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A THEORETICAL STUDY OF THE PROCESS OF TRIMMING BEET TOPS USING PASSIVE BLADES

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Based on the principle that the potential energy of the system is equal to the external work expended during the trimming of sugar beet roots with a passive flat knife, the study substantiates the possibility of reducing the load on the working body by rationally selecting the knife installation angle relative to the axis of motion of the top-trimming unit. It has been established that changing this angle directly affects the cutting force and the length of the knife travel path in the root crown zone. Therefore, a properly selected blade angle makes it possible not only to reduce the force acting on the knife, but also to improve the quality of top removal by increasing the cutting path and ensuring more stable interaction between the blade and the root surface.

Before performing the technological process of sugar beet top trimming, it is advisable to analyze the geometric parameters of the roots, primarily the average crown diameter, since this parameter determines the initial conditions for calculating the cutting force. By setting the blade thickness of the trimming device and using the established analytical dependence, the required force applied to the blade can be determined. Taking into account the strength limit of the blade material, the recommended operating speed of the unit is then calculated. At the same time, speeds that may cause resonance phenomena in the trimming device must be excluded from the acceptable range.

Knowing the cutting force and the knife angle, the natural frequency of the device is determined using the proposed relationship. Further analysis of the obtained results makes it possible to identify the travel speeds at which resonance may occur. These speeds should be avoided during operation, as they can increase dynamic loads, reduce trimming quality, and accelerate wear of the working body. Thus, the proposed approach provides a consistent procedure for selecting the geometric and kinematic parameters of a passive flat knife, ensuring lower cutting resistance, improved top-trimming quality, and more reliable operation of the sugar beet harvesting unit.

Keywords: *root crops, harvesting, tops, cutting tops, cleaning heads from residues, pre-cleaning device, mathematical model, cutting force, static displacement, structural and kinematic parameters, quality of root crop cleaning.*

Eq. 25. Fig. 16. Ref. 7.

1. Problem formulation

The design configurations of machines for beet top removal differ significantly depending on the harvesting technology used, the agronomic requirements for the quality of top removal, the physical and mechanical properties of sugar beet roots, and the number of rows harvested simultaneously. In modern sugar beet harvesting, the process of removing the leaf mass and cleaning the root crop heads is one of the key operations that directly affects the quality of the harvested product, the amount of root losses, the level of damage to root crops, and the further efficiency of storage and processing.

Beet top removing mechanisms, after cutting the tops from the root crop heads, transfer the removed plant mass from the row zone into the inter-row space, onto the harvested field surface, or into a transport

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vehicle. In all cases, the main requirement is to remove the tops beyond the operating area of the digging working bodies of root harvesting machines, since the presence of cut tops in the digging zone can impair the technological process, increase clogging, and reduce the stability of machine operation. Structurally, beet top removing mechanisms may be integrated into specialized top-harvesting machines, mounted on beet harvesters, designed as separate units such as top cutters or root head cleaners, or combined with the digging units of root harvesting machines.

Top-cutting devices are primarily intended to remove the main mass of beet tops, while root crop head cleaners perform the additional operation of removing residual petioles and plant residues from the root head surface. However, despite the variety of existing technical solutions, the problem of achieving high-quality top removal without excessive cutting of the root crown remains insufficiently resolved. If the cutting device is set too high, part of the tops remains on the root head, which worsens the quality of raw material preparation. If the cutting height is too low, valuable root mass is lost, and the root crop may be mechanically damaged. Both situations are undesirable from the standpoint of harvesting efficiency and economic performance.

Another important problem is the uneven position of sugar beet roots in the soil. Root crops differ in crown diameter, height above the soil surface, inclination angle, and resistance to cutting. These variations complicate the interaction between the working body and the root head, especially when passive cutting elements are used. As a result, the cutting force, dynamic load on the knife, vibration level, and stability of the trimming process may change considerably during operation. This creates the need for a more precise substantiation of the geometric and kinematic parameters of top-removing devices.

Therefore, the improvement of beet top removal machines should be based not only on general design modernization, but also on a deeper analysis of the interaction between the cutting element and the root crop head. Particular attention should be paid to the knife installation angle, blade thickness, cutting path, unit travel speed, and possible resonance conditions of the working body. A rational combination of these parameters can reduce cutting resistance, decrease dynamic loads, improve the completeness of top removal, and minimize root crop damage.

Thus, the development and substantiation of efficient working bodies for sugar beet top removal remains a relevant scientific and practical task. Its solution will contribute to improving the technological reliability of harvesting machines, reducing crop losses, increasing the quality of root crop cleaning, and ensuring more stable operation of sugar beet harvesting units under variable field conditions .

2. Analysis of recent research and publications

The analysis of literary sources has shown that most beet top harvesting machines operate at a technological speed of 5–6 km/h and remove beet tops using two or more top-removing mechanisms of different designs. [1, 2] When the operating speed exceeds the recommended limits, the beet top cutting process deteriorates significantly. At the same time, operation at reduced speeds decreases the productivity of harvesting units, which leads to an increase in the duration of sugar beet harvesting. One possible solution to this problem is the use of multifunctional cutting devices that combine mechanisms of different designs and beet top removal schemes. Initially, the beet tops are cut using disc knives at a fixed height [3, 4]. This ensures that the root crop heads are not damaged. The tops cut in this manner can be used as animal feed (green fodder, silage), since they do not contain soil impurities. At the second stage, the removal of the remaining beet tops is advisable to perform using a passive floating cleaning knife, the feelers of which ensure the technological accuracy of beet top trimming [5, 6]

Root crops are considered properly trimmed when the cutting plane passes through the crown zone or the dormant bud zone. In other cases, namely when the cutting plane during additional trimming deviates above or below the permissible cutting limit, the root crops are considered over-trimmed or under-trimmed, which does not comply with agronomic requirements.

