THEORETICAL STUDY OF FLEXIBLE BLADE MOVEMENT IN CLEANING CARROT ROOT CROP HEADS WITHOUT EXTRACTING THEM FROM SOIL

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Abstract. One of the technologies for harvesting carrots is to separate the tops without extracting the carrots from the soil with their subsequent digging up from the soil. Since the cutting of tops is carried out, as a rule, by a continuous rotary top-cutting apparatus, there is a need to further clean the root crop heads from the top residues. A new design has been developed for a two-shaft cleaner without extracting the carrots from the soil, which cleans each head from both sides with flexible cleaning blades, mounted on horizontal drive shafts. For a theoretical research of this process there was constructed a mathematical model of the interaction of the flexible cleaning blade with the head of the carrot. For this purpose, an equivalent diagram was drawn up for the interaction of the flexible cleaning blade with the carrot root crop, which is located in the soil (conventionally, it is actually firmly fixed in it). In addition, in this equivalent diagram the remains of the tops are shown on the head of the carrot root. Besides that, the interaction of the flexible cleaning blade with the head of the carrot root crop is implemented in two phases: first, the phase of impact of the blade upon the head of the root crop, and then its post-impact movement. These phases of impact upon the head provide conditions according to which, during the interaction, first, knocking down, and then combing off the remains of the tops occurs. The equivalent diagram shows the velocities of points during the impact interaction, the actual velocities and the applied forces. Based on the use of the theorem about the change in the momentum of a material point upon impact, the impact impulse is determined, and an analytical expression is obtained to determine the final speed of the impact point. Calculations have been made for the speed of the contact point after the impact, and graphical dependencies, affecting it has been found. The results of the theoretical studies showed that at a low velocity of the machine and tractor unit V_n the influence of the angular velocity ω of the blade has a significant influence on the value of the after impact velocity U of the blade. So, at a speed V_n = 0.5 m·s^{-1}, the after impact speed U increases only by 40…350%. But at V_n = 3.0 m·s^{-1}, the after impact velocity U increases only by 1.3…30.2% when the angular velocity ω of the blade changes in the range from 10 to 50 rad·s^{-1}. The next stage of the research was the study of the post-impact movement of the flexible cleaning blade along the very head of the carrot, which made it possible to determine the conditions for efficient combing off the remains of the tops on it.

Keywords: carrots, harvesting, remains, cleaning blade, shock impulse, mathematical simulation.

Introduction

Carrots are an important cultivated plant, widely used in the food industry and dietetics. The process of its harvesting and purification plays a key role in treating the products for further processing and consumption. Contemporary carrot harvesting technologies require efficient methods for cleaning root crops from the tops and other plant remains. However, to ensure high quality cleaning, it is necessary to take into account not only the efficiency of the process but also minimization of damage to the root crops, as well as optimization of the energy costs.

In this regard, there is a need to develop new technologies and equipment for cleaning carrots that would combine high productivity, cleaning quality and efficiency. Optimization of the process of gathering and cleaning carrots is becoming an urgent task for agricultural production [1; 2]. With high-quality cleaning of carrot heads without damaging root crops and top residues, the quality of the harvest increases, especially during long-term storage.

Contemporary technologies of cleaning the carrot tops suppose initially complete non-cutting of the main green mass, followed by individual post-harvest cleaning of the root crop heads from the foliage residues [3-6] that can subsequently be efficiently used to increase the soil fertility [7]. The operation of additional cleaning of the root crop heads from the top residues (leaves) without separating the heads from the soil must meet high quality requirements for removing the green and dry residues from the surfaces of the heads, excluding damage, caused by additional means of cleaning. We have developed a new design of a two-shaft mounted device for cleaning the carrot heads from the top residues (leaves) with a horizontal cleaning shaft. However, the quality of its work considerably depends on the selected operating parameters and movement forward. In this respect, there is a need to theoretically study the operation of a device for cleaning the root crop heads, attached to a row-crop tractor, and to determine the degree of impact of the design and kinematic parameters upon the behaviour of the cleaning blade. The method for constructing computational mathematical models of agricultural machines is described in detail in [8, 9]. However, there is still a need to improve the theoretical research methods, to develop appropriate numerical calculation programs and extensive simulation capabilities in order to find optimal design and kinematic parameters. The development of an advanced carrot harvesting technology is associated with the development and widespread use of combined machines [10-13]. Thus, the use of row-crop tractors as energy means makes it possible to widely use combined aggregates for harvesting carrots, based on machines for collecting the tops, which carry out complete cutting of the main mass of the carrot tops and cleaning the root crop heads, still fixed in the soil [14-16]. Such an aggregate not only efficiently performs the technological process of collecting the tops but it is also significantly less energy-intensive (unlike the traditional methods of gathering tops) [17-20].

