DETERMINATION OF TECHNICAL-AND-ECONOMIC INDICES OF ROOT CROP CONVEYER-SEPARATOR DURING THEIR MOTION ON CURVED PATH
/
ВИЗНАЧЕННЯ ТЕХНІКО-ЕКОНОМІЧНИХ ПАРАМЕТРІВ ТРАНСПОРТЕРА-СЕПАРАТОРА КОРЕНЕПЛОДІВ ПРИ ЇХ ПЕРЕМІЩЕННІ КРИВОЛІНІЙНОЮ ТРАСОЮ

Hevko R.B.[1)], Tkachenko I.G.[1)], Khomyk N.I.[1)], Gumeniuk Y.P.[2)], Flonts I.V.[3)], Gumeniuk O.O.[2)]
[1)]Ternopil Ivan Puluj National Technical University / Ukraine;
[2)]Ternopil National Economical University / Ukraine;
[3)]National University of Life and Environmental Sciences of Ukraine / Ukraine;
E-mail: r_hevko@ukr.net
DOI: https://doi.org/10.35633/inmateh-61-19

Keywords: *root crops, scrapers, rubber belt, discs, shaft, separation, clearance*

ABSTRACT
The results of theoretical and experimental study of the process of root crops carrying by a conveyer-separator of a three-row trailed root crop harvester whose rubber belt with rods is equipped with scrapers and has a sign-variable direction of transportation to minimize the machine length have been described in the article. *Some analytical dependencies describing the impact of design and kinematic parameters of the conveyer-separator on the root crops motion pattern have been given and analysed. The results of the research including the key factors identification affecting the process of root crops transportation on the curvilinear path between the conveyer-separator members are presented in the experimental part. The theoretical and experimental studies have been compared and the boundaries of the most efficient design and kinematic parameters choice of the conveyer-separator under discussion have been suggested.*

РЕЗЮМЕ
У статті наведені результати теоретичних і експериментальних досліджень процесу переміщення коренеплодів транспортером-сепаратором трирядної причіпної коренезбиральної машини, пруткове полотно якого обладнане скребками і має знакозмінний напрямок транспортування для зменшення повздовжніх габаритів машини. Наведено аналітичні залежності впливу конструктивних і кінематичних параметрів транспортера-сепаратора на характер руху коренеплодів та проведений їх аналіз. В експериментальній частині представлено результати досліджень з визначенням домінуючих факторів на процес переведення коренеплодів на криволінійній ділянці між ланками транспортера-сепаратора. Здійснено порівняння теоретичних і експериментальних досліджень та запропоновано межі вибору раціональних конструктивно-кінематичних параметрів транспортера-сепаратора

INTRODUCTION
To solve the problem of root crops quality cleaning and simultaneous keeping to the allowable level of their damage at harvesting under difficult soil-climatic conditions it would be quite reasonable to use the principle of root crops cleaning along their entire route from digging to unloading. Here, the intensity of tools impact on the thrashed heap has to decrease towards its transportation by the tools as during separation the possibility of immediate interaction of working surfaces with root crops is increasing. First of all, the problem is connected with the modernization of rod and scraper conveyers as they should have some additional functions on simultaneous root crops transportation and after-cleaning.

It allows to provide the maximum possible soil separation from the root crops and to minimize its transportation to the raw material processing points.

The theoretical study of a material particle motion and flow motion including the determination of tools parameters and operation modes impact on the process of their displacement in different environments has been described in the papers (*Baranovsky V.M., Potapenko M.V., 2017; Baranovsky V.M., et.al., 2017, 2018; Bratucu Gh., Paunescu D.D., 2015; Bulgakov V., et.al., 2017; Hevko R.B., et.al., 2018; Lyashuk O.L., et.al., 2018, 2019; Pylypaka S.F., et.al., 2019; Rogovskii I.L., et.al., 2019; Tsarenko O.M., et al. 2003)*.

The increase of transport-technological tools performance characteristics can be achieved due to the simultaneous carrying out of different operations, namely transportation and mixing of different components that has been paid attention to in the papers (*Hevko R.B., et al., 2017, 2018)*. Such approach describing the simultaneous transportation and cleaning of root crops has been implemented in the developed conveyer-separator and the results of its study are presented in the article under consideration.

