

Development of the design and substantiation of the parameters of the working body for digging the roots of sugar beet

N N Romanyuk¹, V N Ednach¹, P N Logvinovich¹, A-M S Dzjasheev², M N Kalimullin³, V I Shamonin⁴ and N P Ayugin⁵

¹ Belarusian State Agrarian Technical University, 99/1, Nezavisimosti av, Minsk, 220023, Republic of Belarus

² North-Caucasian State Academy, Stavropol, 41, Cherkessk, Karachay-Cherkess Republic, 369000, Russia

³ Kazan State Agrarian University, 65, Karla Marksa str., Kazan, 420015, Russia

⁴ Federal Scientific Agroengineering Center VIM, branch in Saint Petersburg, 3, Filtrovskoje Shosse, p.o. Tiarlevo, Saint Petersburg, 196625, Russia

⁵ Federal State Budgetary Educational Institution of Higher Education "Ulyanovsk State Agrarian University named after P.A. Stolypin", 1, boulevard Novy Venets, Ulyanovsk, Ulyanovsk region, 432017, Russia

E-mail: romanyuk-nik@tut.by

Abstract. The article proposes an original design of the forked working body of a beet harvester designed to dig up roots from the soil, which reduces the damage to root crops through the use of elastic elements in its design, which are rubber studded tires and the creation of an additional digging force acting on them. As a result of the analysis of the work of the proposed design, it was found that when interacting with the root crop, the elastic elements partially cover its surface, while creating an additional digging force. Analytical dependences are obtained, as well as the design and kinematic parameters of the forked working body are substantiated on the average size of the sugar beet root crop, which makes it possible to substantiate the optimal operating modes of the machine, to determine the dependence of the influence of the root crop size and the translational speed of the root harvester on the rotational speed of the tip of the active fork. The calculations showed that with an increase in the operating speed of the machine in the range from 1.0 to 2.0 m/s, it is necessary to ensure an increase in the angular velocity of the rotors ω in the range from 24 to 57.4 s⁻¹, which corresponds to a change in their rotation frequency from 230 to 554 min⁻¹, which ensures that root crops are not damaged from interaction with working bodies. Given the versatility of the proposed design of the working body and a wide range of harvested root crops, the number of rows of spikes should be taken equal to 18. With an optimal value of the cylinder radius of 0.036 m, the distance between the rows of spikes is 13 mm. Given the presence of soil and plant residues, the height of the elastic spikes, it is advisable to use equal to 5-7 mm.



1. Introduction

Sugar beet is the main agricultural crop that is intended for sugar production, and the waste is a valuable feed for livestock production. Sugar beet production is one of the labor-intensive and energy-intensive processes in agriculture. Sugar beet is one of the most important agricultural crops. It is the only source of white sugar, a valuable food product and raw material for many industries [1-2].

Sugar beet production is one of the labor-intensive and energy-intensive processes in agriculture. A particularly bottleneck in its production remains the most energy-intensive process - the harvesting of root crops, which does not provide, first of all, the required quality indicators [3-4].

Modern digging working bodies of root harvesters KS-6B, RKS-6, RKM-6 have low technological reliability in conditions of high humidity and soil hardness, resulting in increased damage and loss of root crops due to inefficient disruption of their connection with the soil with simultaneous deterioration of separation soil from the root crop. When the hardness of the soil and its humidity reaches its limit values (moisture content 8-12%, hardness - 3.0-4.5 MPa), losses reach 13%, damage to root crops - 60%, and contamination of the heap with impurities reaches 40% or more [5-6].

Relevance of the problem.

The main machine in the beet harvesting complex is the root harvester, and its main unit is the digging working bodies. Of all the types of digging working bodies that were used in the harvesting process, two stood out in terms of the quality of work and the reliability of the technological process - forked ones with rotating fork tips and disk ones with a drive of one of the disks [7-8;15].

Long-term comparative studies of active fork and disc diggers have shown that fork diggers with rotating conical tips have an advantage, the main advantage of which is reduced damage to root crops when extracting them from the soil, low energy costs for the technological process, better preliminary soil separation in the process of extracting root crops from it, as well as a wider range of soil conditions in which fork diggers remain operational.

Analysis of recent research.

