

Justification of the parameters and development of the design of the mechanism of automated selection and supply of cuttings in energy culture plants

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Abstract. An important field of bioenergy development is the use of biomass energy, which requires significant amounts of raw materials grown in the fields. One of the prospective sources of such raw materials is the planting of fast-growing wood species capable of restoring the above-ground part after cutting in a short period of time. The article sets out the task of developing approaches and constructive solutions regarding the possibilities of creating highly productive aggregates for planting such woody energy crops as willow, poplar, and others that are propagated by cuttings. The analysis of the current state of development of this issue revealed that one of the factors inhibiting the process is the insufficient level of developments and their implementation in the field of automation of the technological process of planting. In most technical solutions, the use of the labor of the planter is included, which makes the process as a whole dependent on human capabilities and other related factors. The work is intended to solve the empirical task of developing an automated planter for plants planted with lignified cuttings. To develop an automated system that would provide uninterrupted and uniform supply of cuttings to the coulter of the planter, a two-factor experiment was conducted on a developed laboratory stand simulating a slotted hopper. As a result of research, it was found that the optimal width of the unloading window of the feeder should be at least 80 mm,

and the optimal angles of inclination of the slotted hopper walls should be at least 40°. These parameters will provide complete and continuous unloading of cuttings both in the absence of external forces acting on them (oscillations, vibrations, etc.) and with them. Taking into account the analysis of existing technical solutions and the results of a laboratory experiment, a number of solutions were synthesized, which were used in the development of a new construction of the cuttings unloading mechanism. The developed construction of the mechanism of automated dosing, selection and supply of cuttings for the planter of energy willow is protected by a patent and embodied in a single-row design and tested in field conditions. Such a planting machine allows to plant without the support of a planter, whose functions are reduced to periodically loading the slotted hopper with cuttings previously oriented in one direction.

Keywords: *energy crops, energy willow, automatic feeder, planting machine, cuttings, feeder, piecemeal selection.*

I. INTRODUCTION

The intensive development of the world energy creates demand for ever greater volumes of energy production, and considering the modern realities of environmental sustainability and the desire of countries for energy

Print ISSN 1691-5402

Online ISSN 2256-070X

<https://doi.org/10.17770/etr2024vol3.8132>

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Published by Rezekne Academy of Technologies.

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independence, more and more attention is paid to the development of alternative energy sources. According to various estimates, by 2050, almost 40% of energy needs will be covered by renewable energy sources, in particular, about 30% - by bioenergy [1]. The main priority of bioenergy development for many countries is the use of different highly productive bioenergy crops. One of the perspective directions is the cultivation of energy raw materials on plantations of fast-growing wood species, in particular, willows, poplars and other crops capable of easy restoration of the above-ground part after its cutting. European countries, which began to actively implement the cultivation of energy raw materials by plantation methods at the beginning of the 18th century, demonstrate the best experience in these issues. The impetus for the development of this direction was the aggravation of the world energy crisis.

In Ukraine, in recent years, this trend has become particularly widespread, so the issue of quickly setting up plantations of energy plants, especially various varieties of willows, on an industrial scale has become urgent.

For growing willow on large plantations, a number of special machines for growing and harvesting energy willow have been developed [2]-[4]. Work technology with this crop has a number of its characteristics, so it is not rare that some aspects remain insufficiently studied. In particular, the issue of automated planting of energy willow remains problematic, because propagation takes place by cuttings, which are usually planted manually by planters, which not only limits the productivity of the aggregate, but also cannot guarantee high quality work. Some attempts to automate the process were implemented through the creation of aggregate whose raw material for planting is long rods. The laying of the rod in them is still carried out manually, but then such a machine cuts the willow rod on the cutting directly during planting and works them into the soil with its compaction around the cutting, which provides a high percentage of rooting [5], [6]. An example of such a machine is the Energy Planter planter of the Danish company Egedal. The advantages of this technology are that the human factor is significantly reduced, the quality of the planting material improves (it is cut immediately before planting), the possibility of parallel driving appears during care and harvesting, and, accordingly, there is less damage to rooted seedlings at the same time [7], [8]. However, such a machine is quite expensive for the Ukrainian consumer and does not give the opportunity to completely do without a planter and requires carefully prepared long straight rods.

In most cases, simpler machines are used, where the planting material is energy willow cuttings 20...25 cm long and 0.7...1.4 cm in diameter [8], [9]. Usually, the laying of material in such machines is manual, but the task of our research is the development of such an automatic machine, which would provide uninterrupted, piecemeal delivery of cuttings from a certain massif and thereby free up the place of a planter.