The purpose of this work is a theoretical study of the movement of the blade for cleaning the heads of carrots without their extraction from the soil, using a two-shaft cleaner with a horizontal axis of rotation performing two-way counter rotation of the blades.

During the study methods were used to construct computational and mathematical models of agricultural machines, based on the compilation and solution of systems of equations [21].

Materials and methods

This paper deals with the theory of interaction of the head of the carrot without its extraction from the soil with the cleaning blade mounted on the drive shaft with a horizontal axis of rotation. Since this is a two-shaft cleaner, the head of the carrot is cleaned from both sides by counter-rotation of the blades, pivotally fixed on these shafts. A general view of the two-shaft cleaner for the carrot heads from the remaining tops on the root is shown in Fig. 1.

Fig. 1. **Two-shaft cleaner of carrot heads from the remaining tops without extracting the heads from the soil**

The experimental model of the machine for cleaning carrot root heads has two parallel drive shafts with an adjustable mechanical axial distance (0.18...0.35 cm), on which rubber cleaning blades are hinged. It is possible to regulate the length of the blade (7...15 cm) and change the point of its attachment relative to the axis of the drive shaft (3...8 cm). The drive shafts rotate at the same speed, which can vary steplessly in the range of 5...58 rad·s^{-1}. This article studies the movement of a flexible cleaning blade along the head of a carrot root crop; therefore, the design parameters of the machine are not considered in more detail.

A significant influence on the efficiency of a machine-tractor unit for harvesting carrots is played by the assessment of crop parameters, including the length of the tops, the length of the root crop, the diameter of the root crop in the upper part, the number of roots per meter of row length and the mass of the root. These yield parameters must be studied during the experimental part of the research.

In order to study theoretically this process, we will construct a computational mathematical model of interaction of a flexible cleaning blade with the head of the carrot [22]. To do this, we first draw up an equivalent diagram of the interaction of the flexible cleaning blade, in which we consider a carrot root, located in the soil (we conventionally assume that it is actually firmly fixed), and in this diagram, on the top of the carrot head, the tops remains are shown after their continuous mowing (Fig. 2).

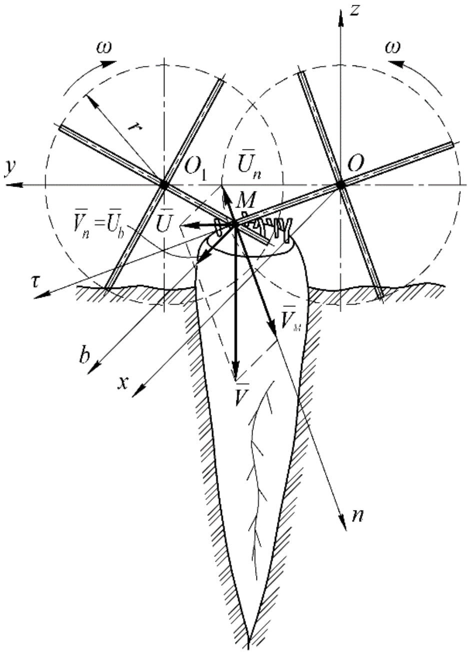

Fig. 2. **Equivalent diagram of interaction of the flexible cleaning blade with the carrot head**

The equivalent diagram shows the velocities of the point contact *M* of the blade with the head of the carrot before the impact and after the blade hits the head of the carrot. Since the interaction of the cleaning blades on both sides of the carrot with its head is the same, the diagram shows such interaction only for one of the blades.

