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THEORETICAL INVESTIGATION AND DEVELOPMENT OF A DESIGN OF A NEW HAULM TOPPING MACHINE

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Abstract. *Theoretical investigations have been conducted of the technological process of a sugar beet haulm topping machine with a rotary cutter mechanism, as a result of which there is developed a refined mathematical model of interaction of the cutting blade with a bundle of leaves, the blade being pivotally fixed on the horizontal drive shaft of the arcuate cutting blade. Basic analytical dependencies have been obtained, application of which in designing and constructing of a haulm topping machine will ensure guaranteed quality removal of the bundles of leaves without extracting the sugar beet roots from the soil. The numerical calculations of the obtained analytical expressions performed on the PC, using a prearranged program, made it possible to determine the design parameters of the rotary haulm topping apparatus.*
KEYWORDS: *SUGAR BEET, HAULM TOPPING, ROTOR, MATHEMATICAL MODEL.*

1. Introduction

Irrespective of the remarkable progress made in the creation, production and operation of high-performance beet harvesting equipment, there remain up to this day a number of unsolved essential problems which are of global importance, as well as a series of still unanswered questions directly connected with sugar beet harvesting in Ukraine and other countries in Eastern Europe. This, of course, is a problem how to improve the quality of the beet raw material, particularly in case it is obtained under complicated harvesting conditions (increased hardness of the soil or its excessive humidity, irregular and not straight sowings, excessive weediness, and so on), which are widespread in the production of this industrial crop [1-4]. That is why a search for new theoretical developments and design solutions are now going on in the world with intensity not less than at the start of the development of the first specimens of beet harvesters [5-6]. Besides improving the quality of the raw material, the scientists and designers of Europe and the world make considerable efforts looking for the conditions of an essential decrease in the specific energy intensity of the root crop extraction process, an increase in the efficiency and reliability of machines, as well as a significantly lower pollution of the heap by soil impurities because, due to ecological requirements, it is not allowed to carry away from the fields the fertile soil together with the root crops.
The above concerns, first of all, haulm topping machines the high-tech and high-quality work of which ensures also the high quality of topping the haulm now used efficiently as a raw material for the biogas extraction. An important condition is also that the root crops must not be damaged and there are minimum losses of their upper parts – the sugar beet heads as a sugar-bearing mass.

2. Materials and methods

The aim of the research is development of a new design of a haulm topping machine the technical and operational performance indicators of which should be at the level of the best world analogues, applying the results of the conducted theoretical investigations of the technological process of its operation.

The methods used for the execution of the investigation were: methods of designing and constructing agricultural machines, methods of building computational mathematical models based on higher mathematics, theoretical mechanics, as well as compilation of programs and numerical calculations on the PC.

On the basis of the developed new theories of beet harvesting machines [7] basic provisions for the calculation and design of rotary haulm topping machines have been elaborated. Thus, a computational mathematical model was constructed for continuous, complete removal of a bundle of leaves by a rotary cutter mechanism, i.e. a mechanism with a horizontally placed drive shaft having pivotally fixed arcuate cutting blades, rotating with a definite frequency and moving with a preset speed of the forward movement. An equivalent scheme of this technological process, used in the theoretical research, is presented in Fig. 1.

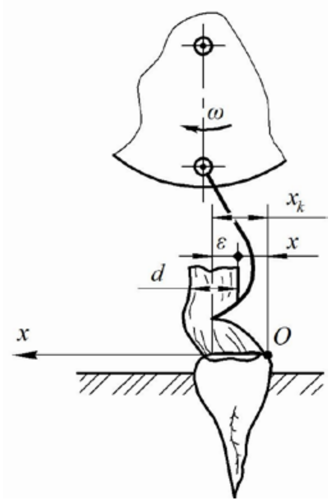

Fig. 1. An equivalent scheme of interaction of the arcuate blade of the rotary cutter mechanism with a bundle of leaves