The patent search shows that a digging tool is known (Device for removing root crops from the soil: author's certificate of the USSR No. 1412633), which contains a body carrying counter-rotating shafts on which root-extracting cones are installed, and a digging paw is rigidly fixed on the body, located along the longitudinal axis.

The disadvantage of this working body is the paw, which is unregulated in height and longitudinal movement, as well as the ripper, which is complex in design, which only breaks the connection of root crops with the soil, but does not help in extracting them from the soil.

Known working body for digging up root crops (Working body for digging up root crops: USSR author's certificate No. 491343), containing a squeeze fork made in the form of counter-rotating cone-shaped tips mounted at an angle to the longitudinal-vertical plane of symmetry of the working body. Below the tips in the plane of symmetry of the working body is a ripper in the form of a flat knife.

The disadvantage of this working body for digging up root crops is that the working surface of the ripper is made concave, which leads to significant friction when interacting with the soil and does not allow keeping the axis of the root crop vertical until they are captured by the rotors of the forks.

Known working body for digging up root crops (Working body for digging up root crops: patent No. 2117422 of the Russian Federation), consisting of an active fork made in the form of counter-rotating cone-shaped tips mounted at an angle to the longitudinal-vertical plane of symmetry of the working body and an adjustable ripper in the form of a flat a straight knife installed with the possibility of displacement in height and direction of movement, and the cylindrical parts of the active fork are equipped with eight cylindrical lugs offset relative to each other by 45°.

The disadvantage of this working body for digging up root crops is that the flat and straight shape of the working surface of the ripper creates additional friction forces between the soil and root crops when they move along it and, consequently, to inefficient lifting and extraction of root crops from the soil.

Known working body for digging sugar beet roots (Working body for digging sugar beet roots: patent No. 2176866 of the Russian Federation), containing a squeeze fork made in the form of

counter-rotating cone-shaped tips having on their cylindrical parts root hooks mounted at an angle to the longitudinal-vertical plane of symmetry of the working body, and an adjustable ripper, while the working surface of the ripper is made along a convex brachistochrone.

The disadvantage of this working body for digging out sugar beet roots is that the rigid shape of the cylindrical parts of the squeeze forks with the lugs located on them at some distance from each other does not provide constant capture of the root crops and a constant digging effort, and also injures the root crops, thereby reducing their presentation and duration of storage, for example, in heaps.

Purpose of research.

The purpose of the study is to develop a design and justify the parameters of the working body of a beet harvester designed to dig up roots from the soil, which allows to reduce energy costs for the technological process, ensure application in a wide range of soil conditions and reduce damage to root crops when interacting with the working body.

2. Materials and methods

To achieve this goal, an original design of the forked working body [9] was proposed, which reduces the damage to root crops and creates an additional digging force acting on them. Schematically, the working body is shown in figure 1. The proposed working body for digging out sugar beet roots contains a ripper 2 fixed on the body 1 with a working surface - brachistochrome 3 (line ab of the ripper 2). The ripper is made with the possibility of its regulation both in height and in the direction of movement. The active fork is made in the form of counter-rotating cone-shaped tips 4 with cylindrical parts 5 installed at an angle to the longitudinal-vertical plane of symmetry. The rotating cylindrical parts of each active fork are made in the form of elastic rubber tires 8 fixed on the drive shafts 7 with glue, with pneumatic rubber chambers 9 with valves built into them. On the outer cylindrical surfaces of the elastic rubber tires 8, elastic outer spikes 6 5-7 mm high and 4-5 mm in diameter are fixed in a checkerboard pattern, located at a distance of 6-8 mm from each other between adjacent spikes 6. The pressure in the pneumatic rubber chambers 9 elastic rubber tires 8 is created using a pump attached to the valves. The cone-shaped tips 4 are driven by the drive shaft 7.