It should immediately be noted that the interaction of the flexible cleaning blade with the head of the carrot occurs in two phases: first, the phase of the blade hitting the root head, and then its post-impact movement. These phases of impact upon the head provide conditions under which, during the interaction, first knocking down and then combing off the remains of the tops occurs. We also believe that the blades on the shafts, which have axes of rotation O_1 and O_2, are pivotally fixed, and the planes of their rotation are perpendicular to the axes of the shafts on which they are installed. In this case, the drive shafts rotate with the angular velocity ω towards each other, as shown in the equivalent diagram (Fig. 2). In addition, during the forward movement of the cleaner the drive shafts are located along the rows of carrots because the plane of rotation of the blades is perpendicular to the rows of carrots, that is, perpendicular to the direction of movement of the cleaner.

Results and discussion

So, let us consider the process of interaction with the head of the carrot of only one of the cleaner blades, assuming that all the other blades interact in a similar way. Let the blade suspension pivot be located at a distance r from the axis of rotation, *l* – the distance from the suspension axis to point *M* of contact of the blade with the head of the carrot.

Let us primarily consider the first phase of interaction - the impact of the blade upon the head of the carrot. Considering that the circular speed $\overline{V}_M$ of the blade point *M* during the impact contact will be quite large, in addition, the speed $\overline{V}_n$ of the forward movement of the aggregate is also added, then the indicated impact will necessarily take place. The equivalent diagram shows the velocities during the impact contact of the blade with the head of the carrot at point *M* of contact, the determination of which is necessary to study the post-impact movement of the blade in the process of combing the tops from the head of the carrot.

Let us select and show on an equivalent diagram a stationary Cartesian coordinate system *xOyz*, the centre of which is on the axis of rotation of the blade (point *O*), the *Ox* axis is directed along the row of carrots in the direction of the translational movement of the cleaner, the *Oy* axis is directed to the right along the direction of the cleaner, the *Oz* axis is vertical up.

Obviously, when the blade meets the head of a carrot, the blade hits some part of the head; yet for simplicity, we will assume that the impact occurs at point *K* that belongs to the head and at point *M* that belongs to the blade. At the moment of impact, these points coincide. Besides, the shock impulse $\bar{S}$ will be directed along normal n to the impact surface of the blade at point *M*.

The absolute velocity $\bar{V}$ of point *M* on the blade before the impact will be equal to:

$$\bar{V} = \bar{V}_n + \bar{V}_M \ , \tag{1}$$

where $\bar{V}_n$ – velocity of the forward movement of the cleaner along a row of carrots (along *Ox* axis) is the transfer speed of the blade;

$\bar{V}_M$ – circular velocity of point *M* on the blade when rotating around the *Ox* axis is the relative speed of point *M*.

The circular velocity $\bar{V}_M$ of point *M* will be equal to:

$$V_M = \omega \cdot \rho = \omega(r + l). \tag{2}$$

The vector $\bar{V}_M$ will be directed along the tangent to the circle of the radius $\rho = r + l$. All the three vectors $\bar{V}_n$, $\bar{V}_M$ and $\bar{V}$ are shown in Fig. 2.

We will construct separately an additional equivalent circuit, which will show all the forces that act upon the head of the carrot during the impact at the point *K* (Fig. 3).