The study of parameters impact of different types of root crop harvesters tools on the process of crops harvesting and storage prior to their processing has been highlighted in the papers *(Dumitru I., et.al., 2017, Becker M., et.al., 2016; Dumych.V., Salo, Ya., 2017; Liebe S., Varrelmann M., 2014)*. The results of theoretical and experimental study of similar types of conveyers-separators have been presented in the papers *(Pavelchak O.B., et al., 2000; Synii S.V., et al., 2018; Tkachenko I.G., et al., 2000; Tunik I.G., et al., 1998).* The materials in the article under discussion are the follow-up study of previous research described in the papers *(Hevko R.B., et.al., 2016, 2018, 2019).*

The purpose of the article under discussion is to find the most efficient design and kinematic parameters of a root crop scraper conveyer-separator during their curvilinear motion prior to the unloading into the harvester hopper so that to provide the maximum cleaning of the root crops from soil and plant remains with their minimal damage.

MATERIALS AND METHODS

To achieve the purpose in view a design-technological scheme of a root crop two-wheeler harvester with increased separating effect has been developed whose design model is presented in fig. 1

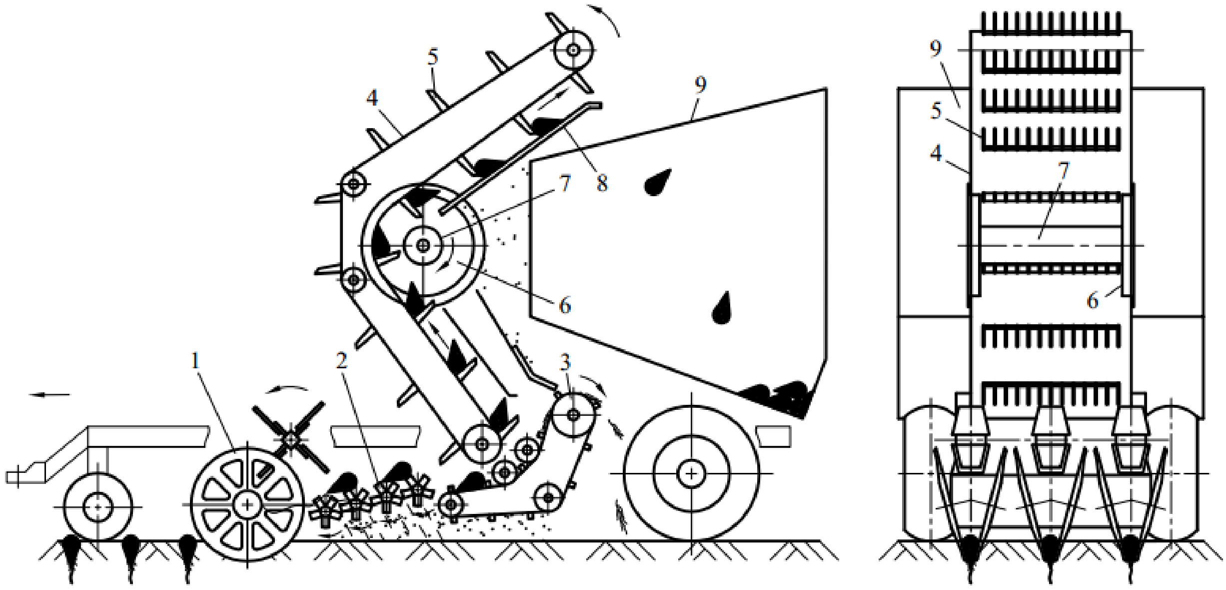


Fig. 1 – Design-technological scheme of a three-row trailed root crop harvester

It contains a disk digger *1*, from which the dug-out thrashed heap of root crops is supplied to the main cleaning unit *2* (auger or beater), where basic separation of the root crops from the soil takes place. After that the root crops are transported to the two-section conveyer *3*, where the remains are thrown away by its unloading link (*Hevko R.B. et.al, 2019).* In the transfer area of the two-section conveyer *3,* the root crops are selected and transported to the unloading section by the scrapers *5* of the rubber belt with rods *4*. The change of root crops transportation direction and their after-cleaning takes place in the curved section where the elastic sides of the rubber belt with rods are interacting with side disks *6*, connected to each other by a hollow shaft *7*. Longitudinal rods *8* with a clearance Δ relative to the external surface of the hollow are placed under the groups of scrapers shaft towards the root crops transportation to the bunker *9*. Root crops are carried by the scrapers on the longitudinal rods and simultaneously their after-cleaning off tare takes place.

To determine the most efficient design and kinematic parameters of the unloading conveyer-separator of a root crop harvester the design model is presented in fig. 2 a. A picture of the conveyer-separator is on fig.2 b.