Nowadays, work on improving the process of planting plants continues. There are many works analyzing both the theoretical aspects of automation [10]-[12], and the automation of a specific type of plant [13] and even before the implementation of robotics into the planting

process [14]-[16]. However, each specific type of plant requires a separate approach. In particular, energy willow or poplar needs to take into account the characteristics of lignified cuttings as planting material.

The authors of the project dealt with issues of automation of the process of planting energy willow cuttings in the Educational and Scientific Laboratory "DAK GPS" of the Higher Educational Institution "Podillia State University", where within the framework of the scientific topic "Agrobiomass of Ukraine as the energy potential of Central and Eastern Europe" for more than five years scientific work was conducted [17]-[21]. In particular, a preliminary analysis of the existing tools for automating the planting of cuttings was conducted. The works [22], [23] highlight the main approaches and strategies of advanced practices for improving the productivity of garden aggregates. Besides solutions that are directly related to the planting of energy willow and poplar, where the work of a planter is mainly used for piecemeal planting of cuttings, technical solutions to solve this problem in seedling planting and forestry were also analyzed [24]. The technological processes on the way of the cuttings getting to the planting site are structured and the main factors that need to be improved are singled out. Thus, the main obstacle in further increasing the productivity of planters is the limitation of human possibilities in supplying cuttings - 40-60 pcs·min⁻¹ [10], which is appropriate to the speed of forward movement of the machine 0.8...2.1 km·h⁻¹. In these conditions, it is important to change the operator's work with means of automation, therefore, it is urgent to search for perspective technological processes and structures of working bodies for the automated supply of cuttings in machines for planting energy wood crops, which can be structurally displayed in the diagram of Fig. 1.

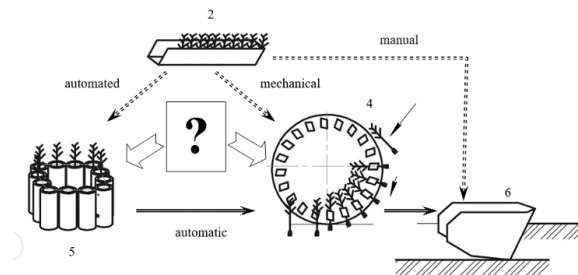


Fig. 1. Structural and logical scheme of operations of the process of planting cuttings of energy willow: 1 – containers with seedlings; 2 – planting devices; 3 – coulters or furrow-forming equipment; 4 – accumulators of planting material; 5 – cuttings supply mechanism.

In Fig. 1, a question mark highlights the position that is responsible for supplying the cuttings from containers with seedlings to the planting site. In modern machines for planting energy willow, this process is performed exclusively manually [27].

Having analyzed various constructions, we came to the conclusion that in order to increase the productivity of planters, it is necessary to improve the process of supplying cuttings from containers to the planting device. It is also necessary to use intermediate stockpiles of cuttings, which creates a buffer that compensates for the discrepancy between the productivity of the planting apparatus and human capabilities. But this only partially

solves the issue of increasing productivity and reducing the share of manual labor.

The creation of mechanisms for the automated supply of cuttings to the planting device or directly to the planting site is an important scientific task on the way to increasing the productivity of planting machines.

II. MATERIALS AND METHODS

The paper sets an empirical task to develop an automated planter for plants planted with lignified cuttings. A number of theoretical and practical research activities were carried out to develop a mechanism that would ensure uninterrupted and uniform supply of cuttings to the coulter of the planter. Previous studies established that when designing the mechanism for supplying cuttings, the process of individual selection and movement can be divided into three functional zones: dosing (bunker + unloading window); compensating (mechanism for cutting off excess cuttings); transporting (transporters, drums, rolling boards). It was found that the issue of primary dosing of cuttings is the least researched, since this material is not typical for most technological processes, so it is worth focusing on the parameters of the bunker in more detail.

A mathematical model of a two-slope bunker with an adjustable unloading window and wall inclination angles was developed, and a formula for the movement of the cuttings array was derived according to this mathematical model [26].

For the practical verification of some parameters, a laboratory stand (Fig. 2) was developed and a study was conducted to identify patterns of cuttings discharge [25] and some of its parameters. The stand consists of two inclined walls with an adjustable position in the horizontal plane and installation angles. These walls are placed between vertical planes, the front of which is transparent for observing the unloading process. In this way, we obtained a typical slotted bunker, which makes it possible to determine the main parameters of the movement of the mass of cuttings during unloading.



