IMPACT OF PARAMETERS OF AN AFTER-CLEANING CONVEYOR OF A ROOT CROP HARVESTER ON ITS PERFORMANCE
/
ВПЛИВ ПАРАМЕТРІВ ДООЧИСНОГО ТРАНСПОРТЕРА КОРЕНЕЗБИРАЛЬНОЇ МАШИНИ НА ЯКІСНІ ПОКАЗНИКИ ЇЇ РОБОТИ

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ABSTRACT

The results of theoretical and experimental study of design and kinematic parameters impact of an after-cleaning rod conveyor with variable path of root crops on their cleaning quality indices are presented in the article. The values of allowable inclination angle of the conveyor intake unit taking into account rod web vibrations have been substantiated in the theoretical part. The impact of inclination angles of the conveyor sections, its linear velocity and the path velocity of loading conveyor scrapers and manufacturing clearances between them on the root crop harvester qualitative characteristics has been determined in the experimental part.

РЕЗЮМЕ

У статті наведено результати теоретичних і експериментальних досліджень впливу конструктивних і кінематичних параметрів доочисного пруткового транспортера із змінною траєкторією переміщення коренеплодів на показники якості їх очищення. В теоретичній частині обґрунтовано значення допустимого кута нахилу приймальної зони транспортера з урахуванням коливання пруткового полотна. В експериментальній частині встановлено вплив кутів нахилу ланок транспортера, його лінійної швидкості, а також швидкості переміщення скребків завантажувального транспортера і технологічних зазорів між ними на якісні показники роботи коренезбиральної машини.

INTRODUCTION

The solution to the problem of root crops quality cleaning and their damage reducing during mechanized harvest is possible due to the complex approach to the development of new root crop harvesters. Their lay-out diagrams will be based on the principle of combination of transport and technological operations to provide the careful attitude to the product under processing and to minimize the negative impact on the environment. Thus, while developing new root crop harvesters the basic ideas are those the introduction of which will provide the maximum separation of soil from the root crops. They will allow leaving the soil on the fields and minimize the degradation of upper humus layer.

Theoretical substantiation and experimental research of the above-mentioned processes and the choice of the most efficient design and kinematic parameters and operation modes of root crop harvesters were done in the papers *(Baranovsky V.M., Potapenko M.V., 2017; Bratucu Gh., Paunescu D.D., 2015; Tsarenko O.M., et al., 2003).*

The results of the study of root crops storage before their processing and agricultural materials transportation were highlighted in the papers *(Liebe S., Varrelmann M., 2014; Lyashuk O.L. et.al., 2015)*.

The procedures of experimental research on this issue are described in the following papers *(Bulgakov V.M. et al., 2000; Hevko, R. et al., 2018)*.

The elastic tools use aimed at reducing the transported material damage and finding the best parameters of the tools was highlighted in the articles *(Hevko R.B. et al., 2015; 2016)*.

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This paper follows the previous research described in the articles *(Hevko R.B. et al., 1998; Pavelchak O.B., Tkachenko I.G., Hladyo Y.B. et al., 2000; Tkachenko I.G., Hladyo Y.B., Hevko R.B. et al., 2000; Synii S.V. et al., 2018)*.

To solve the tasks dealing with the improvement of root crops cleaning quality and their minimum damage a design-technological scheme and a design of a root crop harvester after-cleaning conveyor including its parameters and operation modes substantiation are proposed.

MATERIALS AND METHODS

To increase the root crops cleaning quality at their mechanized harvesting we suggest combining different functions, namely transportation, cleaning from soil and plants remains in one machine. An after-cleaning conveyor can be used in different root crop harvesters which are being developed or modernized.

Let's consider the interaction of an after-cleaning conveyor sections with the root crops thrashed heap. We assume that base coordinate system Oxy refers to the machine where an after-cleaning conveyor is mounted. Centre O of the coordinate system coincides with the axis of a conveyor shaft, axis Ox is directed horizontally, a root crop motion is taking place in vertical plane Oxy (Fig. 1).

