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DEVELOPMENT OF AN ALGORITHM FOR THE SYNTHESIS OF DEVICES FOR SEPARATING TOPS RESIDUES ON ROOT CROPS

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Sugar beet harvesting is a complex technological process, where the operation of separating tops residues from root crop heads on the root remains one of the most problematic due to the variability of the agrophysical properties of the plants and harvesting conditions. Although a large number of various cleaner designs currently exist, the creation of new devices that would increase productivity, reduce energy consumption, and minimize damage and knocking of raw materials out of the soil remains an urgent need in the agricultural engineering sector.

Establishing cause-and-effect relationships and developing a structural and logical scheme for the synthesis of new root crop head cleaners by applying methods of structural and functional analysis of technical systems is of high relevance.

The paper applies methods of morphological analysis, theoretical mechanics, and systematization for a critical review of existing structural and technological schemes of working organs.

The article analyzes known classifications of working organs for the post-cleaning of root crop heads from tops. It has been established that they often rely on scattered features (only on the direction of the load or the type of movement), without forming a unified system for evaluation. For a comprehensive approach, the basic features that directly affect the working process are distinguished: the material and geometric shape of the element, the type of its fastening (rigid or hinged), the type of relative movement (rotary, oscillating, complex), and its orientation to the row axis. The distinction between the concepts of "supporting" and "working" elements has been introduced.

The main criteria for the functional suitability of the cleaner are determined: ensuring rational force factors in the contact zone (preference for tangential load over impact load) and the presence of a restoring force to return the element to its initial position. Based on these parameters, an algorithm and a logical synthesis scheme have been developed. Thanks to this scheme, the existing types of working organs (disk, segment, beater) were analyzed, and new potential types (mesh, ring, with translational-oscillatory motion) were generated. A preliminary assessment of their force interaction with root crops was carried out.

The proposed synthesis algorithm allows systematizing all known devices for tops separation and purposefully creating innovative technical solutions. Evaluation according to the defined criteria makes it possible to reject irrational variants even at the design stage and to develop designs with optimal operating modes without damaging root crops.

Keywords: *cleaner of head of root crops, root crops, working organ, functional fitness, supporting element, working element.*

Fig. 1. Ref. 9.

1. Problem formulation

Well-known constructions and classifications of working organs for the separation of root crops after cutting was analysed in this article. On their basic was developed structure logi-cal schema of synthesis of new working organs. It was given example of synthesis and were analysed basic modes of cleaner of head of root crops.

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2. Analysis of recent research and publications

L.V. Pohorilyi, V.M. Bulhakov, V.Ya. Martynenko, R.B. Hevko, V.M. Baranovskyi, O.P. Hurchenko, M.M. Khelemendyk, V.R. Yaroshovets, M.A. Mishin, V.D. Orekhivskyi, V.M. Martynov, and others have worked on creating designs of working bodies for sepa-rating tops and their justification in different years. Harvesting the tops is one of the most difficult operations in harvesting sugar beets. This is due to a significant variation in the agrophysical properties of sugar beets and the agroclimatic conditions of harvesting. Therefore, the creation of new working organs that increase productivity, reduce energy consumption, and improve the quality of raw materials remains an urgent task [1-6].

3. The purpose of the article

To establish cause-and-effect relationships and develop a structural and logical scheme for the synthesis of root crop head cleaners by using methods of structural and functional analysis of technical and technological systems. This will allow the creation of new designs of root crop head cleaners, their preliminary analysis, and the evaluation of existing ones.

4. Results and discussion

In the conducted studies, different indicators of the quality of work for the same designs of root crop head cleaners are often found. This is explained by the fact that root crop head cleaners can be tested on different agricultural backgrounds. Considering the impossibility of conducting comparative experimental studies of different designs, to analyze the operation of root crop head cleaners, it is necessary to identify the most characteristic features, choose general criteria for their functional suitability.

Currently, a large number of designs of root crop head cleaners are known. They can be divided into cleaners of two classes – with the placement of the axis of rotation in the vertical and horizontal planes [1-3].

