Theoretical justification of fruit separation rolling process by a planetary fruit separator

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Abstract. The article is devoted to the theoretical justification of the process of rolling stems by planetary rollers of the fruit separator in the harvesting of Solanaceae vegetables as reusable as at direct full harvest. The article has a theoretical, research character, expressed in the fact that the issue of Solanaceae vegetables harvesting was theoretically considered, the analysis of methods and means for the introduction of dry inorganic substances was given, when considering the process of rolling stems of Solanaceae vegetables as a rolling of elastic-plastic material there were obtained the dependences that determine the kinematic and energy parameters of planetary multi-rolling fruit separators. The conclusions set out the main results achieved so far. The type of the proposed design was theoretically justified, its description and the flow of the technological process were given. As a result of the work done, the process of fruit removal from a plant with offered working elements was shown.

The researches in the field of Solanaceae vegetables harvesting are conducted in Kuban State Agrarian University at the department of "Processes and machines in agribusiness". The work is aimed at the development of working elements of rotor type for reusable harvesting of Solanaceae vegetables. It is probable, that the present construction allows to improve the qualitative rates of working elements of fruit separators.

During the movement of the fruit separator, located at an angle α to the direction of movement, the fruit mass is rolled by rollers. At the same time, the process of fruit removal is carried out due to two types of deformation of the plant - pulling (vibration) of the bush's stems and combing the fruits. Only large fruits are separated, the size of which is greater than the gap in the working slit. The fruit will be separated if the force of the action of the roller exceeds the force of connection with the peduncle. Small fruits, ovaries and flowers remain on the plant in the field and continue to grow [1].

The technological operation of rolling the stems of the plant's bush with planetary rollers is one of the main, providing the combing of the fruits from the bush.

The input parameters here are the output parameters of the technological operation of the first level, and the criterion for assessing the quality is - $\varepsilon_{пов}$ - the degree of damage to the stems of the plant, which should strive for a minimum value [2].

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Let us consider the technological process of rolling stems by the planetary multi-shaft apparatus (Figure 1). The number of rolls on the drum of the planetary apparatus of K_T by V. V. Derevenko is determined by the formula for the two-drum apparatus [3]:

$$K_T = \frac{\pi}{\alpha + \lambda_{c2} + \sin\alpha} \quad (1)$$

where α- central angle determining the position of initial and final points of contact of rollers with stems;

λ_{c2} – relation of circumferential speed of the drum 2 to the speed of the stem's pulling,

$$\lambda_{c2} = \frac{U_2}{V_c} \quad (2)$$

for single drum apparatus

$$K_T = \frac{\pi}{\alpha + \varepsilon\beta} \quad (3)$$

where α and β – central angles on planetary and cylindric drums defining the point of initial and final positions of a roller on the stem;

$\varepsilon = \frac{\omega_2}{\omega_1}$ - relation of speeds of rotation of cylindrical and planetary drums.

We should take K_T=6÷9 units for two-drum apparatus, for single drum – $\varepsilon = \frac{1}{3} \div \frac{1}{6}$ and K_T = 6 ÷10 units.

If the number of K_T rolls to take more than it can be obtained by formulas (1) and (3), this ratio will be called the overlap coefficient [4].

The angle speeds of planetary drums from the formulas (4) and (5) are as follows:

For two-drum apparatus:

$$\omega_2 = \frac{V_c}{r_2 \cdot \sin\alpha} \cdot \left(\eta \frac{\pi}{K} - \alpha\right), \quad (4)$$

For single drum

$$\omega_2 = \frac{\omega_1}{\beta} \cdot \left(\eta \frac{\pi}{K} - \alpha\right) \quad (5)$$

Condition of stem's rolling in a working slit

$$Q_c + \Sigma T_x - \Sigma N_x \geq 0 \quad (6)$$

where Q_c- effort of stems' rolling from apparatus's motion;

ΣT_x and ΣN_X~ sum of projections of forces of normal pressure from the side of rollers 3 and 4 rolling the stems and forces of friction to the motion of the stems.

$$\Sigma N_X = N_{x3} + N_{x4},$$

$$\Sigma T_x = T_{x3} + T_{x4} \quad (7)$$

To determine the forces N_{x3},T_x,N_{x4}, and T_{x4}, we use the assumption of a professor I.V. Kragelsky about even distribution of normal pressures q_3 and q_4 for points of rollers' contacts with a stem taken which was when studying the collapse of bast crops [5].

