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Developing a New Harvester Head for Tree Felling

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Abstract

Technological progress is constantly advancing. After a detailed analysis of the existing options for technological equipment used in production, as outline in various patent information sources, the idea of modernizing the harvester (processor) head of logging machines emerged, aiming to enhance the function the equipment can perform. However, all currently existing designs of harvester heads either do not allow debarking or, when using them, slow debarking is carried out with multiple starts and stops of the debarking mechanism. The purpose of the variant of the modernization of the harvester head of a logging machine for felling, delimbing, and bucking of trees described in this study is to create such a technical device that will allow the debarking of assortments by a rotary debarking mechanism without stopping its operation at the moments of delimbing and bucking the trunk. The main research method in preparing the article materials was the patent search for analogues and the development of a new technical solution based on them, making it possible to implement the task set by the authors. As an analogue, the impulse type of the harvester head was chosen. As a result of the modernization of the existing technical solution, several important elements were added to the design. The principle of operation of the new technical solution is substantiated. The proposed working body of the feller-lopper-bucker performs capture, sawing, felling a tree, pruning, bucking into assortments, and debarking without stopping the debarking mechanism in the process of delimbing and bucking the tree trunk, which allows debarking timber without reducing the productivity of the harvester head.

Keywords: Full-mechanized, cut-to-length, harvester head, felling, bucking, delimbing, debarking.

1. Introduction

The current economic conditions, high prices for equipment maintenance, and long payback periods for expensive harvester heads have shown a need in the equipment market for a harvester head. Thus, it would be more affordable than conventional harvester heads, distinguished by simplicity, reliability, lightweight and high stem pulling power, lightness operation, and low-cost maintenance and could be installed on light and low-power forest tractors (Demchuk, 2012; Mokhirev et al., 2015; Pilyushina et al. 2019; Pamfilov et al., 2021; Rukomojnikov et al., 2022a).

A similar type of harvester head is a pulse harvester head with cyclic feed. The main difference between these harvester heads and conventional ones is that the trunk pulling operation uses hydraulic cylinders rather than feeding spiked wheels. Thus, these harvester heads do not have hydraulic motors for pulling the tree trunk. The downside of impulse harvester heads is the low (compared to conventional heads) tree trunk pulling speed. However, a positive point when using impulse harvester heads is the absence of spike marks on the tree trunk from the pulling rollers of the harvester head. Pulse harvester heads can also be used to equip small harvesters and processors.

Technological progress is continuously advancing. As a result of a detailed analysis of the existing options for technological equipment used in production and reflected in the sources of patent information, an idea arose to develop a new version of the modernization of the harvester (processor) head of logging machines, which allows increasing the number of functions it implements. The project of a new technical solution is based on combining the functions of harvesting wood assortments with their simultaneous debarking in one technical device.

Currently, debarking of timber is a widespread option for their further processing in the timber warehouses of enterprises. Almost all large woodworking manufacturing enterprises provide for the debarking of raw materials since the bark prevents the penetration of the antiseptic into the wood, which leads to damage to it by fungi or insects. However, when debarking is carried out at the timber warehouses of enterprises, it becomes necessary to further collect and dispose of it, which leads to additional material costs. In addition, the bark contains

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trace elements and minerals necessary to maintain and enrich the nutritional properties of forest soils, which makes it expedient to consider options for debarking timber directly in the process of obtaining assortments.

Another option for the effective use of the described working body may be its use when felling timber when further rafting of logs on the water is expected. The harvester head, which can remove bark, makes it possible to increase the buoyancy of coniferous small logs.

The next positive point realized when debarking logs in the forest is the reduction of damage to wood from the effects of bark beetles. This is a huge problem in the forests of Central Europe (Forest Economic Advisors, 2024), Germany, the Czech Republic and Austria (Ministry of Agriculture of the Czech Republic, 2017, 2020; International Forest Industries, 2024), where a significant part of the wood is harvested for the purpose of timely use of wood damaged by bark beetles. Under conditions of global warming, the resistance of trees to bark beetles is gradually decreasing (Netherer and Schopf, 2010; Jönsson et al., 2011; Seidl et al., 2014, Hlásný et al., 2021; International Forest Industries, 2024).