3. The purpose of the article

The purpose of the article is to improve the efficiency of the sugar beet top cutting process by substantiating the geometric parameters of the cutting device under conditions of ensuring the required strength of its working elements. The study is aimed at determining the rational parameters of a passive flat knife, in particular the blade thickness, installation angle, cutting path, and operating speed of the top-trimming unit, taking into account the force interaction between the knife and the sugar beet root head. Special attention is paid to reducing the cutting force, preventing excessive dynamic loads, and avoiding resonant operating modes that may negatively affect the reliability of the device and the quality of top removal. The proposed approach makes it possible to coordinate the geometric and kinematic parameters of the cutting mechanism with the strength properties of the blade material and the average geometric characteristics of sugar beet roots.

4. Results and discussion

Let us investigate, based on the energy approach, the process of additional trimming of sugar beet tops from root crop heads using passive knives operating after the passage of disc knives that cut the tops at a fixed height. The force parameters of the passive cleaning knife will be substantiated.

The force that must be applied to the passive cleaning knife to ensure additional trimming will be determined from the condition of equality between the potential deformation energy of the sugar beet top cutting process and the external work performed by the knife blade.

$$W = \mathrm{A} \quad (1)$$

The potential deformation energy of cutting, which is required for the destruction of the sugar beet root crop layer in the crown zone (Fig. 1):

$$W = \frac{\tau^2 \cdot V}{2\ G} = \frac{\pi \cdot \tau^2 \cdot R^2 \cdot \delta}{2\ G} \quad (2)$$

where τ – ultimate shear stresses of the sugar beet root crop in the crown zone (dormant buds); G – shear modulus of elasticity of the sugar beet root crop in the crown zone (dormant buds); V – volume of the cut layer of the sugar beet root crop in the crown zone

$$V = \pi \cdot R^2 \cdot \delta \quad (3)$$

where δ – thickness of the blade of the pre-cleaning knife; R – radius of the head of the sugar beet root crop in the crown or dormant buds area.

The external work performed by the blade of the pre-cleaning knife when trimming the heads of beetroots can be determined by analyzing the cutting process depending on the position of the knife (Fig. 1).

Elementary work of the knife for trimming the tops of root crops (Fig. 1, a)

$$d\mathrm{A} = \frac{1}{2} dF \cdot dh \quad (4)$$

where dF – elementary force applied to the knife, $dF = 2\ R \cdot sin\,\phi \cdot \tau \cdot \delta$; dh – elementary movement of the knife along the sugar beet root crop in the crown zone (or dormant buds), $dh = R \cdot d\phi$.

Dependence (4) will take the form $d\mathrm{A} = R^2 \cdot \delta \cdot \tau \cdot sin\,\phi\ \ d\phi$. Accordingly, the total work that needs to be spent on trimming the heads of sugar beet roots is,

$$\mathrm{A} = 2\int_0^{\frac{\pi}{2}} R^2 \cdot \delta \cdot \tau \cdot sin\,\phi\ \ d\phi = 2\ R^2 \cdot \delta \cdot \tau \quad (5)$$

Using the condition of equality of potential energy and external work spent on trimming

$$\frac{\pi \cdot \tau^2 \cdot R^2 \cdot \delta}{2\ G} = 2\ R^2 \cdot \delta \cdot \tau \quad (6)$$

we will obtain a dependence for determining the shear stress necessary for performing the process of trimming the tip

$$\tau = 4 \cdot G/\pi \quad (7)$$

You can ensure high-quality trimming of root crop heads by applying maximum force to the trimming knife.

$$F \frac{4 \cdot G \cdot d_{ch} \cdot \delta}{\pi}_{max} \quad (8)$$

where d_{ch} ·– diameter of the cut of the root crop heads in the crown zone (dormant eyes).

Based on considerations of reducing dynamic loads on the pre-cleaner knife and smooth cutting, the knife should be installed inclined, i.e. at an angle α to the axis of movement of the unit (Fig. 1, b). For both cases of knife installation (Fig. 1, a, b), the work spent on cutting the tops from the heads of root crops should be the same, i.e.

$$\frac{1}{2}F_1 \cdot 2 \cdot OC_1 = \frac{1}{2}F_2 \cdot 2 \cdot OC_2 \text{ or } F_1 = \frac{F_2}{cos\,\alpha} \text{ or } F_2 = F_1 \cdot cos\,\alpha \quad (9)$$

When the knife is installed at an angle α to the axis of movement of the unit, the cutting force decreases, but the path of the knife blade along the heads of beet roots increases, which ensures high-quality trimming of the top.

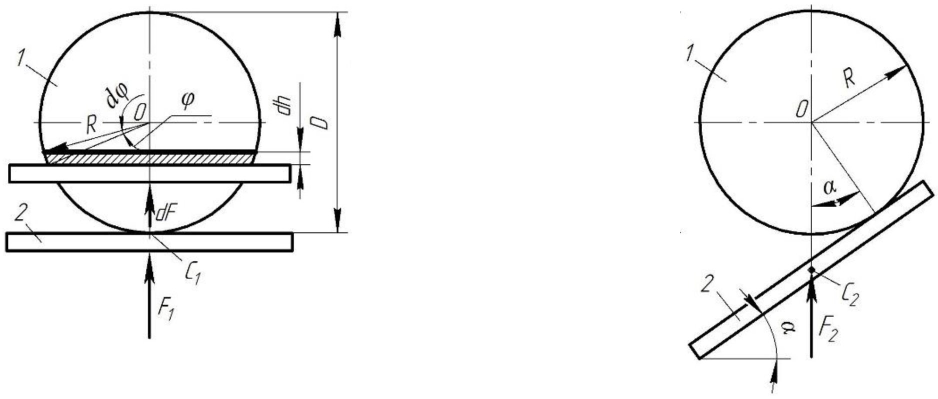


Fig. 1. Scheme of trimming the top of sugar beet roots depending on the position of the knife: a – root head; b – pre-cleaning knife

The range of changes in cutting force depending on the thickness of the pre-cleaning knife blade and the diameters of the root crop heads in the crown or dormant buds area is shown in Fig. 2.