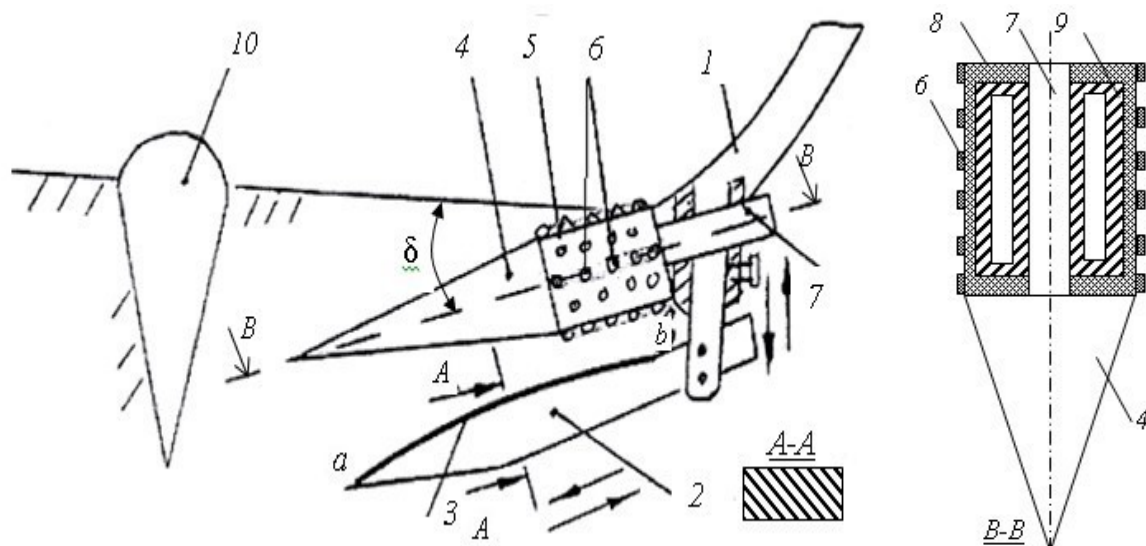


Figure 1. Working body for digging up sugar beet roots.

Works working body for digging sugar beet roots as follows. Rotating conical tips 4 loosen the soil around the root crop 10 at a given depth. The ripper 2 located below the fork loosens the soil over the entire depth of the root crop, completely breaking its connection with the soil, and moves it along its convex working surface - brachistochrome 3 into the capture zone of the fork rotors. In the process of

forward movement of the machine, the fork rotors begin to act on the root crop 11 and the rotating cone-shaped tips 4, including with the help of their cylindrical parts 5, effectively capture and extract them from the soil and transfer them to the root collectors. At the same time, when root crops 11 arrive on the rotating cylindrical parts 5 of the active fork, made in the form of elastic rubber tires 8 fixed on the drive shafts 7 with pneumatic rubber chambers 9, they are captured fixed on the outer cylindrical surfaces of the elastic rubber tires 8 arranged in a checkerboard pattern elastic external spikes 6. The surface of the elastic rubber tires 8 is deformed and acquires outlines covering the root crops, which sharply reduces the pressure and traumatic effect on them, while simultaneously increasing the digging force. At the same time, the deformation of elastic rubber tires 8 promotes self-cleaning of their surface and elastic outer spikes 6 from sticky soil.

By changing the air pressure in the pneumatic chambers 9 of the elastic rubber tires 8, the process of digging up root crops is optimized under various soil conditions and varieties of root crops.

The use of the proposed working body for digging out sugar beet roots will reduce the loss and damage to root crops during digging within the limits established by agricultural requirements.

Consider the work of the working body during its interaction with the soil and the root crop located in it. The mode of operation should provide:

- Violation of the connections of the root crop with the soil in its upper part due to the work of the active fork.
- Violation of the relationship of the root crop with the soil in its lower part due to the work of the ripper.
- Translational movement of the root crop with the soil on it with sliding along the surface of the ripper.

Figure 2, a shows a diagram for determining the design parameters of the rotors and shows the root crop of sugar beet at the time of the final breakdown of ties with the soil (figure 2, b). In this case, the axis of symmetry of the root crop is assumed to be vertical, its body has a conical and elastic shape, the maximum diameter of the root crop d_r is located at the level of the soil surface. When moving in the soil of the digging working body, the rise of the root crop at the first moment before the contact of its body with the conical tips of the fork will occur only due to the ripper. By the moment of transition (lifting) of the root crop to the cylindrical parts of the active fork, it is necessary to raise the root crop with the ripper up so that the diameter of the root crop at the moment of contact with the cylindrical parts is less than or equal to the size d_1 in the solution of the cylindrical parts of the fork.

The movement of the root crop to the cylindrical parts of the fork openings will depend on the angle α_p of the ripper installation, which mainly depends on the diameter of the root crop d_r and the depth of the fork stroke h_f [10;14;17].