2. Materials and Methods

One of the methods of solving the problem is the mechanical removal of the bark, implemented either by stem debarking with harvester heads or the debarking configuration of conventional heads (Labelle et al., 2019; Heppelmann et al., 2019; Mergl et al., 2021), or by scraping the bark, removing the bark only in strips parallel to the stem axis (Rukomoinikov et al., 2022b).

The work was conducted based on the method of patent search for information. During the patent search, the databases Esp@Cenet, Eapatis, Google Patent, Yandex Patent, and the database of the Federal Institute of Industrial Property of the Russian Federation were analyzed. Analysis of the scientific developments (Heppelmann et al., 2016; Murphy and Acuna, 2017; Labelle et al., 2019; Bennemann et al., 2020) along with various technical solutions identified from the patent search (Keskinen et al., 2014; Peterson, 2016; Alfthan, 2017; Alfthan and Palmroth, 2018; Brett, 2018; Rukomojnikov et al., 2018) has enabled us to focus on several designs of the working bodies of harvesters (processors). These designs allow for the debark timber during the process of harvesting assortments. Among the harvester heads of the impulse type, no analogues of the proposed technical solution were found (Budnik, 2012; Posharnikov, 2012; Frolov and Grigoriev, 2017). All such structures are developed based on harvester heads equipped with pulling rollers for pulling the tree trunk (Kroher et al., 1986; Rukomojnikov et al., 2019).

In particular, the currently known method includes harvesting assortments with the removal bulging butt and a working body for its implementation, consisting of a special machine on which a body with cutters is mounted (Kroecher, 1987). Such a machine with a working body is in the technological process in front of the feller-delimber-buncher; that is, an additional rather complex machine is built into the technological process. In addition, it sharply increases the number of passes of the machines along the technological corridor, which leads to an increase in the depth of the track, worsening the possibility of the machines. The access of such a machine to each tree is very problematic since the number of passages along one technological corridor is limited. The main disadvantage of this mechanism is that the previously proposed method and the working body of the feller-delimber-buncher do not provide debarking of assortments, which significantly limits the technical capabilities of the working body.

The closest in technical essence is the device (Tsarev et al., 2018), containing the working body of the feller-delimber-buncher to produce a debarked assortment. It includes a body on which a saw mechanism is mounted, delimbing knives attached to the body using axes, and a pulling mechanism made of rotary rollers. The main difference is that in the lower part of the body, there is a debarking device in the form of a stator, inside which there is a rotor with hinged cutter knife. In turn, a cutter knife is connected to the pressure springs through the rocker's arm, and the rotor itself is connected to the hydraulic motor utilizing a belt drive. In this case, the stator is mounted on the housing with the possibility of rotation parallel to the plane of movement of the saw mechanism.

The main disadvantage of the known method of technical solution for its implementation is that when bucking a tree trunk, it is necessary to suspend the operation of the debarking mechanism, which leads to a decrease in productivity and quality of debarking. In addition, such a design does not provide sufficient impact of the knife on the branches. This is because the speed of the knife is limited by the low speed of the debarking mechanism, which minimizes the shock load on the branches.

3. Results

As a result of the patent search and analysis of analogues, a new technical solution for the impulse harvester head was proposed (Figure 1). The new design of the harvester head is characterized by the transverse sawing of the trunk of a sawn tree, which is carried out without slowing down and without stopping the rotation of the debarking mechanism. The working body of the feller-delimber-bucker for the production of debarked assortments includes a body on which delimbing knives are mounted, attached to the body using axes, a mechanism for measuring the lengths of assortments, saw and debarking mechanisms. The body consists of three telescopic sections, two of which have pairs of delimbing knives, and a debarking mechanism is installed on the third section of the working body with the possibility of its continuous longitudinal movement along the axis of the body.

