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ТЕОРЕТИЧЕСКОЕ ОБОСНОВАНИЕ ТЕХНИЧЕСКОГО СРЕДСТВА МАШИННОЙ УБОРКИ КАРТОФЕЛЯ

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Сепарирующие элеваторы являются наиболее распространенными, так как они достаточно эффективны из-за высокой разделительной и транспортирующей способности. Однако, во время разделения взаимное перемещение компонентов картофельной массы может быть затруднено. Для интенсификации процесса сепарации используются различные устройства для использования всей ленты элеватора вместе с грунтом, что приводит к высокому энергопотреблению. Кроме того, применение активных интенсификаторов приводит к увеличению количества повреждений клубней. Попав на элеватор, клубни часто скатываются по нему, что также увеличивает процент потерь и повреждений. Для повышения эффективности разделения грунта были разработаны элеваторы с шарнирными штангами

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THEORETICAL JUSTIFICATION OF THE TECHNICAL MEANS OF POTATO MACHINE HARVESTING

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Bar separating elevators are the most common ones, as they are quite efficient because of high separating and transporting capacity. However, during separation, the mutual movement of components of the potato heap is difficult (reorientation of particles). To intensify the separation process, various devices are used to throw the entire elevator belt together with the soil, which leads to high energy consumption. In addition, the use of active intensifiers leads to an increase in damage to tubers. Once on the elevator, the tubers often roll down it, which also increases the percentage of losses and damage. To increase the efficiency of soil separation, elevators with joint bars have been developed

Ключевые слова: КАРТОФЕЛЕУБОРОЧНАЯ МАШИНА, СЕПАРАЦИЯ, ЭЛЕВАТОР, УБОРКА, КАРТОФЕЛЬ

Keywords: POTATO HARVESTER, SEPARATION, ELEVATOR, HARVESTING, POTATOES

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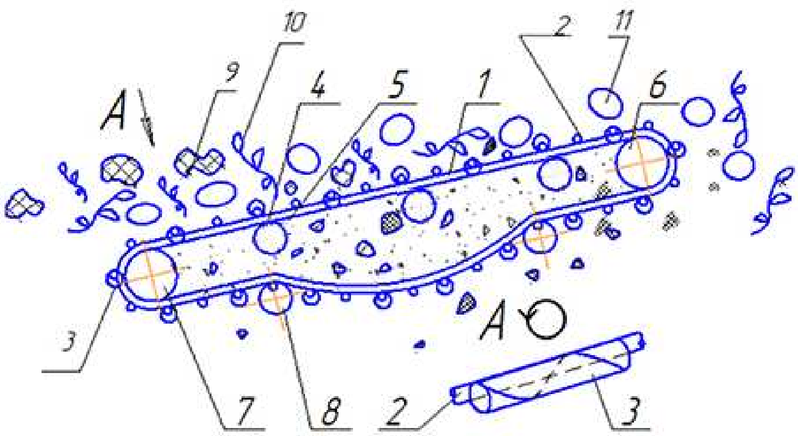
Introduction

Bar separating elevators are the most common ones, as they are quite efficient because of high separating and transporting capacity [1, 4, 5, 8, 10, 11, 13]. However, during separation, the mutual movement of components of the potato heap is difficult (reorientation of particles). To intensify the separation process, various devices are used to throw the entire elevator belt together with the soil, which leads to high energy consumption [3, 4, 12, 15]. In addition, the use of active intensifiers leads to an increase in damage to tubers [2, 6, 15]. Once on the elevator, the tubers often roll down it, which also increases the percentage of losses and damage. To increase the efficiency of soil separation, elevators with joint bars have been developed [7, 9].

Materials and object

The separating elevator of the potato harvester consists of flexible traction elements 1 with joint bars, which are bars 2 with cylindrical tubes 3 put on them, made of low-pressure polyethylene (Figure 1) [9].