The conveyer-separator operation is going on in the following way. At first, in the area *I* the root crops are being transported towards the curved section *II* and are in contact both with the rubber belt with rods *4* and with scrapers *5*. In the curved section due to the action of centrifugal forces the root crops are retained against the rubber belt with rods surface but the soil and plant remains whose mass is much smaller than the root crops mass are in the area approaching the hollow shaft surface. After that, the root crops are moving to the unloading area on the rectilinear path *III*. In this way, due to the gravitation force the root crops are being displaced on the scrapers surface towards the longitudinal grate but the soil and plant remains are thrown away through the clearance Δ, on the harvested field. Then the root crops are being transported by the scrapers on the longitudinal grate 8 that also contributes to their better cleaning from the sticky soil.

The aim of theoretical calculation is to determine the most efficient value of the clearance Δ to provide the maximum separation of the root crops thrashed heap from soil and plant remains.

Let's consider the forces acting on a root crop in the curved section *II.* The root crop is circulating in a random point M between points A and B.

Figure 1a includes the following symbols: mg – gravitation force; F_f – force of friction of the scraper-root crop couple; F_c – centrifugal force acting on the root crop in the curved section area; N_1 – normal force acting on the root crop from the web side; N_2 – normal force acting on the root crop from the groups of scrapers side; f – friction coefficient between a root crop and a scraper; α – rubber belt with rods inclination angle with horizon in section *I*; β – inclination angle of the unloading section of the rubber belt with rods with horizon; r – radius of the hollow shaft; R – radius of side discs; l – scrapers height; V – linear velocity of the web; ω – angular velocity of the hollow shaft; R_{rc} – equivalent radius of a root crop; D_g – distance from the centre of the hollow shaft rotation to the point of root crop interaction with the longitudinal grate; δ – clearance value between the scraper and external surface of the hollow shaft; γ – variable angle of a root crop displacement in the curved section area. Centrifugal force in the curved section area: $F_c = m\omega^2(R - R_{rc})$.

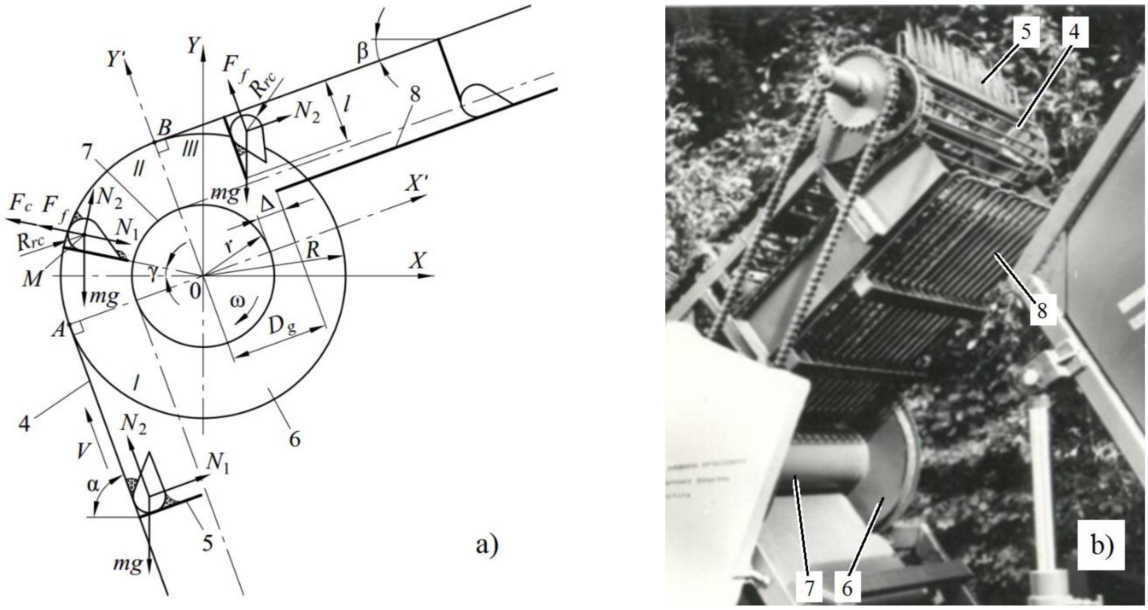


Fig. 2 – Design model to determine the design and kinematic parameters of an unloading transporting-separating tool of a root crop harvester (a) a picture of the conveyer-separator (b)

The equilibrium equations in projections on the axes X and Y are written as:

$$\begin{aligned} & N_1 \cos\gamma + N_2 \sin\gamma - N_2 f \cos\gamma - \frac{mV^2}{R^2}(R - R_{rc})\cos\gamma = 0; \\ & -N_1 \sin\gamma + N_2 \cos\gamma + N_2 f \sin\gamma - mg + \frac{mV^2}{R^2}(R - R_{rc})\sin\gamma = 0. \end{aligned} \qquad (1)$$

The condition when a root crop is retained against the rubber belt with rods: $N_1 > 0$.

