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ADVANCES IN METHODS OF CLEANING ROOT CROPS

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Abstract: *The paper presents new developments of the method and the design of an operating element of a conveyor of a root crop harvester, which is highly functional, since except for transportation, it provides careful cleaning of root crops from soil impurities and crop residues. The results of theoretical calculations aimed at the determination of effective design parameters and power characteristics of such an operating element are covered. The pattern of root crop motion along the technological channel of a conveyor-cleaner has been defined and the amount of root crop damage when contacting bars on the conveyor belt has been determined.*

Key words: *root crops, transportation, separation, damage, beet harvesters.*

1. Introduction

As a rule, the process of cleaning root crops in harvesters is divided into two stages: main cleaning, when most of soil is separated, and final cleaning, when soil impurities and crop residues are separated from root crops [9]. At the first stage screw, rotor, cam and beater cleaning machines are applied and at the second stage gravity separators and leading-out flexible screws are used, which are arranged with a certain clearance space relative to conveyor belts in order to carry various impurities out of an operational area to the field [5].

The conducted theoretical and experimental investigations of the processes of cleaning root crops allowed choosing effective design, kinematic and dynamic parameters of the developed operating elements of beet harvesters and their operation modes respectively [1], [2], [3].

When conducting the research, special attention was paid to the determination of the degree of cleaning and the amount of damage of root crops in the process of their separation by various machine arrangements. Such investigations for the developed small-scale beet harvesters and potato harvesters are presented in papers [6], [7].

Having analyzed typical layout diagrams of root crop harvesters, it can be concluded that, as a rule, a technological route of root

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crop separation from the area of digging to the area of unloading takes less than a half of the general path of their transportation in technological channels of machines, that is to say, sufficient amount of such a route is passive transportation of root crops by raddled chains and drag conveyors.

That is why, the main aim of this research is the development and the substantiation of the parameters of the developed drag conveyor-cleaner, which provides additional cleaning of root crops when they are transported to the unloading area.

Here, the choice of the parameters of transporting-cleaning machine systems should be based on the principle of decreasing the level of “aggressivity” of separation of thrashed heap of root crops in the process of their removal from the area of digging, since in the process of their cleaning, the possibility of direct interaction of operating elements and root crops increases and, in its turn, it causes their damage

2. Materials and Methods

In order to add functional characteristics to moving conveyors-cleaners, which provide final cleaning from soil impurities and crop residues with minimum damage and regulation of the intensity rate of separation, a new design of a drag conveyer-cleaner has been suggested [4], the design and the flow sheet of the arrangement of its operating elements is presented in Figure 1.

On two cross bars 1 of a scraper belt, which is arranged at an angle γ to the horizon, there is a base frame 7, where a group of scrapers 3 is hinged. Laterally, a cam 5 is attached to a group of scrapers. Scrapers are spring biased 2 in the direction of belt movement and their angular rotation is limited by a stop 6. Along the belt movement with travelling speed V_n, there is a support roller 4 fixed on the conveyor frame, which is attached with overlap ratio Δ relative to a cam 5.

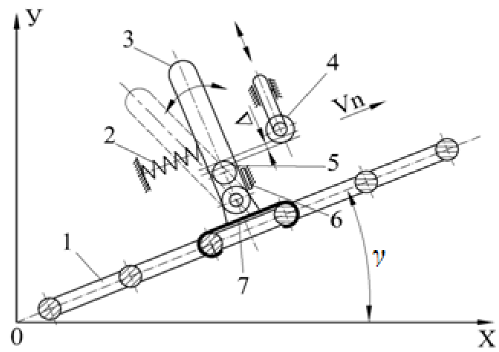


Fig. 1. *Design and Flow Sheet of a Conveyor-Cleaner*

A scraper belt together with root crops moves in the direction of their unloading. When a cam contacts a support roller, a group of scrapers with root crops rotates, which results in spring deflection. After dropping out of engagement of a cam and a support roller, a group of scrapers turns up to it is hand tight by spring force and throws root crops onto the bars of a belt. Such impact interaction of root crops and spring bars causes their cleaning by means of shaking and rolling backwards until the second impact interaction with scrapers, which improves cleaning of root crops from tare as well.