1 - flexible traction element; 2 - bar; 3 - quick-detachable tube with a longitudinal screw section; 4 - roller; 5 - support frame; 6 - leading roller; 7, 8 - driven rollers; 9 - soil element; 10 - plant remains; 11 - potato tuber

Figure 1 – The schematic diagram of a separating elevator with joint bars of potato harvesters

The polyethylene tubes are made sectional, their number on the bar is 4. When the belt moves, cylindrical tubes 3 interact with rollers 5. Since rollers 5 are arranged alternately on the surface of the separating elevator belt, the tuberous formation moves due to the complex movement of the cylindrical tubes. The displacement of the heap causes alternating loads, which lead to the destruction and separation of the soil. The degree of impact of joint bars on tubers is determined by the number of rollers. Due to the rotation of rollers 5, tubes 3 of joint bars are rolled, as a result of which sliding friction is replaced by rolling friction.

Methods

To justify parameters of the separating elevator with joint bars, taking into account the rotation of tubes, the expressions for the velocity, acceleration and angular velocity of rotation of the tube of the joint bar are found, corresponding to the mode of operation of the elevator with a roller [2, 3, 14].

Consider the movement of the joint bar on the roller. Taking into account that the tube of the joint bar does not move in the axial direction, the considered movement is represented in a plane coordinate system. The following assumptions are introduced:

- the elevator belt moves in a straight line;
- in the process of interaction there is a hit;
- the tube has sufficient rigidity.

The tubes of the bar of the separating elevator with mass m and radius r meet with the roller, which leads to the impact of the tube on the roller (Figure 2). Since the tube is loosely put on the bar, the impact will be inelastic. Let us assume that the tube moves along the roller and the bar without slipping. The value of angle α is determined by the geometric parameters of the tube, the bar and the roller. Let us determine the velocity of the center of tube C after the impact, taking into account the mass of the tube and the mass of the tuberous layer per tube. The initial velocity of the tube before the impact is taken equal to the velocity of the elevator belt V_c. To determine the velocity of the tube after the impact, the instantaneous center of velocities is used, which is located at the point of contact between the tube and the roller.

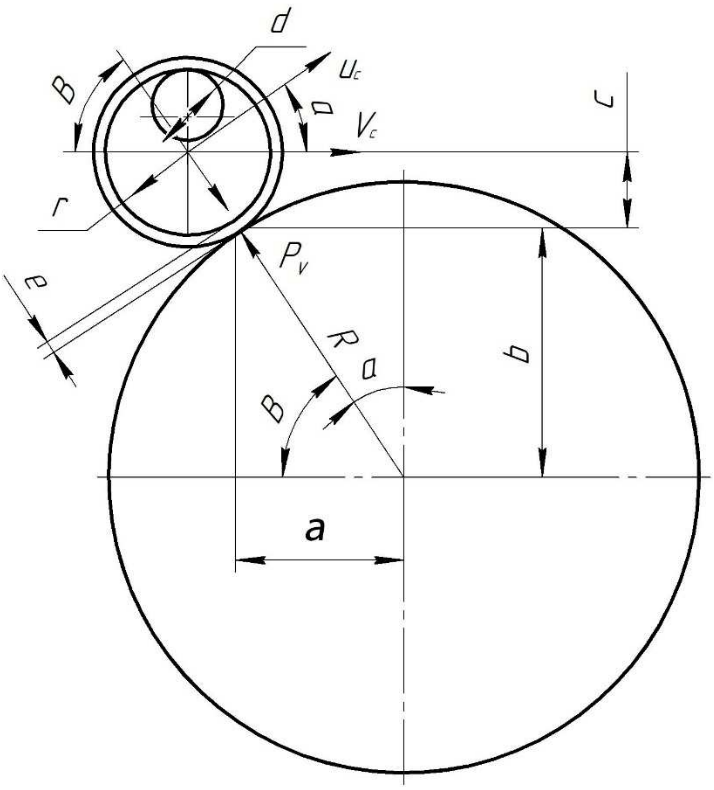


Figure 2 – The scheme for determining the parameters of interaction between the tube of the bar and the roller

Let us decompose the impact reaction that acts on the tube into directions along the tangent and normal to the surface of the tube. Similarly, momentum components $\vec{S}_F$ and $\vec{S}_N$, will be decomposed into a tangent and a normal (Figure 2). After the impact, the tube will rotate around the instantaneous center of velocities. The magnitude of the impact impulse is determined using the following expression:

$$m(\vec{u}_c - \vec{V}_c) = \vec{S}_F + \vec{S}_N \ , , \qquad (1)$$

where m is the tube mass;

V_c is the tube center velocity before the impact;

u_c is the tube center velocity after the impact.