Under the boundary condition (minimal velocity of the web when a root crop isn't displaced on the scrapers surface ($N_1 = 0$) the equations (1) will be written as:

$$N_2(\sin\gamma - f\cos\gamma) = \frac{mV^2}{R^2}(R - R_{rc})\cos\gamma;$$
$$N_2(\cos\gamma + f\sin\gamma) - mg = \frac{mV^2}{R^2}(R - R_{rc})\sin\gamma. \tag{2}$$

After transformations of the system of equations (2) we obtain:

$$\frac{N_2(\sin\gamma - f\cos\gamma)}{N_2(\cos\gamma + f\sin\gamma)} = \frac{\frac{mV^2}{R^2}(R - R_{rc})\cos\gamma}{mg - \frac{mV^2}{R^2}(R - R_{rc})\sin\gamma};$$

$$(\sin\gamma - f\cos\gamma)R^2 g - (\sin\gamma - f\cos\gamma)V^2(R - R_{rc})\sin\gamma = V^2(R - R_{rc})\cos\gamma(\cos\gamma + f\sin\gamma);$$

$$\frac{V^2(R - R_{rc})}{R^2} = g(\sin\gamma - f\cos\gamma). \tag{3}$$

From the equation (3) we find the minimal velocity $V_{\min}$, where a root crop is pressed against the web surface

$$V_{\min} = R\sqrt{\frac{g(\sin\gamma - f\cos\gamma)}{(R - R_{rc})}}. \tag{4}$$

In this case, the condition must be satisfied

$$(\sin\gamma - f\cos\gamma) > 0. \tag{5}$$

When a root crop enters the unloading section area *III* it starts sliding along the scraper surface on the longitudinal grate. Therefore, the further calculations will involve the determination of the time period when the root crop covers the distance so that its bottom edge has a coordinate l.

During this period of time the web should travel over the distance bigger than the value D_g, which means:

$$S = r + \Delta + R_{rc}. \tag{6}$$

Projections of forces on the axes X and Y, acting on the root crop in the third section of transportation are written as:

$$N_2\cos\beta - F_{mp}\sin\beta = m\ddot{X};$$
$$N_2\sin\beta + F_{mp}\cos\beta - mg = m\ddot{Y}, \tag{7}$$

and projections of forces on the natural axes X' and Y' are written in the following way:

$$mg\cos\beta - N_2 f = m\ddot{l};$$
$$N_2 = mg\sin\beta. \tag{8}$$

Upon integrating the equation (8) we find the time when the lower end of the root crop head receives the coordinate l:

$$t = \sqrt{\frac{2(l - 2R_{rc})}{g(\cos\beta - f\sin\beta)}}. \tag{9}$$

If $\cos\beta - f\sin\beta < 0$, a root crop does not displace, i.e. $\cos\beta < f\sin\beta$; $\mathrm{ctg}\beta < f$; $\mathrm{tg}\beta > 1/f$; $\beta > \mathrm{arctg}(1/f)$ are the conditions of root crop motionlessness.

The height of scrapers group l is found from the equation: $l = R - r - \delta$, where δ = 10...20 mm.

While a root crop is traveling along the scrapers group towards the coordinate Y' one should take into consideration the most unfavourable case when the central axis of the root crop is parallel to the rubber belt with rods surface. In this case, its displacement is taking place with a coefficient of rolling friction which is lower than a coefficient of sliding friction and results in time t decrease.

Thus, taking into account the above-mentioned pattern of the root crop location, the condition when $S = Vt$ and dependencies (6) and (9), the equation to find the clearance value Δ in longitudinal grate is written as

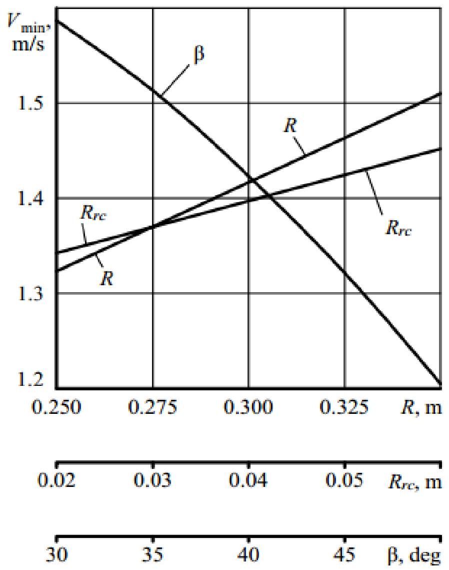
$$\Delta = V\sqrt{\frac{2(R - r - \delta - 2R_{rc})}{g(\cos\beta - f\sin\beta)}} - R_{rc} - r. \tag{10}$$

Before the analytical dependence (10) analysis the minimal velocity of the rubber belt with rods $V_{\min}$ was found when the root crop was pressed to the web surface (formula 4). Afterwards, taking into account the certain value $V_{\min}$, the maximum possible value of the longitudinal grate location relative to the hollow shaft Δ has been calculated.

