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SUBSTANTIATION OF THE PARAMETERS OF A HORIZONTAL CONVEYER-CLEANER OF ROOT CROPS

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Abstract: *The paper covers theoretical substantiation of the rational parameters of a horizontal conveyer-cleaner of sugar beets providing their minimum loss during process performance. The procedure of conducting experimental investigations on the developed design of a horizontal conveyer-cleaner of root crops in configuration with a root crop harvester is presented. The results of the experimental research on determining root crop loss, damage and impurity depending on the design and kinematic parameters of a cleaner are provided. In order to choose the rational parameters, specific recommendations are provided.*

Key words: *transportation-separation system, horizontal conveyer-cleaner, sugar beets, discharge screw, rod conveyer.*

1. Introduction

High quality root crop cleaning contributes to the minimum number of soil impurities that enter processing plants, which corresponds to the environmental standards and decreases the expenses on transportation and the technological processes applied prior to sugar beet processing that, correspondingly, decreases sugar production costs. The results of theoretical and experimental studies on sugar beet digging and cleaning processes are covered in the papers [1, 2], [10]. Theoretical and experimental investigations on determining the parameters and the working modes of

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rigid and elastic screw operating elements for conveying agricultural materials are presented in the papers [6], [8], respectively. The determination of the effectiveness of root crop after-cleaning in the process of their transportation by longitudinal drag conveyers as well as the determination of their optimal parameters and working modes is presented in the papers [5], [7], [9]. The conducted analysis of the known research papers shows that the problem of high quality root crop cleaning during their machine harvesting is not solved to the full extend, especially when root crop harvesters operate in adverse soil and climatic conditions.

The aim of the research is to determine the rational design and kinematic parameters of the developed horizontal conveyer-cleaner in order to provide high quality root crop cleaning with their minimum loss and damage.

2. Material and Methods

2.1. Determination of the Relationship between Design and Kinematic Parameters of a Root Crop Conveyer-Cleaner

In order to improve the cleaning of a root crop heap from soil impurities and plant residues, it is suggested to arrange a discharge horizontal screw with an elastic helix above a horizontal rod conveyer with a certain clearance [3]. While in operation, a horizontal rod conveyer 1 carries impurities to the harvested part of the field and a discharge screw 2 with the central axis located at the distance *H* relative to the working surface of a rod conveyer belt delivers root crops to the other operating elements of a beet harvester (Figure 1).

Various options of the arrangement of standard root crops on the surface of a rod conveyer belt have been considered in order to determine their most unfavorable arrangement. The correspondent calculations have been conducted (Figure 1a). The side arrangement of root crops on a rod conveyer belt, when a root crop body does not deepen between the rods (option d and f), is favorable for their carrying off by the helical surface of a screw. The option when a root crop axis is vertical is favorable as well (option e).

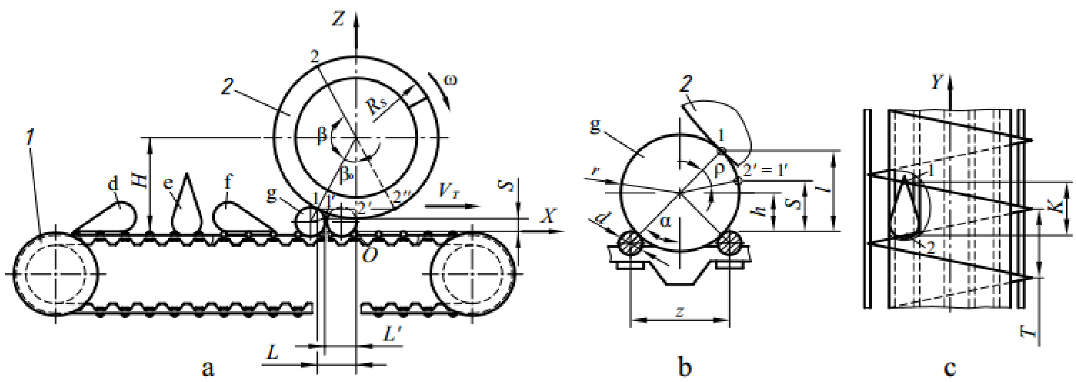

Fig. 1. *Structural model for determining design and kinematic parameters of a horizontal conveyer-cleaner: a – vertical longitudinal cut; b – pattern of interaction of a root crop body and working surfaces; c –model of calculating screw parameters; 1 – horizontal rod conveyer; 2 – discharge screw*

The most unfavorable is the option when a root crop axis is arranged parallel to the rods and its top is in the deepening between the two adjacent rods (option g). In this case, the possibility that a beet can pass the area between the flights together with a rod conveyer belt is the highest (the possibility of beet loss is increased). At the contact point 1 of a root crop and a screw surface (Figure 1b), a spiral rib moves in the vertical direction, that is, a screw working surface does not provide root crop carrying off. On condition a root crop is not shifted in the transverse direction relative to a conveyer belt, its top interacts with the periphery of a screw spiral rib at point 2 (Figure 1c). The displacement *K* of p. 1 relative to p. 2 in the direction of a screw central axis is determined mainly by the diameter of a standard root crop.