Figure 1. Logging harvester working with a new harvester head

The present invention is illustrated by drawings showing the sequence of operations of the technological process of felling, delimbing, bucking, and debarking of timber. Figure 2(a) shows the view of the working body when cutting down a grown tree. Figure 2(b) shows a view of the working body when the tree is moved to a horizontal position and the upper telescopic section is extended with simultaneous delimbing in the area of operation of the knives installed on it during the initial step of the trunk processing. Figure 2(c) shows the view of the working body when moving the middle telescopic section along the shaft with simultaneous gradual movement along the shaft of the lower telescopic section and debarking during the initial step of processing the shaft. Figure 2(d) shows the working body when extending the upper telescopic section with simultaneous cutting of branches in the zone of action of the knives installed on it with simultaneous gradual movement along the trunk of the lower telescopic section and debarking during the second step of processing the trunk. Further, Figure 2(e) shows the view of the working body when moving the middle telescopic section along the shaft with simultaneous gradual movement along the shaft of the lower telescopic section and debarking during the second step of processing the shaft. Figure 2(f) shows the view of the working body when separating the assortment.

The working body for harvesting debarked assortments includes a body on which delimbing knives 1 are mounted, attached to the body using axes, a mechanism for measuring the lengths of assortments 2, a saw mechanism 3, and a debarking mechanism 4. The body consists of three telescopic sections, two of which are pairs of delimbing knives. In the third section of the working body, a debarking mechanism is installed with the possibility of its continuous longitudinal movement along the axis of the body relative to the first two sections when they drag the tree trunk through the delimbing knives in the process of successive harshly extension sections and trunk interception with delimbing knives installed on them with transverse sawing of the trunk with a saw mechanism.

A pulse broaching mechanism is used to move the telescopic sections relative to each other. The speed of movement of the debarking mechanism equipped with a cutter knife is not related to the speed of movement of the knives for delimbing the tree by placing the debarking mechanism on the lower independent telescopic section of the device.

Due to the delimbing knives of the first (upper) and second (middle) telescopic sections, the tree is kept in the power circuit. The saw mechanism is located on the second (middle) telescopic section. The working body is equipped with a mechanism to accurately measure the lengths of the assortments located in the second (middle) telescopic section. The working body is attached to the end of the manipulator handle through bracket 5. Relative to the bracket, the head can rotate from a vertical to a horizontal position.

The work of the proposed working body felling-lopping-bucking machine is carried out by the operator of the forest harvester. It directs the modernized harvester head to a growing tree, capturing, cutting, and felling the tree. In this case, the working body is transferred to a horizontal position together with the trunk of a fallen tree sandwiched between the delimbing knives. At the same time, the debarker is brought into a working position for debarking assortments so that the tree trunk is processed inside the contour formed by the debarking knives. The movement of the working body along the trunk is carried out step by step. The working body moves along the tree trunk due to the impulse mechanism. First, the delimbing knives of the first (upper) telescopic section open, and the upper part of the body sharply moves forward due to the impulse mechanism. At the same time, the upper delimbing knives installed on it produce delimbing. Also, a gradual movement along the trunk of the rotary debarking mechanism mounted on the third (lower) telescopic section is carried out, and the tree trunk is held by delimbing knives of the second (middle) telescopic section.