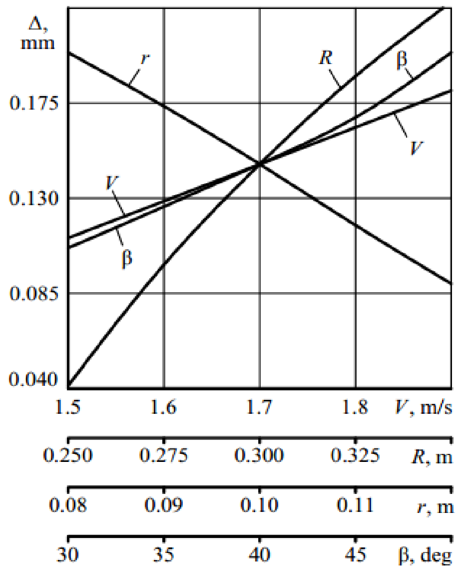
In the analysis of dependencies (4) and (10) the boundaries of variable parameters' values were as follows: R = 0.25…0.35 m; R_{rc} = 0.02…0.06 m; r = 0.08…0.12 m; β = 30…50°; where $\beta = (90^{o} - \gamma)$. The values: f = 0.3; δ = 15 mm; β = 30…50° have been assumed as constant ones.

While studying the impact of one of the parameters on the values $V_{\min}$ and Δ the other ones remained constant, and their absolute values were as follows: R = 0.3 m; R_{rc} = 0.05 m; r = 0.1 m; β = 40°.

Figure 3 represents the curves describing dependencies of parameters R, R_{rc} and β impact on the minimal velocity of the web $V_{\min}$ (a) and parameters V, R, r and β impact on the value of the clearance Δ (b).



a)



b)

Fig. 3 – Curves describing dependencies of parameters R, R_{rc} and β impact on the minimal velocity of the web $V_{\min}$ (a) and parameters V, R, r and β impact on the value of the clearance Δ (b)

The analysis of the curves has proved that angle β (Figure 3a) has the biggest influence on the value $V_{\min}$. The maximum value $V_{\min}$ = 1.59 m/s corresponds to the angle β = 30°, whereas minimal $V_{\min}$ = 1.21 m/s – β = 50°. It can be explained by the increased value of the angle γ, whose maximum value is determined from the condition $\gamma = (90° - \beta)$.

The second one according to the impact on the value $V_{\min}$ is the radius of side disks R, whose range of value change 0.25…0.35 m causes the increase of $V_{\min}$ from 1.325 to 1.514 m/s respectively.

A root crop radius is an uncontrolled factor so, while choosing the most efficient design-kinematic parameters of a conveyer-separator one must take into account the most unfavourable options, namely providing the transportation of standard root crops with minimal radius of a root crop head R_{rc} = 0.02 m. As we can see from the curves the parameter under discussion has a minimal impact on the value $V_{\min}$ and when its value changes from 0.02 to 0.06 m the increase of $V_{\min}$ equals only 0.11 m/s. Thus, while studying the impact of design-kinematic parameters on the value Δ we'll accept an average value R_{rc} = 0.05 m, which corresponds to satisfactory harvest of sugar beet root crops.

Figure 3 (b) presents the curves of parameters V, R, r and β impact on the clearance value Δ.

While studying one of the parameters the others were given their average values. That is why all curves are crossed in one central point. It makes possible to evaluate both the absolute value change of the required parameter within the certain range and to determine its influence degree on the value Δ as well, due to the comparison with the impact degree of other parameters. Having analysed the obtained dependencies it was found that the value Δ is most of all influenced by the radius of side disks R whose increase from 0.25 to 0.35 m enables to increase the clearance value Δ from 0.04 to 0.223 m. Next, according to the impact degree on the value Δ is the radius of hollow shaft r, whose range of value increase 0.08…0.12 m causes the decrease of value Δ from 0.2 to 0.09 m. The third one, according to the impact degree on the value Δ, is the inclination angle of the unloading section of the rubber belt with rods with horizon β, whose range of value increase 30…50° causes the increase of value Δ from 0.115 to 0.198 m.

The minimal impact on the value Δ is made by the conveyer web velocity V, whose pattern of change is of linear behaviour. So, the increase of V from 0.15 to 0.19 m/s results in the 0.07 m/s increase of Δ.

