CONTEMPORARY TRENDS IN THE IMPROVEMENT OF BEET TOP REMOVING MECHANISMS AND MACHINES

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Abstract: *There are considered contemporary trends in the improvement of the technological process for the preparation of sugar beet roots for digging out and directions of the development of the designs of the working tools for the removal of the tops. Analysis of contemporary machines has been carried out according to the indicators of their quality, energy consumption and efficiency of the technological process. Tasks have been determined for creating new working tools. It is noted that at the current stage of development of the beet top removing machines the efficiency and quality problems of the top separation process are solved by increasing the number of operations, which is an energy-consuming, material-intensive and costly way to improve the technological process and the working tools. And, as a consequence, it is necessary to look for technical solutions, technologically allowing operations required only for the preparation of the root crops to be harvested. Therefore, further research should be conducted in the direction of creating a working tool that combines good tracing of the heads by cleaners with low-energy intensity of the cutting tools.*
KEYWORDS: ROOT CROP, HEAD OF THE ROOT CROP, ROOT, SEPARATION OF ROOTS, WORKING TOOL.

1. Introduction

Increased pollution of the heap of root crops with the green mass by 1% reduces the yield of sucrose by 0.1%, and, when storing the root crops in open heaps (в каратах) with the top content of about 4%, the daily sugar losses are, on average, 0.012% [1]. For mechanised harvesting of sugar beet roots crops, there is a wide range of sugar beet harvesters and beet harvesting complexes that have both advantages and disadvantages. Especially these shortcomings are present in the preparation process of the root crops for digging, which includes the operations of separating the tops from root crops and removing it from the area of action of the digging tools or attaching to the haulm properties which do not affect the technological process of digging and separating the heap of root crops from impurities. The working tools for separation of the tops perform satisfactorily the technological process at relatively lower speeds in comparison with the digging tools.

Analysis of a number of designs of the working tools for the removal of the tops has been made in considerable detail in the works by L.V.Pogorelov, V.M.Bulgakov, M.V.Tatyanko, R.B.Gevko, V.Ya.Martinenko, N.M.Helemendik, etc., yet creation of efficient working tools that would be characterised by small energy intensity, high efficiency and simplicity of design remains an actual production and scientific task.

The most complete overview of the designs, technological schemes and working tools for the removal of the tops is given in work [1]. There is the history of creation and development of designs considered, the quality indicators of the technological process performed by the main working tools are analyzed, but there are no indicators of energy intensity.

In [2], a classification of the working tools for the separation of the tops is presented. In [3, 4, 5, 6] there is analysis of various technological schemes for the separation of the tops, the results of comparative tests of machines from the West European firms Holmer, Ropa, Kleine, Matrot, Grimme, TIM-Thyregood.

It should be noted that the assessment of the quality indicators of the top separation process according to the European standard is a visual assessment and therefore it is impossible to estimate the mass content of the tops in the root crop heap left behind different machines. The drive power is given only for individual machines.

The purpose of the work is to analyse contemporary technologies and technical means for removing sugar beet tops and to identify the most promising designs and directions for their improvement.

2. Results and discussion

Let us trace the main trends in the development of the working tools for the top removal using as an example modern sugar beet harvesters and top-separating modules of the leading domestic and foreign manufacturers. As a result of analysis, it has been established that the following operations can be carried out at the present stage when the top is removed [1,3,4,5,6]:

- cutting of the main mass of the tops on the root crop which is growing;
- removal of the basic mass of the tops by shock interactions (defoliation);
- disintegration of the tops and their distribution in rows or inter-rows;
- transportation of the tops to the vehicle or to the harvested field;
- partial disintegration of the plant residues in the inter-row spaces;
- cutting the root crop heads with the residues of leaves which remained after cutting the bulk of the tops;
- cleaning of the root crop heads from the residues of the foliage.

In order to analyse various technological schemes of contemporary machines and to determine the current trends in the development of the designs, we classify the technological process of preparing root crops for digging according to the above-mentioned operations (Fig. 1).

Cutting of the basic mass of the tops can be carried out with tracing of the root crop heads or without their tracing at a fixed height relative to the soil surface. In this case the following mechanisms are predominately used: rotors with a horizontal, vertical or inclined at an angle to the horizon axes of rotation.

Removal of the tops by shock interactions takes place with the help of rotors having flexible elements - defoliators.