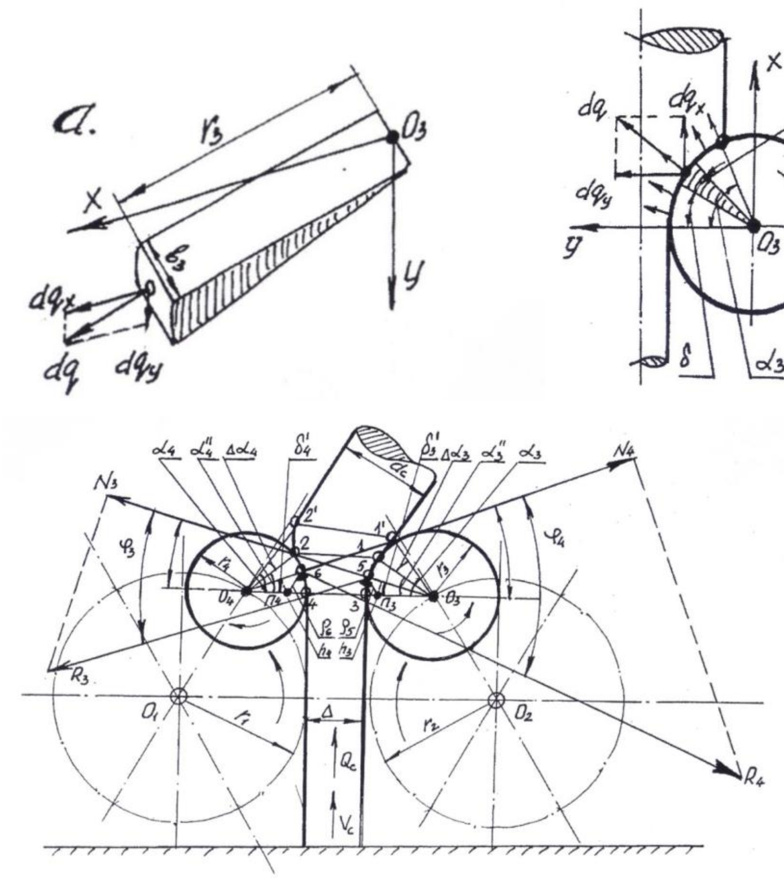

Fig. 1. Rolling of stems by planetary rollers.

If the elementary force is (Figure 1a)

$$dq_3 = q_3 b_3 r_3 d\delta,$$

$$dq_4 = q_4 b_4 r_4 d\delta, \quad (8)$$

where r_3 and r_4 – radii of circumferences of rollers 3 and 4; b3 and b_4 – width of stem's contact area with rollers.

Projections of elementary forces on the axis X and Y are equal:

$dq_{3x} = dq_3 \cdot \cos\delta dq_{3y} = dq_3 \cdot \sin\delta$

$$dq_{4x} = dq_4 \cdot \cos\delta dq_{4y} = dq_4 \cdot \sin\delta \quad (9)$$

In the course of integrated expressions (8) and (9) on α in limits from 0 to a_3 and from 0 to a_4 we obtain

$$Q_{3x} = \int_0^{\alpha_3} dq_{3x} = q_3 b_3 r_3 \cdot (1 - \cos\alpha_3''),$$

$$Q_{3y} = \int_0^{\alpha_3} dq_{3y} = q_3 b_3 r_3 \cdot \sin\alpha_3''; \quad (10)$$

$$Q_{4x} = \int_0^{\alpha_3} dq_{4x} = q_4 b_4 r_4 \cdot (1 - \cos\alpha_4''),$$

$$Q_{4y} = \int_0^{\alpha_3} dq_{4y} = q_4 b_4 r_4 \cdot \sin\alpha_4'' \quad (11)$$

where α_3'' and α_4'' - angles of rollers' coverage,

$\alpha_3'' = \mu\alpha_3$, $\alpha_4'' = \mu\alpha_4\mu$ - coefficient of reduction of angles α_3 and α_4 taking into account the crumpling of a rolled stem before rollers due to its elasticity $\mu = 0{,}76$.