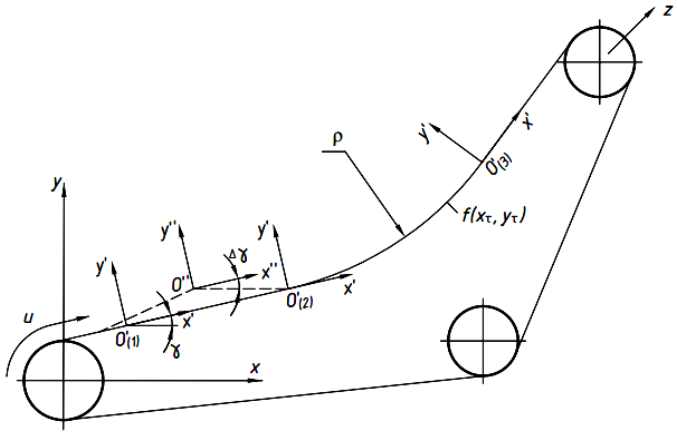


Fig. 1 – Scheme of determining the parameters of conveyor web path

On the line of flight path inclined at a running angle γ with horizon we place in a certain point $O'(x_0'; y_0')$ the fixed, referred to base system Oxy, coordinate system $O'x'y'$ so that the axis $O'x'$ is directed towards the line of flight, and moving coordinate system $O''x''y''$ which is rigidly associated with the moving web where a scraper is fastened, in this case the axis $O''y''$ coincides with the plane of the scraper's location. We assume that at a certain period of time $t = 0$ the coordinate systems coincide. In a general case the coordinate system $O''x''y''$ is travelling referred to the system $O'x'y'$ with velocity v_c which is the same as the conveyor web speed.

Besides, both the web and the system are vibrating along the axis $O'y'$ with a certain amplitude A_ω, cyclic frequency ω_A and angular oscillations $\Delta\gamma$ of the activator with angle γ absolute value change. Centre O'' of the system $O''x''y''$ in the system $O'x'y'$, will have running coordinates: $x_0'' = v_m t$; $y_0'' = A_\omega \sin(\omega_A t)\sin\gamma$. (Fig. 2).

Using the known matrix transformations of uniform coordinate systems, we obtain the following connection between the scraper coordinate system and the base coordinate system:

$$\begin{cases} x_c = x_A''\cos(\gamma+\Delta\gamma) - y_A''\sin(\gamma+\Delta\gamma) + x_O' + v_t t\cos\gamma - A_\omega \sin(\omega_A t)\sin\gamma; \\ y_c = y_A''\sin(\gamma+\Delta\gamma) - x_A''\cos(\gamma+\Delta\gamma) + y_O' + v_t t\sin\gamma - A_\omega \sin(\omega_A t)\cos\gamma. \end{cases} \quad (1)$$

The root crop hold on by the scraper is acted by the forces of reaction N_i from the scraper and rods side, which in the scraper coordinate system $O''x''y''$ and, correspondingly in the base system Oxy (Fig. 2) will be as follows:

$$\overline{N_i''} = N_1''(\cos\alpha_i''\cdot\bar{i} + \sin\alpha_i''\cdot\bar{j}); \qquad \overline{N}_i = N_i(\cos\alpha_i\cdot\bar{i} + \sin\alpha_i\cdot\bar{j}) \quad (2)$$

where directing angles α_i with angles α_i'' are connected by the relationships $\alpha_i = \alpha_i'' + \gamma + \Delta\gamma$ or, in case of small angular oscillations of the scrapers ($\Delta\gamma = 0$), $\alpha_i = \alpha_i'' + \gamma$.

Now we study the possible root crop location on the conveyor web. We denote the web rod radius r, distance between rods – a; scraper height – H.

We assume the scraper width as $S = 2r$ taking into consideration the design and the radius of the scraper rounding is equal to the rod radius. To make calculations more simple, we take the parameter $h = H - r$ as the scraper height before the centre of rounding.