The distribution of the tops in the inter-row spacing occurs simultaneously with the cutting and disintegration processes, by applying guiding surfaces in the housing of the cutting rotor. There is also known a practice of pushing the plant residues into the inter-row soil.

For transportation of the tops, augers, rod conveyors or a set of vertical augers are predominantly used.

Removal of the plant residues from the inter-row zone is carried out using the fan effect at rotary drums with a horizontal axis of rotation.

Cleansing of the root crop heads from the top residues is effected by rotors with flexible cleaning tools. The most common of these are blade cleaners.

Table 1. *Analysis of technological schemes and working tools of the machines made by the world's leading companies for the top removal*

No.	Stages of top removal	The top removal operations / a design used for the execution of this technological operation							
		BM-6B [1]	Kleine SF10, Moreau, Matrot, Holmer, Gilles [1,6,12,10,14]	Ropa Euro-Tiger V8-3 [6]	Grimme Maxtron 620 [13]	Ropa, Holmer, Gilles [5,10,13]	WIC, Grimme BM 330, Aloway Industries [7,3,8]	Garford Victor, MGSh6 (TKZ) [1]	WIC (Amity Technology) [9]
1	Removal of the basic mass of the tops	Cutting with tracing	Cutting without tracing						Top removal by shock interactions
		Active knife	Horizontal cutting rotor					Active knife with vertical shaft	Rotor with flexible blades
2	Elimination of the influence of the basic mass of the tops	Transportation of the tops into the vehicle or the harvested field	Disintegration and transportation to the harvested field	Disintegration and distribution in inter-rows	Disintegration and distribution in inter-rows with compaction	Disintegration and distribution in inter-rows and rows		Transportation to the harvested field	Disintegration and distribution in inter-rows and rows
		Rod elevators	Horizontal auger	Horizontal cutting rotor and guiding surfaces	Horizontal cutting rotor and rollers for pressing the tops into the soil	Horizontal cutting rotor		Vertical auger working tools	Horizontal rotor defoliator
3	Removal of the top residues	Primary cleaning of the root crop heads	Primary cutting of the heads with tracing					Primary cleaning	Primary cleaning with primary cutting
		Blade cleaner of the root crop heads	Passive knife			Passive knife	Passive or active knife	Primary cleaner with a hard surface	Two horizontal rotors-defoliators. Active knife or passive knife.
4	Elimination of the influence of the top residues	Transportation of residues to the harvested field	—	—	—	—	Disintegration and distribution in inter-rows	Disintegration and distribution in rows and inter-rows	Disintegration and distribution in inter-rows
		Blade cleaner of the root crop heads					Rotor from working tools sectionally, arranged above the rows	Primary cleaner with a hard surface	Rotor from working tools sectionally, arranged above the rows
5	Separation of the tops on the digging-separating working tools	Separation of individual particles of the bound and loose tops from the heap	Partial removal of the bound and detachment of the free disintegrated tops						
Required power, kW		44 - full power	—	—	—	—	75…90	24.7 (drive power)	75…90
Working speed, $m \cdot s^{-1}$		up to 1.5	up to 1.8					—	up to 1.8