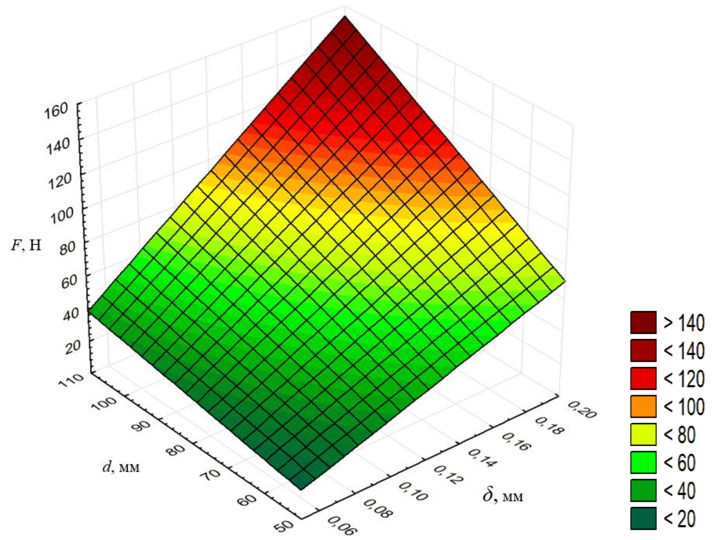


Fig. 2. Dependence of the cutting force on the blade thickness of the topping-cleaning knife and the diameters of root crop heads in the crown zone (dormant buds) at $G = 5,5$ MPa; $\delta = 0,05...0,2$ mm; $d_{зр} = 50...110$ mm

The device for topping sugar beet haulm is made of a steel strip with a rectangular cross-section *b*x*h*. The design of the device is a spatial rod frame rigidly fixed by one end to the frame of the haulm-harvesting unit. The lower part of the device is a passive knife made by bending. The knife is installed at an inclination angle α to the direction of movement of the arperate. A haulm cutting force F_α, directed opposite to the movement direction of the harvesting unit, is applied to the knife. Structurally, it is possible to change the knife inclination angle relative to the initial flat (horizontal) position by the angle α (Fig. 3, a). The maximum force of cutting the heads of root crops F_{max} will occur at the horizontal position of the knife, $\alpha = 0$; at $\alpha > 0$ the cutting force of the root crop heads $F > F_\alpha$. Increasing the knife inclination angle α\alphaα reduces the cutting force F_α.

The analysis of the stress-strain state of the topping-cleaning device and the determination of the recommended dimensions of the cross-sections of its elements will be carried out by schematically representing its elements (Fig. 3, b): 1 – knife, element BC; 2 – stand, element CK; 3 bar, element KT. Neglecting normal and shear forces, we determine the internal force factors, namely: bending and torsional moments acting in the elements of the device during the technological process of haulm cutting. Element BC, namely the knife, undergoes bending deformation:

$$M_{BD}^{B} = 0, \qquad M_{BD}^{C} = F_\alpha \cdot l \cdot cos\,\alpha$$

We will perform a parallel transfer of the cutting force components to sections C and K of elements CK and KT, respectively: section C, element SK (Fig. 3, c); section K, element KT (Fig. 3, d).

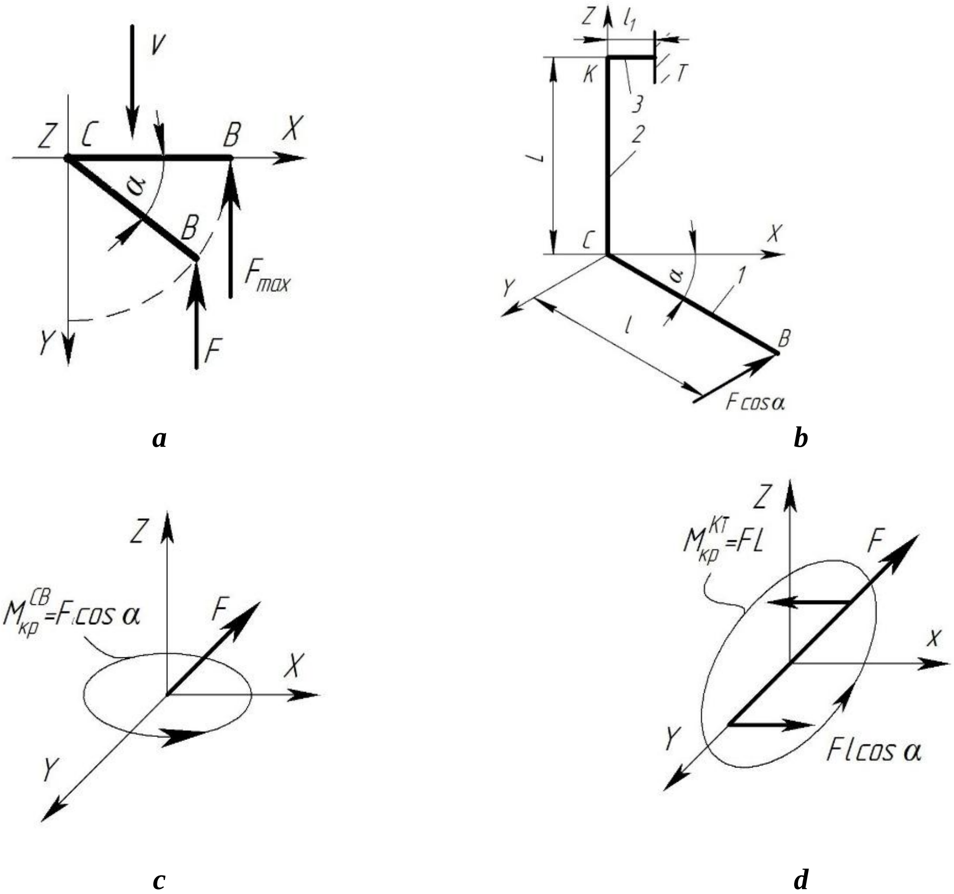


Fig. 3. Diagram of the topping-cleaning device and schematic representation of transferring the cutting force to the device joints. (a) schematic representation of the action of cutting forces relative to the movement of the агрегате; (b) schematic representation of the action of the cutting force relative to the orientation of the device elements; (c) section C, element CK; (d) section K, element KT

