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Mathematical model of oscillating motion of spiral of cleanser of potato from admixtures

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The purpose. To study oscillating process of working spirals of cleanser of potato from admixtures for intensification and improvement of quality of the process. **Methods.** Theoretical researches are carried out with the use of basic methods of simulation, higher mathematics, theoretical mechanics and strength of materials. In particular, methods of research of oscillations of elastic and strained Bernulli-Eiler rods are used. Krylov's special functions, and also methods of creation of programs and numerical modeling by means of PC are applied. **Results.** New construction of cleanser of heap from admixtures which is applied at digging up of potato from soil is developed and consists of console installed clearing spiral springs. At simultaneous rotational and oscillating movements springs qualitatively clear and carry tubers. Simultaneously spirals self-clean themselves. Theoretical researches of oscillating motion of cleanser made it possible to determine optimum constructive and kinematic parameters. New differential partial equation of oscillations of console cleaning spiral was made. Analytical solution of that equation had allowed to gain the law of oscillating process of cleaning spiral in view of its length for any instant and to evaluate its deformation. **Conclusions.** At modeling on the PC it has been established that at angular velocity of twirl of spiral equal to 30 rad. · s–1, density of material of spiral equal to 7700 kg · m–3, coefficient of elasticity equal to E = 2 · 1011 Pa, radius of a bar of cleaning spiral equal to 8,5 mm, and uniformly distributed load, equal to 1000 N · m–1, the full sag of a spiral on its length varies within the limits from 0 up to 0,25 m. That ensures quality of cleaning and transportation of tubers of potato.

Key words: *tuber of potato, digging up, soil admixtures, console spiral, oscillations, differential equation, numerical calculations on the PC.*

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One of the main requirements to the collection of potatoes is to ensure quality cleaning of potatoes from soil and plant impurities, as well as cleaning of tubers from sticky soil, reducing their damage and losses.

However, the existing potato peeling machines used in modern potato harvesters do not meet the above requirements. As potato harvest often takes place in the soil of high humidity and plasticity, in the existing cleaning tools is often observed clogging of separating gaps with sticky wet soil and plant residues, which significantly reduces the ability of potato peelers to remove impurities, and therefore the quality of potato tubers cleaning.

The new spiral type purifier, which constructive scheme is presented in Fig. 1, corresponds to the above mentioned conditions of potato tubers cleaning from impurities at their digging.

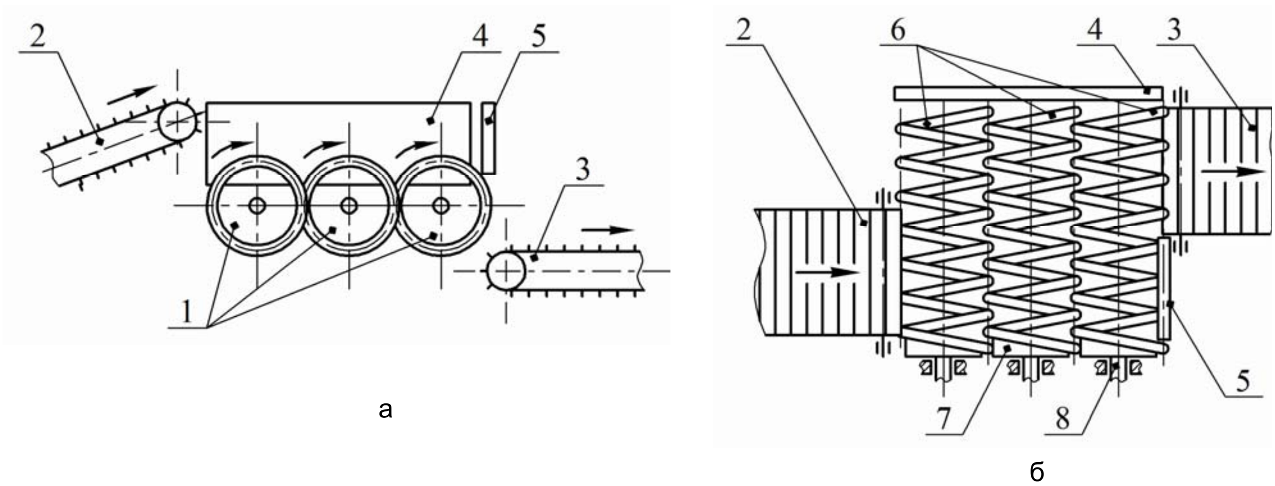

Fig. 1. Spiral potato heap peeler dug out of the soil:

a – side view; b – top view;