Theoretical calculation is aimed at determining analytical dependences of design parameters of roller and cam engagement on the amount of belt movement, at which their contact takes place, as well as the maximum rotation angle of scrapers β_{max} before throwing root crops onto belt bars. The scheme of roller and cam interaction is presented in Figure 2.

Initial contact angle φ_i of the line, which connects the axis of a roller and the axis of a cam and the vertical plane, which passes through the axis of a roller, relative to constant parameters of the radius of a roller *R* and the radius of a cam *r*, as well as the adjustable ratio of overlap between the surface of a cam and the surface of a roller *Δ* is determined as:

$$\varphi_i = \arccos\left[\frac{R - \Delta + r}{R + r}\right]. \tag{1}$$

In general cases, variable value of belt movement X_b is determined as:

$$X_b = l\cos\left\{\arcsin\left[\frac{H-(R+r)\cos\varphi_T}{l}\right]\right\} + (R+r)(\sin\varphi_i - \sin\varphi_T) - l\cos\left\{\arcsin\left[\frac{H-R+\Delta-r}{l}\right]\right\} \tag{2}$$

where: *l* – length of a cam lever 5;
H – distance from the axis of a roller 4 to the base frame of scrapers 7.

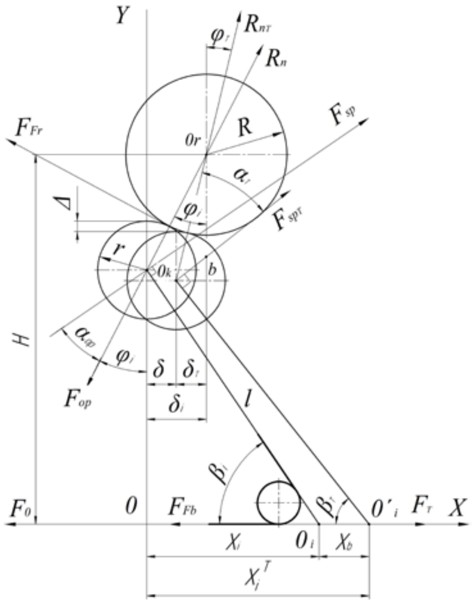


Fig. 2. *Scheme of Determining Interaction Parameters of a Roller and a Cam*

Here, the value of angle φ_i is set from (1), and the value of angle φ_T is set within the limits of φ_i to 0°.

The maximum value of a rotation angle of scrapers relative to a base frame is determined as

$$\beta_{max} = \arcsin\left(\frac{H-R+\Delta-r}{l}\right) - \arcsin\left(\frac{H-(R+r)}{l}\right) \tag{3}$$

Value β_{max} must be chosen based on the angle of inclination of a conveyor-cleaner to the horizon γ, as well as on the field contour, where a harvester operates.

The determination of the parameters of spring elements is conducted taking into consideration tuber yield, travelling speed of a machine and linear velocity of a scraper belt. Here, roller deflection relative to *OY*-axis allows regulating the ratio of its overlap *Δ* with the cylindrical surface of a cam and the maximum rotation angle of scrapers, respectively.

In order to determine additional moving force, which arises, when there is interaction of a cam and a support roller, let us predetermine torque value at the moment rotation of a group of scrapes and a cam respectively.

In case of using a torsion spring for biasing scrapers in the direction of belt bars movement, spring deflection is determined by the rotation angle *β* (rad unit) between spring ends [8]:

$$\beta = \frac{Tl}{EI}, \tag{4}$$

where: T – torque, which influences a spring; $L_{sp} = \pi D_m i$ – total length of a spring turn bar; D_m – mean diameter of a spring; i – number of spring turns; $E = 2\cdot 10^{11}$ N/m^2– modulus of elasticity of spring material; J = $\pi d^4/64$ – second area moment of a bar under bending; d – diameter of a bar.