The angle of installation of the axis of the fork to the horizon δ depends on the angle of the cone of the tip, the value of which for the existing designs of beet harvesters is in the range of 18-20°.

With the assumed travel depths of the fork h_f from 0.04 to 0.12 m and the diameter of the root crop d_r , varying from 0.06 to 0.14 m, the installation angle of the ripper α_p varies from 8.5° to 37.4°.

After breaking the connections of the root crop with the soil and lifting it without changing its position relative to the vertical axis upwards under the influence of the translational movement of the machine and the shape of the working surface of the ripper, it falls into the zone of influence of the cylindrical parts of the tips of the active fork.

The cylindrical parts of the fork tips, due to rotation towards each other and the translational movement of the machine, pinch the root crop and lift it up to the root collector. At the same time, due to the additional impact on the root crop of the spikes on the cylindrical parts, it will be pushed out of the soil much faster, which eliminates breaking off of its tail part and can significantly reduce losses and damage to the sugar beet root crop.

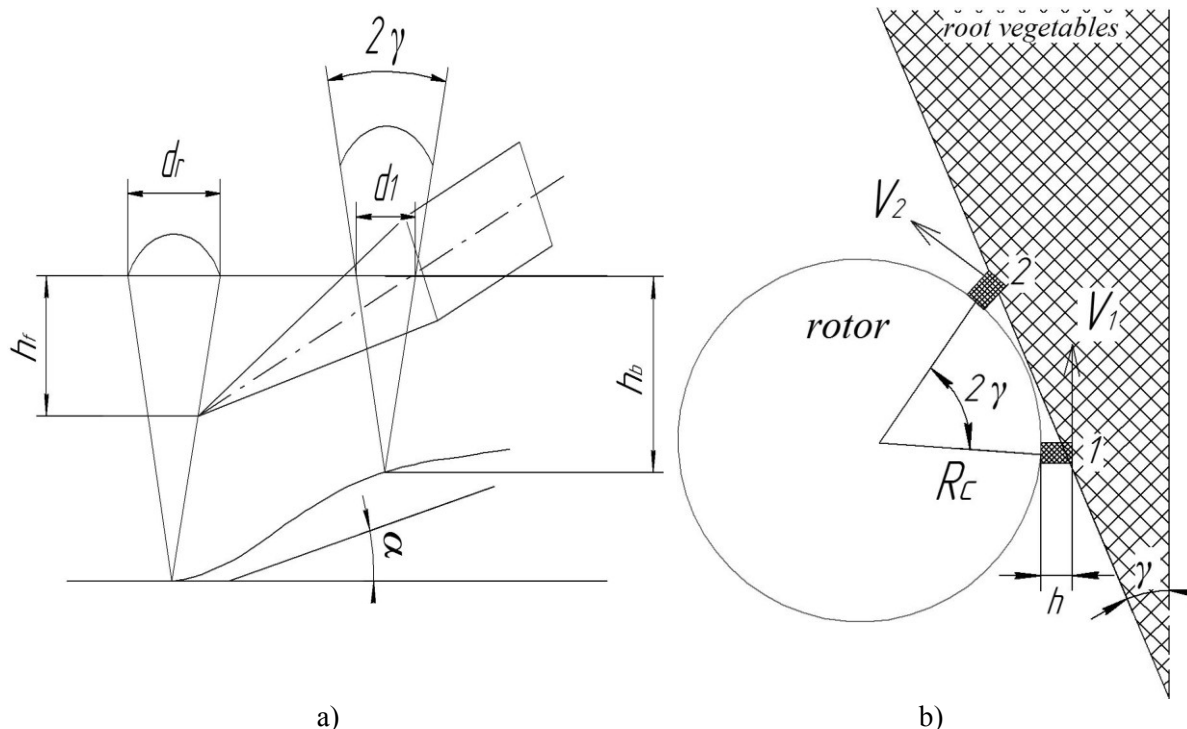


Figure 2. Scheme for determining the design parameters of the rotors.

Consider the process of extracting a root crop from the soil with an active fork equipped with spikes. The translational movement of the root harvester and the rotational movement of the fork tips must be coordinated in such a way that when the machine is moved by the length of the cylindrical parts of the fork, the rotating tips must completely remove the rest of the root crop from the soil.

