Selecting a harvester head using digital modeling

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Abstract. The article presents theoretical and experimental studies on the justification of the harvester head selection. A mathematical model of the harvester’s work has been developed based on natural and constructional-technological factors. The results obtained make it possible to justify the characteristics of the harvester head for the Siberian region of Russia, in particular, the maximum width of the gripping levers opening of the harvester head. When selecting the harvester head, it is recommended to proceed from the fact that some of the large trees can be left in the cutting area. Felling of such trees can be done with chainsaws. For the forests of the Siberian region of Russia, a harvester head with a maximum width of the gripping levers opening of the harvester head of 750-850 mm is recommended. In this case, the harvested number of trees without taking into account the thin gauge will be 94.1-99.1 % of the total number of trees in the cutting area, and the volume of harvested wood-99.1-99.9 %.

1. Introduction

For felling trees, various logging machines are used, for example, harvesters. Such machines are equipped with a manipulator and a mechanism for cutting trees - harvester heads (HH) (figure 1) [1-11].

The performance of the harvester largely depends on the characteristics of the HH. The analysis of the HH operation allows you to distinguish two groups of factors that affect the choice of the HH:

1. Constructional-technological factors, determined by the design of the HH and the processing time cycles of a single tree.
2. Natural factors, determined by the forest inventory indicators of both the stand as whole and individual trees.

It should be noted that trees of different diameters get within the coverage area of the harvester. Trees in diameter (at a height of 1.3 m) can be divided into three groups:

1. Small-sized trees, with a diameter of 60 to 130 mm.
2. Medium-sized trees, with a diameter of 140 to 250 mm.
3. Large-sized trees, with a diameter of 260 mm or more.

Small-sized trees with a diameter of less than 140 mm, due to the low yield of industrial products, are usually left on the cutting area, including as undergrowth.

Large-sized trees that cannot be cut down and processed by the HH due to the fact that the diameter of the tree at the point of cutting exceeds the maximum width of the gripping levers opening of the HH, also remain on the cutting area.

Here the problem of choosing the HH arises. What should be the width of the opening gripping levers of the HH, so that the number and volume of large-sized trees left on the cutting area would meet the forestry requirements and would be economically justified?
2. Methods and Materials

The research was carried out by methods of simulation modeling on mathematical models [8-11, 13-15] for the Siberian region of Russia.

In this article, when choosing the HH, the determining factor was the maximum width of the opening gripping levers of the HH, which determines the maximum diameter of the tree that the HH can grab.

In the experiments, HH with the maximum width of the opening gripping levers of the HH from 250 mm to 950 mm with a step of 100 mm were studied.

A total of 8 series of experiments were planned. To obtain statistically significant results, the duration of the harvester in each experiment was assumed to be 10 000 hours or 36 000 000 sec. At the same time, the size of the cutting area was considered as "infinite".

Each tree generated in the model received a set of attributes: $V_i$ (the volume of the tree), $d_i$ (the diameter of the tree at the cut point), $H_i$ (the height of the tree), $n_i$ (the number of assortments).

The assigning attribute procedure for each tree in the model was adopted as follows:

1. For each series of experiments, head with a certain width of the opening gripping levers was assigned.

2. The diameter at a height of 1.3 m of each $i$-th tree generated in the experiment in the model was determined as a random number, using a beta-distribution with an experimentally established range of diameter variation for the Siberian region. An example of generating trees in one experiment is shown in the form of a histogram in figure 2.

3. The volume of the length-tree was determined for each generated $i$-th tree by the diameter at the cut point according to the empirical formula:

$$V_i = 0.0002 \cdot d_i^{2.3846} \cdot m^3$$  \hspace{1cm} (1)

where, $d_i$ – diameter of the $i$-th tree at the cut point:

$$d_i = 1.2 \cdot d_{i,1.3m} \cdot m$$  \hspace{1cm} (2)

where, $d_{i,1.3m}$ – diameter of the $i$-th tree at a height of 1.3 m.
Figure 2. Histogram of tree generation by diameter at a height of 1.3 m, distributed by beta-distribution for forest plantations of the Siberian region of Russia (average diameter 24.341 cm).

4. The height of the \( i \)-th tree was determined by the diameter at the cut point according to the empirical formula:

\[
H_i = 12.457 \cdot \ln(d_i + 4.692) - 21.709, \text{m}
\]  

(3)

5. The number of assortments obtained from the \( i \)-th tree was determined based on the height of the \( i \)-th tree by dividing by the length of the tree with rounding down:

\[
n_i = H_i \lfloor 6
\]  

(4)

The volume of all trees generated in each experiment was determined by summing up the volume of each tree:

\[
V_{\text{sum}} = \sum_{i=1}^{N} V_i, \text{m}^3
\]  

(5)

where, \( N \) – the total number of trees generated in the experiment, pieces.