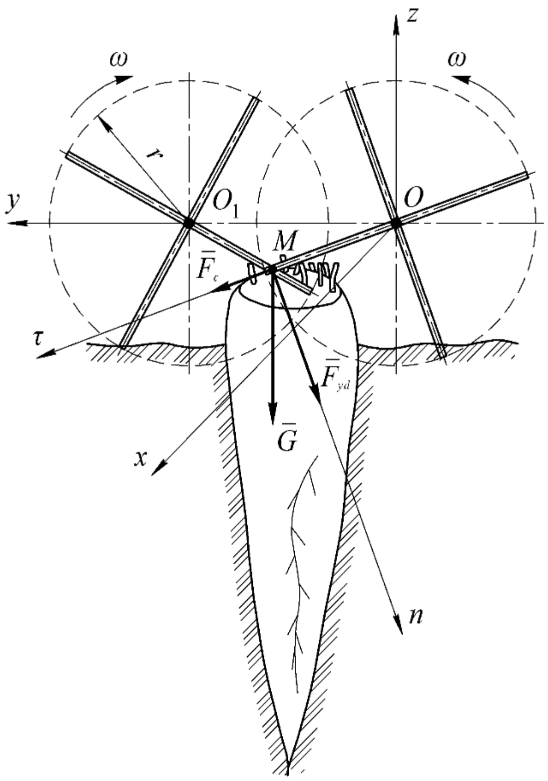

Fig. 3. **Equivalent diagram of forces that act at the point of impact contact upon the carrot head**

The indicated equivalent diagram (Fig. 3) shows the following acting forces: $\bar{F}_{yd}$ – the impact force that occurs during the impact and is directed along normal *n* to the surface of the blade; $\bar{G}$ – the blade weight; $\bar{F}_c$ – the centrifugal force of inertia, which does not act upon the root crop but stretches the body of the blade, making it rigid during rotation. It is directed along the blade, that is, along the radius of rotation (along axis M_τ, as shown in Fig. 3).

Next, we will determine the absolute velocity $\bar{U}$ of point *M* on the blade after the impact, the angle γ of deviation of the vector from the normal, as well as the shock impulse.

Let us apply a theorem on the change in the momentum of a point with mass *m* upon the impact [22]:

$$m\left(\bar{U}-\bar{V}\right)=\bar{S}, \quad (3)$$

where $\bar{S}$ – shock impulse;
$\bar{U}$ – velocity of point *M* of the blade after the impact;
$\bar{V}$ – velocity of point *M* of the blade before the impact.

According to the definition, the shock impulse is determined using the expression:

$$\bar{S}=\int_0^\tau F_{yd}\,dt, \quad (4)$$

where $\bar{F}_{yd}$ – impact force;
τ – impact duration.

Since the duration τ of the impact is a very short period of time, the impulses of all other forces that act upon the head of the carrot at the moment of impact are practically equal to zero.

So, the impact of other forces that act upon the head of the carrot, except for the impact force, can be ignored.

As it is evident from expression (4), when $\tau \to 0$ and $\bar{F}_{yd} \to \infty$.

To describe the process of the blade hitting the head of a carrot, we choose a natural coordinate system τKnb, the axis τ is directed along the axis of the blade, *n* – perpendicular to the axis of the blade, *b* – (binormal), located perpendicular to the plane τKn.

These axes are shown in Fig. 2 and Fig. 3.

Considering that the shock pulse $\bar{S}$ is directed along the normal, expression (3) may be represented as:

$$m\bar{U}-m\bar{V}=S\cdot\bar{n}, \quad (5)$$

where *S* – module of the shock impulse vector $\bar{S}$;
$\bar{n}$ – unit vector located along the normal *n*.

Let us write the vector equation (5) in projections on the axes, n_τ and *b* of the natural coordinate system τKnb.

We will have:

$$\left.\begin{aligned} mU_b-mV_b&=0,\\ mU_n-mV_n&=S,\end{aligned}\right\} \text{ or } \left.\begin{aligned} U_b-V_b&=0,\\ U_n-V_n&=\frac{1}{m}S.\end{aligned}\right\}. \quad (6)$$

The projections of all velocity vectors onto the axis M_τ are equal to zero since they all lie in a plane, perpendicular to the axis M_τ.

As we can see from Fig. 2, the projections of velocities on the axes *b* and *n* will be equal to:

$$V_b=V_n, V_n=V_M, \; U_b=U\cdot\sin\gamma, U_n=U\cdot\cos\gamma, \quad (7)$$

where γ – angle between the velocity vector $\bar{U}$ after the impact and the normal *n*.