The rotation of the tube is determined as follows:

$$J_c(\omega_\tau - \omega_0) = -S_F \cdot r\ .\ , \qquad (2)$$

where J_c is the moment of inertia of the tube;

ω_0 is the angular velocity of the tube before the impact;

ω_τ is the angular velocity of the tube after the impact.

Angular velocities of the tube are related to linear velocities by the following expressions $\omega_\tau = \frac{u_c}{r}$, $\omega_0 = \frac{V_c}{r}$. Let us project equation (1) on axis A_x and A_y, and make a change in equation (2):

$$\begin{cases} m(u_c - V_c\cos\alpha) = S_F \\ m(0 + V_c\sin\alpha) = S_N \\ mr^2\left(\frac{u_c}{r} - \frac{V_c}{r}\right) = -S_F \cdot r \end{cases}, \qquad (3)$$

where α is the angle of the direction of the roller interaction with the tube ($\cos\alpha = \frac{a}{R}$, $\sin\alpha = \frac{b}{R}$).

The measure of angle α is determined by the geometric parameters of the tube of the joint bar and the roller, as well as their mutual arrangement.

$$\cos\alpha = \frac{R-r+d+e}{R+r+e}\ , \qquad (4)$$

$$sin\,\alpha = \sqrt{1 - (\frac{R-r+d+e}{R+r+e})^2}, \qquad (5)$$

When solving equation (3) unknown quantities u_c, S_F, S_N are determined as dependences on initial velocity of the tube V_c, then the equations will be written in the following form:

$$\begin{cases} m(u_c - V_c\cos\alpha) = S_F \\ m(u_c - V_c) = -S_F \end{cases}, \qquad (6)$$

Having carried out the appropriate transformation, components of the impact impulse $\vec{S}_F$ and $\vec{S}_N$ are determined:

$$\begin{cases} S_F = \frac{1}{2}mV_c(1-\cos\alpha) \\ S_N = mV_c\sin\alpha \end{cases}\ , \qquad (7)$$

Then tube center velocity after the impact u_c is determined as:

$$u_c = \frac{1}{2} V_c (1 + \cos\alpha)\ .\ , \tag{8}$$

Let's calculate the tube center velocity after hitting the roller in Mathcad program and build a dependence graph (Figure 3).