1 – cleaning spirals; 2 – feed conveyor; 3 – unloading conveyor; 4 – end face shield screen; 5 – end face protection screen;

6 – free ends of spirals; 7 – hub; 8 – drive shafts

Structurally, this cleaner is made in such a way that the process of destruction of the potato heap dug out of the soil, its division into separate components and removal of soil impurities and plant residues over the cleaning zone is carried out on the successively installed three cleaning spirals 1. Spirals 1 are console mounted on hubs 7 at their one ends, which are mounted on the drive shafts 8, that allow them to rotate in the same direction with a certain angular speed of rotation. The second (free) ends 6 of spirals 1 under the influence of variable load are capable of oscillatory movements in the longitudinal-vertical plane. Supply of the potato tubers heap dug out of the ground is carried out with the help of the feeding conveyor 2, and removal of the peeled potato tubers from the spirals 1 is carried out with the unloading conveyor 3. To prevent loss of potato tubers during the technological process of their cleaning from soil impurities and plant residues around spirals 1, the end 4 and side 5 protective screens of rectangular shape are installed. Cleaning, cantilever located cleaning spirals 1 are installed with mutual overlap, ensuring their self-cleaning from damp sticky soil.

Effective self-cleaning of cleaning spirals 1 occurs due to their oscillatory movements, as a result of which there is a variable deformation of the spirals 1, namely their longitudinal stretching and transverse bending. This leads to the fact that the distance between the adjacent coils of spirals 1, that is, their pitch, is constantly changing, and this contributes to the separation (and compression) of the soil stuck in the intertwist space and its sifting downstream of the cleaner. Thus, in this potato heap cleaner there is not only self-cleaning of cleaning spirals 1, but also intensive separation of soil impurities and plant residues through the gaps between the turns of spirals 1, as well as between the spirals themselves 1.

Analysis of the latest research and publications. The problem of creation and research of potato heap separators was the subject of scientific works [1-8]. However, as it was mentioned above, the cleaning working parts, which were considered in these scientific works, have a significant drawback - sticking of cleaning gaps with soil and plant residues when working on soils of high humidity, which significantly reduces the separating capacity of these working parts. We have developed a spiral separator [9], which is capable not only of effective cleaning of potato tubers from impurities, but also of self-cleaning from sticky soil. We also carried out its tests and previous studies [10, 11, 15]. To optimize the constructive and kinematic parameters of this cleaner it is necessary to conduct theoretical studies of its working bodies.

The investigation of the curved beam axis can be carried out with the help of the differential equation for the case of a free force and torque load at the end [16] or on the basis of the strain compatibility equations [17]. In a simplified form, such deflection calculations can also be carried out with the help of equations, received by S.P. Timoshenko [18]. But in these cases, the beams (rods) of a constant cross section with constant properties are considered. For a spiral whose moment of inertia is a function of longitudinal coordinate and time, these methods do not give new information. Therefore, for this study, the most expedient is the application of the differential equation of transverse bending vibrations of deformed Bernoulli-Euler rods, which consists of the ratio of bending curvature and the differential equation of static bending of self. Bernoulli and the dynamic term attached to it by L. Euler, which takes into account the forces of transverse inertia.For free oscillations, the right part of the equation will be equal to zero, and in case of forcing external influence on the rod, the right part of the equation takes the form of this coercive function. If the load is evenly distributed over time and along the longitudinal coordinate, the right part of the equation takes the form of an evenly distributed load.

The aim of the study - intensification of the impurities removal process from the heap when clearing potato tubers when digging it out.

Materials and methods. Theoretical studies are carried out by using basic methods of modeling, higher mathematics, theoretical mechanics and resistance of materials, in particular methods of elastic vibrations investigation and deformed rods of Bernoulli-Euler and application of special functions of Krylov, as well as methods of programming and numerical modeling using a PC.

Results of the study and their discussion. As an important role in the technological process of potato tubers cleaning from soil and plant impurities is played by vibrational motion of cantilever cleaning spirals, it is necessary to study the mentioned vibrational process first of all analytically.