From the first equation of system (6) we obtain:

$$U_b=V_b=V_n,$$

Then from (7) we will have:

$$U = \frac{U_b}{\sin\gamma} = \frac{V_n}{\sin\gamma} . \tag{8}$$

We determine the coefficient ε of recovery after the impact [22]:

$$\varepsilon = \frac{U_n}{|V_n|} = \frac{U \cdot \cos\gamma}{V_M} . \tag{9}$$

We substitute values (8) into (9) instead of $\bar{U}$, then we will have:

$$\varepsilon = \frac{V_n}{\sin\gamma} \cdot \frac{\cos\gamma}{V_M} = \frac{V_n}{V_M} \cdot ctg\gamma . \tag{10}$$

From expression (10) we find:

$$ctg\gamma = \frac{V_M \cdot \varepsilon}{V_n} . \tag{11}$$

Then:

$$\gamma = arcctg\left(\frac{V_M \cdot \varepsilon}{V_n}\right). \tag{12}$$

So, the resulting expression (12) gives the numerical value of the angle γ, that is, the deviation of the velocity vector $\bar{U}$ after the impact from the normal n to the surface of the blade.

In order to find the velocity modulus U after the impact, we use the trigonometric identity:

$$\sin\gamma = \frac{1}{\sqrt{1 + ctg^2\gamma}} . \tag{13}$$

Substituting expression (13) into expression (8), we will obtain:

$$U = V_n\sqrt{1 + ctg^2\gamma} . \tag{14}$$

Taking into account expression (11), we will have:

$$U = V_n\sqrt{1 + \frac{V_M^2 \cdot \varepsilon^2}{V_n^2}} , \tag{15}$$

or finally:

$$U = \sqrt{V_n^2 + V_M^2 \cdot \varepsilon^2} . \tag{16}$$

Since $V_m = \omega \cdot \rho$, then expression (16) will take the form:

$$U = \sqrt{V_n^2 + \omega^2 \cdot \rho^2 \cdot \varepsilon^2} . \tag{17}$$

So, expressions (12) and (17) determine the direction and modulus of the velocity of point M on the blade after the impact.

Let us further define the shock impulse S. Using the definition of the impact recovery coefficient ε, we can write:

$$U_n = \varepsilon \cdot |V_n| , \tag{18}$$

or

$$U_n = -\varepsilon \cdot V_n . \tag{19}$$

Substituting expression (19) into the second equation of system (6) instead of U_n we obtain:

$$S = m(-\varepsilon \cdot V_n - V_n) = -m \cdot (1 + \varepsilon) \cdot V_n , \tag{20}$$

or, considering expression (7)

$$S = -m(1+\varepsilon)\cdot V_M = -m\cdot(1+\varepsilon)\omega\cdot\rho\,. \tag{21}$$

Because:

$$S = -m\cdot(1+\varepsilon)\cdot\omega\cdot\rho\,. \tag{22}$$

And, after all, it should be noted that the impact process significantly depends on the impact recovery coefficient ε. Since under the action of the shock pulse the remains of the tops on the head of the carrot will be crushed, the impact will be more like a plastic one than elastic. Therefore, the coefficient ε will be rather low (approximately within the range of 0.1...0.3). And therefore, the velocity $\bar{U}$ of point M on the blade after the impact will also be quite small, because:

$$U_n = \varepsilon\cdot V_n = (0.1...0.3)\,\omega\cdot\rho\,, \tag{23}$$

and, therefore, according to expression (17):

$$U = \sqrt{V_n^2 + (0.01...0.09)\cdot\omega^2\cdot\rho^2} \approx V_n\,. \tag{24}$$

At the same time, the velocity U_n will be rather low, so the blade after the impact will practically not bounce off from the head of the carrot, and, therefore, the initial conditions for the state of the process of further combing the tops will be quite favourable since the initial velocity of point M of contact of the blade after the impact will be approximately equal to $\bar{V}_n$, that is, to the velocity of the forward movement of the cleaner.