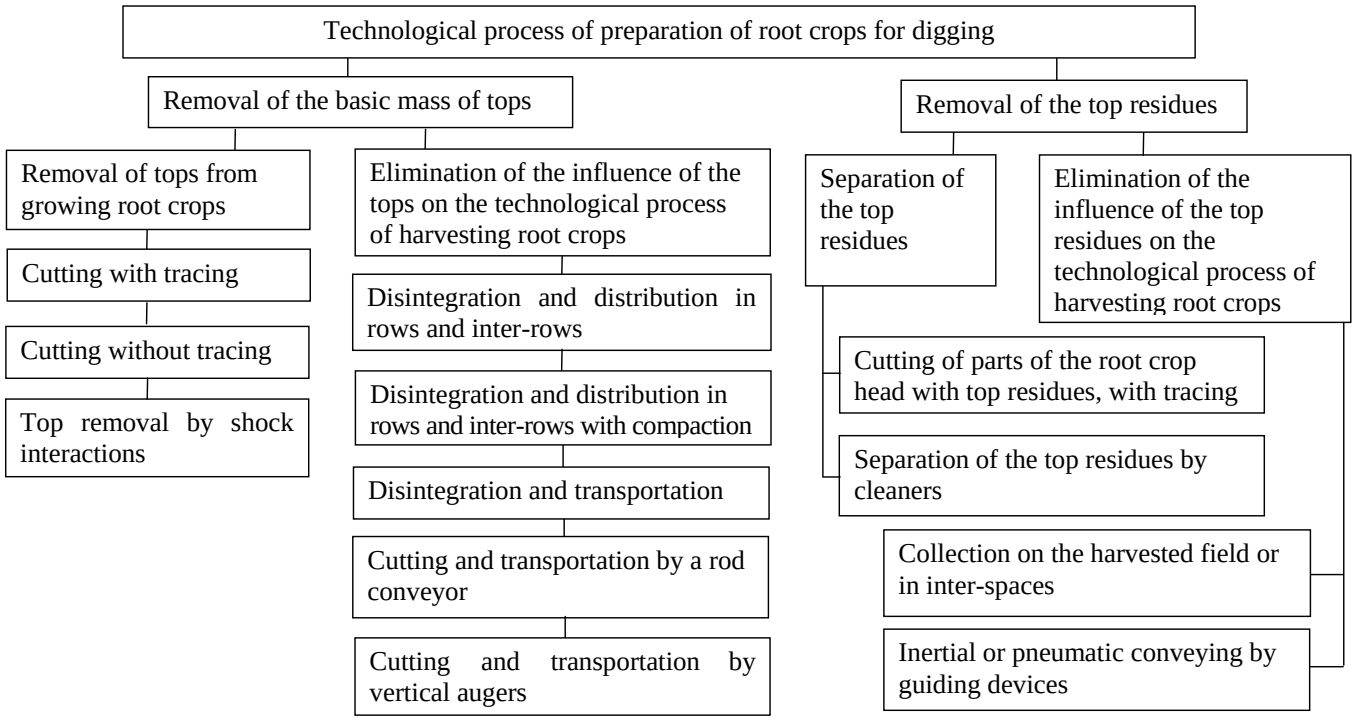


Fig.1. *– Classification of the technological process of the root crop preparation for digging*

On the basis of this classification let us analyse application of the aforementioned operations of the top removal in technological schemes of machines of the world's leading firms (Table 1). Also, we will display with the help of which constructions of working bodies these operations are implemented. We will also show by means of what designs of the working tools these operations are implemented.

Table 1 clearly manifests the tendency of the leading world's firms Holmer, Ropa, Kleine, Moreau et al. (Table 1) to apply cutting of the tops without using a tracer by means of a rotor with a horizontal axis of rotation, and using a tracer when cutting the root crop heads with passive cutters (Fig. 2). In individual combine harvesters a slightly modified technological scheme for the top removal is used. Instead of arcuate knives on the rotary top cutter drum, knives of various shapes are used, which allow the tops to be disintegrated and left in rows and inter-rows. In addition, the top is disintegrated to such a degree that it does not affect the work of the digging and separating tools of the root crop harvesting machines.

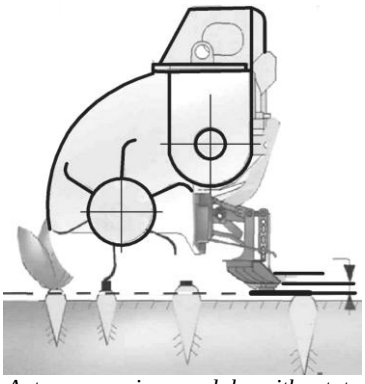
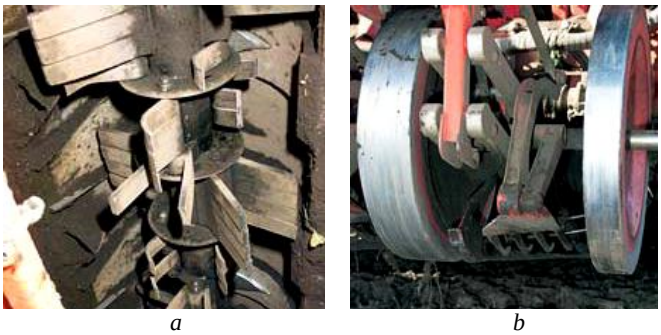


Fig. 2. – *A top removing module without tracing and with passive tracing for primary cutting of the root crop heads*