The topping-cleaning device with a knife (Fig. 4) is made of a strip with dimensions $h \times b,$ considering that $h = k \cdot b$. e perform the strength calculation of individual elements of the device in dangerous sections by determining the parameter (b) from the strength conditions. The schematic representation of the action of internal force factors relative to the orientation of the cross-sections of the elements of the haulm-cutting device is shown in Figure 5, a element BC, $M_{Zmax}^{C\,cos\,\alpha}$; element CK, M_{Xmax}^{K}; $M_{KP}^{CK} = F \cdot l \cdot cos\,\alpha$; element KT, $M_{Zmax}^{K\,cos\,\alpha}$; $M_{KP}^{KT} = F \cdot L$.

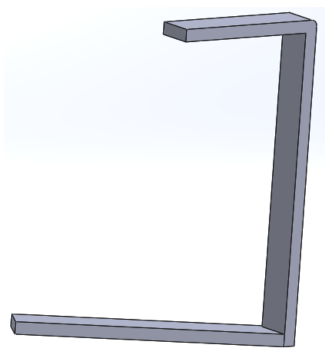


Fig. 4. Model of a pre-cleaning device with a knife

We construct diagrams of bending moments (Fig. 5, b) and torques (Fig. 5, c).

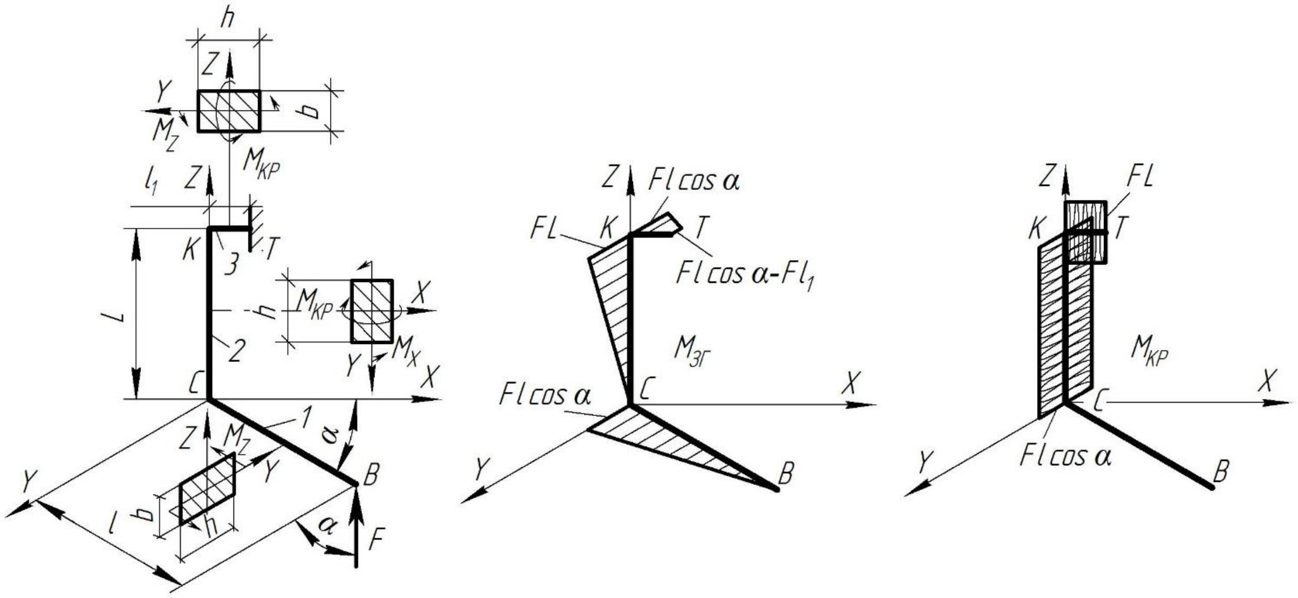


Fig. 5. General structural diagram of the topping-cleaning device and diagrams of the internal force factors acting in the device elements. (a) orientation of the cross-sections of the topping-cleaning device relative to the coordinate axes; (b) diagrams of the bending moments acting in the device elements; (c) diagrams of the torsional moments acting in the device elements

We perform the strength calculation of the elements of the topping-cleaning device. We determine the parameter *b*, assuming that $h = k \cdot b$. Calculation of the device element *BC* with length l (see Fig. 5 a, b, c)

$$\sigma_{\max} = \frac{M^{C}_{Z\max}}{W_Z} = \frac{6 \cdot M^{C}_{Z\max}}{b^3 \cdot k^2} \le [\sigma] \tag{10}$$

where W_Z – axial moment of resistance of the cross section *BC*, $W_Z = \frac{b \cdot h^2}{6} = \frac{b^3 \cdot k^2}{6}$.

From where

$$b \ge \sqrt[3]{\frac{6 \cdot M^{C}_{Z\max}}{k^2 \cdot [\sigma]}} = \sqrt[3]{\frac{F \cdot l \cdot \cos\alpha}{k^2 \cdot [\sigma]}} \tag{11}$$

Calculation of the length of the SK device element (see Fig. 5 a, b, c).

The maximum normal and tangential stresses occur at point K of the cross-section of the strut:

$$\sigma^{K}_{\max} = \frac{M^{K}_{X\max}}{W_x} = \frac{6 \cdot M^{K}_{X\max}}{b^3 \cdot k^2} = \frac{6 \cdot F \cdot L}{b^3 \cdot k^2} \tag{12}$$

$$\tau^{K}_{\max} = \gamma \frac{M^{CK}_{кр}}{W_K} = \gamma \frac{M^{CK}_{кр}}{\lambda \cdot h \cdot b^2} = \frac{\gamma \cdot F \cdot l \cdot \cos\alpha}{\lambda \cdot k \cdot b^3} \tag{13}$$

where λ, γ – coefficients that depend on the ratio $k = h/b$, at $k = 3$, $\lambda = 0{,}267$, $\gamma = 0{,}75$.