The volume of all trees processed in each experiment was determined by summing the volumes of \( V_{i, d_{\text{max}}} \) only of those trees whose diameter at the cut point \( d_i \) was less than or equal to the maximum width of the opening gripping levers of the HH \( d_{\text{max}} \).

Harvester productivity in the model was defined as the volume of all cut and processed trees per hour:

\[
P_{\text{hour}} = \frac{3600 \cdot \sum_{i=1}^{N_{d_{\text{max}}}} V_{i, d_{\text{max}}}}{\sum_{i=1}^{N_{d_{\text{max}}}} T_{i, d_{\text{max}}}}, \text{m}^3/\text{hour}
\]  

(6)

where, \( T_{i, d_{\text{max}}} \) – time for the \( i \)-th processing cycle of the \( i \)-th tree, sec; \( V_{i, d_{\text{max}}} \) – volume of processing of the \( i \)-th tree during the \( i \)-th cycle, \( \text{m}^3 \); \( N_{d_{\text{max}}} \) – number of processed trees during the simulation.

The cycle time for processing each \( i \)-th tree can be calculated using the formula:

\[
T_{i, d_{\text{max}}} = (t_1 + t_2 + t_3 + t_4 + t_5)_i
\]  

(7)
where, $t_1, t_2, t_3, t_4, t_5$ – accordingly, the time cycles for delivering the HH to the tree, clamping the levers, felling the tree (includes cutting, pushing and moving the tree to the processing site), cutting branches and bucking.

The time of moving the harvester from one technological stop to another was not taken into account.

3. Results and Discussion

The results of the research are presented in the form of graphs of the curves shown in the graphs figures 3-4.

From the graph in figure 3, it can be seen that the productivity of the harvester increases with an increase in the maximum width of the opening gripping levers of the HH. For example, with a maximum opening width of the gripping levers of the HH of 250 mm, the harvester capacity is $3.9 \text{ m}^3/\text{h}$. With a maximum width of the opening gripping levers of the HH of 950 mm - $25.4 \text{ m}^3/\text{h}$.

![Figure 3. The dependence of the harvester productivity on the maximum width of the opening gripping levers of the HH.](image-url)

Note that the harvester's productivity increases most rapidly when the width of the opening gripping levers of the HH increases from 250 to 750 mm. This is due to the fact that the number of harvested trees of a larger volume increases in this range, while the time for felling trees increases slightly with the growth of their volume. The reduction in the increase productivity of the harvester in a range of widths gripping levers head from 750 to 950 mm is due to the fact that the number of large trees in the total number of trees according to the law of distribution (figure 2) increases slightly.

The graph in figure 4 shows that the percent of harvested wood volume and number of trees increases with increase of the maximum width of the opening gripping levers of the HH. It should be noted that these percentages were calculated without taking into account small-size wood, which is not harvested. So, for example, at the width of the opening gripping levers HH 250 mm, the percentage of the volume of harvested wood relative to the entire wood is equal to 6.1 %. When the width of the opening gripping levers HH 950 mm - 100 %. If we analyze the number of trees, the corresponding growth is from 46.3 % to 100 %. That is, in the latter case, all large-sized wood is harvested.

Note that the percentage of harvested trees grows most rapidly, both in volume and quantity, with an increase in the width of the opening gripping levers of the HH from 250 to 750 mm. Moreover, the percentage of the number of harvested trees exceeds the percentage of the volume of harvested wood. At the same time, the difference between these percentages decreases rapidly with an increase in the width of the opening gripping levers of the HH, which is especially noticeable in the range from 750
to 950 mm. This is due to the fact that the volume of the harvested tree is proportional to the square of its diameter.

![Graph showing the dependence of the percentage of harvested wood on the maximum width of the opening gripping levers of the HH.](image)

**Figure 4.** The dependence of the percentage of harvested wood on the maximum width of the opening gripping levers of the HH.

4. **Summary**

The results obtained in the experiments allow us to justify the size of the HH for the Siberian region of Russia, in particular, the maximum width of the opening gripping levers of the HH.

When choosing the size of the HH, it should be understood that the HH designed for harvesting all the trees may be unacceptable in size and weight, which will affect the size of the manipulator's departure (it will decrease). And this in turn will lead to a reduce in the processing zone from one stop and a decrease in productivity due to an increase the number of the harvester's movements. It should be assumed that some of the large-sized trees can be left on the cutting area. Moreover, large-sized trees according to modern international requirements for sustainable forest management should be left on the cutting area as seed trees or for the conservation of biological diversity (up to 20 trees per hectare). If necessary, such trees can be cut by chainsaws after the harvester.

If we proceed from the number and volume of harvested trees, the width of the opening gripping levers of the HH for the Siberian region of Russia can be recommended in the range of 750-850 mm. In this case, the percentage of the harvested number of trees, excluding thin-sized wood, will be 94.1-99.1 %. As for the volume of harvested wood, it is close to 100 % and is 99.1-99.9%.

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