Known classifications are given in works [1, 2, 3, 8]. The classification [3] is based on the load applied by the cleaning element to the root crop head. By its type, the load can be impact, combing, impact-combing. The terminology used does not quite correspond to classical terms. Obviously, it can be considered that the author understands under impact load - an impact directed along the normal to the surface; under combing - a load, the direction of which coincides with the tangent to the surface of the root crop head; under impact-combing - a load that does not coincide in direction with the above-mentioned or can be in such a working body that sequentially performs these types of loads.

In work [1], root crop head cleaners are classified by the type of cleaning elements, by the direction of rotation of the rotor relative to the field surface, and relative to the direction of the harvesting machine. The classification proposed in work [2] takes into account many features of the relative movement of cleaning elements, orientation of the plane of relative movement in space, orientation of relative movement to the row axis, the shape of the working surface, placement in the technological scheme, type of material of working elements, type of fastening of working elements, processing zone, type of attachment to the machine, type of drive.

The classification given in work [3] takes into account an important feature - the direction of application of the load, but there is no connection with the features given in works [1;2]. An important feature given in works [1;2] is the type and orientation of relative movement, the shape and material of the working elements, but here the load feature is missing. In general, there is no logical connection between the features of the above classifications. They do not unite all known designs into a single whole. And when analyzing the operation of different cleaners, important designs may be missed.

Therefore, to evaluate the technological process performed by a certain cleaner design, it is necessary to define the main features that characterize the type of cleaner, its design, and the cleaning method, to create a systematic classification that would logically combine these features, and also to choose criteria for the functional suitability of the design.

We will distinguish characteristic features that significantly affect the cleaning technological process and the cleaner design:

- material of the working element;
- geometric shape of the working element;
- orientation of the working element to the direction of relative movement;
- type of fastening of working elements;
- type of relative movement of the working element;
- orientation of the relative movement to the row axis.

The functional suitability of the root crop head cleaner will be determined by such criteria as the presence of the necessary force factors ensuring the required contact of the working elements with the root crop head and the presence of forces restoring the initial positions of the cleaning elements before the next interaction. The force that returns the working element to its initial position will be called the restoring force.

When analyzing different designs of working organs, it was found that the following materials were mainly used: rubber, rubber-cord products, and metal. From these materials, working elements of various geometric shapes were made: segments, disks, flexible meshes, chains, cables, rods of various shapes, rings, and other specialized rigid surfaces in the form of drums. Depending on the type of working element, it itself or its surface can be placed at an angle, parallel, or perpendicular to the direction of relative movement (axis of rotation, axis of oscillation).

The working element is attached rigidly or pivotally. The working element can be given one of the following types of relative movement: rotary, reciprocating, oscillating, translational, and complex, which consists of two rotary movements with mutually perpendicular axes. All types of movements except complex are plane, and the orientation of the plane of relative movement to the direction of the rows can be parallel, perpendicular, and at an angle.

When re-cleaning the heads of root crops, plant residues remain, which must be removed from the area of operation of the working bodies for digging root crops so that the heap of root crops is not clogged [4-8].

Based on the above considerations, we draw up a logical scheme for the synthesis of cleaner designs for root crop heads (Fig. 4), we will give the signs of classification of cleaners with a functional connection between them. With the help of such a classification, various designs of root crop head cleaners are systematized. Using this scheme, a large number of new designs of root crop head cleaners can be synthesized. It should be noted that the above scheme is not perfect. Complex cleaner designs are not included here. Mechanisms that realize relative motion are not displayed. There are no cleaning elements that are attached to the working bodies. For example, threads, chains, spikes, and other elements can be attached to flexible disks. Rods can be of the most diverse configuration. A combination of different working elements, their sizes, shape, and mutual arrangement can also create a new working organ.

