Mathematical simulation of transfer mechanisms of crocheting potato harvesting machine

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Abstract. The article proposes a new basic scheme of a potato harvesting machine, with many times the separation of gruff impurities from potato tubers composition. The transmission mechanisms of the newly developed crocheting potato harvesting machine are mathematically simulated. This model will help the potato harvesting machine developers to determine the required dimensional and dynamic parameters, which are necessary for the development of new machine design. The proposed concept to a certain extent separates the impurities of a heap of potato tubers. Separating devices and improved separator-elevator mechanisms will help to better separate the soil lumps and stone from potato tubers. The mathematical model created by the driving mechanisms of the potato harvester allows you to find the values of the movement on the corresponding working mechanisms. This model will help the developers of the potato harvester to determine the desired dimensional and dynamic parameters that are necessary to develop a new machine design.

1. Introduction

Improving the mechanization of potato raising aims to reduce and prevent damage to tubers. With an increase in damage, the quality of tubers decreases, and their total losses increase. Significantly reduces the quality of the tubers, the stony field, and the formation of clods of the earth, due to the damage they cause during harvesting and post-harvest refinement [1, 2]. So the presence of 1 kg of stones in the mass of tubers leads to damage to 50 kg of the latter. Also, the stony field increases the wear and tear of equipment and the costs of cleaning and processing. Planting with damaged tubers can reduce potato yields by 30% [3, 4].

An electronic-mechanical device for separating impurities from a potato pile weighs each component, determines its geometrical dimensions and mass for converting physical quantities into proportional electrical voltages, calculates the separation criterion, and generates the corresponding electrical signals. An analog processor captures the mass and size of each component of the heap. Then it compares the mass with the product of the sizes [1, 2, 3, 4].

Based on theoretical and experimental studies, in [12,13,14,15,16,17] the parameters of the device separating the potato heap were determined: the height of the fall of tubers should be within 0.2 ... 0.4 m, the angle of inclination of the separation the shield of the actuator - 65 ... 80 degrees., the length and width of the weighing mechanism - 120 ... 150 mm, the width and length of the landmark (apron) - 120 ... 150 mm, the length of the lower and side conveyors - 610 ... 1000 mm, the width of the side conveyor -60 mm, the diameters of the pulleys of the lower and side conveyors - 70 ... 140 mm, the
length divides splicing flap – 120 … 300 mm, a width of dividing flap – 120 … 170 mm. Despite accurate data, highly efficient crocheting mechanisms have not been created. Potato harvesting machines harvest potato tubers with large volumes of soil lumps and stones.

Studies related to finding a method for separating stones and lumps of soil from potato heaps are relevant and timely, and their implementation is of great economic importance for the agro-industrial complex. To maintain the quality of the harvested crop, it is necessary to develop a separator of stones and lumps from potato heaps, simple in design, available in monetary terms, and built into serial machines and lines for harvesting and post-harvest processing of potatoes. The material discusses the improved design of the potato harvester. It is proposed to install reusable separation mechanisms on the machines.

2. Research Methods
The object of study is a schematic diagram of the developed separation mechanisms of a potato harvester. The study is conducted by the method of analysis and mathematical modeling of the action of the drive mechanisms.

3. Results and its discussion
In figure 1 we give a schematic diagram of a newly developed original potato harvesting machine that performs many single-time separations of heap impurities from the composition of potato tubers during harvesting.

Figure 1. Schematic diagram of the potato harvesting machine under development: 1 is lifting elevator-separator conveyor, 3 is incandescent disks, 4 is left and right track rollers, 5 is wheels, 6 is pneumatic balloon, 7 is bogie conveyor, 8 is inclined elevator-separator conveyor, 9 is elevator-separator conveyor, 10 is topper, 11 is pneumatic (hydro) separation chamber, 12 is automatic (or mechanical selection) elevator-separator, 13 is lifting elevator and separation conveyor.
Design is performed so that all conveyor, elevator-separator, the conveyor is reinforced with a change in its overall dimensions, there are several places of reinforcement to the frame. Length 2.5-3 m; height 2.5-3 m (without the height of the lifting conveyor) [5, 6].

The following separation processes were studied [7]:

The first special separation process. The mass passes between the papillon conveyor and the pneumatic balloon and without any damage to the potato tubers, some clumps of soil will break. And when climbing the elevator-separator conveyor, once again, crushed lumps and granules of soil fall to the ground. At the end of this conveyor, the rubber fingers of the topper remove the root and stem leaves from the mass medium. The removed tops rush to the back of the machine far away.

The second special separation process. Brush drums are installed in front of the longitudinal bucket conveyor. In it, elastic brushes run into small stones and lumps between drums. Further, the potato mass above the brush moves and passes over the elevator-separator conveyor.

The third special separation process. The next separation process is carried out in a pneumatic separation chamber. The mass will enter the chamber using an elevator-separator conveyor. The air pump under pressure delivers air inside the chamber and the heavy part of the mass is held down and the light part of the mass occupies the position at the top. Usually, the stones are heavier than the potato tubers and here the bucket conveyor removes the backside of the machine.

The fourth special separation process. The drum with elastic coatings is placed at the end of the elevator-separator conveyor. This drum with its elastic forces, using different masses of potatoes, lumps, and stones, throws them at different lengths and areas of the elevator-separator. The blades mounted above the elevator-separator are removed lumps and stones to the side.

The fifth special separation process. A moisture-retaining film is covered above the mechanical-selective elevator-separator and a sprinkler chamber is fixed. Water rains over the mass, potato tubers are washed and clay is fixed over a moisture-retaining film. Further, the rubber-reinforced counter removes clay. Finally, the lifting elevator and separation conveyor lifts the soil and stone separated from the lump, peeled from various dirt of potato tubers into the bunker of the cart.