Fig. 2. Laboratory stand for research the parameters of a slotted bunker

Empirical research on the laboratory bench was carried out according to the matrices of the two-factor experiment, as a result of which the optimal angles of inclination of the walls of the slotted hopper, the rational width of the unloading window was discovered, which will ensure full and uninterrupted unloading of cuttings in the absence of external forces (oscillations, vibrations, etc.) and with them. During the experiment, at each stage, the corresponding parameters α , β were set, which formed the width of the window b . With the closed unloading

window, the space between the walls of the bunker was filled with cuttings. When the walls were opened, unloading took place. If it stopped due to crypt formation, the experiment was repeated with an increased value of b . In this way, the minimum width of the unloading window was determined, at which the complete unloading of the hopper will be possible at the given values of α and β .

Based on the preliminary theoretical data, as well as the parameters obtained as a result of laboratory research, a number of solutions were synthesized, which were used in the development of a new design of the cuttings unloading mechanism.

III. RESULTS AND DISCUSSION

A. Laboratory research of the parameters of the dosing device

For the design of the cuttings feeding machine, the primary task is to ensure uniform and continuous unloading of a limited array of cuttings, from which they will later be individually selected and sent to the coulter. It was established that the main problem of delays and interruptions of movement when unloading cuttings from the bunker by gravity method is crypt formation. The cuttings in the vault (each of them) are kept from falling by normal reactions and corresponding frictional forces of adjacent cuttings.

Cuttings that occupy extreme positions are held by normal reactions and frictional forces of the sloping board and adjacent cuttings. Previous researches have established the main reasons for the formation of vaults and delays during unloading [25], [26]. It has also been established that there are bunker parameters at which all cuttings will leave the container. These parameters are primarily expressed by the width of the unloading window and the angles of inclination of the walls.

In order to test the hypothesis that there are such parameters of a bunker with passive walls at which crypt formation will not occur (will not affect the unloading process) and to research the parameters α , β and b , the following assumptions were made:

- o The humidity of the cuttings does not significantly affect the character of the crypt formation and the width of the minimum opening for the full unloading of the cuttings.
- o The angles α and β must be greater than the coefficient of friction of the cutting material against the hopper wall (for our research α and $\beta \geq 40^\circ$).
- o Variants of type $\alpha=40^\circ$, $\beta=90^\circ$ i $\alpha=90^\circ$, $\beta=40^\circ$ are specular («mirrors») the measurements on them should be the same.
- o The angle of inclination of one of the walls β can theoretically be more than 90° , by a maximum of $90^\circ - \alpha$. Thus, we will take $\alpha=40 \dots 90^\circ$ $\beta=40 \dots 140^\circ$.
- o An important parameter of the bunker is the opening angle of the walls δ . Which is formed by two walls $\delta = 90 - (\alpha + \beta)$.

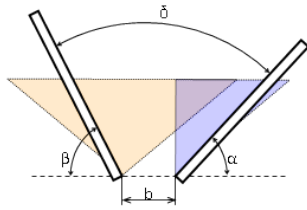


Fig. 3. Scheme for justification the magnitude of the angles α , β , and δ in the experiment.

As a result of the conducted research, it was established that the cuttings are unloaded according to the rules of normal (non-hydraulic) outflow of bulk material (Fig. 4a,b), i.e., first a pillar falls out above the hole, and then the layers move from the side. As research has shown (Fig. 4c, d), cuttings that are placed on a wall that is placed at a smaller angle (α or β) are the last to fall out.

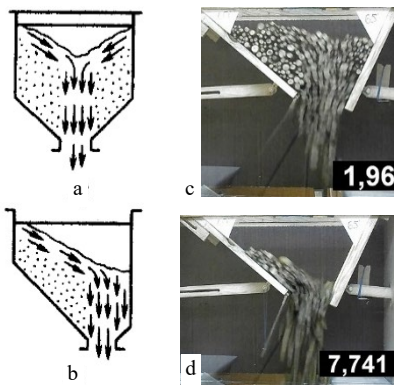


Fig. 4. The nature of cuttings unloading from a slotted hopper: a) the classic scheme of normal unloading from a double-sloped hopper, b) the same from a single-sloped hopper; c) formation of a dynamic flow during the experiment; d) completion of the unloading of cuttings from the hopper.

According to the results of the experiment were created different interpretations of the minimum width dependence of the unloading window b on the angles of inclination of the hopper walls (α and β).