According to the third strength hypothesis, we determine the maximum design stresses and the parameter *b*:

$$\sigma^{K}_{розр} = \sqrt{\left(\sigma^{K}_{\max}\right)^2 + 4\left(\tau^{K}_{\max}\right)^2} = \sqrt{\left(\frac{6 \cdot F \cdot L}{b^3 \cdot k^2}\right)^2 + 4\left(\frac{\gamma \cdot F \cdot l \cdot \cos\alpha}{\lambda \cdot k \cdot b^3}\right)^2} = \\ = \frac{F}{b^3}\sqrt{\left(\frac{6 \cdot L}{k^2}\right)^2 + 4\left(\frac{\gamma \cdot l \cdot \cos\alpha}{\lambda \cdot k}\right)^2} \le [\sigma], \tag{14}$$

from where

$$b \ge \sqrt[3]{\frac{F}{[\sigma]}\sqrt{\left(\frac{6 \cdot L}{k^2}\right)^2 + 4\left(\frac{\gamma \cdot l \cdot cos\,\alpha}{\lambda \cdot k}\right)^2}} \tag{15}$$

The calculation of the device element *KT* with length l_1 ((see Fig. 5 a, b, c) will be performed similarly to the calculation of section *CK*. As a result, we obtain the relationship for the geometric parameter of the cross-section

$$b \geq \sqrt[3]{\frac{F}{[\sigma]}\sqrt{\left(\frac{6 \cdot l \cdot \cos\alpha}{k^2}\right)^2 + 4\left(\frac{\gamma \cdot L}{\lambda \cdot k}\right)^2}} \tag{16}$$

Using relationships (11), (15), and (16) under the condition that, $F = 100$ H, and the knife inclination angle takes values $\alpha = 0°;\ 15°;\ 30°;\ 45°;\ 60°$ we perform the calculation of the geometric parameter b for the elements of the topping-cleaning device. Graphical dependences of the parameter *b* on the knife inclination angle are plotted (Fig. 6). To ensure reliable operation of the investigated device, the larger of the obtained values of parameter *b* (see Fig. 6).

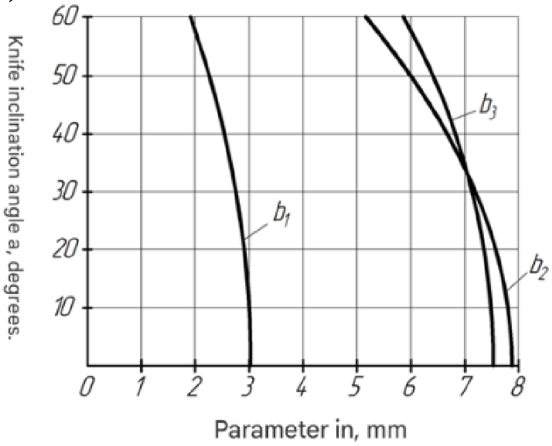


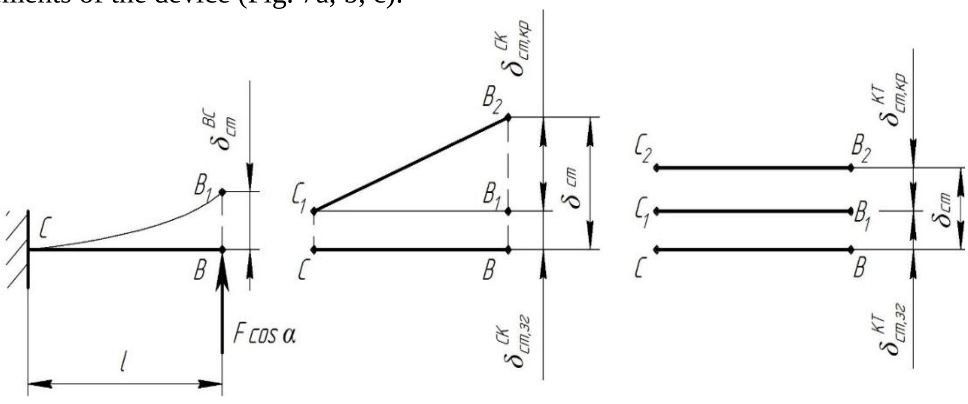
Fig. 6. Dependence of parameter b on the angle of inclination of the knife α in dangerous sections of the cutting device design: b_1 - sections BC; b_2 - sections CK; b_3 - sections KT; at $F = 100$ H; $[\sigma] = 100$ H/mm²; $l = 250$ mm; $L = 210$ mm; $l_1 = 120$ mm

In order to ensure the quality of the technological process, as well as to obtain kinematic and dynamic force characteristics, we will determine the linear and angular displacements of individual sections of the structure of the device for further cleaning of sugar beet tops.

We will perform an approximate determination of dynamic stresses by calculating static stresses by multiplying them by the dynamic coefficient. For the considered design of the pre-treatment device, the main parameter that must be determined is the static displacement of the section *B*, denoted by δ_{cm}. The section is subjected to a static action of an external force F. Using the superposition method, we will determine the total linear static displacement δ_{cm} of the section *B* (Fig. 7, a).

$$\delta_{cm} = \delta_{cm}^{BC} + \delta_{cm}^{CK} + \delta_{cm}^{KT} \tag{17}$$

where δ_{cm}^{BC}, δ_{cm}^{CK}, δ_{cm}^{KT} – components of static displacements of section *B* from displacements of individual elements of the device (Fig. 7a, b, c).



a ***b*** ***c***

Fig. 7. Schematic representation of the linear displacement of section B due to deformation of the device elements: (a) element CB; (b) element SK; (c) element KT