Taking into consideration the fact that a spring has preset angular tension β_p and, in the process of cam and roller interaction, angle β changes $(\beta = \beta_i - \beta_T)$ with the number of springs n, formula (4) takes the following form:

$$T = 0.3125 \cdot 10^{10} \frac{(\beta_i - \beta_T + \beta_p) d^4 n}{i D_m}. \tag{5}$$

When investigating torque behavior, the value of angle φ_T is chosen within the limits of φ_i, which corresponds to β_i, and up to zero.

In the contact area of a cam and a roller, there is normal reaction R_n and opposite acting force F_{op} respectively, the directions of which coincide with the line, which connects the centers of a cam and a roller. In addition, in the process of cam movement relative to a roller, friction force F_{Fr} arises, which is directed perpendicular to R_n and F_{op}. Let us express normal reaction R_n in term of F_{sp}:

$$R_n = F_{sp} \cos\alpha \cdot \tag{6}$$

Taking into consideration that $T = F_{sp}\ l$, and $\alpha_T = \beta_T - \varphi_T$, equation (6) takes the following form

$$R_n = T\cos\alpha_T / l, \tag{7}$$

Since drag force F_{dr} is equal and opposite of the moving force of a belt F_T to the action of a scrapers turning mechanism, the equilibrium of all the forces on the plane of a belt (OX-axis)

$$F_T = F_{op}\sin\varphi_T + F_{Fr}\cos\varphi_T + F_{Fb}, \tag{8}$$

where: F_{Fr} and F_{Fb} friction forces in the following pair couples: cam-roller and lower surface of a belt-set of rollers, which support a belt.

Taking into consideration the fact that $F_{Fr} = F_{op} f_1$, *and* $F_{Fb} = F_{op} f_2 \cos\varphi_T$, the expression (8) of closed form is the following:

$$F_T = F_{op}\left(\sin\varphi_T + f_1\cos\varphi_T + f_2\cos\varphi_T\right), \tag{9}$$

where: f_1 and f_2 – correspondent friction coefficients in the above mentioned pairs.

Since $|F_{op}| = |R_n|$, in its closed form moving force F_T is determined from the system of equations

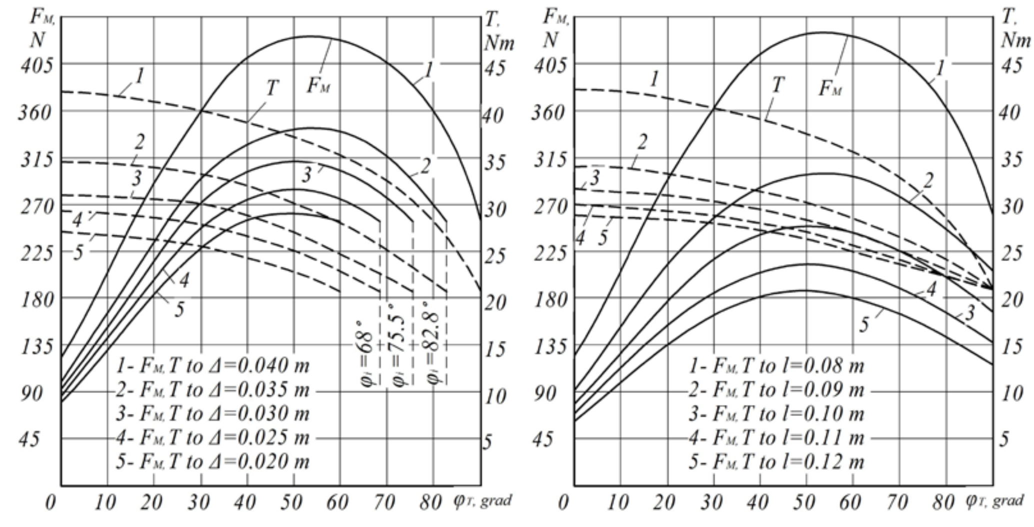
$$\begin{cases} F_M = \dfrac{T\cos(\beta_T - \varphi_T)}{l}(\sin\varphi_T + f_1\cos\varphi_T + f_2\cos\varphi_T); \\ T = 0{,}3125\cdot 1010 \dfrac{(\beta_i - \beta_T + \beta_P) d^4 n}{i D_m}; \\ \beta_i = \arcsin\left(\dfrac{H - R + \Delta - r}{l}\right); \\ \beta_T = \arcsin\left[\dfrac{H - (R + r)\cos\varphi_T}{l}\right]; \\ \varphi_T \in \left(\varphi_i = \arccos\left[\dfrac{R - \Delta + r}{R + r}\right] ... 0^\circ\right). \end{cases} \tag{10}$$