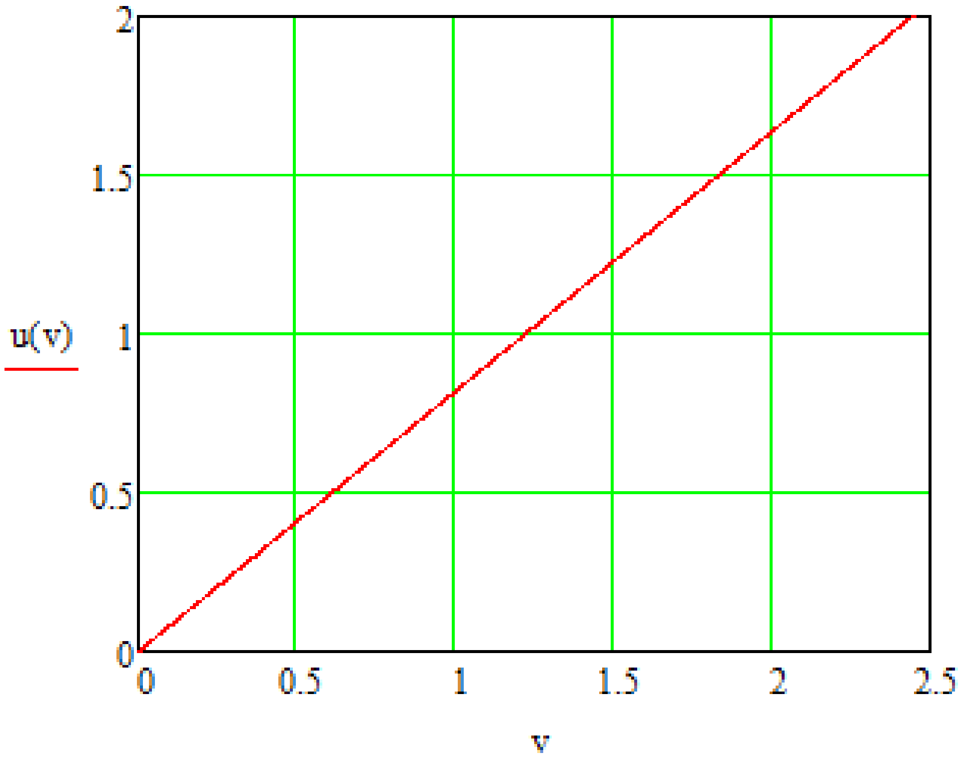


Figure 3 – The dependence of the tube center velocity after hitting the roller on the initial velocity of the tube before the impact (the velocity of the elevator)

The tube center velocity of the joint bar after hitting the roller is largely determined by the initial velocity of the tube before the impact or the velocity of the elevator [7].

Let us determine the condition for tossing up the tuberous layer by applying the theorem on the change in kinetic energy when the tube is rotated around the roller at a certain angle.

$$\mathrm{T} - \mathrm{T}_0 = \sum \mathrm{A}\ , \tag{9}$$

As the disk participates in translational and rotational motion at the same time, then the total kinetic energy of the tube is:

$$\mathrm{T} = \mathrm{T}_{\mathrm{k\,forw}} + \mathrm{T}_{\mathrm{k\,rot}}\,, \qquad (10)$$

where $\mathrm{T}_{\mathrm{k\,forw}}$ is the kinetic energy of the forward motion of the tube;

$$\mathrm{T}_{\mathrm{k\,forw}} = \frac{\mathrm{m}\mathrm{u_c}^2}{2}\,, \qquad (11)$$

$\mathrm{T}_{\mathrm{k\,rot}}$ is the kinetic energy of the rotational motion of the tube.

The kinetic energy of the rotational motion of the tube is determined by the following equation:

$$\mathrm{T}_{\mathrm{k\,rot}} = \frac{\mathrm{J}\omega_\tau^2}{2}\,, \qquad (12)$$

The moment of inertia of the tube of the joint bar is represented as the moment of inertia of the hoop:

$$J = mr^2\,, \qquad (13)$$

The angular velocity of the tube is related to the following linear equation:

$$\omega_\tau = \frac{u_c}{r}\,, \qquad (14)$$

Then the total kinetic energy, considering the forward and rotational components of the tube, is determined by the following equation:

$$\mathrm{T} = \frac{\mathrm{m}u_c{}^2}{2} + \frac{\mathrm{J}\omega^2}{2} = \frac{\mathrm{m}u_c{}^2}{2} + \frac{\mathrm{mr}^2 u_c{}^2}{2\mathrm{r}^2} = \mathrm{m}u_c{}^2 \quad . \qquad (15)$$

Taking into account the rotation of the tube, its kinetic energy before impact is determined by the following equation:

$$T_0 = mV_c^2 \quad . \qquad (16)$$

The kinetic energy of the tube after the impact is determined by the following equation:

$$\mathrm{T} = mu_c^2\,, \qquad (17)$$

The tossing job of the tube with tuberous layer components:

$$\sum \mathrm{A} = m_1 gh\,, \qquad (18)$$

where m_1 is the mass of the tube, considering the mass of the tuberous layer, kg; g is acceleration of gravity, m/s^2.