The purpose of experimental study is to determine the degree of separated dirt and plant remains while using the boundaries of the parameters under discussion and also to check how the results of the theoretical investigation conform to the experimental data on different values of clearance Δ determination.

RESULTS

In comparing the theoretical and experimental studies on observing the root crop displacement prior to its contact with the longitudinal grate (finding the value of clearance Δ) the conventional photo fixation devices (cameras, mobile phones) were used. The discrepancy between the obtained results in determining the value Δ did not exceed 17%.

Moreover, some experimental study has been done to determine the mass of separated dirt and plant remains under the longitudinal grate. The technique of conducting the experimental study under discussion is a standard one and was described in the paper (*Hevko R.B., et al., 2016, 2019).* The obtained data of separated dirt and plant remains mass have been found with 10 m distance of a root crop harvester motion.

While conducting the experimental research, factor fields of variable parameters have the following boundaries: $1.4 \le V \le 1.8$ m/s; $30° \le \beta \le 40°$; $0.1 \le \Delta \le 0.16$ m.

After the necessary statistical manipulations, the regression equation to determine the change of separated dirt and plant remains mass is written as:

$$S_i = -7.46 - 0.98 \cdot V + 1.01 \cdot \Delta + 0.58 \cdot \beta - 0.03 \cdot V \cdot \Delta - 0.1 \cdot 10^{-3} \cdot V \cdot \beta - 0.67 \cdot \Delta \cdot \beta - 0.5 10^{-2} \cdot V^2 + 166.7 \cdot \Delta^2 - 0.4 \cdot 10^{-2} \cdot \beta^2.$$

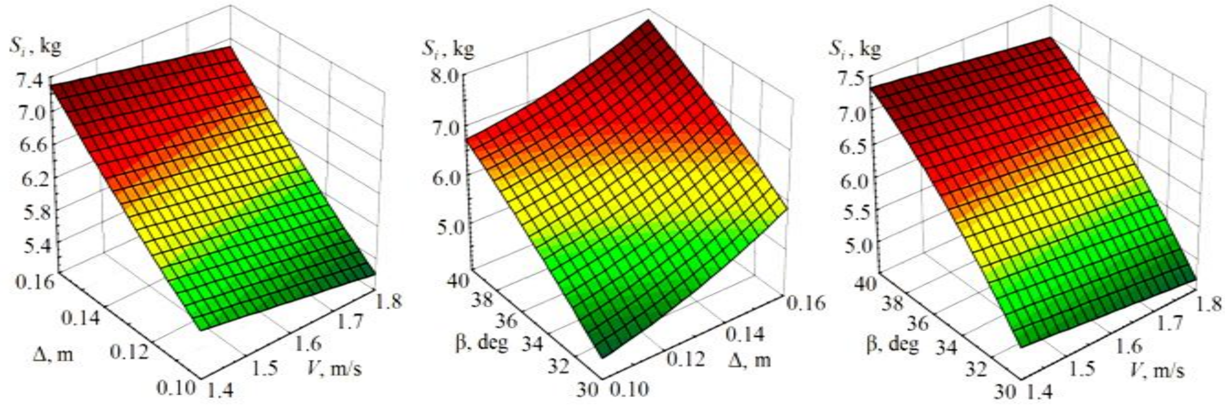
The response surfaces of separated dirt and plant remains mass S_i are presented in Figure 4.

While conducting the statistical analysis, the determination coefficient was $D = 0.978$, correlation coefficient – $R = 0.963$, Fisher's ratio test – $F = 82.399$, standard deviation of assessment – $S = 0.193$.

Having analysed the regression equation and response surfaces, we have found that the value S_i is chiefly influenced by the angle β. The second important making impact on the value S_i is the value of clearance Δ. The conveyer web velocity has a reverse mode and makes a minimum impact on the degree of separation of soil and plant remains. Though the parameter under discussion should conform to the previous transport-technological tools in the layout scheme of a root crop harvester and this parameter must have the maximum value to provide the technological process running.

The separated mass of soil and plant remains by the developed conveyer-separator under discussion with 10 m length of furrow of a three-row trailed root crop harvester is 6…7 kg on average (when inter-row sewing of root crops is 0.45 m). Thus, separated dirt and plant remains will be approximately 4.4…5.2 t per 1 ha. We assume that, the annual load of a three-row trailed root crop harvester during sugar beet root crops harvesting is approximately 80 ra. In this case, the additional mass of separated dirt and plant remains left directly on the fields will be approximately 350…416 t, that has some positive effect both for the ecology and for the economy as it allows to achieve the considerable reduction of transport costs for unseparated soil transportation.

