Selection of parameters of machines for collection of logging waste

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Abstract. The article presents a methodology for a reasonable choice of parameters of a machine for collecting logging waste, which allows to determine the possibility of the machine's movement depending on various design parameters and natural-production factors when performing technological operations based on an assessment of the traction and coupling properties of the base chassis. A relationship has been established to determine the resistance force to dragging of logging waste, which takes into account the taxation characteristics of the plantation (liquid stock, species composition and density of wood), the parameters of technological equipment (its width) and the peculiarities of the location of the shafts of logging waste through the average distance of passes. The results of determining the resistance force of overcoming a stump with a tooth of technological equipment of a rake type are also given. The proposed nomograms allow, based on the specified operating conditions, to determine the total force of resistance to movement from technological equipment and branches. From this value, using the graphical-analytical method, based on the type of soil, the considered layout of the base chassis and the expected speed of operations, the minimum required engine power, tangential force thrust and weight of the base chassis are established. Based on the results obtained, recommendations are given on the use of various types of base chassis, depending on the type of soil.

1. Introduction

The issue of using logging waste is acute in this time. The introduction of collection technologies and their use ensures not only the integrated use of wood [1], but also allows ensuring compliance with fire and sanitary requirements [2–3]. At the same time, collection and transportation of logging waste is a rather laborious operation, for which wheeled and caterpillar forest machines can be used, including those used for the main logging operations using assortment technology [5–7]. In this case, the base chassis can be used with various design features and different technological equipment [5–9]. When carrying out logging operations on soils of type IV, where, apart from using rope skidders, it is not possible to efficiently harvest logging, the collection of logging waste is energy-consuming and ineffective [10]. Taking into account the significant volume of logging work in final felling, the most productive and economically feasible is the collection of logging waste by rake-type machines. At the same time, in view of the possibility of installing this type of technological equipment on the base chassis
of various layouts (tractors, forwarders, skidders, etc.) and the possibility of changing their parameters, it is relevant to study the influence of various operational, technological and technical parameters, which affect the characteristics of a machine for collecting logging waste [11, 12].

2. Materials and methods

The formation of shafts in a felling area from logging waste, as well as the effectiveness of this work, depends on the design and geometric parameters of the equipment. In this case, the effective implementation of the considered technological operation is carried out when the conditions for the movement of the machine are met [13]:

\[ P_\phi \geq P_k \geq P_f \] (1)

where \( P_\phi \) – the traction force of the adhesion, N; \( P_k \) – the tangential force traction force of the base chassis, N; \( P_f \) – the resistance force of dragging logging waste along the felling area, N.

The realizable traction force of the adhesion \( P_\phi \) depends on type of the soil asked in the design studies through the adhesion coefficient \( \varphi \) and the adhesion weight \( G_{AW} \), N. It should be noted that the adhesion weight in the general case depends on the weight of the machine (tractor) \( G_M \), N, and its layout solutions, taken into account through the coefficient of redistribution of the coupling weight \( k \). Its value for all-wheel drive forestry machines is 1, and for non-all-wheel drive it depends on the overall layout and is defined as

\[ k = \frac{R}{G_{AW}} \] (2)

where \( R \) – the total load on the driving wheels (as a rule, the wheels of the rear axle or the tractor balance bogie), N.

Then the traction of force the adhesion \( P_\phi \) is determined by the formula (3)

\[ P_\phi = G_{AW} \cdot \varphi = G_M \cdot k \cdot \varphi. \] (2)

The force of the total resistance to the movement of the machine for collecting logging waste \( P_f \), N, is determined by the expression

\[ P_f = P_1 + P_2 + \sum P_i, \] (3)

where \( P_1 \) – the force of resistance to the dragging of logging waste in front of the processing equipment, N; \( P_2 \) – the force of resistance to movement of the base chassis, N; \( \Sigma P_i \) – the resistance force of overcoming the stump by the teeth of technological equipment, N.

The value of the force of resistance to the dragging of logging waste in front of the processing equipment \( P_1 \), N, is variable from a number of parameters taking into account the design features of the processing equipment (its width \( B \), m), the location of shafts of logging waste through the average distance of passes during their formation \( l_{dp} \), m, taxation descriptions of the cutting area (stock of wood \( q \), m³/ha, species composition affecting the share of generated waste \( \varphi \) and their density \( \rho \), kg/m³) and is determined by the expression [12]

\[ P_1 = Q_{lw} \cdot f_i = f_i \cdot B \cdot l_{dp} \cdot q \cdot \varphi \cdot \rho \cdot g \cdot 10^{-4}, \] (4)

where \( Q_{lw} \) – the weight of logging waste in front of technological equipment, N; \( f_i \) – the coefficient of resistance of the dragging of logging waste.