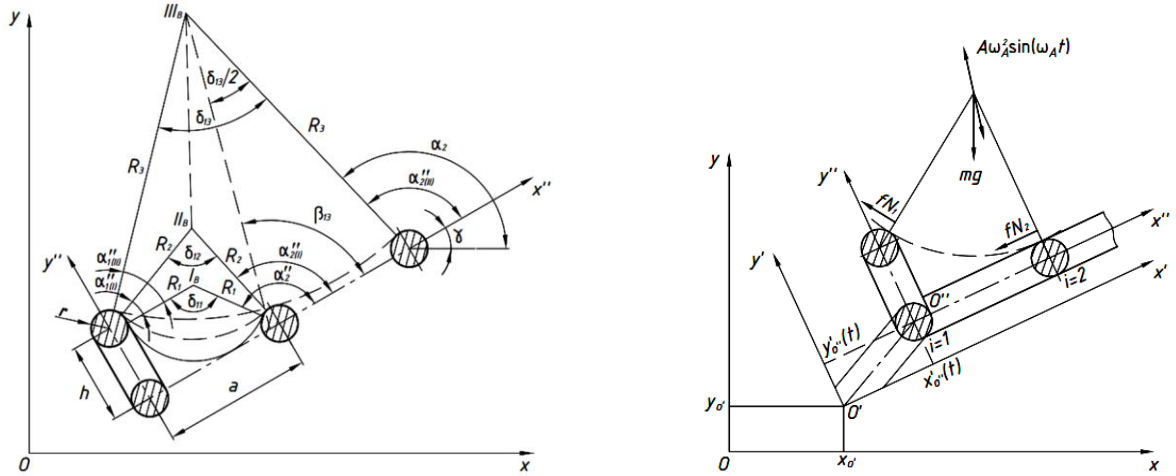


Fig. 2 – Options of a root crop place on the conveyor web (a) and a scheme of forces to find the equations of root crops movement at their transfer and after-cleaning (b)

According to a root crop size some options of its place on the conveyor web in the coordinate system $O''x''y''$ (Fig. 2) are possible.

1. A root crop of radius R is touching the scraper and the nearest rod surfaces. Such location is taking place when the centre of gravity coordinate y_C of the root crop is less than h, $y_C \le h$. In this case the reactions from the scraper and the rod side are found by the dependence (2), where the direction angle of the activator reaction vector $\overline{N_1''}$, is equal to α_1'' = 0, and vector $\overline{N_2''}$ is directed from the rod centre to the root crop centre and is found $\cos\alpha_2'' = 1 - a/(R+r)$; $\sin\alpha_2'' = \sqrt{2a(R+r) - a^2}/(R+r)$.

2. A root crop is touching the scraper edge and a rod ($y_C > h$). Then the root crop centre is found from the solution of the system of equations which determines the crossing point of two circles by radiuses $R + r$ in the centre of scraper rounding $O_S''(0; h)$ and in the rod centre $O_R''(a; 0)$. Hence, the equation of bisector of triangle passing through the root crop centre $A(x_A''; y_A'')$ will be $y'' = h/2 + (a/h)(x'' - a/2)$. Accordingly, the direction angles α_1'' and α_2'' vectors $\overline{N_1''}$ and $\overline{N_2''}$ will be $\alpha_1'' = \beta_{12} - \delta_{12}/2$ and $\alpha_2'' = \beta_{12} + \delta_{12}/2$, where β_{12} – bisector angle of inclination, $\beta_{12} = \operatorname{arctg} a/h$; δ_{12} – angle between vectors $\overline{N_1''}$ and $\overline{N_2''}$. $\delta_{12}/2 = \arcsin[\sqrt{a^2 + h^2}/2(R+r)]$.

3. A root crop is touching simultaneously the scraper and two neighbouring rods. This option is possible only for those root crops the radius of which is equal to $R_3 = \sqrt{(a^2/h + h/2)^2 + a^2/4}$.

In this case the reactions of the conveyor components will be N_1, N_2 and N_3, and the coordinates of the root crop centre: $x_A'' = 3a/2$; $y_A'' = (2a^2 + h^2)/(2h)$. Accordingly, $\cos\alpha_i'' = (x_A'' - x_i)/(R+r)$; $\sin\alpha_i'' = (y_A'' - y_i)/(R+r)$, where x_i, y_i – the coordinates of centres of the scraper and the rods rounding.

4. A root crop is touching the scraper edge and the next rod which is possible for big root crops ($R > R_3$). Similar to the second case, the direction angles $\alpha_1'' = \beta_{13} - \delta_{13}/2$; $\alpha_3'' = \beta_{13} + \delta_{13}/2$, where $\beta_{13} = \text{arctg}(2a/h)$; $\delta_{13}/2 = \arcsin[\sqrt{a^2 + (h/2)^2}/(R+r)]$.

