. For the developed equivalent scheme, a system consisting of three differential equations of motion of the body of potato tubers on the surface of the depression formed by two console-mounted spirals is compiled.

**Conclusions**: After completing the necessary changes and default constant parameters is possible to solve the resulting system of equations on the PC and explore the impact of structural and kinematic parameters spiral separator to pile potato tubers velocity. Defined in this way the kinematic and structural parameters will improve the quality of treatment of potato tubers from soil and vegetable impurities.

**Key words**: potato, bulb, spiral separator, equivalent scheme, forces, differential equations, constructive parameters.

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An Improving the quality of cleaning potatoes from soil and vegetable impurities immediately after digging out of the soil provides an opportunity to improve the main indicators of the process of harvesting. Therefore, a new design of a spiral separator of potato heap is proposed, which differs from the existing with high separating properties and much less material content. This development is protected by the patent of Ukraine [1].

It is necessary to analyze analytically the process of interaction of a potato tuber with a spiral separation surface of a cleaner with the purpose of definition of optimal constructive and kinematic parameters of the mentioned construction. And first of all, it is necessary to construct a calculated mathematical model of this process. Numerical simulation on a PC of this process on the basis of the constructed mathematical model will allow to determine the optimal value of the parameters taking into account the conditions of damage to potato tubers for the realization of the cleaning process.

**Analysis of recent researches and publications**: In world practice there are many different constructions of separators and potato heap cleaners after its digging from the soil, and a significant number of scientific works in this area have been published in various countries. Among the published works there are also devoted to the description of the conditions that provide the steady movement of potato tubers on the separation surfaces of cleaners and quality sifting of soil and plant impurities from the separation zone. The new design of the spiral separator of the potato heap, developed by us, is a set of 3 spirals, console mounted on drive shafts [1]. A pile of potatoes is fed on these spirals from above, as a result, a significant part of soil impurities immediately sifted down. Potato tubers are captured by spiral turns and transported in axial directions to their ascent from the separation surface. Spiral springs are not admired by the turns of the spiral arms, so the spirals have the opportunity to self-clean themselves in the process of working from wet sticky soil. Experimental studies of this separator have shown positive results [2 - 4], which serve as the basis for continuing the study of this process in order to optimize the constructive and kinematic parameters of the new separator device.

**The purpose of the research**: The development of a new potato tuber movement theory on its surface will give an opportunity to determine the constructional and kinematic parameters of the improved construction of a spiral separator of potato heap that provide high quality cleaning and eliminating the tuberculosis.

**Methods:** Theoretical mechanics, higher mathematics.

**Research results**: To build a mathematical model for calculating the transfer of potato tubers on the working surface of a spiral separator, we shall represent a potato bulb in the form of a ball having a mass *m* and radius *rb.* Let's make an equivalent scheme, considering the variants of relative displacement of a single potato tuber on a spiral separator surface. The spiral separator is represented in the form of 2, mounted console, drive spirals 1 and 2 (figure), which rotates around their longitudinal, parallel axes, with the same angular speeds *w*. Consequently, one ends of the specified helix is mounted on a stationary drive shaft, while others are located freely. The winding directions of spirals 1 and 2 are shown by arrows. The same in sizes step S winding is shown in the figure. First, a potato tuber with center of mass at point C, hits the surface of the first spiral 1 of a given radius R with the angle of helix g. Spiral winding 1 helix begins to bring potato tubers into a joint movement, that is, in the rotational movement together with the helical winding and the translational motion in the axial direction of the spiral, i.e. in the direction of its winding.

However, under the influence of the strength of the weight of the bulb itself and the rotation of the spiral 1 potato tubers in a very short time will appear in the between two nearby spirals 1 and 2. Therefore, the main movement of the potato tubers along the axis of the spiral will be carried out only when the bulb is in the formed by two nearby spirals 1 and 2. This way, it is worth considering the transportation of potato tubers for the case when the tuber falls into the cavity formed by two nearby spiral separator.

Let's consider the intrusive movement of potato tubers along the grooves between the turns of spirals 1 and 2 as the most characteristic. Usually, at a certain angular speed w, the rotation of the spiral 1 under the action of the centrifugal forces of inertia can break away from the surface of the spiral 1 and fly through all three spirals, but such a case should be considered uncharacteristic for the working angular speeds of the spiral rotation. Because a potato, while in the specified cavity between helices 1 and 2 at the same time is between two nearby turns of the spiral 1, which continues to rotate, the turns slipping on the surface of the tuber, but holding the bulb on both sides of the groove formed by them, will move it in the axial direction to the east from the working surface.

Since the spiral 2 also rotates in the same direction as helix 1, and the turns are directed in both spirals the same, then turn of the spiral 2, resting in bulb, will slide on its surface, playing the role of a support surface.

Consequently, the contact of a tuber with surfaces of spirals 1 and 2 during its movement along the axis of the spiral will occur at 3 points *K1, K2* and *K3*.

