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Theoretical justification of fruit separation 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 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 type of the proposed design is theoretically justified, its description and the flow of the technological process are given. As a result of the work done, the dependences of the main parameters and values are obtained, which can be used in further work on the study of the parameters and dependencies of the interaction of the fruits of Solanaceae vegetables in interaction with planetary fruit separators.

The research in the field of Solanaceae vegetables harvesting was 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 the 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. The bottom of sweet pepper is on a peduncle which is attached to a stem. When separating the fruit, it is necessary to separate the peduncle at the place of its attachment to the stem.

The rupture is provided if the force of compression acts on the peduncle in the transverse direction, and in the longitudinal direction – the tensile force and the variable bending moment in the direction. The combination of these forces and moment is observed in the work of the planetary fruit-separating apparatus. The breaking force of the peduncle in bending tension is reduced by 3-5 times compared to the tension without bending.

The process of main fruit separation is at the third level of the multilevel scheme of justification. Its input parameters are the output parameters of the second level - the operation of the process of rolling stems. The criterion for evaluating this operation is ε_{otd} - the degree of fruit separation, which should strive to the maximum value.

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Figure 1 shows the scheme of the influence of forces of normal pressure N, friction T and stretching P_p on the bottom of the fruit and the peduncle. In the case, if the diameters and working surfaces of paired rollers are the same, the angles α of a coverage of the rollers by a stem and a fruit, forces N, T and the resultant forces R for both rollers will be the same, and the bending of the peduncle is absent, and its rupture often occurs in the middle. But diameters and working surfaces of the planetary rollers 3 and 4 in general are in pair and they are different, so

$$\alpha_3 \neq \alpha_4,\ N_3 \neq N_4,\ T_3 \neq T_4 \text{ и } R_3 \neq R_4.$$

To separate the fruit, the following condition must be met:

$$Q_c + \Sigma T_y - \Sigma N_y = P_n$$

where ΣTy and ΣN_y- sum of projections of forces T_3 and T_4 and $N_3$and N_4 respectively on direction of stem's motion.

The process of separating the fruit from the stem by the planetary roller consists of two stages: stretching the stem and its double-ended bending.