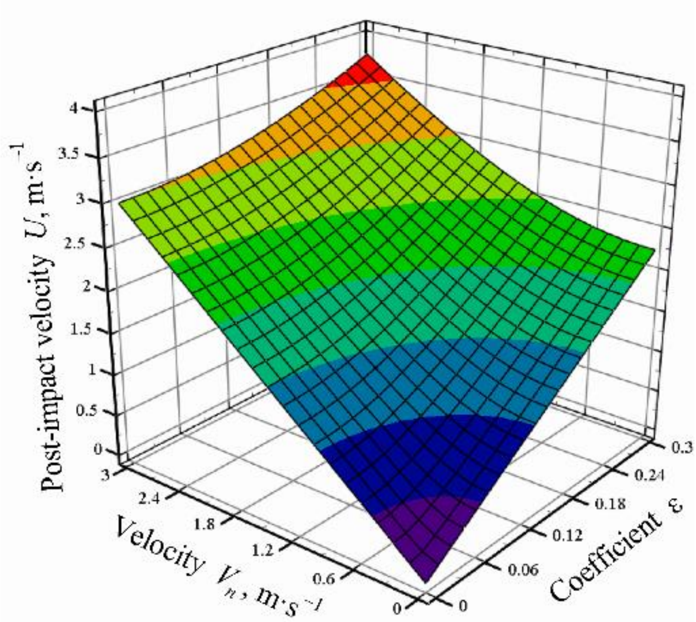

Fig. 4. **Response surface of the velocity U of the blade after the impact depending on the forward velocity V_n of the cleaner and the recovery coefficient ε**

Analysis of the obtained dependence shows that at a low velocity of movement of the aggregate V_n, the influence of the coefficient of recovery ε has a more significant impact upon the value after the impact velocity U of the blade. So, at a velocity $V_n = 0.5$ m·s^{-1} the impact velocity increases by 60...360% in the range of changes in the recovery coefficient $\varepsilon = 0.1...0.3$. But at a velocity of the movement of the cleaner $V_n = 3.0$ m·s^{-1} the impact velocity U increases only by 5...25% when the recovery coefficient ε changes.

As a result of the analysis of the obtained dependence we see that at a low velocity of movement of the aggregate V_n the influence of the angular velocity ω of the blade has a significant influence on the value of the post-impact velocity U of the blade. Thus, at a velocity $V_n = 0.5$ m·s^{-1}, the post-shock velocity U is equal to 0.71 m·s^{-1} at $\omega = 10$ rad·s^{-1} and 2.55 m·s^{-1} at $\omega = 50$ rad·s^{-1}. But at a velocity of movement of the cleaner V_n = 3.0 m·s^{-1}, the post-impact velocity U increases only by 1.3…30.2% when the angular velocity ω of the blade changes in the range from 10 to 50 rad·s^{-1}.

In addition to this, after flattening the strength of the remaining tops decreases due to the impact interaction, which also facilitates the combing process by reducing the energy costs of this process. So, the phase of the impact contact of the blade with the head of the carrot is quite important and has a positive effect on the process of combing off the remains of the tops.

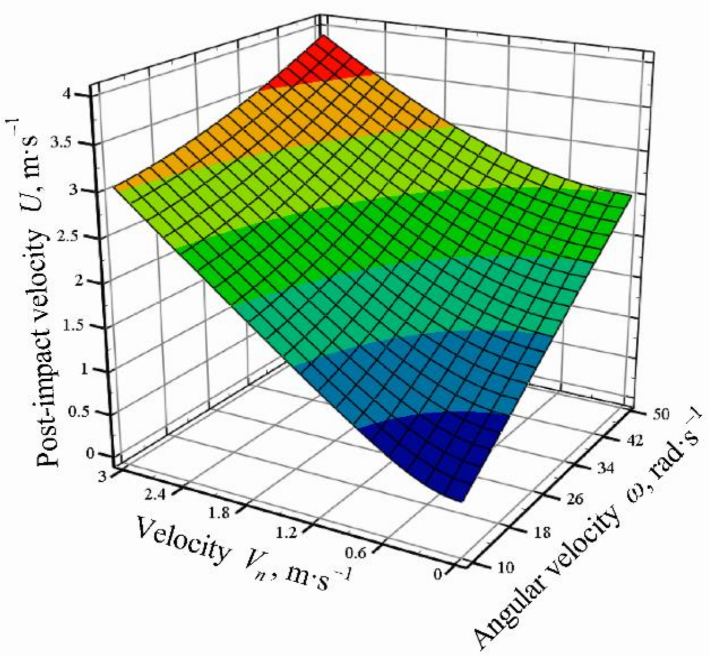

Fig. 5. **Response surface of the velocity *U* of the blade after the impact depending on the forward velocity of the cleaner and the angular velocity *ω***

The results of studies by other authors [13-15; 23] can help when conducting the experimental part of field research. The article [23] carried out a detailed analysis of the root crops of the Madhuvan carrot variety and, as a result of physical measurements, proposed machine settings for digging up carrots. The process of removing tops was not considered.