However, the translational movement of the potato tubers along the axis of the spiral is only theoretically (taking into account the geometric properties of the screw line) will be close to the straight line. In fact, under the influence of a series of random factors, in particular the weight of the potato heap mass, the indicated spirals will, in the first approximation, carry out linear vertical oscillations that contribute to the sifting of potato soil and other plant additives collected together with the potato tubers and to cleaning the lateral surfaces of the tubers from the cluttered soil. Obviously, the indicated oscillations will be random.

Therefore, the main movement of potato tubers will be its translational movement along the axis of the spiral (namely, along the cavity between the spirals 1 and 2) under the action of the reaction from the screw groove. This screw groove serves as a bundle forming on its side the direction of the normal reaction which acts on potato tubers when it moves along the axis of the spiral, and the equation of this line is an equation of the link. It is obvious that during the movement of potato tubers along the axis of the spiral with the simultaneous oscillation of the spirals, the main cleaning of potato tubers from the soiled soil and sifting of soil and other impurities from the potato heap supplied for separation occurs. Therefore, firstly we will study the process of moving the tuber, located in the depression between two spirals, under the action of screw-shaped spiral turns.

To build a calculated mathematical model of this process, we construct an equivalent scheme for the interaction of potato tubers with the surfaces of the turns of the separator spirals. The tuber of a potato is in the cavity between spirals 1 and 2, and spiral 1 is located in the space between two nearby turns leaning its surface on both of the spiral turns. Stage 2, as noted above, will be retaining. Therefore, as shown in the figure, in the points *K1*, *K2* and *K3*, the contacts of the spirals with the surface (close to the spherical view) of the tubers are normal reactions *N1, N2* and *N3*, in accordance. At the center of the masses of potato tubers (point C), the weight *G* of the tuber, directed vertically downwards, is applied.

Potato tuber movement caused by the action of the equivalent system of forces indicated in the equivalent scheme (figure) will be considered in a fixed Cartesian coordinate system *xOyz*, the beginning of which (point O) is located on the longitudinal axis of the spiral 1, whose axis *Oz* coincides with the longitudinal axis of the spiral 1, the axis *Oy* is directed vertically upwards, the *Ox* axis is directed to the right and is located in the plane of the cross-section of the spiral.

Next, characterize the forces applied to the potato tubers and shown on an equivalent scheme. This, above all: *N1, N2* and *N3* - normal reactions of the surface of the turns of the spirals 1 and 2, in accordance, directed along the common norms to the turns and the surface of the tubers at the points of contact *K1, K2* and *K3*, in accordance, and pass through the center of the tuber (point C). Their lines of action intersect at point *C*.

*F1, F2* and *F3* are the frictional forces that arise when slipping the turns of the spirals 1 and 2 on the surface of the potato tubers at the contact points *K1, K2* and *K3*, in accordance. They are directed to the sides of the rotation of the spirals on the common tangent to the turns and the surface of the potato tuber. Slip friction forces will be equal:

$$F_i = f * N_i,\ \ i = 1,2,3, \tag{1}$$

where f is the coefficient of friction slipping potato tubers on the material from which the spiral is made (most often spring steel). For potato tubers we take *f=0.2…0.3 [5,6].*

G-the gravity of potato tubers is determined from the following expression:

$$G = mg.\ H \tag{2}$$

where m - mass of tubers, kg; g - acceleration free fall, $m*s^{-2}$. $\overline{P_v}$- the power of active actions of the fed potato heap on the spiral separator, *H*.

We make the equation of motion of a potato tuber in a vector form based on the obtained equivalent scheme (figure):

$$m\bar{a} = \bar{G} + \overline{N_1} + \overline{N_2} + \overline{N_3} + \overline{F_1} + \overline{F_2} + \overline{F_3} + \overline{P_v} \tag{3}$$

where *a* is the acceleration of the movement of potato tubers under the influence of this system forces*, m*$s^{-2}$.

In projections on the axis of the stationary Cartesian coordinate system *xOyz*, taking into account the fact that the bulb is located symmetrically in the cavity between the spirals 1 and 2, that is, that its center of mass (point C) is located in the middle of the indicated cavity, the vector equation (3) will have the following form:

$$\left.\begin{aligned}
m\ddot{x} &= (N_1 + N_2)\cos\left(x,\hat{\bar{n}}_1\right) - N_3\cos\left(x,\hat{\bar{n}}_3\right) - \\
&\quad -(F_1+F_2)\cos\left(x,\hat{\bar{V}}_1\right) - F_3\cos\left(x,\hat{\bar{V}}_3\right), \\
m\ddot{y} &= (N_1 + N_2)\cos\left(y,\hat{\bar{n}}_1\right) + N_3\cos\left(y,\hat{\bar{n}}_3\right) - \\
&\quad -(F_1+F_2)\cos\left(y,\hat{\bar{V}}_1\right) - F_3\cos\left(y,\hat{\bar{V}}_3\right) - \\
&\quad -G - P_V, \\
m\ddot{z} &= (N_1 - N_2)\cos\left(z,\hat{\bar{n}}_1\right) + N_3\cos\left(z,\hat{\bar{n}}_3\right) - \\
&\quad -(F_1+F_2)\cos\left(z,\hat{\bar{V}}_1\right) - F_3\cos\left(z,\hat{\bar{V}}_3\right),
\end{aligned}\right\} \tag{4}$$