An original technical solution for the top separation was used by the firm Grimme in its Maxtron 620 combine harvester [3]. In it, the tops are cut only above the rows of sectionally arranged arc-shaped knives (Fig. 3a). On the shaft of the rotary top cutter, in the inter-row region, there are placed polyurethane beaters which are by 30 mm longer than the knives. Due to the suction effect, created by the long beaters, the plant residues are selected from the row region and fed into the region of the knifes for disintegration. By means of the guiding flaps, located on the housing, the shredded tops are distributed in the inter-rows and pressed into the soil by steel rollers (Fig. 3b).



a *b*

Fig. 3. – Peculiarities of the Maxtron 620 combine harvester: *a* – the working tools for the top separation; *b* - rollers for pressing the disintegrated tops into the ground

The next operation is primary cutting of the root crop heads with tracing, using passive primary cutters. Remote regulation of the cutting height is carried out by hydraulic cylinders, the top cutter having no supporting wheels. In order to control and automatically maintain the given cut-off height of the rotary top cutter, sensor signals are used from the primary cutter of the root crop heads.

Using the Harford Victor combine harvester (Fig. 4) as an example, it is possible to consider implementation of this technological scheme with the help of fundamentally different working tools. Cutting of the tops also occurs without tracing by means of active knives with vertical-auger transporting tools, but cleaning the root crop heads from the top residues takes place by active-type cleaners with a rigid parabolic surface.

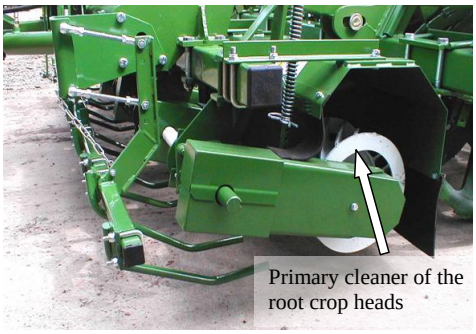


Fig. 4. – *Cleaning device of the combine harvester Garford Victor*

Grimme also puts out Rootster 604 trailed root crop harvesters. They work in a complex with the BM 330/300 top-harvesting machine. In this machine the technological process of separating the tops takes place in three stages (Fig. 5).

At first, the tops are cut off by a rotary top cutter with metal arc-shaped knives. The knives are arranged on the rotor shaft along a helical line (Fig. 6a). The next operation is cleaning of the root crop heads from the residues of the uncut tops by two shafts that rotate in opposite directions.

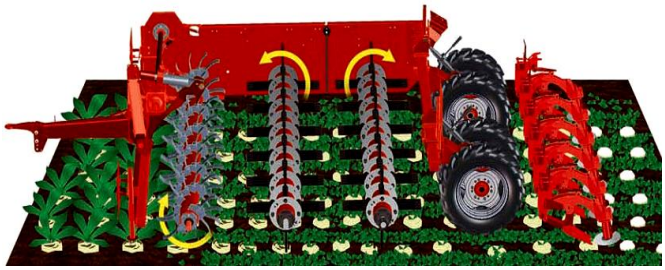
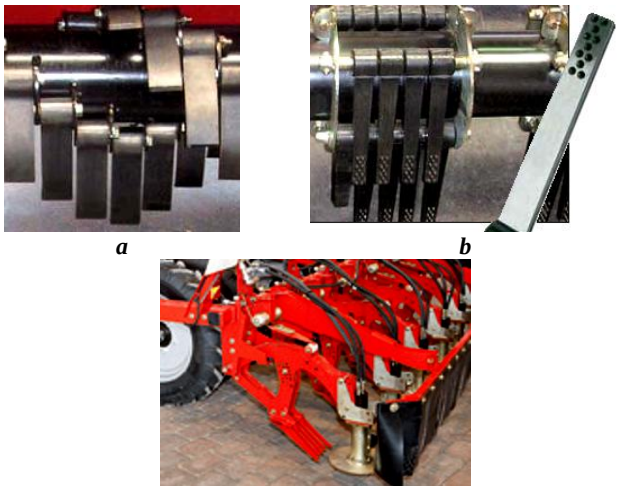


Fig. 5. *– A flow chart of the Grimme BM 330 top-harvesting machine*

On the shafts there are pivotally fixed polyurethane beaters (Fig. 6b). After cleaning the root crops are additionally cut. The cutting-off apparatus, which is used here for primary cutting of the root crop heads (Figure 6c) consists of a comb-shaped tracer and an active disk knife.