Due to the translational movement of the machine, the root crop will move by the value of C_1C_2 (figure 3), which can be determined from the formula:

$$C_1C_2 = L \cos \beta \cos \delta \tag{1}$$

Where L is the length of the cylindrical part of the fork tip, m ; β is the angle between the direction of the translational movement of the machine and the generatrix of the cylindrical part of the fork, deg ; δ is the projection of the tilt angle of the rotor symmetry axis on the vertical plane (figure 1), deg .

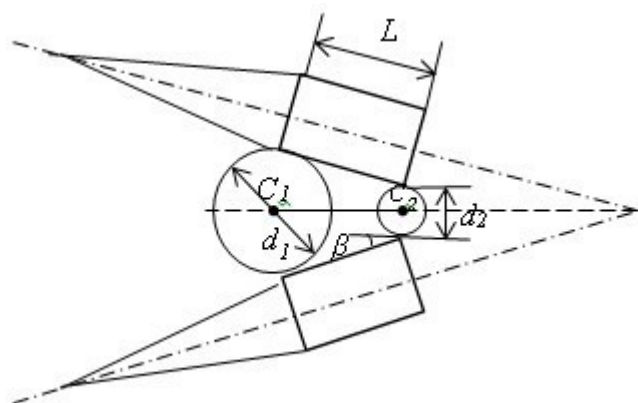


Figure 3. Scheme for determining kinematic parameters.

The angle β can be determined from the relationship (figure 3):

$$\left(\frac{d_1 - d_2}{2}\right)^2 + (L \cos \beta)^2 = L^2 \quad (2)$$

Where d_1 and d_2 are the values of the largest and smallest gaps between the cylindrical surfaces of the rotors, m.

After carrying out the necessary transformations, we get:

$$\cos^2 \beta = 1 - \left(\frac{d_1 - d_2}{2L}\right)^2 \quad (3)$$

Consequently,

$$C_1 C_2 = \sqrt{L^2 - \left(\frac{d_1 - d_2}{2}\right)^2} \cos \delta \quad (4)$$

Due to the rotational movement of the fork cylinders and pinching in their solution, the root crop must completely rise from the soil without slipping, i.e. roll over the cylinders with the part remaining in the soil after lifting it with a flat ripper.

The amount of movement of the root crop upwards under the influence of the cylindrical parts of the fork is equal to the length of the part of the root crop remaining in the soil after it has been lifted by the working surface of the ripper to the cylindrical parts (Figure 2):

$$h_c = \frac{d_c}{2 \sin \gamma} \quad (5)$$

Where $d_c = d_1$ is the diameter of the root crop, equal to the maximum distance between the cylindrical parts of the rotors, m; γ - half of the taper angle of the root, equal to 20 ... 32 degrees.

This means that when the rotational movement of the forks and the translational movement of the machine act on the root crop together, it is necessary that the condition is met under which the circumferential speed of the fork rotors V_o must be somewhat greater than or equal to the translational speed of the root harvester V_k .

The circumferential speed of the fork rotors is determined by the expression:

$$V_o = \omega R_c \quad (6)$$

Where ω is the angular velocity of rotation of the fork rotor, s^{-1} ; R_c - radius of the cylindrical part of the fork with spikes, m.

From the condition of equality of V_o and V_k , we obtain:

$$V_k t = \omega R_c t = \frac{d_c}{2 \sin \gamma} \quad (7)$$

Where t is the time of moving the machine until the root crop is fully lifted, s.

Because the,

$$V_k t = C_1 C_2 = \frac{1}{2} \sqrt{4L^2 - (d_1 - d_2)^2} \cos \delta \quad (8)$$

Then from expressions (7) and (8) we obtain:

$$\frac{\omega R_c}{2V_k} \sqrt{4L^2 - (d_1 - d_2)^2} \cos \delta = \frac{d_c}{2 \sin \gamma} \quad (9)$$

Whence the angular velocity of the fork rotors:

$$\omega = \frac{V_k d_c}{\sqrt{4L^2 - (d_1 - d_2)^2} R_c \cos \delta \sin \gamma} \quad (10)$$

3. Results and Discussion

The main influence on the angular velocity of the tip of the active fork will be exerted by the average diameter of the root crop d_c for calculations, we take it equal to 100 mm [11] in the zone of approach to the cylindrical parts and the translational speed of the root harvester V_k according to agrotechnical requirements is in the range from 5 to 10 km/h [12-13;16-17].

