THEORETICAL RESEARCH AND DEVELOPMENT OF NEW DESIGN OF BEET TOPS HARVESTING MACHINERY

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Abstract: *Beet tops harvesting machines designs working out is actual scientific and technical task for beet industry. Development of beet tops harvesting machine with technical and operational indicators of work on the level of the best world analogs is research objective. In the research used the methods of design and construction of agricultural machinery, methods of creation calculation mathematical models based on higher mathematics, theoretical mechanics, as well as programming and numerical calculations on the PC. Theoretical researches of technological process sugar beet tops cutting by the rotor mechanism are conducted. The mathematical model of interaction beet tops bunch with arc-shaped blade of knife which pivotally mounted on a power horizontal shaft is constructed. New analytical dependence of full cutting beet tops bunch of a given diameter on constructive, kinematic and power parameters of this design of beet tops harvesting machines is obtained. The dependence for speed definition of beet tops cutting device which providing effective cutting of tops bunches from sugar beet root crops which are in the soil is found. Carried out on the PC, numerical calculations, made it possible to determine the design parameters of the new rotary beet tops harvesting device. Tests of the beet tops harvesting machine in different zones of sugar beet cultivation showed that technical and operational indicators of its work correspond to the level of the best world analogs*
KEYWORDS: SUGAR BEET, BEET TOPS CUTTING, ROTOR, MATHEMATICAL MODEL, UNSUPPORTED CUTTING, DESIGN PARAMETERS.

1. Introduction

Ukraine belongs to the highly developed beet-growing countries of Europe where sugar is one of the main strategic products that is produced by agriculture. Therefore, domestic agricultural machinery must produce sugar beet harvesting machines, the functional and operational parameters of which must meet the level of the best world analogues. The improvement of qualitative indicators of the sugar beet harvesting process is a complex scientific and technical problem, the solution of which must be based on the search for new constructive solutions to the working organs and design scheme of machines, the theoretical substantiation of their design and technological parameters, the experimental verification of theoretical studies carried out with ultimate goal of analysis and synthesis their optimal parameters. Further comprehensive production trials of new designs for sugar beet harvesting machines must finally resolve the issue of their production.

2. Preconditions and means for resolving the problem

2.1. Analysis of recent research and publications

The design of the first in our country sugar beet harvesting machines began in the 30th of the last century thanks to the fundamental (by that time) theoretical and experimental research A.A. Vasilenko [1]. In the future, the numerical group of scientific workers, under the guidance of academicians P.M. Vasilenko and L.V. Pogorelogo [2-5] at the end of the last century, basically formulated the main theses of theory and calculation of beet harvesters, which were widely used by design bureaus of combine plants during development domestic sugar beet harvesting equipment. However, despite significant successes (including in the world of scientific and design practice) in creation, production and operation of high-performance beet harvesting equipment, to this day there are still many unsolved major problems that are of global significance and a number of unresolved issues that are directly connected with sugar beet harvesting in Ukraine. One of the problems is improving the quality of beet raw materials, especially if it is produced under difficult harvesting conditions (high hardness of the soil or its excessive humidity, unevenness and non-straightness of crops row, excessive weediness, etc.), which is widespread in the production of this technical crop. Therefore, the search for new theoretical developments and design solutions in the world is now continuing with no less intensity than at the beginning of the creation of the first samples of sugar beet harvesting equipment [6-12]. In addition to improving the quality of raw materials, scientists in Europe and the world are making considerable efforts to find the conditions for a significant reduction in the specific energy intensity of the process of digging out root crops, increasing the productivity and reliability of machines, and also significantly reducing the contamination of the heap by ground impurities, according to the environmental requirements are not allowed to take out fertile soil from the fields together with root crops.

What has been said above relates, first of all, to the harvesting machines, the high-tech and high-quality work of which determines the high quality of beet tops harvesting, which is now effectively used as raw material for biogas production. An important indicator is the degree of root crops damage and the minimum loss of their upper parts – heads of sugar beet root crops, as a sugar-bearing plant material.

2.2. Purpose of the study

The development of a new design of beet tops harvesting machine, technical and operational performance of which would be at the level of the best world analogues, using the results of theoretical studies of technological process of its operation.

2.3 Materials and Methods

During the research, methods of designing and constructing agricultural machines, methods of constructing computational mathematical models based on higher mathematics, theoretical mechanics, as well as programming and numerical calculations on the PC.

3. Results and discussion

Based on the new theories of sugar beet harvesters [10], the basic design and development of rotary type rotary harvesters has been developed. A computational mathematical model of a continuous, non-sensing cut of beet tops bunch by rotary cutting unit has been constructed. The cutting device has located horizontally drive shaft with arched knives, rotates at a certain speed and moves translationally at a specified speed of translational motion. The equivalent circuit of this technological process, used in theoretical studies, is shown in Fig. 1 and Fig. 2.

