Development and theoretical study of the impact of the working body on the soil

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Abstract. The article presents the theoretical results of the performance indicators of the defoliator. They depend on the parameters and modes of the defoliator operation. It operates on the basis of the description of the justification, which is provided in the work. The combined defoliator is aimed at removing potato tops with working bodies. They are multiple in number and they combine the consistency of their rotation including their vertical axis. Moreover, with the horizontal axis they are in the zone of their interaction without touching each other.

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1 Introduction

Experience in extensive mechanized harvesting, accumulated in previous years, revealed the effectiveness of preharvest removal of potato haulm. It has the following advantages. It prevents clogging the working bodies of potato harvesters when harvesting potatoes with strongly twisted haulm, weeds. This reduces downtime of machinery and facilitates their work. Besides, preliminary removal of haulm increases the physiological maturity of tubers, their resistance to mechanical damages during harvesting, transportation, post-harvesting. It also preserves them in storages. Therefore, the effectiveness of preharvest haulm removal is proven and we should go in this direction [1–3].

In the world practice, mainly crushing and shearing types of working bodies are used. Rotary working bodies are mainly used as a working body. They are simple, reliable in operation, have high productivity. Let us consider machines in more detail with respect to the location of the axis of rotation of the working body [4–6].

Rotary crushers with the horizontal axis of rotation are a rotor (drum) with pivotally mounted elements: knives, bits, cables or chains. The length of the elements corresponds to the transverse profile of ridges or beds, which makes it possible to capture dead haulm in between the rows. The disadvantages are the high cost, energy intensity and metal consumption of the device design, which requires a special and high accuracy of balancing the rotor. Manufacturers present machines for removing or crushing potato haulm. They are domestic factories OAO Ryazelsmach, BD-2M, BD-4, UMKV-1.4, LLC Agrotehmash UMKV-1.4, Kolnag-Rafale 2x75, Rafale 4x90, Belarusian POOO Techmash MBU-2.8, MBU-3.6, CJSC AgropromSelMash BTU-1.4 and foreign machines Rumstap RSK (the Netherlands) 2000. There are also GrimmeKS 3000 (Germany); Miedema LKFA (the Netherlands); UN 3604 Kverneland (UK); Botwetcher LKB320 Baselier (Slovakia) and OBN17 MachinesPioro (Poland) [7–9].

Vertical axes of rotation scrapers include working bodies with knives, chains or other scraping elements fixed radially on the periphery and rotating in a horizontal plane. The advantage of these haulm pickers is simplicity of design, the disadvantage is relatively low percentage of haulm removal (50...60%), especially when breaking fallen haulm in inter-row areas. These are represented by the Polish 4-row RLZ-4 and its analogues, the Russian and Belarusian D-POL 2-row devices [10–12].

In order to eliminate the above-mentioned drawbacks, a combined bot-vibrator is proposed. It combines the consistency of rotation of working bodies and their number of both the vertical axis and the horizontal axis in the area of their work.

The purpose of the research is increasing the completeness of haulm removal by justification of parameters and modes of the operation of the combined haulm trimmer.

Based on the above information, and taking into account the existing real need to find the most optimal parameters of the working bodies, the main task of this work is to ensure an increase in the efficiency of the process associated with planting potatoes. For this, it is necessary to improve the existing technologies and design of the working bodies of the device for planting potatoes. In addition, the proposed design changes and operating modes are substantiated.

2 Materials and methods

Having analyzed the work of topers in the field and works on rotary tools and machines by researchers V. P. Goryachkin, E. M. Gutyar, A. Yu Ishlinsky, V. A. Zheglovsky, I. F. Vasilenko, V. J. Kallus, E. S. Bosogo, N. E. Reznik, Matyashin Yu. I. and others, we found that the substantiation of the parameters of working tools proceeds from the consideration of the following conditions [13, 14].

The trajectory of any circular motion of the knives is expressed by parametric equations, which gives us a graphical analysis to represent them as elongated cycloids with a kinematic index λ>1:

\[
\begin{align*}
    x &= V_0 \cdot t + r \cdot \sin(\omega t), \\
    y &= r \cdot \cos(\omega t), \\
    z &= r \cdot \cos(\omega t),
\end{align*}
\]

where \( V_0 \) is the forward speed of the machine, m/s; \( t \) is time, s; \( r \) is the blade radius, m; \( \omega \) is the angular velocity of the rotor, \( s^{-1} \).

Working tools or elements destroy the haulm with a non-supported cut (14...34 m/s, depending on the plant diameter), which can be provided by the critical cutting speed with the kinematic mode parameter λ>1 [1, 3–4]:

\[
\lambda_i = \frac{V_{ni}}{V_M} = \frac{\omega \cdot r_i}{V_M}
\]

where \( V_{ni} \) is the linear (circumferential) speed of knives, blades with radius \( r_i...R_i \), m/s.

The main indicators evaluating the quality of the haulm chopper are the completeness of haulm removal, which is characterized by the minimum height of the remaining haulm petioles \( h_c \) and the minimum average cutting length \( l_c \).