Efficient (without damage) root crop carrying off is performed on condition that the contact point (p. 2') of a spiral rib and the surface of a root crop is located in a vertical plane that passes through a screw axis. If p. 2' is displaced towards the area of impurities removal in the direction of *OX* axis (p. 2''), the damage is possible, since the interaction force is directed towards a rod conveyer belt.

Thus, in order to carry root crops off efficiently, it is necessary to meet the following condition:

$$\frac{L'}{V_t} = \frac{(2\pi - \beta - \beta_0)}{\omega}, \qquad (1)$$

where:

L′ is the distance between p.1′ and p. 2′ in the direction of *OX* axis;

V_t – speed of conveyer belt movement;

β_0 – initial angle of location of the line that connects a screw center and p.1 with a vertical plane that passes through a screw center;

ω – angular velocity of screw rotation;

β – the angle that determines the location of p.1 and p. 2 on the periphery of a screw spiral rib.

The value of the angle β is determined by the dependence:

$$\beta = \frac{2\pi K}{T}, \qquad (2)$$

where T is the screw pitch.

In order to determine the height l of the contact point of a root crop and a screw surface (p. 1) located above the rods of a conveyer belt (Figure 1b), the distance *h* from the center of a root crop top to the surface of rods should be previously determined. The dependence of the angle α that encloses the line, which connects the contact point of a rod and the vertical axis, is of the following form:

$$\alpha = \arcsin\left(\frac{z}{2r + d}\right), \qquad (3)$$

where:

z is the distance between the axes of the two adjacent rods;

d – rod diameter;

r – radius of a root crop top.

Taking into account that $h = r\cos\alpha$ and the equation (3), the dependence determining the value of *h* takes the following form:

$$h = r\cos\left[\arcsin\left(\frac{z}{2r + d}\right)\right]. \qquad (4)$$

The initial angle β_0 of the line that connects the screw center and p.1 to the vertical plane that passes through the center of a screw is determined by the dependence:

$$\cos\beta_0 = \frac{R_s + S - l}{R_s}, \quad (5)$$

where:

S is the clearance setting between a screw and a belt surface;

R_s – radius of a discharge screw.

Taking into account that:

$$l = h + r\cos\beta_0 \quad (6)$$

as well the equation (7):

$$\beta_0 = \arccos\left(\frac{R_s + S - h}{R_s + r}\right). \quad (7)$$

In addition, it is necessary to meet the condition when the angle, which encloses the lines that connect the center of a beet top and its contact point with a rod and a screw surface on the side opposite to the rods, is less than 180°. This can provide root crop carrying off in p.2′ by a screw rib without their damage. Taking into account this condition, the value of a clearance setting between a screw and the surface of a rod conveyer belt is determined by the dependence:

$$S = h + r\cos\left[\arcsin\left(\frac{z}{2r + d}\right) + \rho\right], \quad (8)$$

where ρ is the angle of friction between the surface of a root crop and the helical surface of a screw.

A clearance setting *S* is an important technological parameter of a transportation-separation system, since it determines the number of separated impurities and the loss of standard root crops. That is why it is necessary to conduct the analysis determining the influence of the design and kinematic parameters of a discharge screw and a rod conveyer belt on its value.

Taking into account (8), the dependence (7) takes the following form:

$$\beta_0 = \arccos\left\{\frac{R_s + r\cos\left[\arcsin\left(\frac{z}{2r + d}\right) + \rho\right]}{R_s + r}\right\} \quad (9)$$

In order to determine the relationship between the parameters of a screw and a rod belt, let us determine the length L of a root crop movement from the point of its intersection with the rotational surface of a discharge screw (p. 1) to the point of its interaction with a spiral rib (p. 2′).

$$L = R_s \sin\beta_0. \quad (10)$$

Taking into account that the position of p. 1 and p. 2′ are displaced in the circular direction, the value of L' is determined from the condition:

$$L' = (R_s + r)\sin\beta_0 - r\sin(\alpha + \rho). \quad (11)$$

Taking into account the dependences (1), (2), (3), (9) and (11), it is mandatory that in order to provide guaranteed root crop carrying off and to avoid the loss of standard root crops, the angular velocity of a discharge screw rotation should be within the limits of 90…150 rad/s, which leads to intense vibrations and breakdown of the drives of the operating elements as well as heavy root crop damage. That is why it is recommended to apply a double-lead screw and the interrelation of its design and kinematic parameters should be determined from the system of equations (12). A clearance setting S of a screw surface located above a rod belt is determined by the equation (8).