When a root crop of circular section ($R = \text{const}$) is falling outside the scraper, its centre will be rotating in the coordinate system $O''x''y''$ against the centre of scraper's rounding with angular velocity $\omega_A = \text{d}(\Delta\alpha_t)/\text{d}t$ and the coordinates of its centre will be the following $x_A'' = (R+r)\cos(\alpha_t'' + \Delta\alpha_t)$, $y_A'' = (R+r)\sin(\alpha_t'' + \Delta\alpha_t)$. Accordingly, linear velocity components of a root crop will be the following: $\dot{x}_A'' = -y_A''\omega_\alpha$; $\dot{y}_A'' = x_A''\omega_\alpha$, and acceleration components: $\ddot{x}_A'' = y_A''\dot{\omega}_\alpha + x_A''(\omega_\alpha)^2$; $\dot{y}_A'' = x_A''\dot{\omega}_\alpha + y_A''(\omega_\alpha)^2$. Angular velocity of a root crop rotation: $\omega_K'' = (1 + r/R)\omega_\alpha$.

In the root crops intake area the motion path is described by a rectilinear function $x_T = x_O' + (u - u_O)\cos\gamma_\alpha$; $y_T = y_O' + (u - u_O)\sin\gamma_\alpha$, where u – path length parameter, $u = u_0 + v_t t$.

In the transition section the conveyor path is considerably curved and has a variable angle γ_t. We assume that, the path is always curved, i.e. the trajectory is described by a circle of radius ρ. The running angle of the path inclination at initial angle γ_{OI} is equal to $\gamma_t = \gamma_{OI} + v_t t/\rho$ and equations of the path are written as $x_T = x_O' + \rho[\sin(\gamma_{OI} + v_t t/\rho) - \sin\gamma_{OI}]$, $y_T = y_O' + \rho[\cos(\gamma_{OI} + v_t t/\rho) - \cos\gamma_{OI}]$.

Linear and angular velocities and acceleration of the system $O''x''y''$ will be determined by the dependencies

$$\dot{x}_{O''}'' = v_t\cos(\gamma_{OI} + v_t t/\rho); \quad \dot{y}_{O''}'' = v_t\sin(\gamma_{OI} + v_t t/\rho); \quad \dot{\gamma}_t = v_t/\rho; \tag{3}$$

$$\ddot{x}_{O''}'' = -(v_t^2/\rho)\sin(\gamma_O + v_t t/\rho); \quad \ddot{y}_{O''}'' = -(v_t^2/\rho)\cos(\gamma_O + v_t t/\rho); \quad \ddot{\gamma}_t = 0. \tag{4}$$

In the area, where root crops start rolling down the conveyor web the angle of its inclination is equal to $\gamma_\beta = \beta$ and is determined from the condition of capture of soil and plant remains of the trashed heap and does not include the root crops grab.

In the intake area the necessary requirement of the transporter operation is that all root crops, including the biggest ones, will not lose the contact with their supports (a scraper and a rod). This condition is met when $N_1 > 0$ and $N_2 > 0$. As $\gamma > 0$, it is possible when $N_3 > 0$.

Taking into account that $\alpha_i = \alpha_i'' + \gamma$ and $N_3 > 0$, the condition of the root crop contact with the supports is written as: $\gamma \le \pi/2 - \alpha_1''$.

Taking into account the acceleration force of the conveyor web during its vibration the equilibrium equation is written as:

$$\begin{cases} N_1\cos\alpha_1 + N_3\cos\alpha_3 + mA\omega_A^2\sin(\omega_A t)\sin\gamma = 0; \\ N_1\sin\alpha_1 + N_3\sin\alpha_3 + mA\omega_A^2\sin(\omega_A t)\cos\gamma = mg. \end{cases} \tag{5}$$

For the case $N_3 = 0$ from the solution (5) $(A\omega_A^2/g)\sin(\omega_A t)\cos(\alpha_1 + \gamma) = \cos\alpha_1$. Taking into account that $\alpha_i = \alpha_i'' + \gamma$, the condition of the root crop contact with the supports is written as

$$\cos(\alpha_1'' + \gamma) = (A\omega_A^2/g)\sin(\omega_A t)\cos(\alpha_1'' + 2\gamma). \tag{6}$$