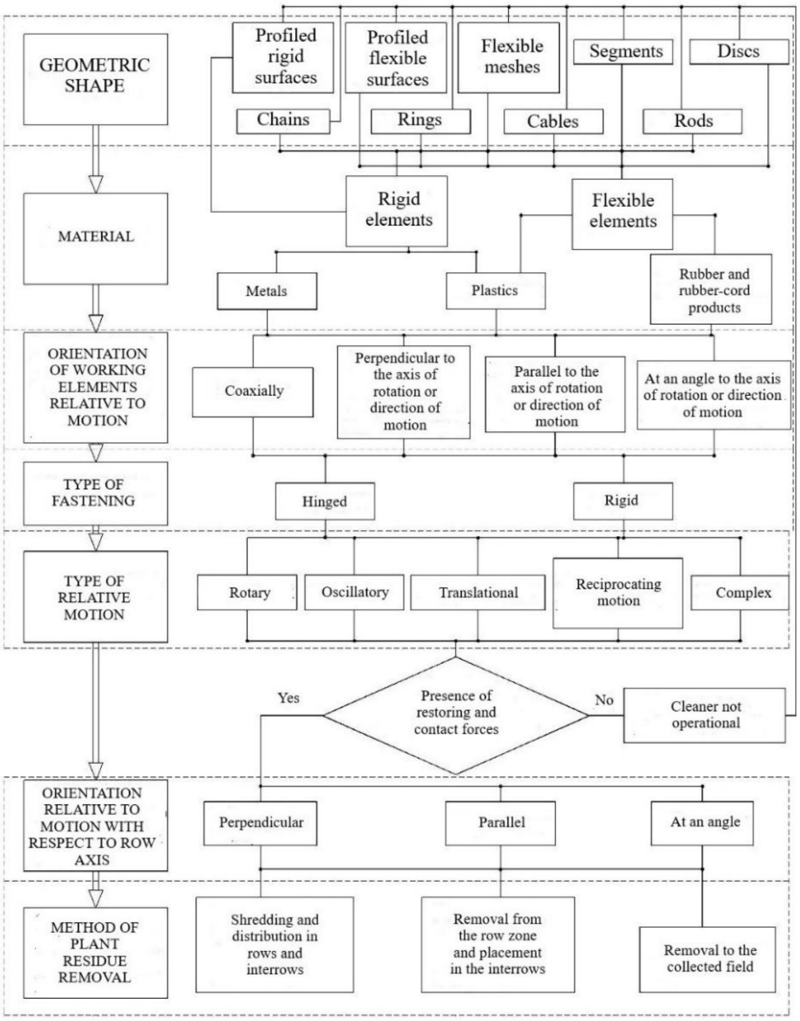

Fig. 1. Scheme of synthesis and classification of working organs for separating tops residues after cutting

A cleaner design can be formed by simply combining the material, geometric shape, type of relative movement, and its orientation in space according to the logical scheme of Fig. 1. But it is necessary to consider how the structural and kinematic parameters of the cleaners and the properties of root crops affect the work process (strength, internal structure, size and mass characteristics of the tops and root crop, mutual arrangement of root crops, their location relative to the soil surface).

The analysis of the designs of working organs will be carried out according to the above classification. Considering the large number of combinations of working organs, we will analyze only known and most probable designs. Due to the fact that not all working bodies have been experimentally investigated, we will evaluate them by possible force factors in the contact of the working body-root crop and by the presence of forces that restore the initial position.

We will introduce the concepts of a supporting element and a working element. A supporting element is an element that is in a certain type of relative movement, is attached to the drive body and is located relative to it. The element attached to the supporting element and in contact with the tops and the root crop head will be called the working element. Of course, there are cleaners in which the supporting element is simultaneously the working one. For example, radially mounted blades, cables, chains, etc. Mainly, the type of load acting in contact, the restoring force is affected by the type of supporting element, its relative movement. Therefore, in the future, we will analyze cleaning working bodies by supporting elements.

We will determine the main types of working bodies and their possible variants. The schemes of working bodies will be given in Fig. 5. Cleaners with rotary relative movement of supporting elements and horizontal placement of the axis of rotation are the most common. Such cleaners have a simple design, reliable in operation. Rods, blades, chains, disks, segments, and others can be in rotary motion.