In order to analyze the system of equations (12), first of all, it is necessary to determine the limits of the absolute values of the variable parameters under study.

$$\begin{cases} \omega = \dfrac{\pi V_t \left(1 - \dfrac{2K}{T} - \dfrac{\beta_0}{180^\circ}\right)}{(R_s + r)\sin\beta_0 - r\sin(\alpha+\rho)}; \\ \beta_0 = \arccos\left\{\dfrac{R_s + r\cos(\alpha+\rho)}{R_s + r}\right\}; \\ \alpha = \arcsin\left(\dfrac{z}{2r+d}\right). \end{cases} \qquad (12)$$

Taking into account that the conveyers of root crop harvesters are unitized operating elements with the set rod spacing and the standardized rod diameter, the parameters z and d are assumed to be invariable and their absolute values are $z = 0.04$ m and $d = 0.01$ m, respectively.

Taking into account that the suggested transportation-separation system should provide standard sugar beet carrying off (without their damage), according to agro-requirements, the minimum radius of a root crop top should be 20 mm [4]. Taking into account the ability of a machine to operate under various environmental and production conditions (increased soil moisture or firmness), the angle of friction-sliding of the surface of a discharge screw on a root crop body is within the limits of $\rho = 10°…20°$.

According to the considerations concerning the choice of rational design parameters of a discharge screw and the working modes of rod conveyers [4], the limits of the change in the absolute values of these parameters are assumed to be within the range of $R_s = 0.14…0.22$ m; $T = 0.16…0.22$ m; $V_t = 1.0….1.5$ m/s; $K = r… 2r$. In the course of investigating one parameter, the other ones remain unchanged and their absolute values are $\rho = 15°$; $r = 0.02$ m; $T = 0.19$ m; $V_t = 1.25$ m/s; $R_s = 0.18$ m; $K = 1.5r$, respectively. It is to the point to give the average values to these parameters in order to determine the intensity level of their influence, within the set limits, on the angular velocity of a discharge screw rotation that is which parameters are worth operating.

2.2. Experimental Research Procedure

Based on the suggested calculation model (Figure 1), a structural and technological model of the transportation-separation system of a harvester with a conveyer-cleaner of root crops has been made, which is presented in Figure 2.

It contains sequentially arranged cleaning screws 1 and a loading inclined drag conveyer 2. In the area of unloading root crops from the conveyer 2, there is a horizontal rod conveyer 3 arranged and above its operating element there is a discharge cross screw 5 arranged with a certain clearance S. The screw is fixed with the possibility of clearance adjustment in the vertical direction depending on the yield of root crops and the distribution of their size and mass characteristics.

Below a rod conveyer there is an unloading drag conveyer 6 arranged with the external location of rods on the belt, its horizontal segment transforms into a vertically inclined one. On the side where roots are carried off by the screw, there is an inclined shield 4.

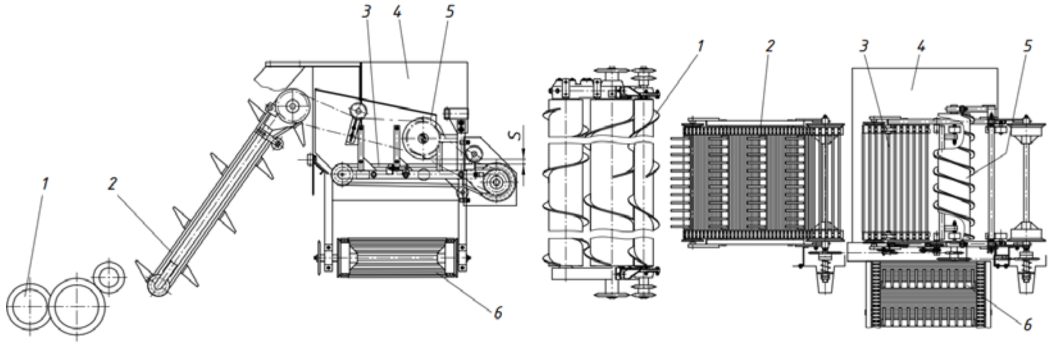

Fig. 2. *Structural and technological model of the transportation-separation system of a root crop harvester in configuration with a conveyer-cleaner of root crops*

After the main separation of heap by the screws 1, roots impurities are fed to a loading inclined drag conveyer 2 and are transported to a horizontal rod conveyer 3. In the process of their transportation, root crops proceed to the area of a discharge cross screw 5, which moves them to the inclined shield 4, where the roots roll down to the receiving segment of an unloading drag conveyer 6. Here, plant residues and soil impurities are discharged to the harvested part of the field through the clearance *S*. The general view of a conveyer-cleaner of root crops mounted on a harvesting machine is presented in Figure 3.