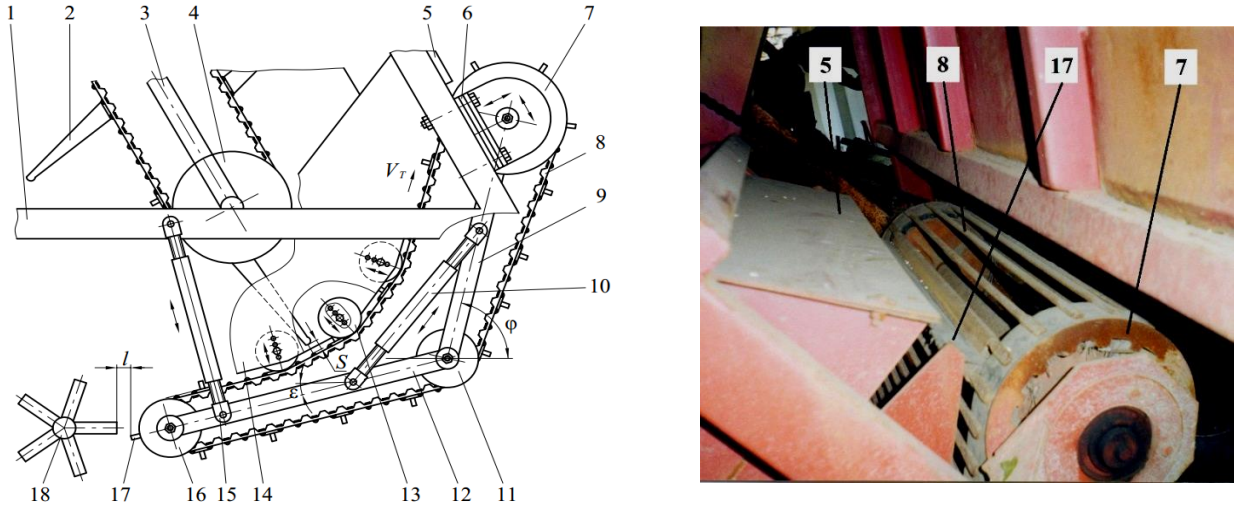
Hence, the condition of the root crop contact with the supports which depends on the inclination angle of the conveyor in the intake area, is found from the equation solution (6) for the case when $\sin(\omega_A t) = -1$.

Limiting value of angle γ_m, when the root crop losses ties with the supports is found by the approximating dependence $\gamma_m = (0{,}5\pi - \alpha_1'')(1+k)/(1+2k)$, where $k = A\omega_A^2/g$ – coefficient of impact of conveyor web lateral oscillations.

Experimental study on determining the root crops losses, damage and dirtiness was conducted on a combination of an after-cleaning conveyor together with a drag-type loader. The scheme of their parameters control is given in Fig. 3 a.

The conveyor was mounted on a tractor-drawn three-row root crop harvester the design and operation principle of which, as well as the program and methods of experimental research are given in the paper *(Hevko R.B., Tkachenko I.G., Synii S.V., et al., 2016)*.

An after-cleaning conveyor and a loader are mounted on the root crop harvester frame 1. They are running simultaneously carrying and cleaning the root crops. The after-cleaning conveyor has a frame with upper *9* and lower *12* sections which are articulated. The main transporting element is the web with rods *8* which is driven by power shaft *7*, the head pulleys of which are made with grooves for the teethed belt clutching. The bearing supports of the driven shaft are fixed on the frame *1* by shims *6* enabling to estimate the position of the after-cleaning conveyor relative to the frame *1* and separating shaft *18*. Thus, the clearance l adjustment is taking place to study its impact on the quality characteristics of the after-cleaning system operation. Curve *11* and turning *16* sheaves serve for the change of the web motion direction, and supporting rollers *13* provide the proper shape of the web *8* in the section where the root crops are leaving the after-cleaning conveyor for the loader. The axes of supporting rollers *13* are fastened on the side-frames *14* where four holes are made in radial direction relative to the drums axes *4* to change the value of concentric clearance *S*.



a) b)

Fig. 3 – Scheme of parameters control of after-cleaning conveyor and loader (a) and general view of after-cleaning conveyor upper section (b)

The web *8* of the after-cleaning conveyor is equipped with the elastic scrapers *17* for the cut-off soil and plants remains unloading on the harvested part of the field. Screw couplings *10* and *15* are used for the after-cleaning conveyor fixed on the machine frame and for the angles ε and φ change.