When calculating, it was assumed $L = 0.3$ m; $d_c = 0.1$ m; $d_1 = 0.12$ m; $d_2 = 0.03$ m; $R_c = 0.036$ m; $\delta = 20^\circ$ figure 4.

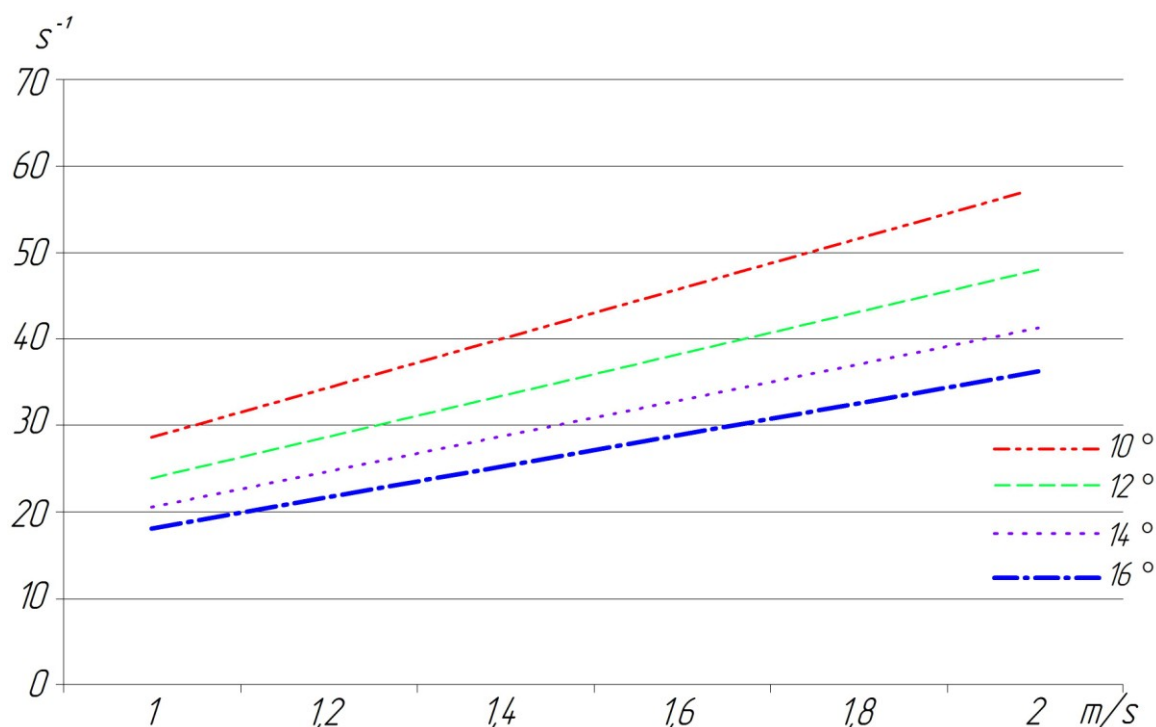


Figure 4. Graph of the dependence of the change in the angular velocity ω_p on the working speed of the machine V_k at different taper of the root crop γ .

The calculations presented in the graphs (figure 4) show that with an increase in the operating speed of the machine in the range from 1.0 to 2.0 m/s, it is necessary to ensure an increase in the angular velocity of the rotors ω_r in the range from 24 to 57.4 s $^{-1}$, which corresponds to a change in their rotation frequency from 230 to 554 min $^{-1}$. At the same time, for larger root crops, due to the increase in the angle 2γ , the angular velocity of the rotors can be reduced. Thus, at an angle of 20 degrees and a machine speed of 2 m/s, the angular velocity will be 57.4 s $^{-1}$, and for extracting a root crop with an angle of 32 degrees, the angular velocity will be 36.2 s $^{-1}$.

When interacting with the root of the cylindrical parts of the tips of the active fork, on which there are cylindrical spikes, the process of their further lifting from the soil to the root collectors should proceed without slipping of the tip cylinder along the body of the root crop. This is possible only if the rotating cylindrical parts of the tips will have spikes located along the generatrix of the cylinders and their location will allow to act on the body of the root crop so that the spike (figure 2, b), moving from

position 1 to position 2, will lift the root crop until the direction of peripheral speed \vec{V}_1 changes to direction \vec{V}_2 . In this case, the cylindrical part of the tip will rotate through an angle of 2γ .