The value of the force of resistance to movement of the base chassis \( P_2 \), N, depends on the weight of the \( G_M \) machine, N, type of the soil, and is defined as

\[ P_2 = G_M \cdot f, \] (5)

where \( f \) – the rolling resistance coefficient.
The magnitude of the force of resistance to overcome the stump by the tooth of the technological equipment \( P_t \), N, is determined by the corresponding previously developed method [7].

An important operational indicator of forestry machines is the average technological speed of their movement \( \nu \), m/s. The overall technical, and as a consequence, the actual performance, as well as the base chassis engine power \( N \), W, required for the implementation of the technological process, directly depends on its value, which can be determined by the dependence

\[
N = P_f \cdot \nu = N_1 + N_2,
\]

where \( N_1, N_2 \) – the powers spent on moving the base chassis through the cutting area and dragging the logging waste, taking into account the power consumption for overcoming obstacles in the form of stumps, respectively, W.

As a result of the joint solution of expressions (1) – (6), the required mass parameters of the machine for collecting logging waste, its force and power parameters are determined, depending on the specific natural production conditions of operation.

3. Results and discussion

The main indicator of the efficiency of a machine for collecting logging waste is its productivity, which depends on the weight \( Q_{lw} \) (volume \( V_{lw} \)) of the transferred logging waste generated during the collection process. On the basis of the above methodology, a nomogram has been developed (figure 1) that allows setting their weight \( Q_{lw} \) depending on the average distance of passage during shaft formation \( l_{dp} \), the width of the technological equipment \( B \), the stock of wood \( q \), the share of generated logging waste \( \varphi \), and the density of wood \( \rho \). The last two parameters make it possible to take into account the species composition of plantations when determining them according to the appropriate methods [12].

![Figure 1. Nomogram for determining the weight of logging waste in front of technological equipment.](image)

It has been established that with an average distance of passage during the formation of a logging waste shaft of 35 m, a width of technological equipment of 2.4 m, a liquid stock of 270 m³/ha and a wood density of 800 kg/m³, the weight of branches \( Q_{lw} \), taking into account the share of generated waste
equal to 0, 15 (15%) will reach 2.8 kN, and the resistance force of the movement of waste \( P_1 \) in front of the equipment will be 1.4 kN. It was found that the average passage distance \( l_{dp} \) will have a significant effect on the value of the force \( P_1 \). So, with a width of an apiary of 20 m, the distance between the shafts of felling waste can be 20 m when the shaft of logging waste is formed on one side or 10 m – on both sides [3,15]. However, under similar operating conditions, but the formation of a shaft from two apiaries (with a low concentration of waste and operation on soils of I and II categories), the distance between the shafts will increase 2 times compared with the case considered above. Particular attention should be paid to the choice of the width of the processing equipment, an increase in which proportionally increases the productivity and resistance force of dragging logging waste. However, the dependence is proportional, provided there is a sufficient power reserve and traction-coupling properties, since in the case of insufficient power, the speed of technological operations will decrease. However, the dependence is proportional, provided there is a sufficient power reserve and traction-coupling properties, but in the case of insufficient power, the speed of technological operations will decrease. A similar situation will be observed with a lack of tangential traction force (the movement will be carried out in a low gear) and in conditions of insufficient adhesion properties, which lead to the slipping process and can lead to the impossibility of performing the technological process according to the developed technology, as well as significant downtime machines.

At the same time, the achievement of a significant width is possible due to the improvement of the design by introducing additional teeth or retractable sections with teeth, which complicates the design and imposes a number of restrictions on the transportation of technological equipment, ensuring high maneuverability and traction properties. Currently, technological equipment with a width of 2.4 m is most widespread (despite the permissible width of 2.55 m based on restrictions on admission to road traffic on public roads), which is due to the dimensions of tractors of traction classes of 14 kN and 20 kN.

In the process of collecting logging waste, the teeth of the technological equipment have to overcome stumps of various heights. Depending on various technological parameters, the number of stumps to be overcome at the same time will differ, and accordingly, the resistance force \( \Sigma P_t \) to overcome the stump will change. On the basis of the studies carried out according to the previously developed methodology [14], a nomogram was developed (figure 2) to determine the resistance force of overcoming the stump by the teeth \( \Sigma P_t \), depending on the height of the obstacle \( h, \text{m} \), spring stiffness \( c, \text{kN/m} \), and the number of stumps \( n, \text{pcs} \), simultaneously overcome by the technological equipment.