Theoretically, the residual height of the haulm is the sum of the installation height of the tool \( l \) in relation to the average soil surface and the scallop height. (This is the difference between the height of the stem cut and the height of the blade in the lower position). It can be found from the absolute trajectory of the blade using the previous expressions (1-3) and after transformation we can write the following dependence:

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\[ h_{eq} = h + r - \sqrt{r^2 - \frac{V_m^2 \times \pi \times r^2}{m^2\left(V_m + V_n\right)^2}} \]

Theoretically, the length of the cut is characterized by its average value of \( l_{eq} \). It can be determined through the coordinates of the beginning of the stem of the first knife and the next knife, taking into account the rotor rotation and translational speed using the previous expressions (1–3). And after such transformations, the following dependencies are obtained:

\[
V_m = \frac{\frac{V_m}{m} \left( \arccos \frac{l_{cp}}{r} + \frac{2\pi}{m} - \frac{\pi}{2} \right)}{1 - \sin(\arccos \frac{l_{cp}}{r})}.
\]

where \( m \) is the number of knives rotating at a given radius, pcs.

The equation expressed through the translational velocity of the machine has the following view:

\[
V_m = \frac{V_m \left( 1 - \sin(\arccos \frac{l_{cp}}{r}) \right)}{\arccos \frac{l_{cp}}{r} + \frac{2\pi}{m} - \frac{\pi}{2}}.
\]

where

\[
B = \sin \alpha \cdot \sin \beta \cdot \sin(\omega t - \gamma) + \cos \alpha \cdot \cos(\omega t - \gamma),
\]

Expressions (5-7) allow you to comply with the operating mode of the working body of the haulm chopper depending on the residual height of the haulm, the height of the average length of the cut stems on agricultural requirements. That is, it is allowed to determine the maximum speed of the machine or the required circumferential speed of knives and their number.

Based on the above, we presented a scheme of the 2 row new combined botworms with the working organs of rotation in both the horizontal and vertical planes (Figure 1) [15].

The proposed topper has a frame 1 resting on two pneumatic support wheels 2. In the front part of the machine there is a connecting device (suspension) 3 (Figure 3) to the tractor. Behind it on the frame 1 there are three bevel gears 4, 5, 6, connected with each other by chain couplings 7. On the shafts of bevel gearboxes there are working tools with horizontal 8 and vertical 9 axes of rotation [16–18].

Fig. 1. Front view of the combined rotary crusher.

Working elements 8 on the horizontal axis of rotation in Figures 1, 2, 3 in the design version include a hub 10 (Figure 2) with a disc fixed to it 11, having knives 12 with additional working elements 13 in the form of elastic rods (scourers – haulm elevators).

Fig. 2. Top view of the combined rotary topper.

Actuators 9 on the vertical axis of rotation are mounted on the secondary shafts 4, 6 and also include a hub 14 (Figure 3) with a disk attached to it 15 having knives 16 turned to the plane of rotation at an acute angle to reduce the energy intensity of the cut [2].

Fig. 3. Left view of the combined rotary topper.
3 Results and discussion

In Figure 4 there are results of calculations of expressions (6–7) and dependences of the circular blade speed at various forward speeds of the machine within the limits of agricultural technical requirements. And there are dependences of the forward speed of the machine movement at circular blade speed $V_m = 14; 20; 26$ m/s on average cutting length of stems ($0.05...0.1$ m) in the number of knives $m = 2$ and 3 pieces.

![Fig. 4. Dependence of the peripheral speed of the knife and progressive speed of the machine on the average length of stalk cutting with the number of knives $m = 2$.](image)

We analyzed this graph of the calculation results of expressions (6–7) for the Botvodcher and used the progressive speed of the machine $v_m = 1.43...2.55$ m/s and rotor revolutions $n = 1365...1775$ min$^{-1}$. Then we solved the problems of assessing performance Botvodbiker and its parameters and modes of operation. They included the height of petioles cut $h_c = 0.02...0.08$ m, cutting length $L_c = 0.5 ... 0.10$ m, the number of knives, blades $m = 3$, the radius of small knives $r = 0.25 ...0.3$ m, the radius of large beats $R = 0.45...0.5$ m.

Based on these calculations, we made the rotary topper with multiple working bodies and combined the consistency of their rotation, both with the vertical axis and with the horizontal axis in the area of their interaction without contacting with each other (Figure 5, 6).

![Fig. 5. Scheme of the technological process of removing the haulm (movement of the machine to us).](image)

During the forward movement of the machine working bodies on a horizontal axis of rotation due to elastic whips-bottom lifters, we pick up and lift the fallen haulm from the inter-row with the subsequent crushing of haulm by knives of working bodies. This includes both horizontal and vertical rotation planes, strictly coordinated with their movement. Working bodies on the vertical axis of rotation undercut the main mass of the haulm located along the ridges. Knives with a horizontal plane of rotation, turned to the latter by an acute angle, create a vacuum under their plane of rotation, thus contributing to the supply of stems to the blades of the haulm harvester [19].

4 Conclusion

As a result, the analytical dependences evaluating the work quality of the haulm crusher as residual haulm $v_h$ and average cutting length $l_c$ on the forward speed of the haulm crusher $v_m$. The peripheral speed of knives $v_m$, the radius of knives $r$ and their number $m$ were obtained. With the translational velocity of the machine $v_m = 1.43...2.55$ m/s and the rotor speed $n = 1365...1775$ min$^{-1}$, the cutting height of petioles is equal to $h_c = 0.02...0.08$ m, the length of cutting is $l_c = 0.5 ... 0.1$ m.

We made a 2-row experimental combined crusher haulm with the following parameters and operating modes. The number of working elements revolutions was up to 1500 min$^{-1}$, the number of knives on the rotor in the horizontal plane was 3 pieces. The number of the beech-beater was 3 pieces, the radius of knives in the horizontal plane was 0.3 m, the radius of the beech in the vertical plane was 0.5 m.

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