Also, many studies [13; 15] pay a lot of attention to the search for the dependence of fragility and injury to carrots during digging depending on the temperature, moisture content and growth intensity. These studies can help choose optimal conditions for harvesting carrots. There are also works [14] in which the quality of work of existing carrot harvesting machines is assessed.

Thus, the issues of studying the process of movement of the cleaning blade, the influence of its rigidity and geometric parameters on the quality of cleaning the heads of carrot root crops have not been sufficiently considered. After the impact phase the phase of post-impact movement of the blade along the head of the carrot begins during which the process of combing the tops from the head of the carrot takes place. Therefore, the conducted investigations should be the basis for the development of a theoretical apparatus that describes the process of combing the tops.

Conclusions

1. The work is devoted to the developed theory of interaction between the cleaning blade, which is installed on a drive shaft with a horizontal axis of rotation, and the head of a carrot without extracting from the soil.
2. As a result of calculations, it was established that at a low velocity of the aggregate V_n the influence of the angular velocity ω of the blade has a significant influence upon the value of the after impact velocity U of the blade. So, at a speed V_n = 0.5 m·s^{-1}, the after impact speed U is equal to 0.71 m·s^{-1} at ω = 10 rad·s^{-1} and 2.55 m·s^{-1} at ω = 50 rad·s^{-1}. But at a velocity of movement of the cleaner equal to V_n = 3.0 m·s^{-1}, the after impact velocity U increases only by 1.3…30.2% when the angular velocity ω of the blade changes in the range from 10 to 50 rad·s^{-1}.

3. The conducted investigations may be used in the future to develop a theoretical apparatus that describes the process of the post-impact movement of the blade along the head of the carrot and combing the tops.

Author contributions

Conceptualization, V.B.; methodology, V.B., M.B. and I.H.; software, I.S., P.R.; validation, V.B., A.A. and M.B.; formal analysis, V.B. and I.H.; investigation, V.B., I.S., J.O., Y.I.; data curation, A.A., V.B. an I.H.; writing original draft preparation, V.B.; writing review and editing, A.A., A.R. and V.B.; visualization, P.R., M.B., Y.I.; project administration, V.B.; funding acquisition, A.A. and A.R. All authors have read and agreed to the published version of the manuscript.