The loader consists of a frame *3* and drums *4* including the web with scrapers *2*. The loader is mounted on the frame *1* with possibility of vertical and horizontal shifting. Conveyor casing *5* is used for preventing the root crops to be thrown away from the machine while they are being cleaned on the unloading section of the after-cleaning conveyor.

RESULTS

Results of theoretical investigation

Moving from theoretical to experimental research we assume that the angle ε is equal to the angle α-α″, and angle γ_m = φ, as it is shown in Fig.3. Dependencies of angle ε=α-α″ of reaction N_1 of the scraper and limiting angle of inclination γ_m = φ of the after-cleaning conveyor intake unit on the root crop radius at the web vibration with different values of the impact coefficient are given in Fig. 4, 5.

According to the data of experimental research, the coefficient of lateral oscillations impact is widely ranging depending on the operation modes, oscillations measuring point and is equal to k = 0.2…0.9.

For guaranteed root crops keeping of all size on the after-cleaning conveyor intake unit in the loading section its inclination angle γ must be within the range of 0…30°.

Taking into account possible elastic angular displacement of the scraper which, according to the experimental data, does not exceed $\Delta\gamma = 5°$ under the equivalent load, the proposed angles of inclination of the intake unit are $\gamma < 25°$. For the unloading section free rolling down the web of all conditioned crops is the condition of the after-cleaning conveyor efficient operation.

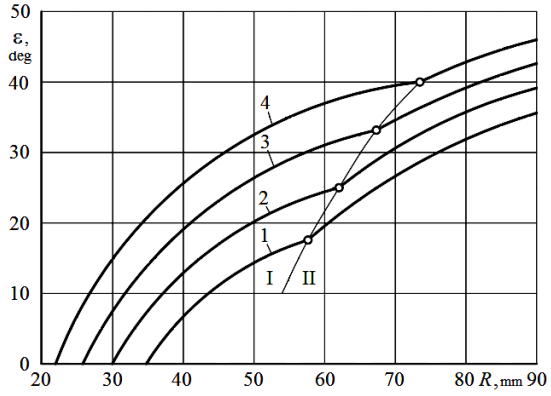


Fig. 4 – Curves of direction angle ε reaction N_1 scraper of different height H and root crop radius R:
1 – H = 45 mm; 2 – H = 40 mm; 3 – H = 35 mm; 4 – H = 30 mm; I, II – respectively areas of a root crop interaction with a scraper and the following rod

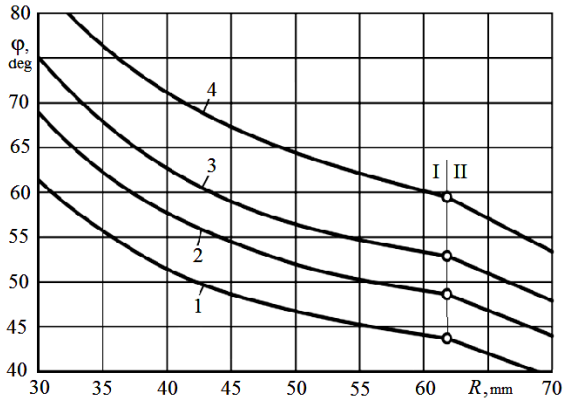


Fig. 5 – Curves of limit value of inclination angle φ of intake unit at web vibration with coefficient of impact k:
1 – k = 1; 2 – k = 0,5; 3 – k = 0,3; 4 – k = 0,1; I, II – respectively areas of a root crop interaction with a scraper and the following rod

Theoretical dependencies can be used for the choice of tools parameters while conducting experimental research.

Results of experimental research

According to the results of theoretical research the experiments have been conducted taking into account the recommended angles of inclination of lower section ε (range of value change ε = 10…24 deg.) and upper section of after-cleaning conveyor (range of value change φ = 50…80 deg.).