For this purpose it is necessary, first of all, to construct mathematical model of vibrating process of spirals under the influence of variable loading.

First of all, we will build an equivalent cantilever oscillation scheme on the drive shaft of the spiral, rotating and is under the influence of external load caused by the potato heap, which is on it (Fig. 2).

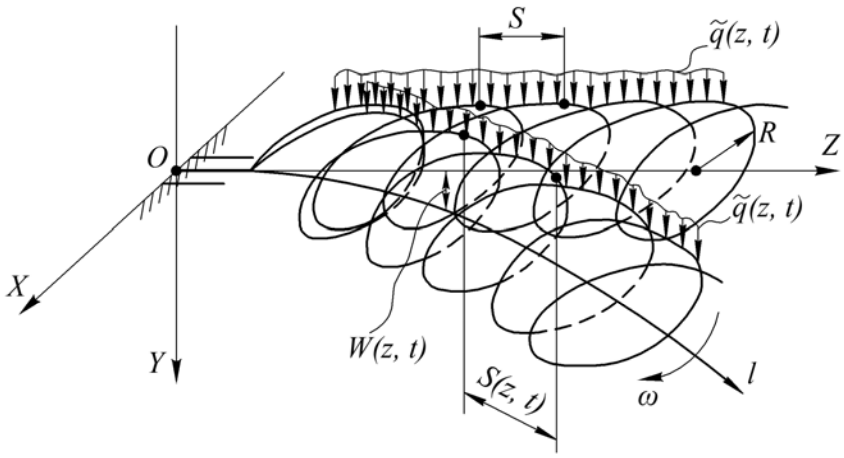

Fig. 2. Equivalent scheme of the spiral spring oscillation potato heap separator

The equivalent scheme (Fig. 2) shows the cleaning spiral in two positions: in the non-deformed state, when its longitudinal axis coincides with the axis *OZ* and in a deformed state when its longitudinal axis has been flexed under the influence of a variable distributed load, indicated $\tilde{q}(z,t)$. This load is due to the continuous flow of potatoes heap from the loading conveyor onto the surface of the cleaning spirals. This diagram shows S – the step of the undeformed spiral, which is of constant importance along the entire length of the spiral, and is also shown S(z, t) – the spiral pitch deformed by an external load. This spiral pitch is variable in the length of the spiral itself and is time dependent as a result of the oscillatory movement of the spiral.The deflection of the longitudinal axis of the spiral marked W(z, t), is also a variable in the length of its axis (coordinate z) and depends on the time (parameter t) as a result of the oscillating motion of the spiral. R – spiral radius. ω – the angular speed of the spiral rotation around its longitudinal axis (the direction of rotation is shown by the arrow).

Study of transverse oscillations of the cantilever cleaning spiral will be carried out in the absolute coordinate system OXYZ, where the axis OZ is directed along the longitudinal axis of the undeformed spiral, the axis OY is directed down, and the axis OX – perpendicular to the plane OYZ. The longitudinal axis of the curved spiral is indicated by O*l*.

Thus, there are all grounds for theoretical consideration of the process of potato heap cleaner helix oscillation, considering it as an elastic rod, which is made in the form of a cylindrical spring with a radius R with a winding step S and angle Y lifting the screw line along the spiral axis.

Note at once that under operating conditions at variable load along the length of the spiral and variable properties of the spiral itself to bending and torsional deformations, the spiral step parameter S becomes variable on length and this change does not correspond to the law of flat sections.

To simplify the consideration in this case and taking into account the rigidity of the spiral, replace the curved rod with a console with the given parameters.

Therefore, in our case, in the first approximation, the bending oscillations of the spiral (conditionally the rod) can be described by the equation of this kind [19]:

$$\frac{\partial^2}{\partial z^2}\left(E\cdot I_R\frac{\partial^2 W}{\partial z^2}\right)+\rho\cdot F\frac{\partial^2 W}{\partial t^2}=\tilde{q}(z,t)\,, \qquad (1)$$

where W – deflection of the longitudinal axis of the spiral; $\tilde{q}(z,t)$ – distributed and time-variable load by the potato heap on the cleaning spiral ; ρ – density of the spiral material; F – Cross-section area of the cleaning spiral bar ; E –Young's modulus; I_R – production spiral moment of inertia.