References

[1] Smith L. The effect of defoliator flail configuration, speed and crown removal on sugar beet yield, quality and profitability. Sugar beet Research and Extension Reports, vol. 22, 1991, pp. 222-227.
[2] Lilleboe D. Optimizing defoliator & harvester performance. The sugar beet grower, vol. 53(6), 2014, pp. 6-13.
[3] Lammers S., Olaf P., Olaf R. Defoliation of sugar beets – assessment of quality and gain in delivered beet mass. Landtechnik, No.3, 2010, pp. 464-467.
[4] Линник А. В. Определение динамических параметров жесткого очистителя при взаимодействии с корнеплодом (Determination of dynamic parameters of a rigid cleaner interacting with a root crop). Вестник Тернопольского национального технического университета. No.73 (1), 2014, pp. 165-171. (In Ukrainian).
[5] Bulgakov V., Adamchuk V., Ivanovs S., Ihnatiev Y. Theoretical investigation of aggregation of top removal machine frontally mounted on wheeled tractor. Engineering for Rural Development, 16, 2017, pp. 273-280
[6] Burdina I., Priss O. Effect of the Substrate Composition on Yield and Quality of Basil (Ocimum basilicum L.). Journal of Horticultural Research, 24(2), 2016, pp. 109-118.
[7] Yermakov, S., Hutsol, T., Glowacki, S., Hulevskyi, V. & Pylypenko, V. Primary assessment of the degree of torrefaction of biomass agricultural crops. Vide. Tehnologija. Resursi – Environment, Technology, Resources, 1, 2021, pp. 264-267.
[8] Bulgakov V., Adamchuk V., Nozdrovický L., Ihnatiev Y. Theory of Vibrations of Sugar Beet Leaf Harvester Front-Mounted on Universal Tractor. Acta Technologica Agriculturae, 20(4), 2017, pp. 96-103.
[9] Ivančan S., Sito S., Fabijanić G. Factors of the quality of performance of sugar beet combine harvesters. Bodenkultur, No 53(3), 2002, pp.161-166.
[10] Bulgakov V., Nikolaenko S., Holovach I., Boris A., Kiurchev S., Ihnatiev Y., Olt J. Theory of motion of grain mixture particle in the process of aspiration separation. Agronomy Research, 18(Special Issue 2), 2020, pp. 1177-1188
[11] Mady M.A. Mechanization of some operations for sugar beet production. Misr Journal of Agricultural Engineering. 18(2): 2001, pp. 339 – 355.
[12] Kowalczuk J., Leszczyński N., Bieganowski F. Evaluation of the quality of carrot root harvested with Alina and Simon one-row harvesters. Actaagrophysica, 2(1), 2003, pp. 105-111.
[13] Gracie A. J. and Brown P. H. Partial defoliation treatments to reduce carrot (Daucus carota L.) taproot splitting. Australian Journal of Agricultural Research, 55(8), 2004, pp. 887-894. DOI: 10.1071/AR02160
[14] Leszczynski N. The influence of working parameters of a carrot harvester on carrot root damage. Eksploatacja i Niezawodnosc – Maintenance and Reliability, 49(1), 2011, pp. 35-41
[15] Gracie A. J. and Brown P. H. Effects of climatic factors, fluctuating water availability and partial defoliation on the diurnal radial growth pattern of carrot (Daucus carota) taproots. Australian Journal of Experimental Agriculture, 44(12), 2005, pp. 1231-1240. DOI: 10.1071/EA03040
[16] Ibrahim U., Auwalu B.M., Udom G. N. Effect of stage and intensity of defoliation on the performance of vegetable cowpea (Vigna unguiculata (L.) Walp). African Journal of Agricultural Research Vol. 5(18), 2010, pp. 2446-2451.

[17] Khan N.A., Khan M., Ansari H.R., Samiullah. Auxin and defoliation effects on photosynthesis and ethylene evolution in mustard. Scientia Horticulturae, 96, 2002, Issues 1-4, pp. 43-51.
[18] Tae In Ahn, Jung-Seok Yang, Soo Hyun Park, Ju Young Lee. Inter-lighting and defoliation in a soilless culture system require more dynamic water management for improving the yield-promotion effect. Scientia Horticulturae, 293, 5, 2022, 110671.
[19] Islam A.F.M.S., Haque Md.M., Tabassum R., Islam Md.M. Effect of defoliation on growth and yield response in two tomato (Solanum lycopersicum Mill.) varieties. J. Agron., 15, 2016, pp. 68-75. DOI: 10.3923/ja.2016.68.75.
[20] Ivanovs S., Bulgakov V., Nadykto V., Ihnatiev Ye., Smolinskyi S., Kiernicki Z. Experimental study of the movement controllability of a machine-and-tractor aggregate of the modular type. INMATEH – Agricultural Engineering, 61(2), 2020, pp. 9-16. DOI: 10.35633/inmateh-61-01
[21] Vilde A., Rucins A. Development of agricultural mechanics. Proceedings of 11th International Scientific Conference "Engineering for Rural Development", Volume 11, Jelgava, 2012, pp. 67-73
[22] Dreizler R.M., Ludde C.S. Theoretical Mechanics. Springer, 2010, 402 p.
[23] Gaadhe S.K., Chavda S.K., Bandhiya R.D., Gojiya D.K. and Chavda D.B. Optimizing Carrot Harvesting Machine Design: Incorporating Soil and Crop Parameters. International Journal of Environment and Climate Change, 2023, 13(10), pp. 3680-3689.