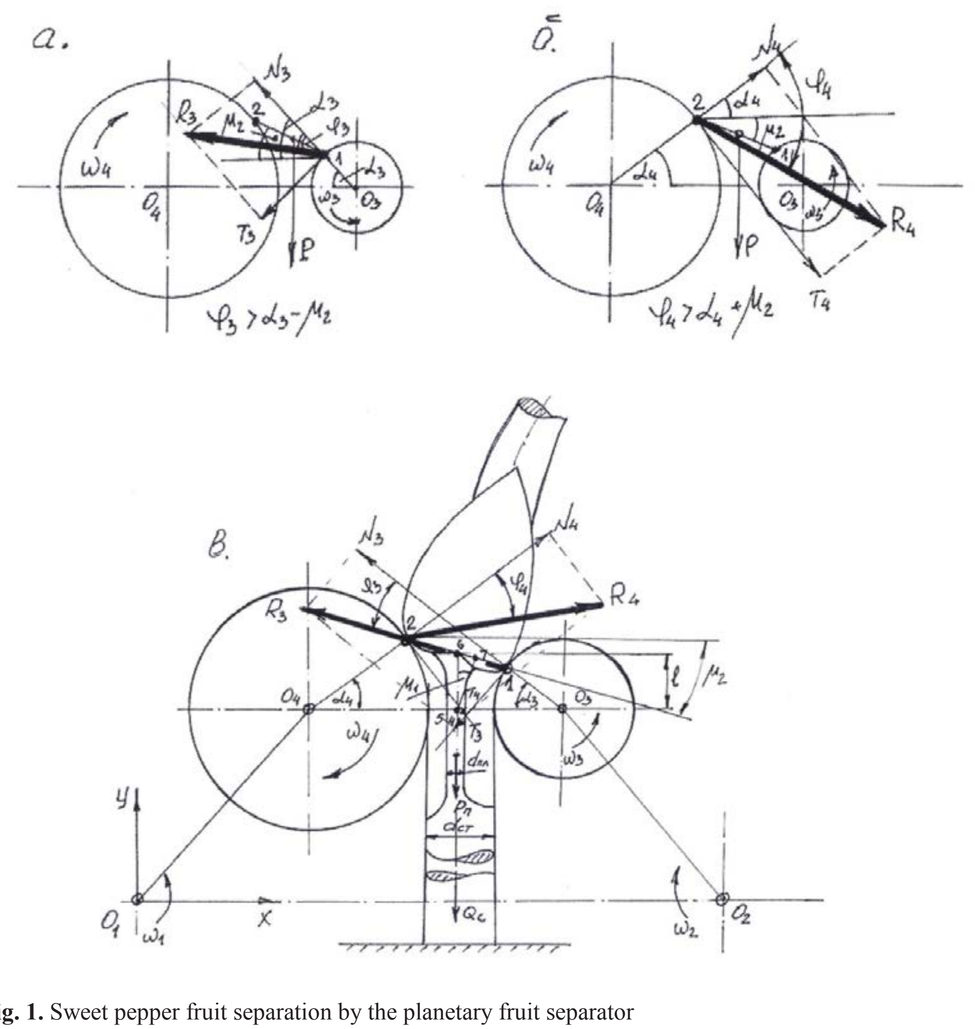

Fig. 1. Sweet pepper fruit separation by the planetary fruit separator

Consider the first step. In the result of the relative movement of the rollers 3 and 4 and the impact on the bottom of the fruit of variable forces R_3 and R_4, the fruit influences a variable moment in magnitude and direction. The peduncle bends and stretches so, that the most tension influences the extreme external or internal fibers in the place of attachment of the peduncle to the fruit. The rupture of the peduncle will take place as only the tension in the place of connection with the fruit will achieve the critical values.

Suppose, that the peduncle is a flexible fiber attached to the middle of the fruit's bottom and the force P is directed along the middle fiber of the peduncle, d_n- diameter of fruit: l – length of peduncle in the place 5-6; μ_1- angle between direct 5-6 and 5-7, defining the direction of force P, μ_2 – angle between direct 1-2 and 0_3-0_4, defining the position of the fruit's bottom in a working chink.

According to calculations $\mu = 0\text{-}\div 10°$. In the result of projecting of sides of trapezoids $1O_356$ and $2O_456$ in the direction 5-6 and O_3O_4 and transformations we obtain

$$\sin\alpha_3 = \frac{4\cdot l\cdot n\cdot r_3 \pm \sqrt{4\cdot l\cdot n\cdot r_3 - 2(m^2-4\cdot l^2)[n^2-(2m-r_3)^2]}}{2(m^2-\Delta\cdot l^2)\cdot r_3^2}$$

$$\sin\alpha_4 = \frac{2\cdot l - r_3\cdot \sin\alpha_3}{r_3}, \quad (1)$$

where m- difference of radii of adjacent rollers, $m = r_4 - r_3$; n – difference between length of peduncle, $n = 4\cdot l - r_4 - r_3 + m$.

Length of peduncle 1 can be equal

$$l = r_{cp}\cdot \sin\left(\arccos\frac{c-d_n}{2r_{cp}}\right), \quad (2)$$

where r_{cp} – middle radius of rollers, $r_{sr} = \frac{r_3 + r_4}{2}$

From the trapezoid $1O_356$ it follows:

$$\sin\mu_2 = \frac{2(l - r_3\cdot \sin\alpha_3}{d_n} \quad (3)$$

If $\varphi_3 < \alpha_3 - \mu_2$ and $\varphi_4 < \alpha_4 + \mu_2$, so from equations of forces R_3, R_4 and P moments relatively to points 1 and 2 it follows:

$$R_3 = \frac{P\cdot d_n\cdot \cos\mu_2 - 2M_\mu}{2d_n\cdot \sin(\alpha_3+\varphi_3-\mu_2)}; \qquad R_4 = \frac{P\cdot d_n\cdot \cos\mu_2 - 2M_\mu}{2d_n\cdot \sin(\alpha_4+\varphi_4+\mu_2)} \quad (4)$$

where M_μ – moment of resistance of peduncle to bending (M_μ= 0,04-0,07 Нм)

