Simulation modelling of the multioperational felling-bunching machine

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Abstract. The article considers the multioperational felling-bunching machine proposed by the authors, the one equipped with an accumulating head (AH) and a bunching device. The MFBM is designed for felling small-diameter trees in the accumulation mode and processing small-diameter trees into bunches. The diameter of the bunches is 0.1-0.2 m with the length of 6 m. Compacted bunches can be transported by forwarders and timber carriers as ordinary assortments. The MFBM effectiveness was studied on mathematical models using simulation methods for two modes of machine operation. The first mode of the MFBM operation is performed without combining tree bunching with moving the machine between work sites and accumulating trees in the AH. The second mode includes combining these operations. For comparison, simulation experiments were carried out using a conventional LP-19 FBM. The LP-19 FBM performance when felling small-diameter trees with a volume of 0.046 m$^3$ drops by almost 10 times as compared with felling trees with a volume of 0.4 m$^3$. The MFBM performance in all modes and similar working conditions turned out to be 2-3 times as high compared to the LP-19 FBM performance. When felling small-diameter wood, the MFBM shows the highest performance in the mode of combining operations. The MFBM performance in this mode with an average volume of a small-diameter tree of 0.046 m$^3$ and the number of trees on the site being 8 pcs. turned out to be three times as high compared with the LP-19 FBM.

1. Introduction

Small-diameter trees [1-3] and logging debris [4-6] are currently regarded as a valuable source for the production of fuel chips [7-8]. For machine harvesting of such trees, felling-bunching machines (FBM) are used. To improve the performance, FBMs can be equipped with accumulation cutting heads (AH) (Figure 1) [9-12]. In this case, the cut trees are accumulated in AH and then laid on the ground (Figure 2).

The disadvantage of the small-diameter tree felling technology using the FBM is that the cut trees are laid on the ground as unbound bunches for the purposes of subsequent transportation by forwarders (Figure 2).

Since the FBM technology does not provide for the compaction of branches and twigs, the dimensions of the tree bunches can be quite large due to their low compactness coefficient. Such bunches of trees are difficult to transport by a forwarder across the site and it is almost impossible to use such vehicles on public roads and motorways.
At present, bunchers are used to compact logging debri (i.e. treetops, branches and twigs) (Figure 3). The buncher collects and compacts logging debri, forming bunches.

![Figure 1. Accumulation cutting head (the author’s photo).](image1)

![Figure 2. A bunch of cut small-diameter trees (the author’s photo).](image2)

![Figure 3. Logging debri buncher (the John Deere photo).](image3)

2. Materials and methods
In this paper, we consider the technology of harvesting small-diameter wood with its processing into compacted bunches on the site. To implement this technology, equipping the FBM with the AH is proposed (Figure 1) along with combining the machine with a bunching mechanism (Figure 3).

The currently used bunching machine (Figure 3) is designed to make bunches of a quite large diameter (0.6-0.8 m). As a result, such bunching device is rather sizeable and therefore has been manufactured so far as a separate vehicle to be used on a working site.

When harvesting small-diameter trees off one site, the FBM accumulation head typically cuts 3 to 6 trees. In this case, the volume of the bunch will be much smaller than the bunches of logging debris. According to our estimations, the diameter of such bunches can be 0.1-0.2 m, with the length of 6 m. Therefore, the FBM bunching device can be more compact to be installed on FBM.

This article considers the way the multioperational felling-bunching machine (MFBM), the one that we designed, operates. MFBM allows both harvesting small trees in the accumulation mode and compacting branches and twigs, as well as processing small trees cut off a single site into bunches.
The proposed solution should increase the overall performance of the tree harvesting machine system by reducing the size of the transported tree bunches. The technical solution of the task is ensured by the fact that the MFBM is additionally equipped with a device for processing trees into bunches.

Figure 4 shows the MFBM general conceptual model. The machine contains a cutting mechanism (1) in the form of the AH and a mechanism for moving trees (2) in the form of a manipulator (3), as well as a device for processing trees into bunches (4).

The MFBM operation flow chart along with the forwarder is shown in Figure 5.

![Figure 4. MFBM conceptual model.](image1)

![Figure 5. MFBM operation flow chart along with the forwarder.](image2)

Work on the site (1) with small-diameter trees (2) starts with harvesting trees and processing them into bunches (4) using the MFBM (3). The forwarder (5) picks up bunches (4) and takes them to the forest depot, where bunches are stacked or loaded for transportation.