It is convenient to choose the optimal width of the unloading window according to the bar chart, which takes into account the angle of inclination of one of the walls (α or β) and the angle of inclination of the walls (δ). We will have the diagram of Fig. 5.

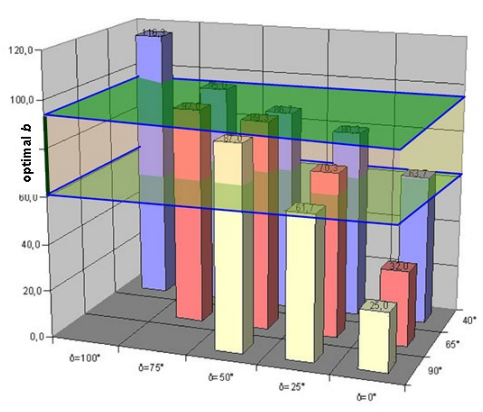


Fig. 5. Bar chart of the size of the width of the unloading window depending on the angle of inclination of the walls δ .

Figure 5 shows that the theoretically acceptable, minimum permissible value of the width of the unloading window b is 61-95 mm. However, as a result of research, it was observed that at critically small values of the window width, the cuttings are unloaded unevenly due to "temporary" crypt formation and its destruction. The movement of the flow becomes intermittent, and during unloading, as a result of the destruction of "temporary" vaults and micro vaults, the cuttings fly out disorderly (at different angles). When the value of the width of the unloading window b increases, this effect decreases, the movement of cuttings is smoother, the flow of cuttings is more uniform, and delays in the short-term formation of micro vaults and their destruction are reduced. Note that in a dynamic flow, emerging crypt formations self-destruct more easily, so it is important that the flow of cuttings "accelerate". It was also noticed that the unloading of cuttings is not affected by a slight (up to 20°) deviation of individual cuttings from the direction of the rows. During the researches, they were self-aligned while moving to the unloading window. That is, when unloading without vaults (large b), the unloaded material managed to be collected in an ordered array, composed of parallel rod-like elements, which could be considered as described in the mathematical model [26], [27].

Thus, to ensure a more uniform and smooth unloading of the cuttings flow, it is worth taking the width of the unloading window with a margin of the minimum permissible. When constructing the bunker, we will take the minimum value of the bunker to be 80 mm. Such a gap will provide with a margin (minimum permissible - 61.5 mm) unloading with a one-sided hopper with an angle of inclination of 25° and angles of inclination of the walls to the horizon α and β more than 40° .

B. Development of a dosing mechanism, individual selection and feeding of cuttings into the coulter.

On the basis of laboratory researches, it was found that by choosing the rational parameters of the slotted hopper, it is possible to achieve a complete discharge from it of rod-like materials with an imperfect shape (cuttings). These parameters were laid down in the mechanism of automated selection and supply of cuttings from the slotted hopper [33].

The basis of the development was the task of increasing the reliability and reducing labor costs for the process of planting cuttings, due to the development of an automatic machine for feeding them into the coulter, which ensures the possibility of obtaining uniform unloading of the hopper and uninterrupted individual delivery of planting material to the planting site.

To solve the problem, the design of an automatic machine for feeding cuttings into the opener is offered, in which the storage capacity is a slotted hopper formed with the help of two inclined walls. The walls of the hopper create a narrowing, forming an unloading window at the bottom (Fig. 6). The hopper is made so that the cuttings are located in it between two vertical parallel walls, the distance between which corresponds to the placement of the cuttings across the gap. The working elements of the machine are a drum with cells, a stop and a guide funnel (Fig. 6).

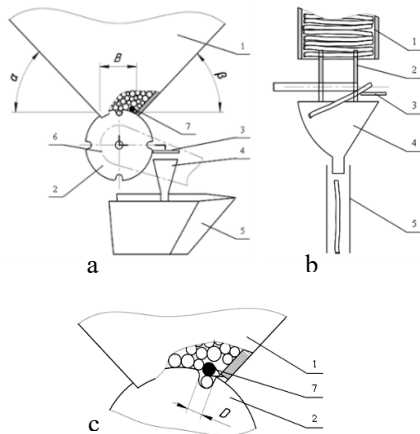


Fig. 6. Construction scheme of the machine for feeding cuttings into the coulters: a - side view of the automatic planter (with partial cuts); b - cross-section of the mechanism in the machine; c - scheme of operation of the cuttings separator; 1 - slotted hopper, 2. drum with cells, 3. stop, 4. guide funnel, 5 - coulters, 6 - flexible transmission (chain), 7 - cleaner.