Taking into account the influence of the cutting force and the geometric dimensions of the device elements, we obtain the dependence for determining the static displacement $\delta_{ст}$ of the section *B*

$$\delta_{cm}=\frac{4\cdot F\cdot\cos\alpha\cdot l^3}{E\cdot k^3\cdot b^4}+\frac{4F\cdot L^3}{k^3\cdot b^4}+\frac{F\cdot L\cdot l^2\cdot\cos\alpha}{G\cdot\beta\cdot k\cdot b^4}+$$
$$+\frac{12F\cdot l_1^2}{E\cdot k^3\cdot b^4}\cdot\left(\frac{l_1}{3}-\frac{l\cdot\cos\alpha}{2}\right)+\frac{F\cdot L^2\cdot l_1}{G\cdot\beta\cdot k\cdot b^4}\approx\frac{F\cdot L}{G\cdot\beta\cdot k\cdot b^4}\cdot\left(l^2\cdot\cos\alpha+L\cdot l_1\right), \tag{18}$$

where $I_{кр}$ - moment of inertia of the cross-section of the device element during torsion, $I_{кр}=\beta\cdot k\cdot b^4$, there β - coefficient that depends on the ratio $k=h/b$, at $k=3$, $\beta=0{,}263$.

We neglect the linear displacement of section B from bending deformations of the device elements, since they constitute less than 5% of the total displacement.

During the execution of the technological process with the passive knife of the tip trimmer (see Fig. 4a), the elements of the device are subjected to dynamic loads, namely: shock and vibration loads, which increase the stress state of the elements:

$$\sigma_{\partial\max}=k_{\partial\, y}\cdot\sigma_{cm.\max}+k_{\partial\,\kappa}\cdot\sigma_{cm.\max}=\sigma_{cm.\max}\cdot\left(k_{\partial\, y}+k_{\partial\,\kappa}\right) \tag{19}$$

where $\sigma_{\partial max}$ – maximum dynamic stresses arising from impact and vibration in the system; $\sigma_{cm.max}$ – maximum static stresses arising in the system from the action of a static load; $k_{\partial\, y}$ – dynamic coefficient upon impact; $k_{\partial\,\kappa}$ – dynamic coefficient during oscillations.

Dynamic coefficients for shocks and vibrations:

$$k_{\partial\, y}\approx\sqrt{\frac{v^2}{g\cdot\delta_{cm}}} \qquad k_{\partial\,\kappa}=1+\frac{1}{\left|1-\left(\omega/\omega_0\right)^2\right|} \tag{20}$$

where v – linear speed of the unit; ω – cyclic frequency from the exciting force F, $\omega=2\cdot\pi\cdot f$, there $f=1/T$ – excitation frequency; T – period of excitement, $T=a/v$, a – distance between root crop heads in a row, then

$$\omega=\frac{2\cdot\pi\cdot v}{a} \tag{21}$$

where ω_0 – natural frequency of the system, $\omega_0=\sqrt{g/\delta_{cm}}$.

Therefore, the dynamic coefficient during oscillations will take the value

$$k_{\partial.\kappa.}=1+\frac{1}{\left|1-\frac{(2\cdot\pi\cdot v)^2\cdot F\cdot L\cdot\left(l^2\cdot\cos\alpha+L\cdot l_1\right)}{a^2\cdot g\cdot G\cdot\beta\cdot k\cdot b^4}\right|} \tag{22}$$

To ensure the operation of the device elements without destruction, it is necessary to ensure the condition:

$$\sigma_{\partial\max}=\sigma_{cm.\max}\cdot\left(\left(\sqrt{\frac{v^2\cdot\beta\cdot k\cdot G\cdot b^4}{g\cdot F\cdot L\cdot\left(l^2\cdot\cos\alpha+L\cdot l_1\right)}}\right)+\left(1+\frac{1}{\left|1-\frac{(2\cdot\pi\cdot v)^2\cdot F\cdot L\cdot\left(l^2\cdot\cos\alpha+L\cdot l_1\right)}{a^2\cdot g\cdot G\cdot\beta\cdot k\cdot b^4}\right|}\right)\right)\le[\sigma] \tag{23}$$

The dangerous section of the device for trimming the tip with a passive knife is the section K of the section *CK*. The maximum dynamic stresses that arise in the dangerous section are described by the dependence

$$\sigma^{K}_{\partial.\max}=\frac{F}{b^3}\sqrt{\left(\frac{6\cdot L}{k^2}\right)^2+4\left(\frac{\gamma\cdot l\cdot\cos\alpha}{\lambda\cdot k}\right)^2}\cdot\left(\left(\sqrt{\frac{v^2\cdot\beta\cdot k\cdot G\cdot b^4}{g\cdot F\cdot L\cdot\left(l^2\cdot\cos\alpha+L\cdot l_1\right)}}\right)+\left(1+\right.\right.$$
$$\left.\left.+\frac{1}{\left|1-\frac{(2\cdot\pi\cdot v)^2\cdot F\cdot L\cdot\left(l^2\cdot\cos\alpha+L\cdot l_1\right)}{a^2\cdot g\cdot G\cdot\beta\cdot k\cdot b^4}\right|}\right)\right)\le[\sigma]. \tag{24}$$

The graph of changes in maximum dynamic stresses that occur in the dangerous section of the finishing device, depending on the speed of movement of the unit and the cutting force, is shown in Fig. 8.

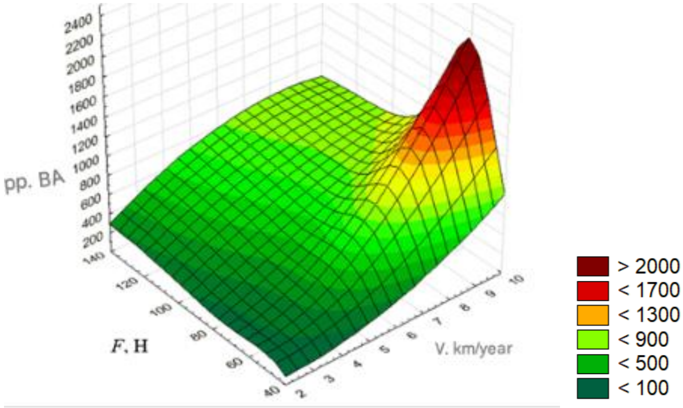


Fig. 8. Dependence of the change in maximum dynamic stresses on the speed of movement of the unit and cutting force

To prevent resonance in the device, it is necessary to ensure that the following conditions are met: $\omega \neq \omega_0$, or:

$$\frac{2\cdot\pi\cdot v}{a}\neq\sqrt{\frac{g}{\delta_{cm.}}}=\sqrt{\frac{g\cdot G\cdot\beta\cdot k\cdot b^4}{F\cdot L\cdot\left(l^2\cdot\cos\alpha+L\cdot l_1\right)}}. \tag{25}$$

The graph of the change in the frequency of forced oscillations of the device from the kinematic parameters of the technological process of trimming the tip is shown in Fig. 9.