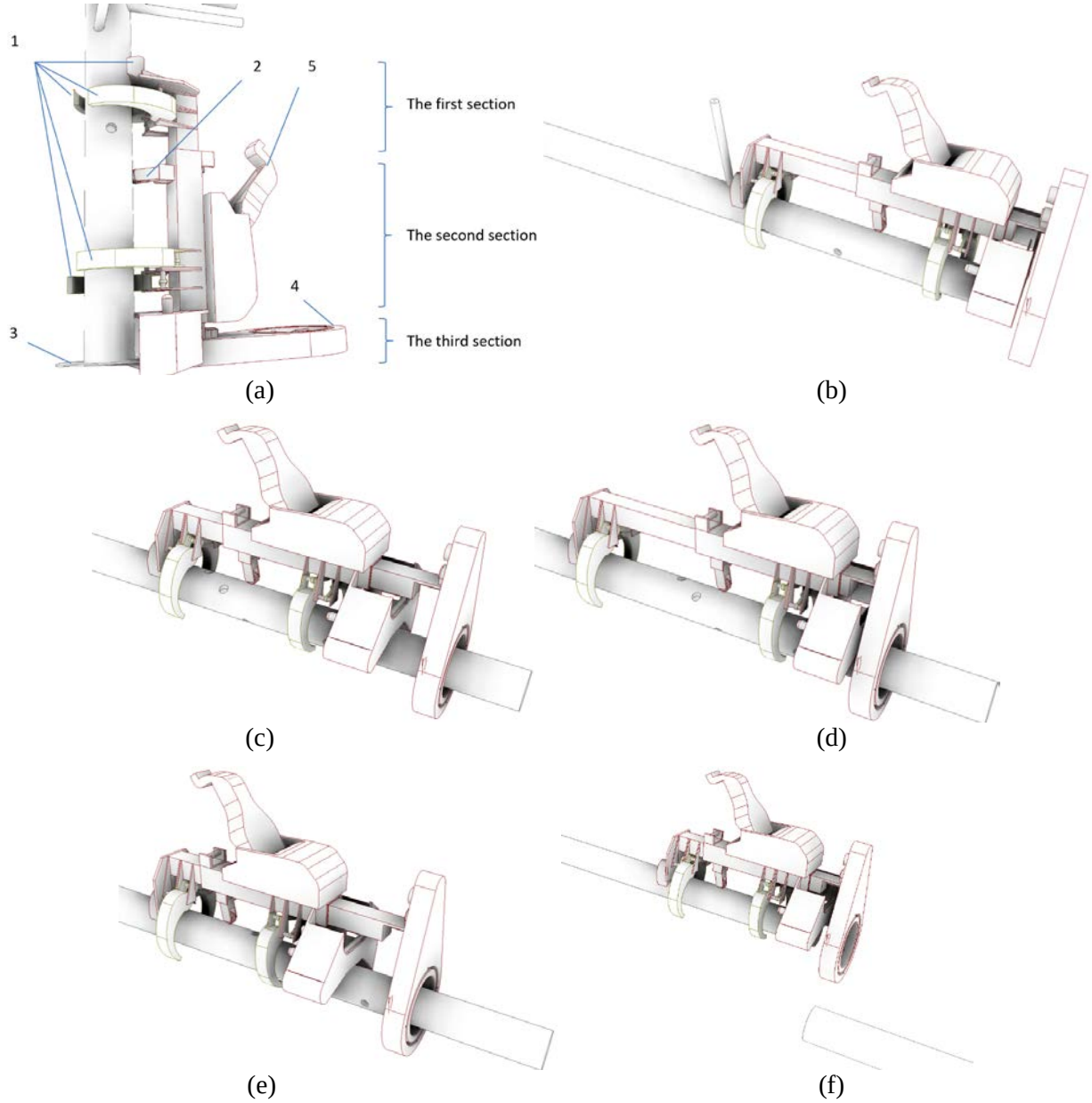

Figure 2. Modernization of the design of the harvester head for logging. *Source:* Compiled by the authors

When the rotary debarking mechanism approaches the second telescopic section of the device, the delimbing knives installed on the second (middle) section of the device are opened, and the second (middle) section is sharply extended until it reaches the first (upper) section of the device. Meanwhile, the movement of the third (lower) telescopic section and the uniform debarking of the tree trunk do not stop but are carried out at the same speed, and the tree trunk is held by delimbing knives of the first (upper) telescopic section of the device. The process of successive alternate sharp extension of the first (upper) and second (middle) sections of the device with constant, uniform movement along the trunk of the third (lower) section of the device, equipped with a debarking mechanism, continues until the tree trunk is completely processed. Also, without slowing down and stopping the movement of the third (lower) section and rotating the barking mechanism barbers, each time the specified length of the assortment is reached, the tree trunk is sawn transversely. Subsequent assortments are processed in the same way.