where $\overline{n_1}$, $\overline{n_3}$- general normal to the turn surface and potato tubers at the points of contact *K1, K2* and *K3*, in accordance; $\overline{V_1}, \overline{V_2}$-the speed vector relative movement of the potatoes tubes along the turns of the spirals at the contact points *K1, K2* and *K3*, accordance, which are directed at the common tangent to the surface of the coil and tubers in the direction opposite to the circular speed of revolution at the point of contact.

Directional *cos* of the angles which are included in (4) between the axes of the coordinate system *xOyz* and the direction of the normal to the surface of the turns in the points *K1, K2* and *K3* of the contact of the tubers with the turns of spirals 1 and 2 are determined according to [3].

For cylindrical spiral 1 with dimensioned sizes, whose longitudinal axis coincides with the axis of coordinates Oz, the equation of the binding in the Cartesian coordinate system *xOyz* will look like [7, 8]:

$$f_1 = \frac{S^2}{4\pi^2}\left[\frac{x*sin\frac{2\pi z}{S} - y*cos\frac{2\pi z}{S}}{\sqrt{x^2+y^2}}\right]*\cos\left(\frac{S}{2\pi\sqrt{x^2+y^2}}\right) + \left(\sqrt{x^2+y^2} - R^2\right) - r^2 = 0 \qquad (5)$$

where S is the step of the spiral winding.

Since the longitudinal axis of symmetry of the spiral 2 is shifted to the right along the *Ox* axis with an interaxial distance equal to a, then its equation of the link in the Cartesian coordinate system *xOyz* can be obtained from expression (5) by replacing the variable *x* to *x-a.*

Substituting the above expressions of the *cos* of the angles between the coordinate axes and the normal reactions of the spiral turns at the points of contact *K1, K2* and *K3*, as well as the expressions of the cos of the angles between the vectors of the relative speeds of moving the tubes along the turns of the spirals and coordinate axes at the points of contact *K1, K2* and *K3*, which can be determined according to [9,10] in the system of differential equations (4), we obtain the following system of differential equations:

$$\left.\begin{aligned} & m\ddot{x} = (N_1 + N_2 - N_3)A_1 - (fN_1 + fN_2 + fN_3)B_1, \\ & m\ddot{y}(N_1 + N_2 + N_3)A_2 - (-fN_1 - fN_2 + fN_3)B_2 - \\ & -mg - P_V, \\ & m\ddot{z} = (N_1 - N_2 + N_3)A_3 - (fN_1 + fN_2 + fN_3)B_3, \end{aligned}\right\} (6)$$

This way, we obtain a system of differential equations (6) for moving a potato tuber under the action of turns of a rotating spiral when the bulb is in the cavity between nearby spirals in the absolute *xOyz* coordinate system.

However, since the rotation of the spirals is carried out with constant angular speeds *w = const*, then with such a steady motion potato tubers will move at a constant speed i *V, i = 1, 2, 3*, relative to the surface of the turns of the spirals 1 and 2.

In the absolute coordinate system of the projection of its speed, the displacement will be equal to: *Vx =*

*Vy = 0, Vz = Sw· (2p) - 1 = const*, since the potato tuber in the form of a material particle will only move

along the *Oz* axis.

Consequently, the acceleration of the bulb *x, y* and *z* along the 3 axes of *Ox, Oy* and *Oz* coordinates respectively, can be considered equal to zero. Therefore, equating the left-hand sides of the differential equations of system (6) to zero, we obtain a system of linear equations of uniform rectilinear motion of potato tubers along the cavity between 2m nearly spirals of relatively unknown *N1, N2* and *N3*, which, for example, can be solved by the Cramer method.

The next step in constructing a mathematical model for cleaning the potatoes on the surface of a spiral separator is the compilation of a program and a numerical solution on the PC obtained system of equations, which will enable to determine its optimal parameters. Further, it is also necessary to analytically investigate the possible rotations of the potato tuber body when its found on the surface of a spiral separator under the action of moments created by frictional forces.

**Conclusion**:

A new theory of potato clearing by the working organs of a spiral separator was constructed, which enables to determine rational structural and kinematic parameters of it by calculation method.It is established that the main movement of potato tubers is carried out in the cavities between two nearby spiral separators, where the clearing of the tubers from the stuffed soil and impurities takes place. The system of linear equations of uniform rectilinear motion of potato tubers is obtained, which, in essence, are equations of the relative equilibrium of the position of the tuber in the cavity between the turns of the two nearby spirals.

The solution of the obtained system of equations using the PC makes it possible to construct graphic dependencies that characterizing the influence of the structural and kinematic parameters of the spiral separator on the separation of potato heap and the cleaning of the tubers from the soil and admixtures.

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