Figure 3a represents characteristic curves showing the dependence of torque *T* and additional moving force F_M, when a group of scrapers rotates, depending on φ_T at various values of Δ. The maximum value of angle φ_T corresponds to the position, where a cam contacts a roller, and its zero value corresponds to the moment of their dropping out of engagement. Having analyzed the changes in the value of *T*, it has been determined that the decrease of Δ from 0.04 to 0.02 m results in the decrease of torque for 34.6 %.

The initial value of *T*, which corresponds to the moment of engagement of a cam and a roller, is equal for all the values of Δ and is 21 Nm. The change of F_M has the form of a parabolic characteristic, the value of which increases from the moment of engagement of coupling elements and further there is a sharp decrease of F_M.

The initial value of *T*, at which the rotation of scrapers takes place, is constant and is equal to 262 N. The maximum increase of the value of F_M from its initial value is observed for Δ = 0.04 m and its increment is 39.5 %.

Figure 3b represents characteristic curves showing the dependence of torque *T* and additional moving force F_M, when a group of scrapers rotates, depending on various values of arm *l* as well as on the instantaneous value of φ_T.



a *b*

Fig. 3. *Characteristic curves of torque T and additional moving force F_M at rotation of a group of scrapers depending on: a - Δ; b - l and the value of φ_T*

Having analyzed the curves, it has been determined that, in contrast to the previous case, at the above mentioned constant parameter values, the change of *T* and $F_M = f(\varphi_T)$ is within the limits of $\varphi_T = 0...90^0$.

The maximum increase of value F_M is observed when *l* = 0.08 m, and the change of

l from 0.08 to 0.12 m results in the decrease of the peak value of F_M in 2.33 times. The change of T in the initial position is equal for all the values of l and is 20.95 Nm. The increase of l causes the decrease of the final value of T and, within the set range of l = 0.08...0.1 m, the decrease of T_{max} is 31.4%.

Assuming the mean value of the fundamental capacity for the process of transporting root crops N_f = 3.75 kW, it has been determined that the change in values within the limits of Δ = 0.02...0.04 m; l = 0.08...0.12m and R = 0.03...0.06 m results in the increase of additional energy expenditures ΔN for Δ for 12.5%...20.5%, for l for 8.9%...20.5%, for R for 13.3%...20.5%, respectively, comparing to fundamental capacity N_f.

Let us consider the process of movement of a root crop along the surface of a scraper at spring actuation, which is deflected for a certain angle relative to the initial position as well as its further free motion after a scraper stops and until it falls on the bars of a conveyer belt.

The initial position of a scraper and a root crop is shown in Figure 4.

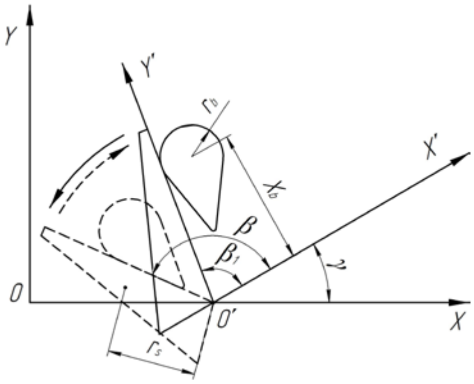


Fig. 4. *Pattern of root crop motion along the surface of a scraper*

Rotational equation of a scraper can be written in the following form:

$$J_s\ddot{\beta} = -C_s\left(\beta - \beta_1 - \beta_t\right) + m_s r_s g\cos\left(\pi - \beta - \gamma\right) + N_b x_b \ , \qquad (11)$$

where: J_s – moment of inertia of a scraper relative to its rotation point; C_s – angular stiffness of a scraper spring; β – rotation angle of a scraper relative to a conveyer belt; β_1 – inclination angle of a scraper to a belt; β_t – initial tension of a scraper spring; γ – ascending angle of a conveyer to the horizon; m_s – mass of a scraper; r_s – center-of-mass radius of a scraper; g – gravitational acceleration; N_b – force of pressure of a root crop on a scarper (reaction), which is perpendicular to its surface; x_b –center-of-mass coordinate of a root crop relative to a conveyer belt.

The equation of root crop motion along the surface of a scraper, taking into consideration centrifugal inertial force

$$m_b\ddot{x}_b = -N_b f - m_b g\sin\left(\pi - \beta - \gamma + \Delta\right) + m_b\dot{\beta}^2 x_b \qquad (12)$$

where:

m_b – mass of a root crop;

f – friction coefficient of a root crop on the surface of a scraper;

Δ = arctg(r_b/x_b) – angle of deflection of root crop mass center from the surface of a scraper relative to the point of rotation;

r_b – radius of a root crop head.

The expressions for accelerations of $\ddot{x}_b$ and $\ddot{\beta}$ are of the following form:

$$\ddot{x}_b = \frac{\dfrac{\left(J_{b0} + m_b x_b^2\right)\ddot{\beta}}{x_b} + 2m_b \dot{x}_b \dot{\beta} - m_b g \cos(\pi - \beta - \gamma + \Delta)}{m_b} f - g \sin(\pi - \beta - \gamma + \Delta) + x_b \dot{\beta}^2 \quad (13)$$

$$\ddot{\beta} = \frac{-C_s(\beta - \beta_1 + \beta_t) + m_s r_s g \cos(\pi - \beta - \gamma) - 2m_b x_b \dot{x}_b g \cos(\pi - \beta - \gamma + \Delta)}{J_s + J_{b0} + m_b x_b^2} \quad (14)$$

In the process of numerical integration of differential equations (13) and (14), at each step all the process parameters were determined until the condition $\beta = \beta_1$ was reached.

Based on the developed mathematical model, the influence of mechanical parameters of the system (root crop mass, spring stiffness and the initial value of its tension, an inclination angle of a conveyer frame to the horizon and rotation angles of scrapers) on the main characteristics of the cleaning process – the velocity of root crop throwing, the length of their flying and the velocity of impact interaction with the bars of a belt was investigated. The values of the above mentioned parameters were changed within the following limits: m_b = 0.5...2.5 kg; angular stiffness of a scraper spring: C_s = 30...150 Nm/rad; an initial angle of spring tension: β_t = 30...150 grad; a rotation angle of a scraper relative to a belt β = 30...150 grad; an inclination angle of a conveyer belt to the horizon γ = 0...60 grad. Here, when investigating the influence of one of the parameters on the main characteristics of the cleaning process, the following constant values were set for others: m_b = 1.5 kg; C_s = 100 Nm/rad; β_t = 90grad; β = 90 grad; γ = 40 grad.

It has been determined that the increase in spring stiffness from 30 to 100 Nm/rad results in the increase of angular rotation velocity of scrapers in 1.94 times. Here, the vertical component of flying out velocity of a root crop at the given parameters of spring stiffness at its starting moment is equal to 0.19 m/s and 0.47 m/s, that is to say, it increased in 2.47 times.