If $\varphi_3 > \alpha_3 - \mu_2$ (Figure 1 a) and $\varphi_4 > \alpha_4 + \mu_2$, it follows

$$R_3 = \frac{2M_u - Pd_n\cdot \cos\mu_2}{2d_n\cdot \sin(\varphi_3-\alpha_3+\mu_2)}; \quad R_4 = \frac{2M_u - Pd_n\cdot \cos\mu_2}{2d_n\cdot \sin(\varphi_4+\alpha_4+\mu_4)} \quad (5)$$

We assume that $\varepsilon_1$and ε_2 are angles between the directions of the normal pressure $N_3$and N_4 and speeds V_1 and V_2, respectively. If speeds V_1 and V_2 are directed to angles inside angles of friction φ_3 and φ_4, so $\varepsilon_1 > \varphi_3$ and $\varepsilon_2 > \varphi_4$, rollers 3 and 4 slip along the fruit's bottom, and directions of vectors R_3 and R_4 are defined by values of angles φ3 and φ_4, and modules R_3 and R_4 on formulas (5). If $\varepsilon_1<\varphi_3$ and $\varepsilon_2< \varphi_4$, so the direction of vectors R_3 and R_4 coincide with vectors V_1 and V_2, respectively. Then, determining the modules R_3 and R_4 in the formulas (5) and (6) instead of φ_3 and φ_4 should be put E_1 and ε_2, respectively.

And so, the position of the bottom of fruit at the beginning of contact with the rollers is determined by the ratio of the roller diameters d_3 and d_4 and the fruit's bottom d_n. In turn, values and directions of powers R_3 and R_4 depend on position of fruit's bottom in a working chink and as well as on values φ_3 and φ_4.

If $\varepsilon_1>\varphi_3$ and $\varepsilon_2> \varphi_4$, the conditions for non-gripping of fruit by rollers 3 and 4 will be:

$$\alpha_3 - \mu_2 > \varphi_3 \text{ and } \alpha_4 + \mu_2 > \varphi_4 \tag{6}$$

where $\alpha_3 - \mu_2$ and $\alpha_4 + \mu_2$ – angles, closed between the flatness of fruit's bottom and directions of forces N_3 and N_4 respectively. If $\varepsilon_1< \varphi_3$ and $\varepsilon_2< \varphi_4$, the conditions for gripping of fruit by rollers 3 and 4:

$$\alpha_3 - \mu_2 < \varphi_3 \text{ и } \alpha_4 + \mu_2 < \varphi_4, \tag{7}$$

Period of fruit separation from the stem by planetary rollers t_0 was defined by the formula:

$$t_0 = \frac{\varepsilon_0 \cdot l}{\rho_0' \cdot \omega_1 + V_{ст}}, \tag{8}$$

where ε_0- relative elongation of peduncle; l- length of peduncle; ρ_0'- radius of initial circumference of the rolling of the drum 1 along the drum 2,

$\rho_0' = \frac{A \cdot \omega_2}{\omega_1 + \omega_2}$, $A = O_1 O_2$ - distance between centers of drums 1 and 2; $V_{ст}$- speed of stem.

Power which is necessary for fruit's separation from the stem by rollers of two-drum device W_n, is equal:

$$W_n = t_0 \text{-} e_c - e_n[M_3'(\omega_3 - \omega_2) + M_4'(\omega_4 - \omega_1)], \tag{9}$$

where e_c – amount of stems which are simultaneously in the working chink; e_n – average amount of fruits on the stem; M_3 and M_4 – moment of resultant forces R_3 and R_4 relatively to momentary axes of rotation of rollers 3 and 4.

Power for fruit's separation by rollers W_q is defined by the formula

$$W_q = \frac{q}{9{,}8} \cdot e_c \cdot e_n (V_{ст} + \rho_0' \cdot \omega_1)^2, \tag{10}$$

where q- mass of one fruit.

Thus, it is theoretically defined the rationale of the fruit separation process by the planetary fruit separator. The obtained dependences of the main parameters and values can be used to study similar structures and parameters and dependencies of the interaction of fruits of Solanaceae vegetables in the interaction with planetary fruit separators in a further study.

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