4. Discussion

This study showed similarities with previous works that any constructive solution of the harvester head should be able to capture, cut down, fell trees, and delimb them. However, comparing the proposed technical solution with technical solutions previously patented by other researchers allow us to conclude that there are currently no options for the practical use of structures that allow performing the complex of operations described in this study. All similar technical solutions have not yet been implemented in a real production process. They exist only in the form of patents. T They have a number of shortcomings that can be eliminated at the stage of modernization. According to our study, the

modernization of the harvest head increases the productivity of the harvester in comparison with the option of using designs proposed by other researchers.

The use of the proposed variant of the pulsed harvester head makes it possible to reduce damage to wood from the effects of bark beetles, increase the buoyancy of coniferous thin-gauge logs when rafting wood along rivers, concentrate most of the waste from logging operations in the cutting area and avoid additional material costs for their disposal during debarking in warehouses of timber enterprises.

Currently, there are designs of harvester heads with rollers for grabbing and dragging the trunk of a tree (Bisballe, 2017; Rukomojnikov and Vedernikov, 2019; Rukomojnikov and Kuptsova, 2021) and impulse-type harvester heads (Frolov and Grigoriev, 2017). However, they are not capable of debarking timber.

There are also similar harvester heads with rollers for grabbing and dragging the trunk of a tree, allowing debark timber (Shegelman et al., 2012; Tsarev et al., 2018; Rukomojnikov et al., 2022b). However, some of these designs require the rotation of the tree trunk for its debarking and two-stage processing. This significantly limits their technical capabilities (Shegelman et al., 2012). Other designs are characterized by a low impact of the knot-cutting knives on the branches while dragging the tree with rollers and debarking it with a debarking mechanism rotating around the axis of the tree. This reduces productivity harvester (Tsarev et al., 2018).

In addition, there are designs of harvester heads with rollers for grabbing and dragging the trunk of a tree, which remove the bark in longitudinal strips along the axis of the trunk (Rukomojnikov et al., 2022b). These structures do not allow the removal of bark from the entire trunk of the tree.

Technical solutions use different different traction types of feed rollers (Shegelman and Vasiliev, 2018; Heppelmann et al., 2019). Since a debarking process requires them to be fed through the harvesting head on multiple occasions to remove bark, average harvesting productivity might be reduced by approx. 10% compared to productivity measured with conventional harvesting heads.

All harvester head designs found during the patent and literature search for debarking tree trunks is made based on harvester heads equipped with dragging rollers for pulling the tree trunk. The analysis showed that currently, there are no designs of impulse-type harvester heads similar to the technical solution proposed in the article.

5. Conclusion

For this study, new constructive solution of the harvester head was proposed to the attention of specialists of researchers and specialists in scientific and industrial organizations, which ensures the high-quality characteristics of finished products. The technical solution described can contribute to the technical and economic development of the industry.

To create the new design and introduce it into production, a complex and lengthy process of further laboratory and production tests is necessary. However, attracting the attention of enterprises to the possibilities of effectively solving the problems of the forest complex is the first important step towards further development. It allows expanding the range of existing equipment options for cutting machines with increased process efficiency.

The next stage in the development of the technology of work presented in the article and the design of the device for its implementation should be creating an experimental device, conducting experimental research and introducing it into production. The prospects for further theoretical study of the issues of improving the efficiency of the harvester head can be reduced by improving its individual parts, reducing weight, and increasing the speed, reliability, and durability of operation.

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