a ***b***

c

Fig. 6. *– The working tools of the top harvesting machine BM 330: a – a rotary top cutter; b - counter-rotating polyurethane beaters on the shafts; c – a primary cutter of the active type with tracing*

The WIT top harvesting machine from the Amity Technology (Fig. 7) [7] has an original design of the working parts. Instead of the traditional rotary top cutter a three-shaft beater-disintegrator (defoliation) is used in it. The working tools (beaters) are made from rubber of high mechanical strength. The working part of the beaters contains metal inserts, which increases the impact force of the beaters when they come into contact with the tops. Due to the high intensity of the action of the beaters the tops are crushed into small-size particles and sprayed into the inter-rows without adversely affecting the operation of the root crop harvesting machine.

The final completion of the top cutting process of the root crops is carried out by passive primary cutting knives moving above each of the rows and having an individual system for tracing the height of the root crop heads.

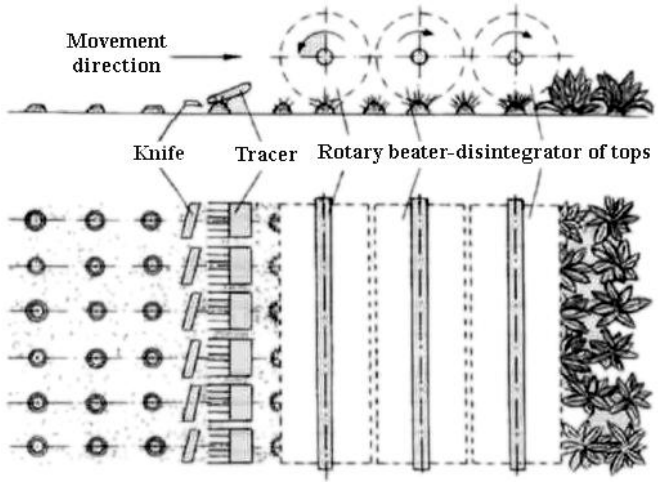


Fig. 7. *– A flow chart of the WIC top harvesting machine from the Amity Technology*

Analysing Table 1, we can draw a conclusion that the basic mass of the tops are removed:

- by cutting the tops without tracing, with primary cutting of the root crop heads with tracing (Fig. 8);
- by cutting the tops with tracing and cleaning the root crop heads from the top residues (Fig. 9);
- by shock interactions (Fig.10).

The technological scheme (Fig.8) is characterised by the complexity of the structures that are used, high metal intensity, and high energy costs due to the use of rotors with a horizontal and vertical arrangement of the rotation axis.

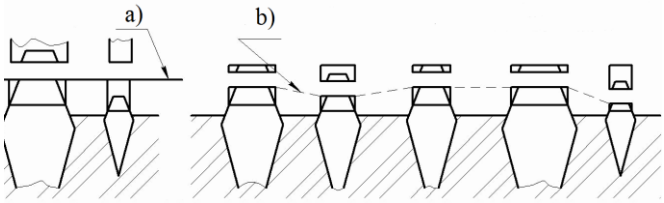


Fig. 8. *A technological scheme of separation of the tops by cutting without a tracer (a); by primary cutting of the top residues from the heads with tracing (b)*

Due to the application of cutting without tracing, the quality of the top removal in this technological scheme is insufficient, and it is possible that the sugar-bearing mass in the removed tops exceeds the agrotechnical requirements. The forward speed in this scheme is not greater than 1.8 $m \cdot s^{-1}$ since the working tools for the passive primary cutting of the root crop heads knock them out and form bevelled surfaces when the speed increases. It should also be noted that irregularities of the soil cause oscillations of the machine. In combination with varying heights of the root crop heads relative to the soil, this significantly affects the location of the cutting plane relative to each head of the root crop, which will lead to different thickness of the layer of the tops of the tops on the root crop heads (Fig. 8), worsening the tracing conditions, and, accordingly, lowering the cutting quality. Due to the increased thickness of the head, the quantity of the top residues on the root crops will diminish, yet the loss of the saccharіferous mass will increase.