It was also found that under dry working conditions of the machine operation when the clearance value exceeds $\Delta > 0.12$ m (soil humidity ≈ 14%) and maximum humidity $\Delta > 0.16$ m (soil humidity ≈ 22 %) the considerable damage of root crops takes place especially in their tail part.



a) b) c)

Fig. 4 – Response surfaces of separated dirt and plant remains mass S_i:
a) – $S_i = f(\Delta; V)$; b) – $S_i = f(\beta; \Delta)$; c) – $S_i = f(\beta; V)$

The separated mass of soil and plant remains by the developed conveyer-separator under discussion with 10 m length of furrow of a three-row trailed root crop harvester is 6…7 kg on average (when inter-row sewing of root crops is 0.45 m). Thus, separated dirt and plant remains will be approximately 4.4…5.2 t per 1 ha. We assume that, the annual load of a three-row trailed root crop harvester during sugar beet root crops harvesting is approximately 80 ra. In this case, the additional mass of separated dirt and plant remains left directly on the fields will be approximately 350…416 t, that has some positive effect both for the ecology and for the economy as it allows to achieve the considerable reduction of transport costs spent on unseparated soil transportation.

CONCLUSIONS

The results of theoretical and experimental studies of a root crop conveyer-separator which provides the sugar beet root crops after-cleaning during their transportation to the unloading area have been described in the article.

Due to the results of theoretical investigation it was found that the minimal velocity of the conveyer web should be not less than 1.4 m/s.

The value of clearance Δ must be within the limits 0.12…0.16 m under satisfactory conditions of root crops harvesting (soil humidity 15…20 %; soil hardness 1.6…2.2 MPa). In this regard, one should provide the clearances Δ and δ adjustment when developing the conveyer-separator design to adapt the machine as quickly as possible for the change in soil and climate conditions during sugar beet root crops harvesting.

The conducted theoretical investigation has been proved correct by the results of experimental study and can be applied in similar types of conveyers-separators design.

REFERENCES

[1] Baranovsky V.M., Potapenko M.V., (2017), Theoretical analysis of the technological feed of lifter root crops, *INMATEH-Agricultural engineering*, vol. 51, no. 1, pp. 29-38, Bucharest/Romania;

[2] Baranovsky V., Dubchak N., Pankiv M., (2017), Experimental research of stripping the leaves from root crops, *Acta Technologica, Nitra: Slovaca Universitas Agriculturae Nitriae*, vol. 20, no. 3, pp. 69-73, Nitra/Slovakia;

[3] Becker M., Varrelmann M., Christ D., (2016), Impact of genotype, harvest technology and harvesting conditions on storage rot formation and invert sugar accumulation during long-term storage of sugar beet, *Sugar Industry-Zuckerindustrie*, vol. 141 (5), pp. 322-330, Berlin/Germany;

[4] Bratucu Gh., Paunescu D.D., (2015), Establishing the optimum operating mode of sugar beet head cutting equipment using a cylindrical palpator, *Bulletin of the Transilvania University of Braşov*, Series II, vol. 8, pp. 51-56, Braşov/Romania;

[5] 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, *Journal of Agricultural Engineering*, vol. 48, no. 4, pp. 235-244, Bologna/Italy. https://doi.org/10.4081/jae.2017.676;

