Technological Process of Interaction of the Brush Rod with the Surface of the Root Crop

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Abstract. Before feeding, forage root crops must first be cleaned of dirt. The use of machines for dry cleaning of root crops reduces energy and labor costs, and is also cost-effective compared to cleaners based on the hydro-mechanical cleaning principle. This article presents the technological process of interaction of the brush rod with the surface of the root crop. Three cases are considered: "absolutely rigid rod", "absolutely flexible" and real. The forces on the surface of the root crop when exposed to rods of different stiffness are indicated. An equation is proposed for determining the work of destruction when separating the polluting particles from the treated surface. It is noted that zootechnically acceptable cleaning quality with an acceptable amount of feed mass loss can be obtained only at a certain speed of rotation of the internal drum-brush.

The brush working body (rod) must have sufficient rigidity for the required shear force and must be elastic in order to follow the surface of the root and be able to remove dirt from various depressions, eliminating the possibility of injury to protruding parts on the surface of root crops.

1. Introduction
Clearing the soil is one of the main post-harvest operations when collecting root crops. Practically, the contamination of root crops after harvesting by harvester-threshers is 5...28%. Currently, the average contamination of root crops in Russia is 14-16%. The incoming tubers contain earth, herbage admixtures, tops and damaged root-crops, which worsen aeration. In addition, small roots and damaged ones are easily affected by microorganisms, thereby leading to mass rotting of raw materials.

Cleaning root crops from contamination and storing them in a purified form is the most effective way to reduce product spoilage. The most common hydro-mechanical cleaning method has many disadvantages [2]. The use of brush working bodies avoids problems associated with the use of water in the working process, but they do not provide the necessary quality of cleaning [1, 3-11, 14-20]. Therefore, improving the process of interaction of brush working bodies is an important and relevant issue.

2. The objectives of the study are
To study the effect of rods of different stiffness on the surface of the root crop; to obtain functions that allow determining the optimal parameters of the rod and operating modes of an anhydrous root crop cleaner.

The main active element of the drum-brush cleaner is an internal drum-brush.

The process of interaction of the cylindrical brush with the surface of the root crop consists of the interaction of individual rods. Our research shows that there are 3 points in the work of the bar:
• embedding the bar in the contaminant layer;
• sliding the bar along the contact path;
• the output of the contact.

The behavior of the bar will be determined by both the rigidity of the bar itself and the hardness of the surface to be treated. In this regard, 3 cases can be considered: "absolutely rigid rod", "absolutely flexible" and the actual one (figure 1).

An absolutely rigid rod (figure 1 (a)) affects the surface with its outer end. When working, the rod does not deviate from its original position. The action of such a bar is similar to the action of a cutter.

![Figure 1. Diagram of the impact on the plane of bars of different stiffness: absolutely rigid (a), flexible thread (b) and real bar (c); (d) – diagram of normal pressures of a real bar on the plane.](image)

Such a rod is not able to copy the relief of the root and is not able to remove dirt from the recesses. In addition, it will injure protruding parts on the root surface. The shear resistance acting on the outer end of a rigid bar is defined as:

\[ T_{sf} = S \cdot p_{sp} = p_{sp} \cdot d \cdot h \]

where \( T_{sf} \) is the soil shear force, sdf;
\( S \) is the cross-sectional area of the chip, cm\(^2\);
\( P_{sp} \) is specific resistance to soil shear, sdf/cm\(^2\);
\( h \) is the depth of penetration of the rod, cm;
\( d \) is the bar diameter, cm.

The complete opposite is an absolutely flexible rod (Figure 1 (b)), which, without rigidity, is not able to develop a shear force. The vast majority of brush rods occupy an intermediate position, i.e. they are flexible rods with some elasticity (Figure 1 (b)).

Successful separation of a particle due to friction forces is possible if:

\[ S \cdot p_{sp} \leq F_{fr} = f \cdot P_{Nv} \]

where \( p_{sp} \) is the specific resistance to soil shear, kgf/cm\(^2\);
\( S \) is the cross sectional area of the chip, cm\(^2\);
Friction force between the bar and the cleaning surface;  
Normal bar pressure on the surface to be treated;  
A coefficient of friction.

The coupling forces of contacting bodies depend on their nature, as well as on the state and shape of their surface, the external environment, and contact conditions.

Our search experiments show that a zootechnically acceptable cleaning quality with an acceptable amount of feed mass loss can be obtained only at a certain speed of rotation of the internal brush drum [12-21].