In the course of conducting the experiments, the main factors that can be regulated in the process of investigation and have sufficient influence on the quality of the technological process are the following: the angular velocity of rotation of a discharge screw ω, the linear velocity of a horizontal rod conveyer V_t and the clearance *S*.

a) 

b) 

Fig. 3. *General view of the drive of the operating elements (a) and a conveyer-cleaner of root crops mounted on a harvesting machine (b)*

Kinematic parameters of a horizontal rod conveyer and a discharge screw are connected with each other by certain chain drive ratios.

During the operation of the harvesting machine, the impurities, which should be carried off to the field surface, are gathered in a vessel and weighed. Here, plant residues, soil impurities and the lost standard root crops are weighed separately. Thus, if certain parameters of the transportation-separation system are changed, their influence on the process performance characteristics of the developed operating elements are determined.

3. Results

3.1. Results of Theoretical Investigations

According to the results of theoretical investigations that the angular rotation velocity of a discharge screw ω, which prevents the passing of standard root crops, depends to a considerable degree on the absolute values of V_t and R_s and to a lesser extent on the absolute values of T and K.

The increase of a screw radius R_s causes the increase of the distance L from the initial contact point of root crops and a screw rib to a vertical OZ axis, which results in the decrease of the value ω.

In the course of analyzing this system, a discharge screw pitch was sufficiently increased in order to make it possible for root crops to penetrate the inter-flight space. Since a screw was made to be a double-lead one, the limits of the change in the value T are (T = 0.16…0.22 m).

Taking into account that small values of R_s result in significant angular velocities of screw rotation, in the further analysis the range of change in a screw radius was assumed to be within the limits of R_s = 0.14…0.2 m. The linear velocity of the belt is changed within the range of V_t = 1.0….1.5 m/s.

The results of analyzing the system of equations (12) $\omega = f(T)$ is based on the conducted theoretical calculations of the process performance of a horizontal conveyer cleaner, with the condition of excluding the loss of standard crops, the following limits of the rational parameter values have been determined: at the conveyer speed V_t = 1.0 m/s (screw radius R_s = 0.14...0.18 m; screw pitch T = 0.18...0.2 m; angular velocity of screw rotation ω = 38...45 rad/s); at V_t = 1.2 m/s (R_s = 0.16...0.2 m; T = 0.17...0.19 m; ω = 40...48 rad/s); at V_t = 1.4 m/s (R_s = 0.18...0.22 м; T = 0.16...0.18 м; ω = 42...50 rad/s).

Effective process performance is carried out when the clearance between the surfaces of a discharge screw rotation and a horizontal conveyer does not exceed S < 0.026 m.

By applying the above mentioned dependences, it is possible to choose rational design and kinematic parameters of the operating element of a transportation-separation system. Here, it is not to the point of choosing the angular velocity of rotation of a discharge screw to be more than 25 rad/s because of the significant vibrations. In addition, it is necessary to take into account linear velocity of drag conveyers, which are arranged just ahead of a horizontal rod conveyer in a machine technological line. Their linear velocity must be equal to or greater than the linear velocity of the previous drag conveyer. Otherwise, the accumulation of root crops is possible, which can stop the technological process of heap separation and transportation.

3.2. Results of Experimental Research

When conducting a multi-factorial experiment, the main controllable parameters that influence the level of loss (L_r, %), cleaning (D_r, %), and damage (W_r, %) of root crops when they pass through the technological line of the developed conveyer-cleaner were changed. They include the angular velocity of a discharge screw (ω, rad/s); linear conveyer velocity (V_t, m/s) and the value of clearance between the surfaces of a discharge screw rotation and a horizontal rod conveyer (S, m).

The factorial field was determined by such a range of parameter variation as: $11.4 < \omega < 25.2$ (rad/s);
$1.24 < V_t < 2.52$ (m/s); $0.02 < S < 0.05$ (m).