Let us express the values of velocities from equation (9) by substituting the values of equations (16), (17) and (18):

$$V^2 = u_c^2 - \frac{m_1}{m} gh\,, \qquad (19)$$

Lifting the tube of the joint bar is possible under the following condition:

$$u_c^2 \geq \frac{m_1}{m} gh \,, \tag{20}$$

Having substituted the value of velocity after the impact u_c from (7), the following equation is got:

$$\frac{V_c^2}{4}(1+\cos\alpha)^2 \geq \frac{m_1}{m} gh \;, \tag{21}$$

The magnitude of the jump of the tuberous layer is expressed in the following way:

$$h \leq \frac{\frac{V_c^2}{4}(1+\cos\alpha)^2}{g}\frac{m}{m_1} \tag{22}$$

Results

The numerical modeling of the jump height of the components of the tuberous layer was done in Mathcad program, given the geometric parameters of the joint bar and the intensifier roller, as well as the velocity of the separating elevator: m = 0.05 kg, R = 0.10 m; r= 0.0127 m; d= 0.012m; e=0.002m; Vc=2.0 m/s (Figure 4).

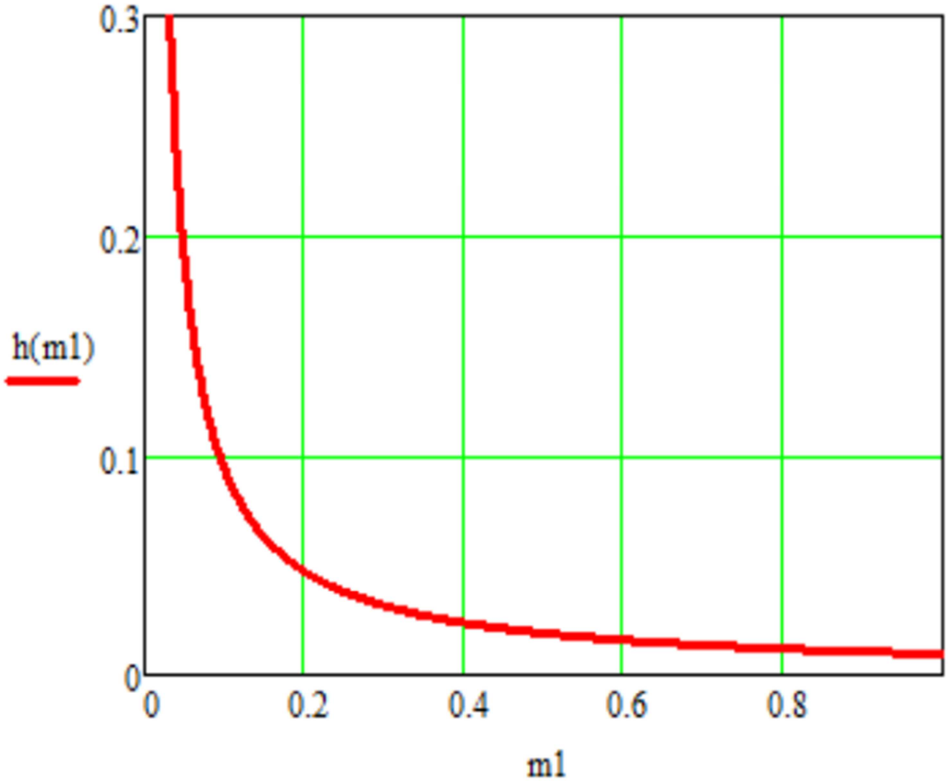


Figure 4 – The dependence of the height of the jump of the tuberous layer components on the mass of the layer on the tube of the joint bar

Analysis of the figure showed that the height of the jump is largely determined by the mass of tuberous layer m1 per tube. Varying the size of the tube, its thickness, and the radius of the intensifier roller has little effect on the jump height. With an average size of tubers, their weight is about 0.15 kg, then the height of their jump will be 0.06 m. A further increase in the mass of the tuberous layer will lead to a decrease in the jump height.

The condition for the absence of slippage of the tube when hitting the roller can be presented using Routh hypothesis for the impact:

$$|S_F| \le S_{F_{max}} = fS_N \quad , \tag{23}$$

where S_F and S_N are tangential and normal impact impulses;

f is the coefficient of sliding friction of the tube on the roller intensifier when the impact.