When the brush is turned, the angular and linear speeds of the individual parts of the brush do not match. Assuming the angular velocity of the brush core is constant, we can assume that both the angular and linear velocity of the bar base are also constant. The speed of the outer end of the bar changes continuously throughout the contact path with the surface to be treated. To analytically determine the circumferential velocity of the outer end of the bar, we note that before coming into contact with the surface to be processed, it had an angular velocity and a circumferential velocity.

At the moment of coming into contact with the surface, an impact occurs. In this case, the rotational movement of the outer end of the bar is replaced by a straight line along the surface to be processed. At the moment of impact, the peripheral speed decreases to 0, and then as the movement along the surface continues, it increases again.

When the rod loses the contact with the surface, the previously peeled off particles are discarded.

The increased impact of the bar on the treated surface during its sliding is determined by two factors: the amount of rigidity of the bar in a static state and the speed of its rotation, which causes the appearance of a dynamic component of the force: i.e.: 

\[ P = P_c + P_d \]

where \( P \) is the total force with which the rod impacts the treated surface, kg(f);  
\( P_c \) is the value of the component due to the statistical stiffness of the bar, kg(f);  
\( P_d \) is the dynamic (high-speed) component of the kg(f) force.

To identify the role and approximate the value of each of these components, consider the forces impacting the rod during operation.

Figure 2 shows that the following forces impact the rod:

1. The weight of the bar \( G = m \cdot g \), directed vertically down.
2. The reaction of the surface \( R_s \), which holds the outer end of the bar and deflects it from the radial direction by an angle \( \theta \).
3. The force of inertia \( P_i \), conditionally applied at the center of gravity of the bar "C" and tending to keep the speed of this point unchanged: \( P_i = m \cdot a \).
4. The centrifugal force \( P_c \), conditionally applied at the same point and directed along the radius of its rotation \( R' \): \( P_c = m \cdot (\omega')^2 \cdot R' \), where \( \omega' \) and \( R' \), respectively, are the angular velocity and radius of rotation of point C.

The value of the static component is obviously determined by the material of the bar, its geometric dimensions and the amount of angular deformation \( \theta \).

The group of dynamic forces \( (R_i \text{ and } R_c) \) depends both on the material and geometric dimensions of the bar, and on the speed of its rotation.
When using a cylindrical brush, energy is spent both on destroying the contaminant layer and on overcoming additional resistance: aerodynamic, friction in bearings, etc. The work of destruction when separating the contaminant particles from the treated surface due to the friction force of the bar against the contaminant layer can be found from the equation:

$$A_c = \int_a^b f \cdot P_N(X) dX = \int_0^{\beta} f \cdot P_N(\beta) d\beta,$$

where $f$ is the coefficient of friction of the bar material on the surface to be treated;

$P_N$ is the value of the normal pressure of the bar on the surface;

$\beta$ is an angle of rotation of the brush core during contact;

$X$ is the length of the contact path (Figure 3).

The normal pressure force $P_N$ is determined from the expression:

$$P_N = \{k \{ \arccos \frac{d + R \cdot (1 - \cos \beta)}{L} - \beta \} + k_v \cdot V_m \} \cdot \sqrt{L^2 - [d + R \cdot (1 - \cos \beta)]^2}.\]
The drive power expended to destroy the surface of the contaminant by friction can be determined from the expression:

$$N = \frac{1}{75} A,$$

where $A$ is bar friction work per second, kgm.

The bar operation for one second is defined as:

$$A = \frac{1}{60} A_c \cdot \Pi_{ip} \cdot n_m,$$

where $A_c$ is work of destruction of a bar for one cycle of interaction with a surface; $\Pi_{ip}$ is the number of brush bars; $n_m$ is the speed of rotation of the cylindrical brush per minute.

$$\Pi_{ip} = \frac{1}{60} \pi \cdot d_c \cdot B \cdot \rho,$$

where $d_c$ and $B$ are the core diameter and length, respectively; $\rho$ is the density of the bars on the core (the number of bars per unit area).

The total energy consumption for the brush drum drive consists of the costs of destroying the contaminant layer, discarding separated particles, overcoming the aerodynamic drag of the brush, deforming the bars, and overcoming the resistance in the transmission.

3. Conclusion
As our research shows, the brush working body (rod) must have sufficient rigidity for the required shear force. However, to copy the topography of the root and the ability to remove dirt from various depressions, eliminating the possibility of injury to protruding parts on the surface of the root, the rod must be elastic.

The conducted experiments show that a zootechnically acceptable cleaning quality with an acceptable amount of feed mass loss can be obtained only at a certain speed of rotation of the internal drum-brush.

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