3. Results and discussion

On the basis of the conducted theoretical investigation a condition of complete removal of the entire bundle of leaves with a diameter d was specified at the first contact of the edge of the arcuate blade with this bundle of leaves. Taking into consideration the penetration value ε of the blade into the bundle of leaves (Fig. 1), which is equal to $\varepsilon = x_k - x$, and considering the condition that for complete removal of the bundle of leaves with a diameter d at the first contact of the edge of the arcuate blade with the bundle it is necessary that $\varepsilon = d$, the finally obtained condition for complete removal of the bundle of leaves is:

$$d = \varepsilon = V_{cr}\,t - \frac{P_m}{\mu}\left(1 - \cos\sqrt{\frac{\mu}{M_{br}}}\,t\right) - \frac{P_m}{\mu}\left(1 - \cos\sqrt{\frac{c}{m_{bt}}}\,t\right). \qquad (1)$$

where ε – the penetration value of the tip of the arcuate blade into the bundle of leaves; P_m – the average cutting force; M_{br} – the applied mass of the blade (the mass of the knife applied to the point of impact of the blade upon the bundle of leaves); m_{bt} – the mass of the bundle of leaves applied to the point of impact; V_{cr} – the critical speed of the forward movement of the blade at which non-supported cutting of free-standing bundles of leaves is possible; $V_{cr}t$ – movement of the edge of the blade at the moment of time t when no contact with the bundle of leaves takes place and the blade is in a radial position; c – the elasticity coefficient of the leaves; μ – the proportionality coefficient (the intensity of the load which acts upon the blade when it deviates per unit of length).

The obtained expression (1) provided a possibility to set such design and kinematic parameters of the rotary haulm topping mechanism at which cutting of the bundle of leaves takes place in the process of a single contact of the edge of the arcuate blade with the bundle.

Theoretically determined was also the rotational speed n of the shaft of the rotary cutter mechanism on the basis of the critical linear velocity V_{cr} that is necessary for cutting free-standing bundles of sugar beet leaves. The analytical expression for the determination of the number of revolution n of the shaft of the rotary cutter mechanism, on condition of guaranteed and quality cutting of the haulm, has the following form:

$$n > \frac{30\,V_{cr}}{\pi R}, \qquad (2)$$

where R – the radius of the rotor (in this case from the rotation axis of the rotor to the edge of the arcuate blade), which is selected on condition that the vertical dimension of the cutting area should not exceed its size, i.e. $R > H - h$; H – the height of the leaves above the soil surface; h – the height of the installed continuous, uncopied cut of the sugar beet leaves.

By numerical calculations performed on the PC the value of radius R of the rotor of the rotary cutter mechanism was determined, which is within the limits 300...350 mm. Also on the basis of numerical simulation the width of the arcuate blade was found out considering the maximum diameter $d_{\max}$ of the bundle of leaves, which is equal to $B = d_{\max} + (30 \div 50)$, mm. In order to achieve qualitative non-supported uncopied cutting of the sugar beet haulm, the rotational speed n of the rotor of the cutter mechanism should be not less than 600 min^{-1}.

The numerical calculations of the obtained theoretical dependences provided a possibility to design a rotary cutter mechanism of the sugar beet haulm with new design parameters for which patents of Ukraine have been granted [8]. A superlight highly reliable rotary haulm topping machine was developed the design and technological scheme of which is presented in Fig. 2 [9]. At the same time, the haulm topping machine of such a design is frontally mounted on the wheeled tractor of traction class 1.4 – 3.0.

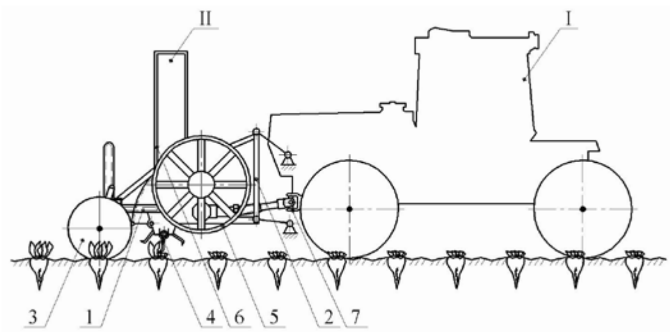

Fig. 2. A design and technological scheme of the haulm topping machine frontally mounted on a wheeled tractor:
I – the tractor; II – the haulm topping machine; 1 – the frame; 2 – suspension; 3 – pneumatic tracer wheels; 4 – the rotary haulm cutter; 5 – the screw conveyer and the paddle thrower; 6 – the discharge chute

The haulm topping machine may be used practically under all weather conditions. The use of an aggregating tractor of traction class 3 is allowed in the case of a rear mounted root harvesting machine.