The slip boundary condition is described by the following equation:

$$|S_F| = S_{F_{max}} = fS_N \ , \tag{24}$$

Having transformed equation (23), expressing the condition for the absence of slippage of the tube along the roller, and having substituted the values of shock impulses S_F and S_N from equation (7), one gets:

$$\frac{1}{2} mV_c(1 - \cos\alpha) \le fmV_c \sin\alpha \ , \tag{25}$$

Hence, the value of the sliding friction coefficient of the tube on the roller is determined by the following inequation:

$$f \ge \frac{1 - \cos\alpha}{2\sin\alpha} \ , \tag{26}$$

Calculating the coefficient of sliding friction of the tube on the roller was done in Mathcad program and the dependency graph was plotted (Figure 5).

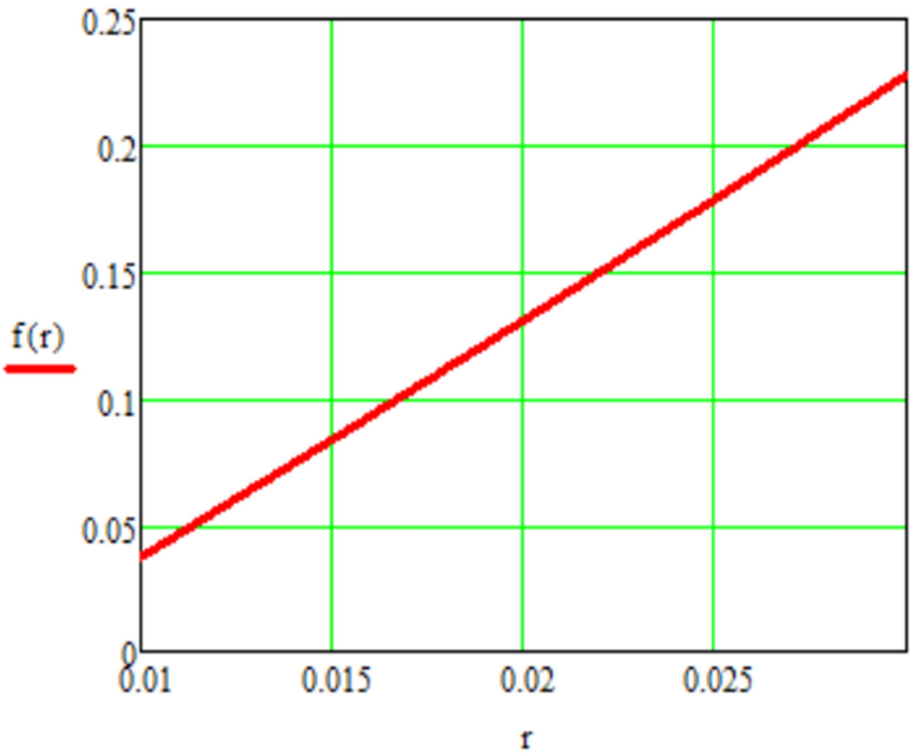


Figure 5 – Зависимость коэффициента трения скольжения трубки о ролик от радиуса трубки комбинированного прутка

Analyzing the dependence of the coefficient of sliding friction of the tube on the roller, it can be seen that the condition for the absence of the tube slippage when the impact is fulfilled, when coefficient of sliding friction $f \geq 0.08$ for the tube radius r = 0.015 m. Thus, an impact without the tube slipping on the roller is possible in a wide range of conditions.

Conclusion

Thus, to improve the efficiency of soil separation in potato harvesters, elevators with joint bars have been developed. The joint bar tube hits the roller. The velocity of the tube center of the joint bar after hitting the roller is largely determined by the initial velocity of the tube before the impact or the velocity of the elevator.

It has been established that the height of the jump is largely determined by the mass of the tuberous layer per tube. Varying the size of the tube, its thickness, the radius of the roller slightly affects the height of the jump. With an average size of tubers with the weight of about 0.15 kg, the height of the jump of the tubers will be 0.06 m. Analyzing the dependence of the coefficient of sliding friction of the tube on the roller, it can be seen that the condition of the absence of slippage of the tube when it hits the roller is possible in a wide range of conditions.

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