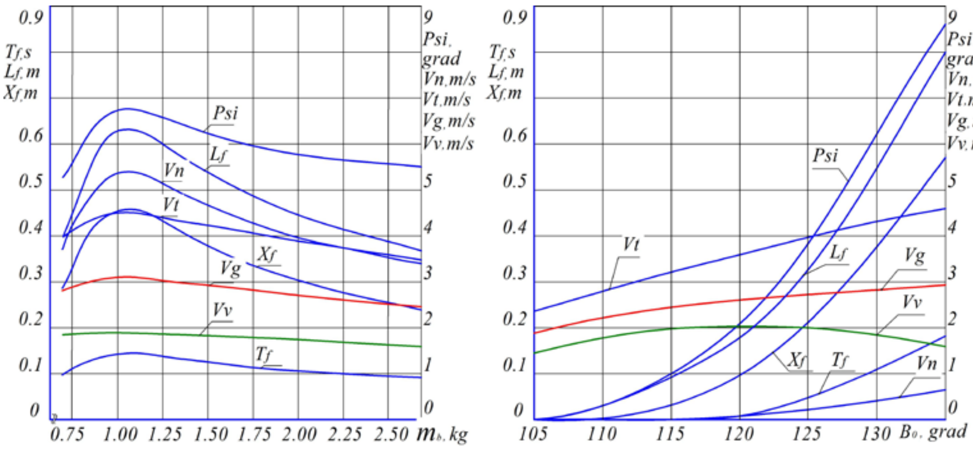
The results of the conducted calculations are presented in the form of curves, which are shown in Figure 5.

On *y*-axes of the curves the following data are indicated: P_{si} – flying off angle of a root crop over the surface of a conveyer; V_n – normal flying off velocity component; V_t – tangential flying off velocity; V_g – a horizontal component of falling velocity of a beet root onto a conveyer; V_v – a vertical component of falling velocity of a beet root onto a conveyer; X_f – a coordinate of beet root falling onto a conveyer; L_f – the length from a scraper to the point of beet root falling onto a conveyer; T_f – time of beet root flying until its falling.

Having analyzed the influence of root crop mass (Fig. 5a) on the parameters of the process of their throwing, it can be concluded that, at the above mentioned parameters, the increase of root crop mass up to 1.1 kg results in the increase of almost all the dependences, except for a vertical velocity V_v.

In case of actual root crop mass ranging from 0.5 to 1.5 kg, relative values change within the following limits: V_g = 2.8...3.1 m/s; V_v = 1.85...1.9 m/s; L_f= 0.45...0.63 m.

Thus, in case of actual inclination angle range of a scraper β = 105...140 grad at spring stiffness C_s = 100 Nm/rad, relative values changed within the following limits: V_g = 1.5...3.1 m/s; V_v = 1.1...2.1 m/s; L_f = 0...0.95 m (Fig. 5b). The maximum vertical contact velocity of a root crop and a belt corresponds to a rotation angle of scrapers 120 grad.



a *b*

Fig. 5. *Change in parameters of root crop throwing depending on: a – mass* m_b*; b – an angle of deflection of a scraper* β

In order to conduct experimental research, a stand was developed and its general view is represented in Figure 6.

The experimental research was conducted the following way. A conveyer frame was fixed at the preset angle γ. Further, scrapers were rotated with their following fixturing and a root crop was placed in a set position.