In the classical theory of bending, the hypothesis is accepted, according to which the flat sections retain their flatness even after bending, and the bending deformation itself is directed according by normal to the longitudinal fibers of the rod. That is, for simplification of theoretical researches in our case position that there is a flat bending is accepted.

The solution of the differential equation (1) is the dependence of the console deflection on length for the case of natural and forced oscillations [20, 21].

As a result of the solution of the differential equation (1) according to the method [20, 21] its general solution will have the following form:

$$W=\left[AS(\lambda z)+BT(\lambda z)+CU(\lambda z)+DV(\lambda z)\right]\cdot\cos(\omega\cdot k\cdot t)+\frac{qL^2\left(\frac{z^4}{L^2}-\frac{2z^3}{L}+6z^2\right)}{24E\cdot I_R}\,. \qquad (2)$$

where S(λz), T(λz), U(λz) and V(λz) – the special functions that Krylov has introduced into the mechanics; A, B, C and D –steels, which are determined, from the boundary conditions; λ – the spectrum of the natural frequencies of oscillation; k – the multiplicity of oscillations (ratio of the natural oscillation frequency to the angular rotation speed of the helix); L – the length of the spiral.

The solution of this differential equation (2) is a dependence reflecting the process of the console helix oscillation as a function of the construction parameters of the helix and the properties of the material.

Since the coefficients at Krylov's function have certain numerical values for each position of the spiral, the solution (2) of the differential equation (1) can be implemented on a PC in the form of graphical dependences, taking into account such structural, kinematic and power parameters: at the angular velocity of the spiral = 30 rad.·s^{-1}, the density of the material (spring steel) from which the coil is made ρ = 7700 kg·m^{-3}, modulus of elasticity E = $2\cdot10^{11}$ Pa, spiral rod radius r = 8,5 mm under the action of evenly distributed load with intensity 1000 H·m^{-1} in moments of time: 1) 0 s; 2) 0,05 s; 3) 0,25 s (fig. 4, 5).

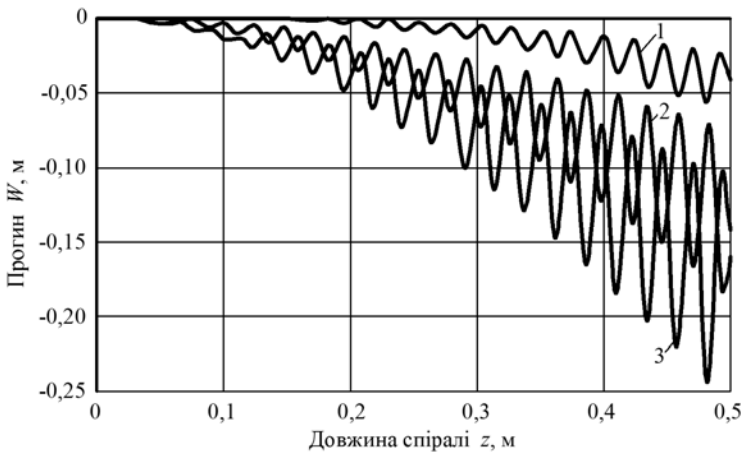

Fig. 3. Dependence of complete deflection W the spiral axis from its length z with its own bending oscillations and the action of evenly distributed load: in moments of time: 1 – t = 0 s; 2 – t = 0,05 s; 3 – t = 0,25 s

Simultaneously taking into account the effects of unloaded helix and distributed load oscillations the deflection of the spiral axis varies from 0 to 0.25 m.

CONCLUSIONS

1. The calculated mathematical model of vibrations of the working bodies of the spiral separator of potato heap is constructed, as a result of which the differential equation of transverse bending vibrations of its cantilever cleaning spiral is made.
2. On the basis of the solution of the differential equation of transverse bending oscillations of the cleaning spiral the analytical expressions which describe the law of vibrational process and deflection of the spiral at any moment of time for any point of its longitudinal axis are received.
3. At an angular velocity of the helix equal to ω = 30 rad.·s^{-1}, the density of the spiral material, ρ = 7700 kg·m^{-3}, modulus of elasticity E = 2·10^{11} Pa, bar radius r = 8,5 mm, uniformly distributed spiral load by potato helix intensity 1000 H·m^{-1} the total deflection of the spiral along its length varies from 0 to 0,25 m.

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