In order for the process of lifting the root crop from the soil with an active fork with spikes to proceed in this way, it is necessary to determine the height of the spikes and the number of their rows located along the generatrices of the cylinders. Based on the above, you can determine the number of rows of studs N on the fork cylinder.

$$N = \frac{360^\circ}{2\gamma} \quad (11)$$

The process of the impact of the thorn on the body of the root crop described above makes it possible to determine its height h from relation (4):

$$R_c + h = \frac{R_c}{\cos \gamma} \quad (12)$$

After transformation we get:

$$h = \frac{R_c (1 - \cos \gamma)}{\cos \gamma} \quad (13)$$

Expression (13) shows that the height of the thorn depends on the radius of the cylinder and half of the average taper angle of the root crop (figure 5)

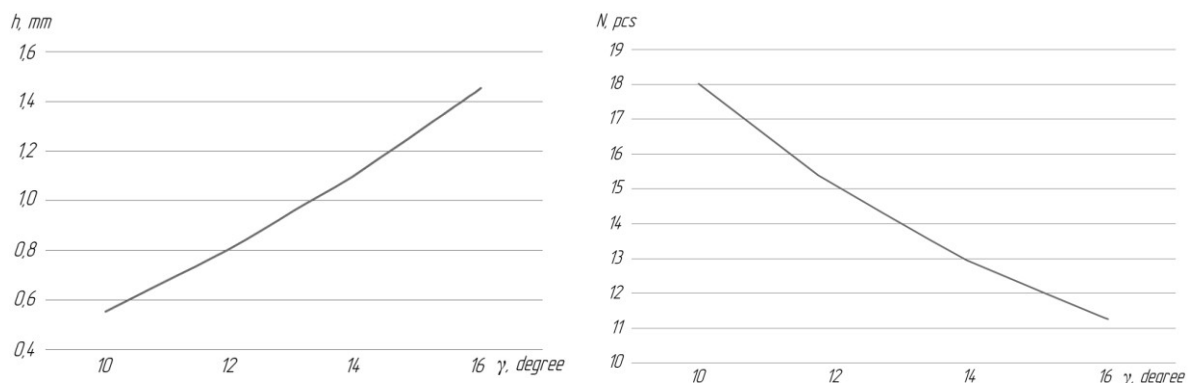


Figure 5. Dependence of the height of the spike and the number of rows of spikes on the angle γ

For the accepted value of the radius of the cylinder of the active fork of 0.036 m and half of the average taper angle of the root crop of 10-16 °, the height of the spike, calculated by expression (13), will vary from 0.5 to 1.5 mm. Considering that the calculation was carried out for an absolutely rigid cylinder and spikes, the height of elastic spikes, equal to 5-7 mm, adopted in the design of the working body, is justified. When using the value of half the average angle of the root taper from 10 to 16°, the number of rows of spikes will vary from 12 to 18. Structurally, $N = 18$ should be taken. With a value of the cylinder radius of 0.036 m, the distance between the rows of spikes should be no more than $2\pi R_c / N = 13$ mm.

Based on the values of the size-mass characteristics of root crops, it is necessary to clarify the limits of change in the parameters of the digging working body according to the obtained analytical expressions. This will provide a basis for choosing the limit values for their change during the harvesting of sugar beets.

4. Conclusion

The process of digging out sugar beet root crops by various types of digging working bodies does not always proceed in the same way in different soil and climatic conditions, but these working bodies must dig out root crops with minimal losses, damage and contamination. Each type of digging working bodies has its own advantages and disadvantages. The disadvantage of the forked working body for digging out sugar beet root crops is that the rigid shape of the cylindrical parts of the squeeze forks with root hooks located on them at some distance from each other does not provide a constant capture of the root crops and a constant digging effort, and also injures the root crops.

Invention proposes original design of forked working member ensuring reduction of root crops damage and creation of additional digging force acting on them.