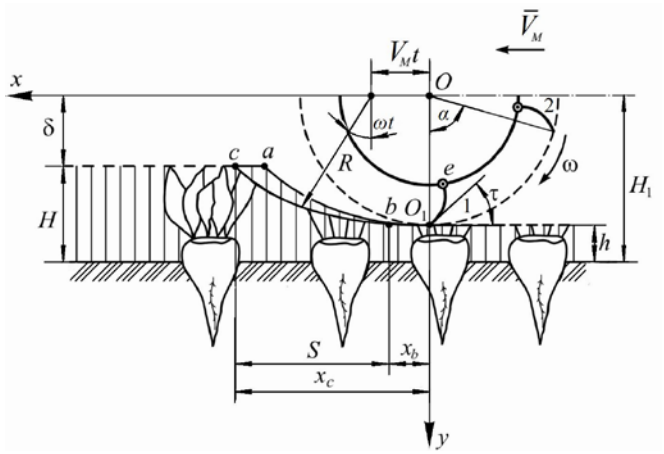

Fig. 1. – Equivalent scheme for theoretical study of the technological process of the rotary beet tops harvester: 1 – first knife; 2 – second knife

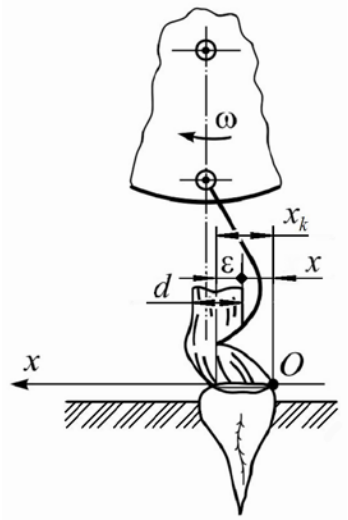

Fig. 2. – Equivalent scheme of interaction of arc-shaped knife of a rotary beet tops harvester with bundle of tops

On the basis of the theoretical study, the refined condition for the complete shearing of the entire bundle of tops with a diameter d at the first impact of arc-shaped knife blade with a bundle of tops was justified.

Taking into account determination of penetration value ε of knife into tops bunch (Fig. 2), which is equal $\varepsilon = x_k - x$, taking into account the condition for complete cutting of tops bundle with diameter d at the first impact of arc-shaped knife blade with beet tops bundle is that $\varepsilon = d$, final condition for the complete shearing of the tops in this form is as follows:

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

where ε – penetration value of blade end of arc-shaped knife into tops bunch (in the case of a complete cut ε_{max}); P_m – average cutting force; M_{br} – reduced mass of knife (mass of knife that is brought to point of impact blade about tops bunch); m_{cr} – mass of tops bunch, reduced to impact point; V_{cr} – critical speed of knife translational motion for unsupported cut of free-standing bundles of leaves; $V_{cr} t$ – knife blade edge displacement at time t in absence of impact with tops bunch, when the knife is in the radial position; c – Coefficient of tops elasticity; μ – coefficient of proportionality (load intensity, which acts on the knife when it is deflected per unit length); ω – angular rotational speed of rotor.

The obtained expression (1) made it possible to specify such constructive and kinematic parameters of the rotary beet tops cutting unit, in which the cut of tops bunch occurs during a one-time impact of blade of arc-shaped knife with tops bunch.

Also, the rotational speed of beet tops cutting unit was determined theoretically, based on the critical linear speed V_{cr} required to cut free-standing beet tops of sugar beet. The analytical expression for determining number of rotations n of rotary cutter unit, provided that tops are guaranteed and quality cut, is as follows:

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

where R – radius of rotor (in this case from the rotor rotation axis to blade edge of arc-shaped knife), which is chosen on condition that size of cutting zone along vertical should not exceed its value, i.e. $R > H - h$; H – height of tops location above soil surface; h – height of installed continuous and non-sensing cut of sugar beet tops.

Numerical calculations carried out on PC determined the value of rotor radius R of beet tops cutting unit, which is in range 300...350 mm. Also based on the numerical calculation width of arc-shaped knife, taking into account the maximum diameter d_{max} of tops bunch, which equals $B = d_{max} + (30 \div 50)$, mm is determined. The rotor speed n of cutting unit for implementation of a quality unsupported and non-sensing cut of sugar beet tops should be no less than 600 rpm.