From conditions of a stem's balance $Q_{3y} = Q_{4y}$. by the axis Y and balance $\frac{q_3}{q_4} = \frac{b_4}{b_3}$:

$$r_4 \cdot \sin\alpha_4'' = r_3 \cdot \sin\alpha_3'' \quad (12)$$

taking the expression (12) from trapezium $0_3 1 2 0_4$, we obtain after transformations

$$\cos\alpha_3'' = \frac{(C_m - d_c')^2}{2(C_m - d_c')\cdot r_3} \quad (13)$$

where C_m – distance between centers of rollers 3 and 4,

$$C_m = r_3 + r_4 + \Delta,$$

d_c'.- thickness of a stem gripped by rollers 3 and 4 in the input of a working slit is determined in dependence on diameter of a stem d_c and relation $\frac{r_3}{r_4}$; Δ - gap between rollers 3 and 4.

Substitute for $N_3 = \sqrt{Q_{3x}^2 + Q_{3y}^2}$ and $N_4 = \sqrt{Q_{4x}^2 + Q_{4y}^2}$ from expressions (10) and (11), we obtain the value of forces R_3 and R_4 after transformations [6]:

$$R_3 = N_3\sqrt{1 + f_3^2} = 2q_3 b_3 r_3 \cdot \frac{\alpha_3''}{2}\sqrt{1 + f_3^2},$$

$$R_4 = N_4\sqrt{1 + f_4^2} = 2q_4 b_4 r_4 \cdot \frac{\alpha_4''}{2}\sqrt{1 + f_4^2} \quad (14)$$

where f_3 and f_4 – coefficients of rollers s and 4' friction by stems. Application points of forces R_3 and R_4 are defined by values of angles δ_3' and δ_4'

$$\delta_3' = \mathrm{arctg}\frac{Q_{3x}}{Q_{4y}\,\sin\alpha_3} = \mathrm{arctg}\frac{1-\cos\alpha_3''}{\sin\alpha_3''} = 0{,}5\alpha_3''$$

$$\delta_4' = \mathrm{arctg}\frac{Q_{4x}}{Q_{4y}\,\sin\alpha_4} = \mathrm{arctg}\frac{1-\cos\alpha_4''}{\sin\alpha_4''} = 0{,}5\alpha_4'' \quad (15)$$

If we accept that

$$\alpha_3'' = 0{,}76a_3 \quad \text{and} \quad \alpha_4'' = 0{,}76a_4 \quad (16)$$

It will be $\delta_3' = 0{,}38a_3$ and $\delta_4' = 0{,}38a_4$

Due to N.M. Nikolaev $\delta' = (0{,}22 \div 0{,}39)\alpha$.

Moments of forces R_3 and R_4 relative to the instantaneous axes of rotation of the rollers 3 and 4 will be equal to: $M_3 = R_3\rho_5$.

$$M_4 = R_4\rho_6 \quad (17)$$

where ρ_5, ρ_6 – according to arms of forces R_3 and R_4.

Values ρ_5 and ρ_6 (Figure 1) are determined from triangles $\Pi_3 0_3 5$ and $\Pi_4 O_4 6$:

$$\rho_5 = \frac{r_3}{\lambda_{c3}}\sqrt{\lambda_{c3}^2 + 1 - 2\lambda_{c3} \cdot \cos\delta_3'},$$

$$\rho_6 = \frac{r_4}{\lambda_{c4}}\sqrt{\lambda_{c4}^2 + 1 - 2\lambda_{c4} \cdot \cos\delta_4'} \quad (18)$$

Power W_c needed for stems' rolling by two-drum apparatus:

$$W_c = e_c[M_3(\omega_3 - \omega_2) + M_4(\omega_4 - \omega_1)], \quad (19)$$

where e_c – amount of stems which are in a working slit simultaneously;

$$e_c = \frac{LmBV_k}{360Vc} \quad (20)$$

where L- average length of stem; m – amount of stems on 1ha; B – width of a harvester's coverage; V_K- speed of a harvester; V_c- speed of stem's motion in a working slit; M_3 and M_4 – moments of appropriate equal forces N and T relative to the instantaneous axis of rotation [7,10].

Thus, when considering the process of rolling Solanaceae vegetables stems as a rolling of elastic-plastic material, there were obtained the dependences that determined the kinematic and energy parameters of planetary multi-roller fruit separators [8,9].

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