[6] Dumitru I., Voicea I., Găgeanu I. et al. (2017), Technical considerations regarding the harvesting potatoes and carrots equipment, Annals of the University of Craiova - Agriculture, Montanology, Cadastre Series, vol. XLVII, pp. 317-323, Craiova/Romania;
[7] Dumych V., Salo Ya., (2013), Analysis of structures of technical means for combine harvesting of potatoes, *Engineering and Technology AIC*, vol. 41, no. 2, pp. 19-22, Kyiv/Ukraine;
[8] Hevko R.B., Tkachenko I.G., Synii S.V., Flonts I.V., (2016), Development of design and investigation of operation processes of small-scale root crop and potato harvesters*, INMATEH-Agricultural engineering*, vol. 49, no. 2, pp. 53-60, Bucharest/Romania;
[9] Hevko R., Brukhanskyi R., Flonts I., Synii S., Klendii O., (2018), Advances in methods of cleaning root crops, *Bulletin of the Transilvania University of Braşov*, Series II*,* vol. 11(60), pp. 127-138, Braşov/Romania;
[10] Hevko R.B., Tkachenko I.G., Rogatynskyi R.M., Synii S.V., Flonts I.V., Pohrishchuk B.V., (2019), Impact of parameters of an after-cleaning conveyor of a root crop harvester on its performance*, INMATEH-Agricultural engineering*, vol. 59, no. 3, pp.41-48, Bucharest/Romania;
[11] Hevko R.B., Yazlyuk B.O., Liubin M.V., Tokarchuk O.A., Klendii O.M., Pankiv V.R., (2017), Feasibility study of mixture transportation and stirring process in continuous-flow conveyors, *INMATEH-Agricultural engineering*, vol. 51, no. 1, pp.49-59, Bucharest/Romania;
[12] Hevko R.B., Liubin M.V., Tokarchuk O.A., Lyashuk O.L., Pohrishchuk B.V., Klendii O.M., (2018), Determination of the parameters of transporting and mixing feed mixtures along the curvilinear paths of tubular conveyors, *INMATEH-Agricultural Engineering*, vol. 55, no. 2, pp. 97-104, Bucharest/Romania;
[13] Liebe S., Varrelmann M., (2014), Impact of root rot pathogens on storage of sugar beets and control measure, *Sugar Industry-Zuckerindustrie*, vol. 139 (7), pp. 443-452, Berlin/Germany;
[14] Lyashuk O.L., Sokil M.B., Klendiy V.M., Skyba O.P., Tretiakov O.L., Slobodian L.M., Slobodian N.O., (2018), Mathematical model of bending vibrations of a horizontal feeder-mixer along the flow of grain mixture, *INMATEH-Agricultural Engineering*, vol. 55, no. 2, pp. 35-44, Bucharest/Romania;
[15] Lyashuk O.L., Vovk Y.Y., Sokil M.B., Klendii V.M, Ivasechko R.R, Dovbush T.A, (2019), Mathematical model of a dynamic process of transporting a bulk material by means of a tube scraping conveyor, *Agricultural Engineering International*: *CIGR Journal*, vol. 21, no. 1, pp. 74-81; Fengmin Zhao/China;
[16] Pavelchak O.B., Tkachenko I.G., Hladyo Y.B. et al., (2000), Definition of rational parameters of the conveyor-separator (Вибір раціональних параметрів транспортера-сепаратора), *Collection of scientific works of the National Agrarian University (Збірник наукових праць національного аграрного університету),* vol. 8, pp. 41-47, Kyiv/Ukraine;
[17] Pylypaka S.F., Klendii M.B., Nesvidomin V.M., Trokhaniak V.I., (2019), Particle motion over the edge of an inclined plane that performs axial movement in a vertical limiting cylinder, *Acta Polytechnica, Journal of Advanced Engineering*, vol. 59, no. 1, pp. 67-76, Prague/Czech Republic;
[18] Pylypaka S.F., Nesvidomin V.M., Klendii M.B., Rogovskii I.L., Kresan T.A., Trokhaniak V.I., (2019), Conveyance of a particle by a vertical screw, which is limited by a coaxial fixed cylinder, *Bulletin of the Karaganda University. Mathematics series*, vol. 95, no. 3, pp. 108-119, Karaganda/Kazakhstan;
[19] Rogovskii I.L., Titova L.L., Davydenko O.O., Trokhaniak V.I., Trokhaniak O.M., (2019), Technology of Producing Reinforced Concrete Columns of Circular Cross-Sectional and Investigation of Their Strain-Stress State at Transverse-Longitudinal Bending, *Acta Polytechnica, Journal of Advanced Engineering*, vol. 59, no. 5, pp. 510-517, Prague/Czech Republic;
[20] Synii S.V., Hevko R.B., Flonts I.V., et al., (2018), Improvement of the root crop cleaning efficiency (Підвищення ефективності очищення коренеплодів), *Agricultural machines. Collection of scientific articles*, vol. 40, pp. 89-100, Lutsk/Ukraine;
[21] Tkachenko I.G., Hladyo Y.B., Hevko R.B., et al., (2000), Substantiation of the conveyor-separator parameters (Обґрунтування параметрів транспортера-сепаратора), *Scientific notes*. *Intercollegiate collection (Наукові нотатки. Міжвузівський збірник)*, vol. 7, pp. 260-266, Lutsk/Ukraine;
[22] Tunik I.G., Hevko R.B., Hladyo Y.B., Synii S.V., (1998), Substantiation of the structural and kinematic parameters of the loading conveyor of the root crop harvesting machine (Обґрунтування конструктивно-кінематичних параметрів завантажувального транспортеру коренезбиральної машини), *Agricultural machines. Collection of scientific articles (Сільськогосподарські машини. Збірник наукових статей)*, vol. 4, pp.135-143, Lutsk/Ukraine;
[23] Tsarenko O.M., Voityuk L.M., Shvayko M.V. et al., (2003), Mechanical and technological properties of agricultural materials (Механіко-технологічні властивості сільськогосподарських матеріалів), *Textbook (Підручник)*, 448 p, Kyiv/Ukraine.