The graph of the frequency of natural oscillations of the knife from changes in cutting force and knife inclination angle is shown in Figure 9.

By analyzing the obtained dependencies (Fig. 9 and 10), it is possible to select the operating modes of the device for trimming the tip so as to prevent the appearance of resonance.

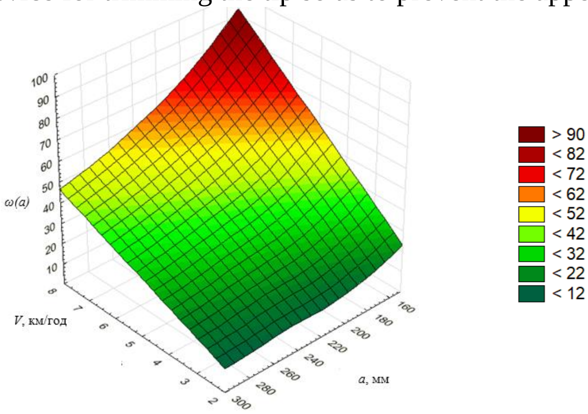


Fig. 9. Change in the frequency of forced oscillations of the knife of the trimming device

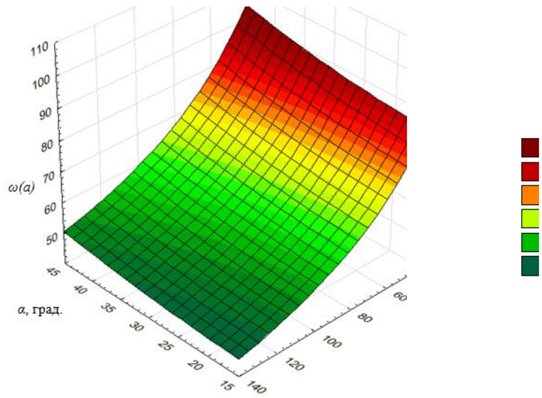


Fig. 10. Change in the natural oscillation frequency of the knife of the trimming device

For the proposed knife design, a study of displacements (deflections) was performed for knife cross-section sizes of 8 mm (Fig. 11) and 10 mm (Fig. 12). The stressed state and dangerous cross-sections were established for knife cross-section sizes of 8 mm (Fig. 13 and Fig. 14) and 10 mm (Fig. 15 and Fig. 16).