Segment working elements can be attached perpendicularly and at an angle to the axis of rotation. They can interact with the root crop head by the end (front part) of the segment or by the side surface. When interacting with the end, an impact force arises, which quite effectively cleans the remains of the tops, but this can damage and knock root crops out of the soil. Interacting with the lateral surface, with slight lateral deformations, the segment is pressed against the root crop head by centrifugal force and elastic force and slides over it at a fairly high relative speed, creating a tangential application of load. With larger deformations, when the segment begins to contact the end with highly protruding root crops, the impact force first acts, then the segment deforms and begins to slide with the side surface - a tangential force acts. A positive quality of this cleaning body is lateral deformation when interacting with a root crop. If we take into account the known design parameters of such cleaners [4] - rotor diameter 500 mm, rotational speed 10... 11 s-1. Then, with the deformation of the segments to the height of the protrusion of the main mass of root crops, 50...60 mm above ground level, the sliding speed will be at least 15 m/s. The deformed segment will be returned to its initial position by the centrifugal force of inertia and the elastic force of the segment. But, as a rule, such working bodies have quite low rigidity, and therefore the elastic component of the restoring force will be insignificant. This type of working bodies was used in a cleaner (Fig. 5a), which was designed at the Institute of Sugar Beets.

Data on the quality of work are given in work [4]. Analyzing the performance indicators of this cleaner, one should note a high degree of cleaning of root crops from the tops at elevated speeds. But the use of such organs, as we can see, leads to knocking root crops out of the soil and further losses of sugar-bearing mass. In addition, the paper does not provide such an indicator as damage to root crops, the probability of which is quite high when using such a working organ. Since the lateral surface of the segments is not equipped with cleaning elements, it can be assumed that additional cleaning occurs mainly due to the intensive interaction of the edges of the segments with the heads of root crops. At the same time, the ends of the segments significantly deform, their intensive wear and tearing off the edges passes. The use of such working bodies is expedient only in the row zone, because intensive interaction with plant residues in the row spacing zone can lead to unproductive energy consumption.

Since the supporting element ensures the application of a rational tangential load to the root crop head, it can be improved by installing working elements - spikes, protrusions, or other elements. The articulated fastening of segments will soften the interaction process with the root crop head. In this case, the same force effects occur in the contact as with rigid fastening, but smaller in value. Cleaner designs with such working bodies are unknown.

Installing the segments at an angle to the axis of rotation by turning around the radial axis (similar to the design of an axial fan) at small angles causes the same force effects as when placed perpendicularly to the axis of rotation. With an increase in the angle to the position of the segment plane, close to parallel to the axis of rotation, the action of such a cleaner becomes similar to the action of a cleaner with blade working bodies, which will be analyzed later.

Disk working elements are made of flexible materials, mainly rubber or rubber-cord products. Disks can be arranged perpendicularly or at an angle to the axis of rotation. If you place a flexible disk at an angle to the axis of rotation, then under the action of centrifugal forces, the edges of the disks will bend back, trying to set the disk surface perpendicular to the axis of rotation. At small angles, the process of its interaction with the head of the root crop will be similar to the interaction of a disk with a root crop head installed perpendicularly to the axis of rotation. At larger angles, it can lead to an increase in loads on the root crop head and knock them out of the soil. Cleaners with an inclined arrangement of the axis of rotation of the disks to the soil surface are unknown, so it is impossible to give a full objective assessment of their interaction with root crops.

The most common cleaner designs with flexible disks installed perpendicular to the axis of rotation. Various elements can be attached to the surface of the disks. Holes can be made in the disks. An analysis of the interaction of disk working organs with root crop heads was carried out in work [5].

When the disk interacts with the head, it deforms with the help of elastic and centrifugal inertial forces pressing the lateral surface to the head, creating tangential forces. The sliding speed, due to the lateral deformation of the disk, is quite high, which contributes to a high intensity of cleaning. The author believes that the working body in the form of a disk copies the surface of the root crop head quite well, which significantly improves the quality of cleaning. In addition, placing rigid elements on the disk, for example, chains, significantly intensifies the cleaning of root crop heads located at ground level.