According to the results of independent tests [6], the number of root crops with a height of the tops higher than 2 cm was on average 2% for the machines of this technological scheme, there were 26.6% of the high-cut root crops, 7.5% of the low-cut root crops, but satisfactorily cut root crops - 60.1% %. Such statistics indicate the losses of the saccharіferous mass and a significant amount of tops left on the root crops. These results are given for an average working speed of the machines 6 km / h. This is a small speed of movement, and its choice is determined by a desire to achieve a quality of the passive primary cutters as satisfactory as possible. The digging tools can work at a much higher speed. Therefore the use of the passive primary cutters in this flow chart allows reduction of the residues of tops on the root crops after cutting without tracing by a rotary top cutting apparatus, yet the efficiency of the harvesting process of the root crops remains at a low level.

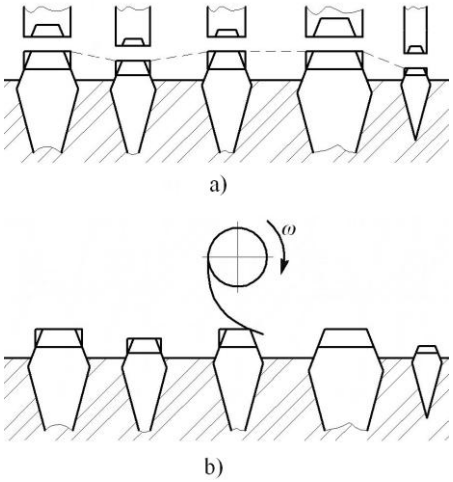


Fig. 9. *– A technological scheme for the separation of the tops by cutting with tracing (a) and primary cleaning of the root crop heads by cleaners (b)*

Thanks to cutting without tracing by means of a rotor with a vertical axis of rotation combined with an active-type cleaner (Garford Victor Harvester), the requirements for the separation quality of the tops can be more satisfied; however there may be root crops, damaged and kicked out of the soil. Considering that the required drive power of such an MGSH-6 machine is 24.7 kW, a considerable amount of energy is wasted for cutting and transportation of the tops using a set of vertical augers.

A combination of cutting without tracing with a primary cutting of the root crop heads by means of active-type cutting apparatus of a small mass (Grimme BM 330 machine) provides a possibility for higher quality separation of the tops at working speeds up to 1.8 $m \cdot s^{-1}$, but the required power is 75 ... 90 kW. A characteristic feature of this design is an individual hydraulic drive for each knife, which made it possible to reduce the weight of the top cutter apparatus. But such a drive is rather expensive, which will definitely be reflected on the total cost of the machine.

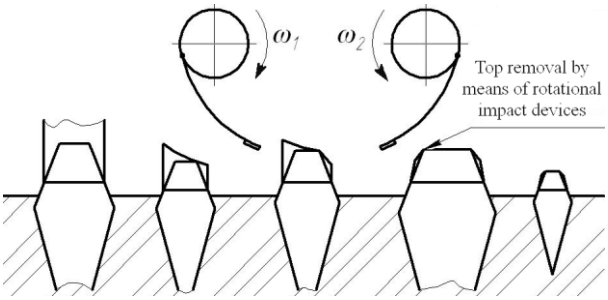


Fig. 10. *– A technological scheme of the top separation of the tops by shock interactions*

The technological scheme of cutting with tracing and primary cleaning of the root crop heads by a cleaner (BM-6B) is also characterised by the complexity of the design and the metal intensity through the need to use the tracing device in combination with the cutting tool. The quality of the top removal in such a technological scheme is much better; however, this time the forward speed of the machine is not high - up to 1.5 $m \cdot s^{-1}$. This is due to the fact that at higher speeds in the links of the tracing mechanism and in the cutting tool there arise inertial forces, and tracing of the heads deteriorates. The total power required to ensure the technological process is 44 kW.

Removal of the tops by shock interactions (separate models of the WIC machines) is characterised by significant energy losses due to additional disintegration of the tops and by the need to use three shafts with different directions of rotation. In this case the tops are disintegrated and distributed on the uncollected field. When the working speed is increased above 1.8 $m \cdot s^{-1}$, the quality of the top removal remains low. In order to carry out such a process, the required power is 75 ... 90 kW.

3. Conclusions

1. At the present stage of development of the top harvesting machinery the problems of efficiency and quality of the top separation process are solved by increasing the number of operations, which is an energy-consuming, material-intensive and costly way to improve the technological process and the working tools.

2. It is advised to carry out further research in the direction of creating a working tool that combines good tracing of the heads by cleaners with low-energy intensity of the cutting tools.

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