Mathematical simulation of potato harvesting driving mechanisms.

To facilitate the simulation, we accept the following assumptions: energy division in the transfer gearbox, we believe that evenly divide between the seven mechanisms; we accept that the automatic elevator-separator does not take energy from the transfer gearbox; the oscillation and stability parameters are neglected, etc.

Equations describing rotationally moving mechanical mechanisms from an energy source (Figure 2), for ease of understanding, the angular velocity $\omega$ is replaced by the angle $\varphi$.

\[
\begin{align*}
(J_d + J_{at1})\dot{\varphi}_d + k_d(\varphi_d - \varphi_{at1}) + c_d(\varphi_d + \varphi_{at1}) &= M_d - \frac{M_{at1}}{I_d}, \quad \varphi_d = \varphi_{at1} \\
(J_{at1} + J_{at2})\dot{\varphi}_{at1} + c_{at1}(\varphi_d + \varphi_{at1}) &= -M_{at2}\text{sign}(\varphi_{at2})\dot{\varphi}_{at2} \\
J_{tr}\dot{\varphi}_{tr} + k_{at3}(\varphi_{at2} - \varphi_{tr}) + c_{tr}(\varphi_{at2} + \varphi_{tr}) &= -M_{tr}\text{sign}(\varphi_{tr})\dot{\varphi}_{tr} \\
J_{1}\dot{\varphi}_1 + k_1(1/7 \dot{\varphi}_{tr} - \dot{\varphi}_1) + c_1(1/7\dot{\varphi}_{tr} + \varphi_1) &= -M_1\text{sign}(\varphi_1)\dot{\varphi}_1,
\end{align*}
\]

Figure 2. Equivalent design diagram of the drive mechanisms of the developed potato harvesting machine.
\[ J_7 \ddot{\varphi}_7 + k_7(1/7 \dot{\varphi}_7 - \dot{\varphi}_r) + c_7(1/7 \varphi_{rr} + \varphi_7) = -M_7 \text{sgn}(\varphi_7)\tau_7, \]
\[ J_8 \ddot{\varphi}_8 + k_8(1/7 \dot{\varphi}_8 - \dot{\varphi}_8) + c_8(1/7 \varphi_{rr} + \varphi_8) = -M_8 \text{sgn}(\varphi_8)\tau_8, \]
\[ J_9 \ddot{\varphi}_9 + k_9(1/7 \dot{\varphi}_9 - \dot{\varphi}_9) + c_9(1/7 \varphi_{rr} + \varphi_9) = -M_9 \text{sgn}(\varphi_9)\tau_9, \]
\[ J_{10} \ddot{\varphi}_{10} + k_{10}(1/7 \dot{\varphi}_{10} - \dot{\varphi}_{10}) + \varphi_{10} = -M_{10} \text{sgn}(\varphi_{10})\tau_{10}, \]
\[ J_{11} \ddot{\varphi}_{11} + k_{11}(1/7 \dot{\varphi}_{11} - \dot{\varphi}_{11}) + \varphi_{11} = -M_{11} \text{sgn}(\varphi_{11})\tau_{11}, \]
\[ J_{12} \ddot{\varphi}_{12} + k_{12}(1/7 \dot{\varphi}_{12} - \dot{\varphi}_{12}) + \varphi_{12} = -M_{12} \text{sgn}(\varphi_{12})\tau_{12}, \]
\[ J_{13} \ddot{\varphi}_{13} + k_{13}(1/7 \dot{\varphi}_{13} - \dot{\varphi}_{13}) + \varphi_{13} = -M_{13} \text{sgn}(\varphi_{13})\tau_{13}. \]

where \( J_d, J_{MS1}, \omega_d, \omega_{MC1}, M_d, M_{MS1} \) are the moment of inertia, angular speeds and torques of the engine and the left side of the clutch; \( J_{MS2}, \omega_{MC2}, M_{MS2} \) are the moment of inertia, angular velocity and torque of the right side of the clutch; \( J_T, \omega_T, M_T \) are the moment of inertia, angular velocity and torque of the transfer gearbox; \( J_1, \omega_1, M_1 \) are the moment of inertia, angular velocity and torque of the separating mechanism; \( J_7, \omega_7, M_7 \) are the moment of inertia, angular velocity and torque of the arched conveyor; \( J_9, \omega_9, M_9 \) are the moment of inertia, angular velocity and torque of the inclined elevator-separator conveyor; \( J_{10}, \omega_{10}, M_{10} \) are the moment of inertia, angular velocity and torque of the elevator-separator conveyor; \( J_{11}, \omega_{11}, M_{11} \) are the moment of inertia, angular velocity and torque of the topper; \( J_{12}, \omega_{12}, M_{12} \) are the moment of inertia, angular velocity and torque of the pneumatic (hydro-) separation chamber; \( J_{13}, \omega_{13}, M_{13} \) are the moment of inertia, angular velocity and torque of the elevator and separation conveyor; \( k_i \) and \( c_i \) are the damping and stiffness coefficients of the respective drive and separation mechanisms, respectively. 1/7 is the values that are divided into seven mechanisms on the transfer gear of movement.

4. Conclusions

The proposed concept to a certain extent separates the impurities of a heap of potato tubers. Separating devices and improved separator-elevator mechanisms will help to better separate the soil lumps and stone from potato tubers.

The mathematical model created by the driving mechanisms of the potato harvester allows you to find the values of the movement on the corresponding working mechanisms. This model will help the developers of the potato harvester to determine the desired dimensional and dynamic parameters that are necessary to develop a new machine design.

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