Fig. 6. *General view of a stand and its separate elements*

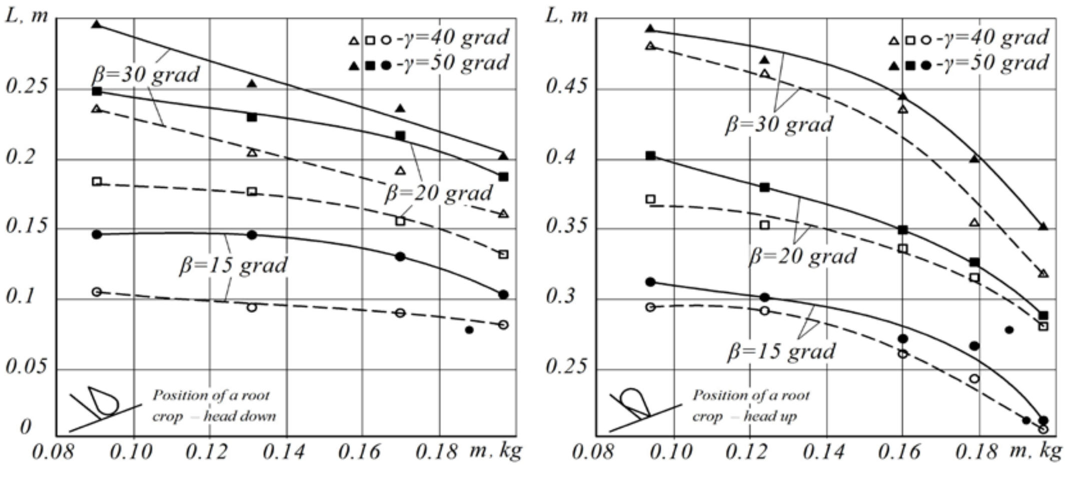
Further, scrapers were rotated with their following fixturing and a root crop was placed in a set position. After that, there was sharp loosing of the turned scrapers, which returned to their initial position under the action spring force and threw root crops onto belt bars. The flying distance of sugar beets was fixed with the help of a digital photo camera.

3. Results and Discussion

Figure 7 represents a photographic shooting sheet of the conducted experiments aimed at the determination of the trajectory and the distance of root crop flying, based on which corresponding curves are built.

Figure 8 represents the flying distance of root crops *L* until their second interaction with belt bars-vs-beet root mass *m* curves at various positions of root crops.

Fig. 7. *A photographic shooting sheet of the conducted experiments aimed at the determination of the trajectory and the distance of root crop flying*



a *b*

Fig. 8. *Flying distance of root crops L until their second interaction with belt bars-vs-beet root mass m curves at various positions of a root crop: a – head down; b – head up*

It has been determined, that if an inclination angle of a conveyer to the horizon is γ = 40^0, the increase of root crop mass from 0.92 to 1.96 kg results in the decrease of *L* for 26% at β = 15^0; for 25% at β = 20^0; for 27% at β = 30^0. The increase of angle γ from 40^0 to 50^0 results in the increase of the absolute value of *L* for 7.4%...2.1% within the indicated range of angle β change.

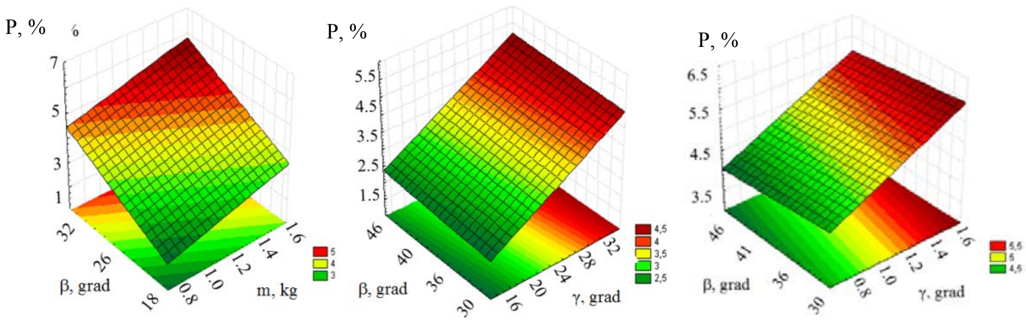
The angle of deflection of scrapers β from their initial position has the most sufficient influence on the distance of root crop flying *L*.

Based on the conducted multi-factor experiment aimed at the determination of root crop damage at their interaction with belt bars, a regression equation has been built and it has the following form in natural coordinates:

$$P = -3{,}88 + 4{,}68m + 0{,}22\beta + 0{,}08\gamma - 0{,}067m\gamma - 0{,}003\beta\gamma - 0{,}11m\beta + 0{,}003m\beta\gamma. \quad (15)$$

Response surfaces of the dependences of root crop damage on various factors are represented in Figure 9.