Theoretically substantiated kinematic and design parameters of the working body. The calculations showed that with an increase in the operating speed of the machine in the range from 1.0 to 2.0 m/s, it is necessary to ensure an increase in the angular velocity of the rotors ω_r in the range from 24 to 57.4 s^{-1} , which corresponds to a change in their rotation frequency from 230 min^{-1} to 554 min^{-1} , which ensures that root crops are not damaged from interaction with working bodies. Given the versatility of the proposed design of the working body and a wide range of harvested root crops, the number of rows of spikes should be taken equal to 18. With an optimal value of the cylinder radius of 0.036 m, the distance between the rows of spikes is 13 mm. Given the presence of soil and plant residues, the height of the elastic spikes, it is advisable to use equal to 5-7 mm.

References

- [1] Baigy M, Sahebi F, Pourkhiz I, Asgari A and Ejlali F 2012 Effect of deficit-irrigation management on components and yield of sugar beet. *International journal of Agronomy and Plant Production* **3** 781-787
- [2] Spichak V V and Sapronov N M 2007 Modern requirements for sugar beets. *Sugar* **7** 12-17
- [3] Hoffmann C 2006 Zuckerrüben als Rohstoff. *Die technische Qualität als Voraussetzung für eine effiziente Verarbeitung* (Göttingen) 200
- [4] Martynov V M 2010 Modern technologies and technical means for harvesting root crops. *Mechanization and electrification of agriculture* **3** 27-29
- [5] Bashkirev A P 2007 Development of the theory and improvement of digging working bodies of beet harvesters. *Abstract of the thesis. ... doctor of technical sciences, Moscow* 31
- [6] Romanyuk N N, Ageichik V A, Khartanovich A M and Gildyuk K V 2021 The original working body for digging up root crops. *Innovations in environmental management and protection in emergency situations: Proceedings of the VIII International Scientific and Practical Conference - Saratov State Agrarian University; Saratov: Amirit* 454-456
- [7] Klimov N S 2006 Improving the quality of work of forked digging working bodies of beet harvesters. *Abstract of the thesis. dis. ... cand. tech. Sciences, Voronezh* 20
- [8] Semykin V A 2004 Study of the work of improved root harvesters. *Successes of modern natural science* **10** 114-115
- [9] Romanyuk N N, Ageychik V A, Gildyuk K V, Khartanovich A M, Voinash S A, Sokolova V A., Partko S A, Troyanovskaya I P, Lopareva S G and Loparev D V 2021 *Working body for digging up sugar beet root crops: patent 2762844 Russian Federation, IPC A01D 25/04 / 2021114112*
- [10] Bashkirev A P 2007 *Development of the theory and improvement of digging working bodies of beet harvesters. Abstract of the thesis. dis. ... doc. tech. Sciences, Moscow* 35
- [11] Nikitin A F 2019 Sizes of root crops and sugar content in them depending on different methods of basic tillage and growing conditions. *Sugar* **2** 34-36
- [12] Komlach D I, Goldyban V V and Ednach V N 2015 Determination of the energy performance of a roller cleaner. *Agropanorama* **3** 10-15
- [13] Nukeshev S O, Kakabaev N A, Romanyuk N N, Troyanovskaya I P, Smelik V A and Voinash S A 2021 Design and rationale for parameters of the seed-fertilizer seeder coulter for subsoil

- broadcast seeding. *IOP Conference Series: Earth and Environmental Science* **677(5)** 052010
- [14] Rogovskii I L, Sivak I M, Voinash S A, Sokolova V A, Garbuzova T G, Rzhavtsev A A, Kokieva G E and Romanyuk N N 2021 Research of microdeformation and stress in details of agricultural machines by implementing holography. *IOP Conference Series: Earth and Environmental Science* **677(5)** 052038
- [15] Nosov V V, Tindova M G, Zhichkin K A, Vorob'Eva D A, Pakhomova T V, Ayugin N P and Kalimullin M N 2022 Forecasting the production of agricultural machinery in the Russian Federation. *IOP Conference Series: Earth and Environmental Science* **1045** 012014
- [16] Ayugin N P, Morozov A V, Ulyanov M V, Kalimullin M N, Artemova E I and Ukhalina O V 2022 Theoretical aspects of root crop grinder development. *IOP Conference Series: Earth and Environmental Science* **1045** 012126
- [17] Ismagilov D, Kalimullin M, Latypov R, Gilfanov R and Mukhametshin I 2021 Study in dependence of operating mode on completeness of haulm removal. *Engineering for Rural Development* **20** 1722-1727