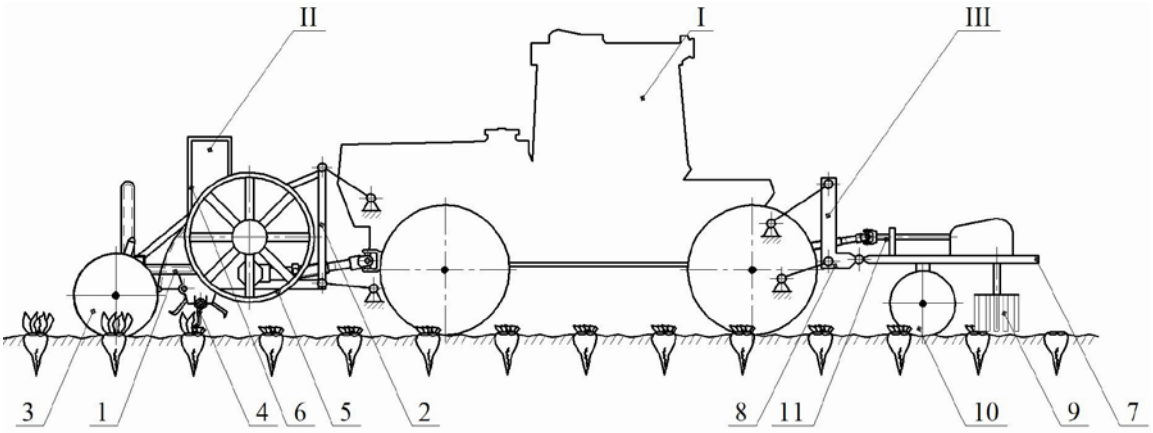

Fig.3. Structural-technological scheme of beet tops harvesting unit:
I – tractor; II – front-mounted beet tops harvesting machine: 1 – frame; 2 – hinged device; 3 – pneumatic support wheels; 4 – rotary beet tops cutting apparatus; 5 – screw conveyor and vane conveyor; 6 – loading tube; III – root crops heads cleaner from tops remains: 7 – frame; 8 – hinged device; 9 – cleaning shaft; 10 – support wheel; 11 – drive unit

Numerical calculations of the obtained theoretical dependences made it possible to design a rotary beet tops cutting unit with new design parameters for which obtained patents of Ukraine [11, 12]. There was developed an ultra-light, highly reliable rotary-type beet tops harvesting unit, structural-technological scheme of which is shown in fig. 3 [13]. In this case, the beet tops harvester of this design is frontaly mounted on wheeled tractor of drawing class 1.4 - 3.0 (There is a specific tractors' classification which is based not on the engine power, but on the draft force of the tractor measured by 1000 N. It is called 'Drawing Class'). In fig. 4 is given a general view, of the beet tops harvester, which is mounted on a wheeled tractor of drawing class 1.4. At the combine plant, a beet tops harvesting machines of this design was manufactured and successfully passed production tests in different areas of beet-growing.

The technical characteristics of new beet tops harvester unit are such: working width – 1.35 m (or 3 row of sugar beet root crops); working speed up to – 2.1 $m \cdot s^{-1}$; weight – 850 kg; performance of the machine for 1 hour of pure time – 1.0...1.2 ha. The rotor speed of beet tops cutting unit must be within 650…850 rpm (if harvesting machine is used for mowing grasses and other thick-stemmed plants, the rotor speed should be within 1200...1600 rpm). The beet tops harvesting machine can be used in almost all weather conditions. The use of tractor of drawing class 3.0 is necessary in case of also mounting with it a root harvester machine.

Fig. 4. Universal beet tops harvesting machine in working with tractors of drawbar category 1.4

The results of production trials of beet tops bottom harvesting machine showed significant reduction in the number of tops residues on the heads of sugar beet roots – up to 1.5…3.0%; reduction of beet tops losses by 5…7%; decrease in energy parameters of process of sugar beet tops cutting by average of 1.5…1.8 times in comparison with the harvesting machines that are now serially produced in the world [14].

4. Conclusions

1. The use of modern theories of the working organs of sugar beet harvesters has the ability to design and manufacture beet harvesters, the technical level of which is at the level of the best foreign analogues, and according to conditions of Ukraine it exceeds the specified level. This concerns, first of all, the harvesting machines, the high quality of which determines the high quality of harvesting (for later use as a source of biogas), minimal losses and damage of heads of sugar beet root crops, as a sugar-bearing plant material.

2. The developed mathematical model of technological process of the uncontrained and non-sensing cutting of beet tops bunch made it possible to obtain analytical expressions for determining the main design parameters of the rotary cutting units. Analytical condition for the complete cutoff of tops bundle of given diameter, depending on the structural and power parameters of the rotary cutter apparatus is obtained. Analytically new expression for determining the minimum rotational speed of the rotor of cutting unit, which performs tops cutting and width of cutting knife is obtained. The numerical calculations of the analytical expressions obtained on the PC made it possible to determine the concrete values of these kinematic and design parameters.

3. The results of the conducted production tests of new design of a beet tops harvesting machine in a three-row version show that the achieved technical and operational indicators are at the level of the best world machines, and some of them exceed this level.

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