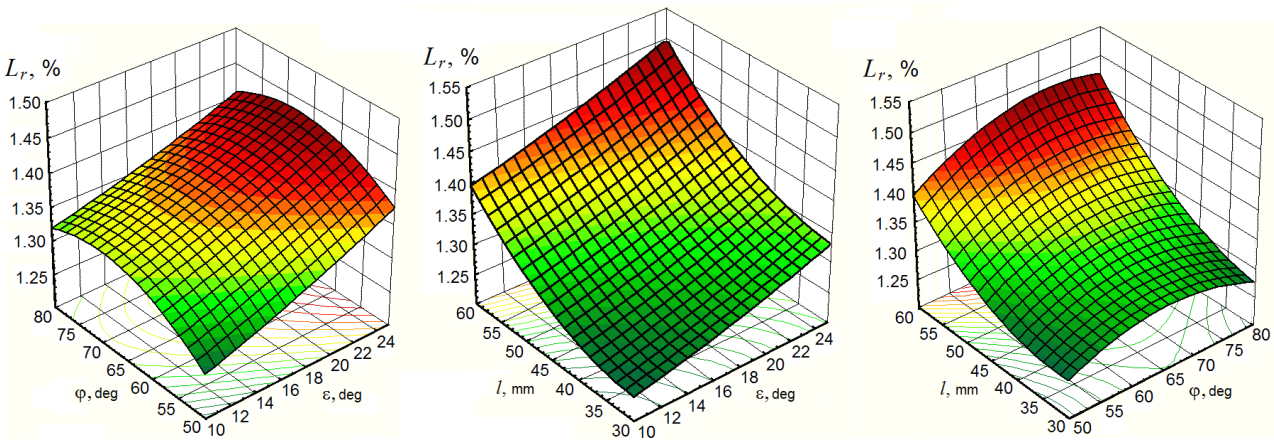
The experiment-based response surfaces describing dependencies of losses (L_r), damage (D_r) and dirtiness (W_r) of root crops are presented in Fig. 6, 7 and 8.

The obtained regression equations to find L_r, D_r and W_r are written as:

$$L_r = 0.074 + 0.007\varepsilon + 0.032\varphi - 0.00024\varphi^2 + 0.00058l^2, \quad (10)$$

$$D_r = 4.15 + 0.05\varepsilon - 0.026\varphi - 0.0009\varepsilon S + 0.00025\varphi^2 - 0.00015\varphi S + 0.00012S^2, \quad (11)$$

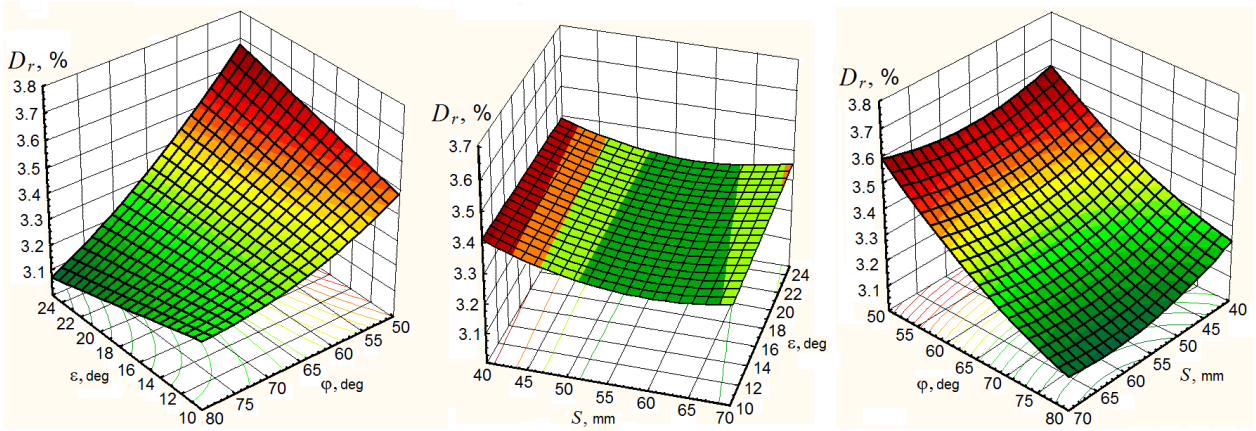
$$W_r = 11.515 + 0.113\varphi - 14.36V_T - 0.05\varepsilon V_T - 0.0008\varphi^2 + 6.25\,V_T^2. \quad (12)$$



a) b) c)

Fig. 6 – Response surfaces of root crops losses
a) $L_r = f(\varphi; \varepsilon)$; b) $L_r = f(l; \varepsilon)$; c) $L_r = f(l; \varphi)$

Having analyzed the response surfaces of root crops losses L_r it was found that apart from angles ε and φ the clearance size l has the biggest influence on the parameter under discussion, as when the clearance is more than 45 mm the root crops losses are much bigger.