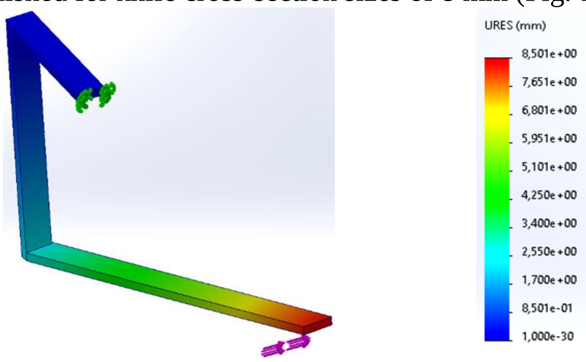


Fig. 11. Deflections in knife sections with a cross-sectional size of 8 mm

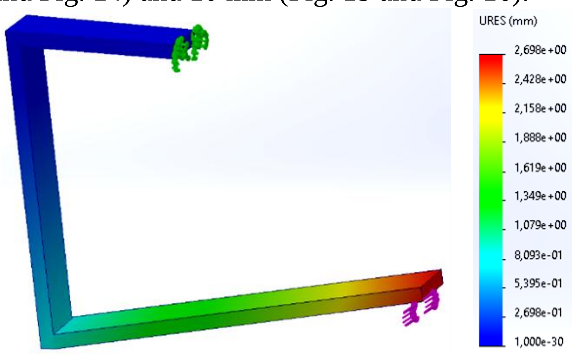


Fig. 12. Deflections in knife sections with a cross-sectional size of 10 mm

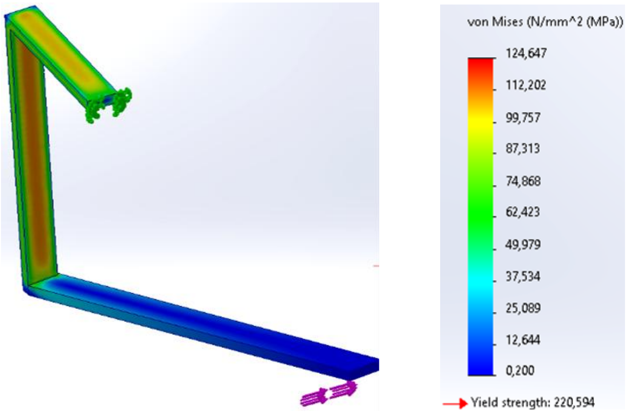


Fig. 13. Stressed state of the knife with a cross-sectional size of 8 mm

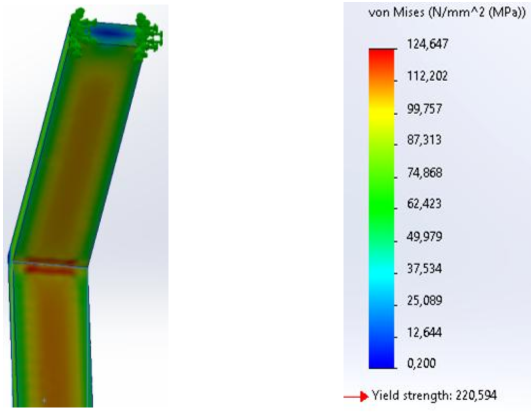


Fig. 14. Stress state in the most stressed section

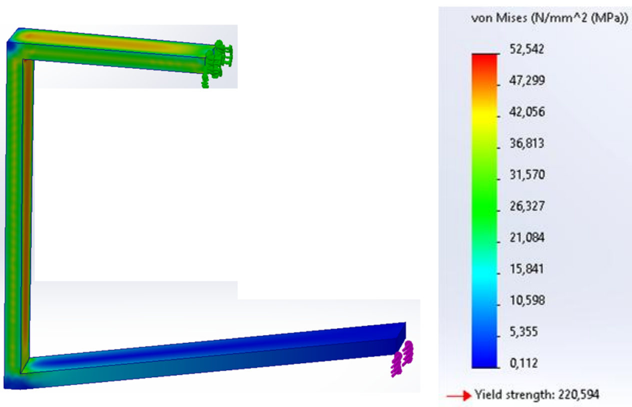


Fig. 15. Stressed state of the knife with a cross-sectional size of 10 mm

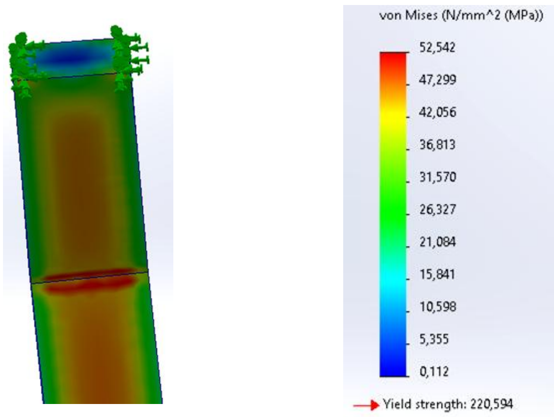


Fig. 16. Stress state in the most stressed section

As a result, possible options for using the developed design of the pre-cleaning knife for removing the tip were proposed.

5. Conclusion

Based on the condition of equality of potential energy and external work spent on trimming the heads of sugar beet roots with a passive flat knife, it was found that due to the correct choice of the angle of inclination of the knife to the axis of movement of the top-harvesting unit, it is possible to achieve a reduction in the load on the knife due to a decrease in the cutting force, while improving the quality of the top trimming due to an increase in the path of the knife, i.e. the cutting path. Before starting the technological process of trimming the tops of sugar beet, it is advisable to analyze the geometric parameters of the heads of sugar beet roots in order to determine the average diameter of the crown. Given the thickness of the blade of the pre-cleaning device (Fig. 5), using the dependence (Fig. 2), we will obtain the cutting force that must be applied to the knife. Knowing the tensile strength of the material of the pre-cleaning device knife, we determine the recommended speed of movement of the unit using the dependence (Fig. 7). From the obtained speed spectrum we exclude the speed at which the device can experience resonant frequencies. Knowing the cutting force and the angle of inclination of the knife, guided by the dependence (Fig. 9), we determine the frequency ω_0 of the device's natural oscillations. Analyzing the obtained results (Fig. 8), equating $\omega = \omega_0$, we obtain the unit's movement speeds, which must be avoided when performing the technological process of sugar beet tip trimming.

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ТЕОРЕТИЧНЕ ДОСЛІДЖЕННЯ ПРОЦЕСУ ДОБРІЗУВАННЯ ГИЧКИ БУРЯКІВ ПАСИВНИМИ НОЖАМИ

На основі принципу рівності потенціальної енергії системи та зовнішньої роботи, що витрачається під час дообрізування головок коренеплодів цукрових буряків пасивним плоским ножем, у роботі обґрунтовано можливість зменшення навантаження на робочий орган шляхом раціонального вибору кута встановлення ножа відносно осі руху гичкозбирального агрегату. Встановлено, що зміна цього кута безпосередньо впливає на силу різання та довжину шляху переміщення ножа в зоні головки коренеплоду. Отже, правильно підібраний кут встановлення леза дає змогу не лише зменшити силу, що діє на ніж, а й підвищити якість видалення гички завдяки збільшенню шляху різання та забезпеченню стабільнішої взаємодії леза з поверхнею коренеплоду.

Перед виконанням технологічного процесу дообрізування гички цукрових буряків доцільно проаналізувати геометричні параметри коренеплодів, насамперед середній діаметр головки, оскільки саме цей параметр визначає початкові умови для розрахунку сили різання. За заданої товщини леза дообрізувального пристрою та з використанням встановленої аналітичної залежності можна визначити необхідну силу, що прикладається до леза. З урахуванням межі міцності матеріалу леза надалі розраховують рекомендовану робочу швидкість руху агрегату. Водночас зі допустимого діапазону необхідно виключити швидкості, за яких у дообрізувальному пристрої можуть виникати резонансні явища.

Знаючи силу різання та кут встановлення ножа, за запропонованою залежністю визначають власну частоту коливань пристрою. Подальший аналіз отриманих результатів дає змогу встановити швидкості руху агрегату, за яких можливе виникнення резонансу. Таких швидкостей слід уникати під час роботи, оскільки вони можуть збільшувати динамічні навантаження, погіршувати якість дообрізування та прискорювати зношування робочого органу. Отже, запропонований підхід забезпечує послідовну процедуру вибору геометричних і кінематичних параметрів пасивного плоского ножа, що дає змогу зменшити опір різанню, підвищити якість дообрізування гички та забезпечити надійнішу роботу бурякозбирального агрегату.

Ключові слова: *коренеплідні культури, збирання, гичка, видалення гички, доочисний пристрій, математична модель, сила різання, статичне переміщення, конструкційно-кінематичні параметри, якість очищення коренеплодів.*

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