Thus, the proposed solution allows to compact branches and twigs, as well as to process cut trees into transportable bunches.

According to the conventional technology that uses the FBM, unbound trees are laid on the ground. The trees are then loaded and transported by a forwarder, the volume of the transported trees being significantly larger as compared with the volume of compacted trees bunches. Experience in applying bunching technology for logging debris shows that the volume of compacted logging debris in bunches gets reduced by 80%. Thus, upon bunching, the forwarder will be capable of transporting a much larger volume of small-diameter trees in solid cubic meters, which might lead to an increase in overall performance.

The effectiveness of the technological processes discussed above was studied on mathematical models [13-14] using simulation methods [15-17].

The obtained data was compared with indicators of the current harvesting technology using the FBM.

3. Results and discussions
The intensity of harvesting small-diameter trees by the felling machine can be determined according to the formula:
\[ \lambda = \frac{1}{T} \]  

(1)

where, \( T \) – a felling machine cycle time, s.

The felling machine hourly productivity (\( P_{hr} \)) can be determined according to the formula:

\[ P_{hr} = \frac{3600 \cdot q \cdot n}{T} \]  

(2)

where, \( q \) – average tree volume, m\(^3\); \( n \) – number of trees in the AH.

Herein, the maximum number of trees in the AH is equal to the number of trees on the site.

Cycle time for small-diameter trees cutting using the LP-19 FBM with a regular cutting head, in terms of a single tree, can be determined by the formula:

\[ T_{FBM} = t_1 + t_2 + t_3 + t_4 + t_5 + t_6 + t_7 + \frac{t_8}{n} \]  

(3)

**Figure 6.** MFBM performance based on the average tree volume.

The graph above (Figure 6) shows that the MFBM performance depends on both the average tree volume and the number of trees on the site. In the case of combining the operations, the machine performance reaches its maximum, all other factors being equal. For example, for 4 trees on the site, the MFBM performance without combining the operations is 0.4 m\(^3\)/hr to 9.4 m\(^3\)/hr. When operating the MFBM with combining the operations, its performance can be 0.5 m\(^3\)/hr to 13 m\(^3\)/hr.

As the number of trees on the site increases, productivity goes up. For example, for an average volume tree, its size being of 0.046 m\(^3\), with 4 trees on the site, the MFBM performance (with combining the operations) starts at 6.3 m\(^3\)/hr; 12 trees on the site result in the machine performance rate of 8.2 m\(^3\)/hr. Operating the MFBM without combining the operations result in the performance rates of 4.5 m\(^3\)/hr and 7 m\(^3\)/hr, respectively.
4. Summary

The research results allow us to draw certain conclusions.

For the purposes of harvesting small-diameter trees, the multioperational felling-bunching machine (MFBM) equipped with a storage head (AH) and a bunching device was proposed by the authors of the research paper. The MFBM enables one to fell small-diameter trees in the accumulation mode, compact branches and twigs and process small-diameter trees cut off a single site into bunches. According to our estimations, the diameter of such bunches can be 0.1-0.2 m, with the length of 6 m. Compacted bunches can be transported by forwarders and timber carriers as ordinary assortments.

The effectiveness of the way the MFBM operates was studied on mathematical models using simulation methods. The two modes of operation were considered. The first mode of the MFBM operation is performed without combining tree bunching with moving the machine between work sites and accumulating trees in the AH. The second mode includes combining these operations.

For comparison, simulation experiments were carried out using a conventional LP-19 FBM. The results of the experiments showed that the piece by piece felling of small-diameter trees using FBM is ineffective. The LP-19 FBM performance when felling small-diameter trees with a volume of 0.046 m³ drops by almost 10 times as compared with felling trees with a volume of 0.4 m³.

The MFBM performance in all modes and similar working conditions turned out to be 2-3 times as high compared to the LP-19 FBM performance.

When harvesting small-diameter wood, the MFBM shows the highest performance in the mode of combining operations. The MFBM performance in this mode with an average volume of a small-diameter tree of 0.046 m³ and the number of trees on the site being 8 pcs. turned out to be three times as high compared with the LP-19 FBM.

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