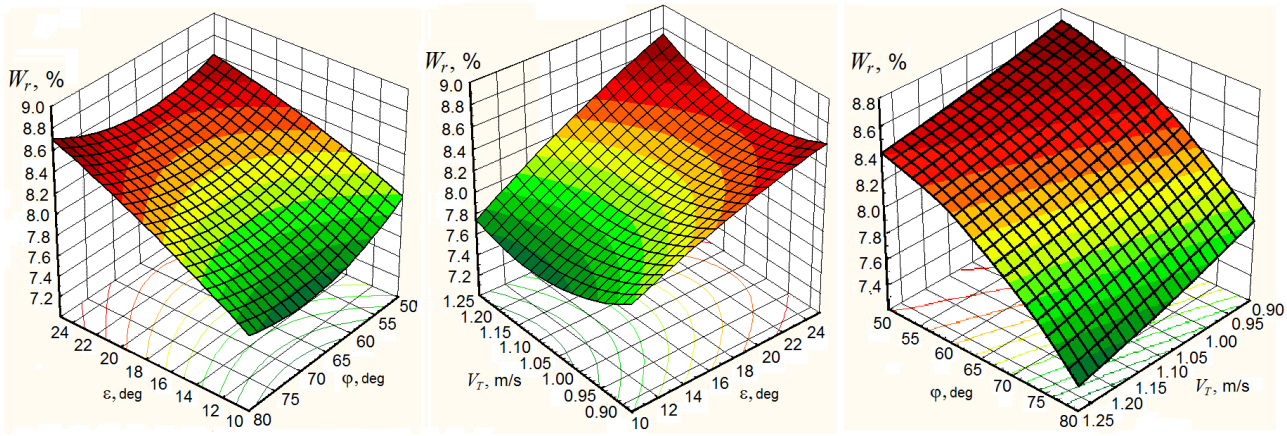


a) b) c)

Fig. 7 – Response surfaces of root crops damage

a) $D_r = f(\varepsilon; \varphi)$; *b)* $D_r = f(S; \varepsilon)$; *c)* $D_r = f(\varphi; S)$

Having analyzed the response surfaces of root crops damage D_r, it was found that apart from angles ε and φ the clearance size S influences the parameter under discussion. Thus, in case when S = 50…60 mm the root crops damage is the minimal one.



a) b) c)

Fig. 8 – Response surfaces of root crops dirtiness:

a) $W_r = f(\varepsilon; \varphi)$; *b)* $W_r = f(V_T; \varepsilon)$; *c)* $W_r = f(\varphi; S)$

Having analyzed the response surfaces of root crops dirtiness W_r, it was found that apart from angles ε and φ the linear velocity of after-cleaning conveyor belt V_T has the biggest influence on the parameter under discussion. The root crops are the most cleaned at the conveyor velocity V_T = 1.25 m/s, which can be explained by more active running of root crops on the belt surface and soil and plants remains are thrown to the field.

CONCLUSIONS

The paper under consideration presents a mathematical model of a root crop harvester after-cleaning conveyor operation and conducted experimental research which enabled to make integrated assessment of interaction of root crops and after-cleaning conveyor sections at different operation modes and finds its main design parameters. Within the known range of oscillations of the after-cleaning conveyor web the

mathematical model allows obtaining the complete picture of its operation and can be used in similar systems designing.

Theoretical study on determining the inclination angles of an after-cleaning conveyor parts has allowed narrowing the range of rational values of design parameters of the improved after-cleaning conveyor before its designing and manufacture.

The regression equations to determine losses, damage and dirtiness of root crops have been obtained and correspondent response surfaces have been built on the basis of conducted experiments and statistic processing of the obtained results. It allowed having the most efficient parameters of the after- cleaning conveyor which would meet the agricultural requirements.

The experimental research has proved that the set requirements on root crops losses, damage and dirtiness are satisfied to a greater extent at the following parameters: ε = 15…20°; φ = 60…65°; V_T = 1.1…1.25 m/s; l = 40…50 mm, S = 50…60 mm.

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