Structural and technological parameters of the cleaner: diameter of disks 500 mm, thickness of disks 8...10 mm, distance between disks 80 mm, angle between shaft axis and rows 20°, shaft rotation frequency 350 rpm. The decrease in rotational frequency is explained by the need to reduce force factors when interacting with the root crop head. With a shaft rotation speed of 500...600 min-1, as in conventional cleaners, root crops are significantly damaged and knocked out of the soil. You can increase the rotor speed to 500...600 rpm if a ring is made of the disk and hinged. This will soften the interaction regime with the root crop head.

Indicators of the quality of cleaning with a flexible disk with radially fixed chain links in comparison with serial double-blade cleaners are given in work [5]. With an increase in travel speed over 2 m/s, the quality of top separation improves, but by the indicator of the number of root crops knocked out of the soil, it significantly exceeds the serial one. The disk cleaner, constantly interacting with the surface soil layer, destroys it. As a result, an unproductive increase in energy consumption for the post-cleaning process is possible. Therefore, such working bodies are installed only on a row.

Cleaners with radial attachment of cleaning elements are the most common in production. They are characterized by a simple design and reliable operation. Caprone, polyurethane, rubber, rubberized rods in cross-section in the form of circles, rectangles, rings with a variable longitudinal section, as well as chains and cables are used as working elements here. Curvilinear rods of various shapes can also be used as working elements. Only flexible rods and rods of curved shape of sufficient elasticity are rigidly attached at an angle to the axis of rotation, which would keep them in a certain position in the field of centrifugal forces.

Not only flexible and elastic working elements are pivotally attached, but also rigid working elements. Cleaners whose working organs are pivotally mounted and the axis of the hinge is placed parallel to the plane of rotation, when the working bodies deviate from the plane of rotation at the moment of contact with the head of the root crop, can have such positive qualities as high sliding speed over the head and a centrifugal component of the restoring force. Working bodies with parallel placement of the hinge to the axis of rotation are used on the rear shaft of the OHD-6 in the form of rubber beaters with spikes. The disadvantage of such a design is the deviation of the working element in the radial direction. Which leads to a decrease in its linear velocity and, accordingly, a decrease in sliding speed over the head. When interacting with high protruding root crops, mainly impact forces close in direction to the normal surface will be present. There are known developments with hinged fastening of curvilinear knives [6], but they can be used as additional head trimmers. Obviously, working bodies with articulated fastening of rigid working elements on a horizontal shaft are constructions with a rigid mode of operation, but it is necessary to study more thoroughly the process of their interaction with the head, conduct a theoretical analysis, and at the same time it is necessary to create a working body with a more optimal tangential load.

Mesh surfaces made in the form of blades, disks have not been used in production, and basically the process of their interaction with the root crop head is similar to blades, segments and disks respectively. It should be noted that mesh surfaces can interact quite intensively with root crop heads, and the execution of working surfaces in the form of meshes can lead to the creation of effective working bodies. The reason for the lack of such organs is certain requirements for the material from which they must be made - flexibility, strength, wear resistance. Drum cleaner designs (flexible meshes) have not received wide distribution [8]. With a rigid surface, copying the shape of the head deteriorates and their mounting on radial suspensions is necessary, which leads to a deterioration of inertial-dynamic properties. With a flexible surface, it is possible to knock root crops out of the soil.

Intensive interaction of chains tangentially allows obtaining certain results, but research presented in work [7] indicates that an unstable movement is characteristic for this design. The reason for this is the lack of connection of the elements of the lower part with the axis of rotation. With free rotation, each link is balanced by its opposite. Upon interaction with the root crop head, the surface deforms and the opposite part, under the action of centrifugal forces, begins to move away from the axis of rotation and pulls with it the part interacting with the root crop. Damage to root crops, as noted in work [7], is 4.3% at a rotor speed of 500 min-1, which significantly reduces the quality of the raw materials. Besides, the use of working bodies of this type in multi-row machines complicates their design.