According to the conducted analysis, it can be determined that, in case of a factor field being 15 < β < 35 (grad); 0.8 < m < 1.6 (kg); 30 < γ < 50 (grad), an angle of scrapers deflection (β) has the maximum influence on the amount of root crop damage followed by root crop mass (m) and an angle of inclination of a belt to the horizon (γ) has the least influence.



a *b* *c*

Fig. 9. *Response surfaces of dependence P = f(m,β): a – at γ = 30°; b – at m = 0.8 kg; c - at m = 1.6 kg*

Thus, applying regression equation 14, it is possible to determine the amount of beet root damage during their cleaning on a conveyor-cleaner with oscillating scrapers within the parameter variation range.

A general view of a drag conveyor-separator, which is mounted on a root crop harvester, is represented in Figure 10.

Fig.10. *A general view of a conveyor-separator*

4. Conclusions

In order to improve cleaning of root crops in harvesters and in order to provide regulation of this process, a design of a conveyor-separator with oscillating scrapers has been developed and its rational parameters have been substantiated.

Analytical dependences in order to determine belt deflection relative to the angle, at which there is a contact of a cam and a roller, as well as the maximum angle of scrapers rotation from the length of a lever have been deduced.

Having conducted power analysis, a system of equations for determining the influence of torque T on the process of rotation of a group of scrapers and additional moving force F_M on the parameters of the rotating mechanism of scrapers has been built.

A mathematical model of the process of moving root crops along operating surfaces of scrapers and in their free motion has been developed and the influence of the parameters of an operating element on root crop motion pattern has been determined.

Based on photographic shooting sheet of the conducted investigations, the trajectories and the flying distances of root crops L until their second interaction with belt bars, depending on root crop mass L, m at various positions of root crops on the scrapers have been determined. The greatest flying distance of root crops is observed, if they are positioned heads up relative to a belt.

According to the obtained results of the experiment determining the influence of β, m, γ on the amount of root crop damage, the angle of deflection of a group of scrapers β has the greatest influence. It is followed by the mass of root crops m and the angle of inclination of belt bars to the horizon γ.

References

1. Bulgakov, V., Golovats, I., Špokas, L. et al., 2005. Theoretical investigation of a root crop cross oscillations at vibratinal digging up (in Russian). In: Research papers of IAg. Eng LUA & LU of Ag, vol. 37(1), pp. 19-35.
2. Bulgakov, V., Adamchuk, V., Nozdrovicky, L. et al., 2017. Theory of the interaction of flat sensing organ with the head of the sugar beet root. In: Journal of Agricultural Engineering, vol. 48(4), pp. 235-244.
3. Dumych , V., Salo, Ya., 2013. Analysis of structures of technical means for combine harvesting of potatoes. In: Engineering and Technology AIC, vol. 41(2), pp. 19-22.
4. Flonts, I., Hevko, R., Tkachenko, I., 2008. A conveyor-separator for root crops and potatoes. In: Pat. № 31875, MPK A01D 27/00, u200713963; Bul. 8, p. 3, Ukraine.
5. Hevko, R.B., Tkachenko, I.H., Synii, S.V., 1999. Ways of improvement of beet root harvesters. Publishing in LDTU, Lutsk, Ukraine.
6. Hevko, R.B., Synii, S.V., Pankiv, M.P. et al., 2014. Development and analysis of machine operation for energy saving technologies of root crop harvesting. In: Bulletin of Engineering Academy of Ukraine, no. 3-4, pp. 46-52.
7. Hevko, R.B., Tkachenko, I.H., Synii, S.V. et al., 2016. Development of design and investigation of operation processes of small-sclale root crop and potato harvesters. In: INMATEH. Agricultural Engineering, vol. 49(2),

pp. 53-60.

8. Pysarenko, H.S., 1979. Strength of Materials. Higher Education Publishing House, Kyiv, Ukraine.
9. Voitiuk, D., Baranovslyi, V., Bulhakov, V., 2005. Agricultural machinery. Principles of Theory and Calculations. Book, Higher Education Publishing House, Kyiv, Ukraine.