In order to theoretically assess the efficiency of a haulm topping machine which front-mounted on the wheeled tractor, using the well-known dependencies to determine the productivity of the machine-tractor unit, the following expression was obtained:

$$W = 0{,}1B\left\{\frac{3600\cdot\xi\cdot N_e\eta_t\eta_v\left[1+\frac{1}{b}\ln\frac{\left[(mg\cdot\psi+kB)\cdot(mg\cdot\lambda)^{-1}\right]-\varphi}{\alpha}\right]}{(kB+mg\psi)\eta_v+10N_pB\cdot H\eta_t\left[1+\frac{1}{b}\ln\frac{\left[(mg\cdot\psi+kB)\cdot(mg\cdot\lambda)^{-1}\right]-\varphi}{\alpha}\right]}\right\}, \qquad (3)$$

where: N_e – nominal efficient engine capacity, kW; ξ – engine loading factor; N_p – specific energy consumption of energy for the execution of the technological process of harvesting sugar beet tops, kW·s·kg^{-1}; $Í$ – yield of sugar beet tops, cent·ha^{-1}; η_t – coefficient of efficiency of the transmission of a wheeled aggregating tractor; η_v – coefficient of efficiency of the frontal power take-off shaft of the tractor; α – angle of elevation, rad; m – mass of the wheeled aggregating tractor, kg; g – acceleration of gravity, m·(s^2)$^{-1}$; k – specific resistance of the frontally mounted top removal machine, N·m^{-1}; ψ – resistance coefficient to the movement of the wheeled aggregating tractor; φ – coefficient of the use of the drawbar weight; a, b – constant coefficients, which depend on the type of the wheeled aggregating tractor and the agrobackground on which the removal of the sugar beet leaves takes place; λ – coefficient of the drawbar weight of the tractor; $\hat{A}$ – working width of the top removal machine frontally mounted on the wheeled tractor, m.

The obtained expression (3) is a mathematical model of aggregation of the top removal machine frontally mounted on the wheeled tractor. Using this expression (3), we will determine the efficiency of the given machine and tractor aggregate, which consists of a developed haulm topping machine and tractor of traction class 3 (Fig. 3).

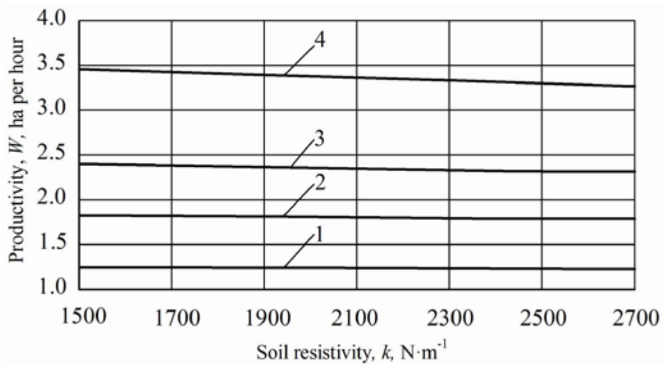

Fig. 3. – Dependence of the efficiency W of the top removal machine frontally mounted on the wheeled tractor, traction class 3, on the specific resistance k at various working widths B:
1 – B = 0.9 m; 2 – B = 1.35 m; 3 – B = 1.8 m; 4 – B = 2.7 m

As a result of numerical simulation on the PC it was established that the wheeled tractor of the traction class 3 will ensure efficiency more than 3.0 ha·h^{-1} when a six-row frontally mounted top removal machine is aggregated at any values of the specific resistance, and, due to the power reserve, there remains a possibility to use a rear-mounted cleaner of the sugar beet heads or a similar sugar beet harvesting machine.

The results of the manufacturing tests of the new haulm topping machine showed that a significant reduction in the amount of the haulm on the sugar beet heads is achieved – up to 1.5... 3.0 %; a reduction in the losses of the haulm – by 5...7 %; a decrease in the energy parameters of the cutting process of the sugar beet haulm, on the average, 1.5 – 1.8 times in contrast to the haulm topping machines which are now produced in the world in large quantities [10].

4. Conclusions

A theory of the technological process for a non-supported uncopied cutting the bundle of leaves, which allows to determine the analytical condition of complete removal of the bundle of leaves of a preset diameter depending on the design and power parameters of the rotary cutter mechanism has been developed.

The numerical calculations of the obtained analytical expressions performed on the PC made it possible to determine concrete values of the indicated kinematic and design parameters.

The results of the conducted manufacturing tests show that the developed design of the haulm topping machine has good technical and operational characteristics with aggregating tractor of traction class 3.

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