The ring cleaner [8] is characterized by a 2-3 times lower energy intensity than the blade one, but the normal impact load applied to the root crop head is less effective than the tangential one. Working organs with translational and translational-oscillatory motion, made in the form of meshes, cables, rods, chains are the simplest in structural execution, but there are no known facts of their manufacture and use. Only oscillating-type cleaners are known, which were used on Volvo machines. V. Ya. Martynenko considered the scraping process with an elastic element [6-8]. But these working bodies have not been widely used.

In working organs with a complex movement (Fig. 5), force factors acting in contact with the head of the root crop do not differ significantly from force factors of known working bodies with simple movement. Such structural performances are quite complex, highly expensive and metal-consuming.

5. Conclusion

A structural and logical scheme for the synthesis of working organs for separating tops residues from root crop heads has been developed, which systematizes known cleaner designs and establishes functional relationships between their main structural features.

The key criteria of functional suitability of root crop head cleaners have been substantiated, including the formation of rational tangential force interaction in the contact zone and the presence of restoring forces ensuring stable operation of working elements.

The proposed synthesis approach enables the generation and preliminary evaluation of new types of working organs, allowing the rejection of inefficient design solutions at the design stage and creating prerequisites for improving the efficiency and quality of root crop harvesting.

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РОЗРОБЛЕННЯ АЛГОРИТМУ СИНТЕЗУ ПРИСТРОЇВ ДЛЯ ВІДОКРЕМЛЕННЯ РЕШТОК ГИЧКИ НА КОРЕНЕПЛОДАХ

Збирання цукрових буряків є складним технологічним процесом, де операція відокремлення залишків гички з головок коренеплодів залишається однією з найпро-блематичніших через мінливість агрофізичних властивостей рослин та умов збиран-ня. Хоча нині існує велика кількість різноманітних конструкцій очисників, створення нових пристроїв, які б підвищували продуктивність, знижували енерговитрати та мінімізували пошкодження і вибивання сировини з ґрунту, залишається нагальною потребою галузевого машинобудування.

Встановлення причинно-наслідкових зв'язків та розроблення структурно-логічної схеми синтезу нових очисників головок коренеплодів шляхом застосування методів структурно-функціонального аналізу технічних систем є актуальним.

У роботі застосовано методи морфологічного аналізу, теоретичної механіки та систематизації для критичного огляду існуючих конструктивно-технологічних схем робочих органів.

У статті проаналізовано відомі класифікації робочих органів для доочищення головок від гички. Встановлено, що вони часто спираються на розрізнені ознаки (лише на напрямок навантаження або вид руху), не утворюючи єдиної системи для оцінки. Для комплексного підходу виокремлено базові ознаки, що безпосередньо впливають на робочий процес: матеріал і геометрична форма елемента, тип його кріплення (жорстке чи шарнірне), вид відносного руху (обертальний, коливальний, складний) та орієнтація до осі рядка. Визначено головні критерії функціональної придатності очисника: забезпечення раціональних силових факторів у зоні контакту (перевага дотичного навантаження над ударним) та наявність відновлювальної сили для повернення елемента у вихідне положення. На основі цих параметрів розроблено алгоритм та логічну схему синтезу. Завдяки цій схемі проаналізовано існуючі (дис-кові, сегментні, бильні) та згенеровано нові потенційні типи робочих органів (сітчасті, кільцеві, з поступально-коливальним рухом). Проведено попередню оцінку їхньої силової взаємодії з коренеплодами.

Запропонований алгоритм синтезу дозволяє систематизувати всі відомі при-строї для відокремлення гички та цілеспрямовано створювати інноваційні технічні рішення. Оцінка за визначеними критеріями дає змогу ще на етапі проєктування відкидати нераціональні варіанти та розробляти конструкції з оптимальними режи-мами роботи без пошкодження коренеплодів.

Ключові слова: *очисник головок коренеплодів, залишки гички, робочий орган, функціональна при-датність, відновлювальна сила, несучий елемент, робочий елемент.*

Рис. 1. Літ. 9.

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