Having processed the experimental results, the following regression equations have been obtained:

$$L_r = -0.413 - 0.012 \cdot \omega + 0.163 \cdot V_t + 25.2 \cdot S$$
$$D_r = 1.65 + 0.09 \cdot \omega + 0.453 \cdot V_t - 1.27 \cdot S \qquad (13)$$
$$W_r = 7.05 + 0.026 \cdot \omega - 0.348 \cdot V_t - 25.27 \cdot S$$

The response surfaces of the dependence of loss (L_r, %), damage (D_r, %) and impurity (W_r, %) of root crops on the change of the parameters ω, V_t and S, respectively, are presented in Figure 4.

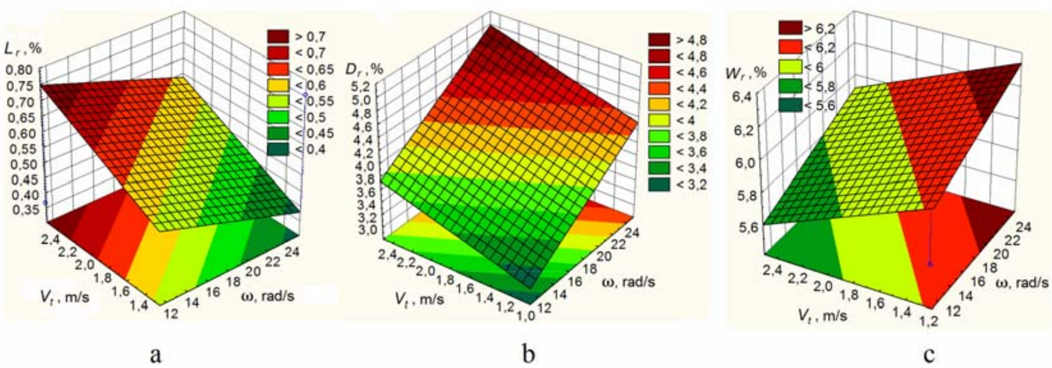

Fig. 4. *Response surfaces of the dependence of root crop loss L_r, damage D_r and impurity W_r at S = 0,035 m: a – $L_r = f(V_t, \omega)$; b – $D_r = f(V_t, \omega)$; c – $W_r = f(V_t, \omega)$*

Having analyzed the regression equations and the response surfaces, the following conclusions can be drawn.

The level of root crop loss is maximally influenced by the value of clearance S followed in its intensity by the linear velocity of a conveyer belt V_t. The increase of the angular velocity of screw rotation ω contributes to the reduction in the loss of standard root crops.

Root crop damage is maximally influenced by the angular velocity of screw rotation ω followed by the linear velocity of a conveyer belt V_t. The increase of the value of clearance S results in the reduction of the level of root crop damage.

The decrease in the level of root crop impurity is maximally influenced by the value of clearance S followed by the linear velocity of a conveyer belt V_t. The increase in the angular velocity of screw rotation ω causes the increase of the level of root crop impurity.

According to the results of the field investigations of a root crop harvester (Figure 3b) aimed at determining the influence of the parameters of a horizontal conveyer-cleaner on the level of root crop loss and the quality of their cleaning, it has been found that the clearance setting S should be within the limits of 0,028...0,032 m at R_s = 0,18 m; V_t = 1.4 m/s; ω = 16 rad/s; T = 0.18 m. The highest quality process performance is achieved at the following relation ω (rad/s) / V_t (m/s) = 10...12.

4. Conclusions

A new design and the process flow diagram of a horizontal conveyer-cleaner of root crops have been suggested and the analytical dependences determining the interrelation of its design and kinematic parameters have been deduced. Experimental research procedure has been presented in order to investigate a horizontal conveyer-cleaner of root crops in configuration with a root crop harvester.

As a result of the conducted multi-factorial experiment, regression equations have been deduced. Their analysis shows that, while a horizontal conveyer-cleaner of root crops is in operation within the range of the following parameter change: $11.4<\omega<25.2$ (rad/s); $1.24<V_t<2.52$ (m/s); $0.02<S<0/05$ (m), the clearance setting S has the most significant influence on the loss of root crops followed by V_t and ω. The damage of root crops is maximally influenced by ω followed by V_t and S in its intestity. The decrease in the level of root crops impurity depends maximally on the value of S followed by V_t and ω.

According to the results of the field experiments on determining the influence of the parameters of a horizontal conveyer-cleaner on the level of root crop loss and the quality of their cleaning, it has been determined that the clearance setting S should be within the limits of 0,028...0,032 m at R_s = 0,18 m; V_t = 1.4 m/s; ω = 16 rad/s; T = 0.18 m. Process performance is of the highest quality at the following relation ω (rad/s) / V_t (m/s) = 10...12.

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