The slotted hopper is filled with a layer of cuttings, which, under the influence of gravity, tend to advance to the unloading window. Narrowing of the layer of cuttings before their individual selection is carried out by narrowing the hopper in the lower part, until the edges form the walls of the unloading window. The width of the hopper corresponds to the placement of the cuttings transversely with a gap for their free movement. The angle of inclination of the sloping walls of the bunker α and β should be at least 40° , which will ensure the free rise of cuttings under the action of gravitational forces. To avoid the possibility of crypt formations, the width of the unloading window of bunker B, for cuttings with a diameter of 10...18 mm, should be at least 8 cm. The drum is made in the form of two disks with cells. The disks are placed at a distance of 0.3...0.5 of the length of the planting material, which allows cuttings to be accepted even with defects in shape. The cells are made in such a way as to ensure the retention of one cutting in them and the free emergence of others (Fig. 6c). Their width and depth should be 1.3...1.8 diameters of the cuttings, and the shape should ensure a smooth exit. A spring-loaded cleaner is installed on the front wall of the hopper for the free descent of excess cuttings. The diameter of the cleaner should correspond to the average diameter of the cuttings and have sufficient amplitude to enter the cells of the drum at least 1/3 of the depth. At the point where planting material falls from the cells of the drum, a stop is installed on one side, which ensures a change in the horizontal position in one direction. A guide funnel is installed under the stop, which finally orients the cuttings in a vertical position. The watering can at the bottom ends with a planting pipe from which the planting material enters the gap prepared by the coulters.

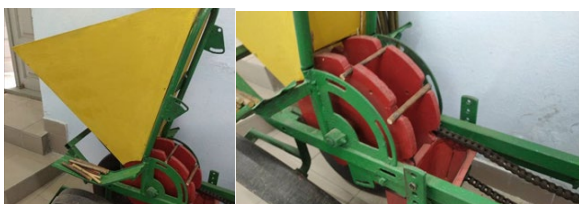


Fig. 7. General view of a field installation equipped with an automatic machine for feeding cuttings into the coulters

Before starting the operation of the machine equipped with this automatic device for feeding cuttings into the coulters, planting material is loaded into the slotted hopper so that its upper parts are on the side of the stop. The cuttings in the hopper continue to maintain their orientation, gradually moving towards the unloading window of the hopper under the influence of gravitational forces. When the aggregate moves, a drum with cells is activated by means of a flexible (chain) transmission. Cuttings that fall to the bottom of the cell are fixed there, and others are removed due to the shape of the back wall of the cell and the spring-loaded cleaner. When the drum rotates, the cuttings that got into its cells are taken out from under the hopper and fall out of the cell in a certain position, meeting the upper part with a stop, due to which their position changes from horizontal to inclined only in a certain direction and the cutting continues to move in the lower part forward. In the directional watering can, the planting material finally acquires a vertical position and enters the coulters, into the gap made by it, after which its position is fixed by wrapping or rolling means. The size of the step of planting cuttings can be adjusted by changing the gear ratio of the flexible transmission of the drive or the number of cells on the drum.

IV. CONCLUSIONS

In the conditions of the growing need for rapid expansion of the areas of energy crop plantations, there is a problem with the existing technical park for these purposes. In particular, increasing the productivity of planters inhibits the use of planters' labor for laying planting material. The development of a mechanism for individual selection and feeding of cuttings of energy willow to the opener will significantly increase the efficiency of planting both in terms of the quality of work and in terms of increasing the productivity of the aggregate. This paper proposes a solution to this problem, for which:

1. It has been experimentally proven that to ensure full gravity unloading of the hopper with a uniform and uniform flow of cuttings, it is necessary that the width of the unloading window be at least 80 mm, and the angle of inclination to the horizon (α or β) of at least one of the inclined walls should be more than 40° .
2. The developed design of the machine for feeding energy willow cuttings into the opener allows for the smooth individual selection of previously oriented energy willow cuttings from the slotted hopper and feeding them into the opener.
3. The automated system for supplying cuttings consists of a slotted hopper, a drum with cells, a flexible transmission of the drum drive, a guide funnel to the coulters. This design is protected by a patent of Ukraine.
4. The presented solution makes it possible to automate the process during the movement of the unit along the furrow, and accordingly, the need for a for an employee who would accompany the planter throughout the technological process, disappears.

The results obtained in the work can further serve to clarify and improve the machines that work with piece-by-piece selection of rod-like materials.

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