![Figure 2. Nomogram for determining the resistance force of overcoming the stump (stumps).](image)

The stiffness of the spring \( c \) significantly affects the resistance force to movement of the teeth \( \Sigma P_t \). So, when overcoming a single obstacle with a height of 20 cm, the resistance force of one tooth will be 0.45 kN, and while overcoming obstacles of the same height by two or more teeth, the resistance force will increase in proportion to the number of interacting teeth. In practice, the simultaneous overcoming
of stumps by four or five teeth is extremely rare. All the teeth of the technological equipment overcome the obstacle in case of interaction with a fragment of a trunk that has grown into the ground or collection of felling waste at windfall logging sites. These conditions are the most challenging when using a machine for collection of logging waste and are usually accompanied by a reduction in operating speed. This operating mode is calculated to determine the peak loads acting on the technological equipment, which are used for subsequent strength calculations. The interaction of 3 teeth are possible with large root diameters. In this case, with a spring stiffness of 2.5 kN/m, the resistance force $\Sigma P_t$ will be about 1.35 kN.

The established values of the forces of resistance to the dragging of logging waste in front of the technological equipment $P_1$ and the resistance of overcoming the stump by the teeth $\Sigma P_t$ are summed up for the subsequent establishment of the required parameters of the machine for collecting felling waste based on the operating conditions. To solve the problem posed to determine the required minimum engine power $N$, based on the summation of the values of $N_1$ and $N_2$, the tangential thrust force $P_k$, equal to the sum of the arising resistances $P_1$, $P_2$, $\Sigma P_t$, and the weight of the machine $G_m$, taking into account the soil operating conditions (2nd and 3rd quadrants), the general layout diagram (1 quadrant) and the speed of technological operations (4 quadrant), the corresponding nomogram was obtained (figure 3).

![Figure 3. Nomogram for determining the consumed power.](image)

Taking into account the operating conditions considered above (width of the technological equipment 2.4 m, the average distance of passage during the formation of a shaft of logging waste 35 m, stock of wood 270 m$^3$/ha, the share of generated waste 0.15 and a density of wood 800 kg/m$^3$) resistance to the movement of cutting waste will amount to 1.4 kN with a weight of logging waste 2.8 kN. Taking into account the interaction of the 3 teeth with the obstacle, the resistance force is 1.35 kN. Then the total resistance $\Sigma P_t$ and $P_1$ is 2.75 kN, and to ensure efficient collection of felling waste on category III soils, the minimum adhesion weight of the machine must be at least 70 kN. This can be achieved by using an all-wheel drive chassis weighing more than 70 kN, with a power of over 22 kW (18.7 kW and 3.05 kW) at a speed of 4 km/h and a tangential traction force of at least 19.5 kN (16.8 kN and 2.75 kN) or based on the use of a universal row-crop tractor or tractors based on them that do not have all-wheel drive. In the second case, the weight of the machine must be at least 110 kN with an engine power of more than 32 kW (29.33 kW and 3.05 kW) and the tangential thrust force must be at least 29.15 kN (26.4 kN and
2.75 kN). Based on the obtained values, it should be noted that the creation of a machine for collecting felling waste on type III soils is possible on the basis of the BELARUS L1221 chassis, its analogs, or on the basis of the use of a tracked chassis. The use of the BELARUS L82.2 chassis as energy carrier under the given conditions is impossible in the form of the impossibility of implementing the required traction properties.

It should be noted that when collecting felling waste on soils of categories I and II, it is not required to ensure such high indicators of traction and coupling properties. At the same time, the entire range of possible operating conditions can be realized on the basis of the use of a base chassis even not equipped with an all-wheel drive with a weight of 50–60 kN, a power of 16–19 kW, the possibility of implementing a tangential traction force of 12–16 kN. The forest tractor BELARUS L82.2 is suitable for these operating conditions, having a weight of 50.5 kN with installed technological equipment, a tangential traction force of 14 kN at a speed of 4 km/h, as well as a power of 59.6 kW, which ensures the operation of the machine in medium modes loading.

4. Conclusions

As a result of the research, a technique was developed and graphical dependencies of the influence of the taxation parameters of the logging area, the overall dimensions and stiffness of the elastic elements of the teeth of technological equipment, the speed of operations, as well as soil conditions on the required coupling, traction and power parameters of the base chassis were obtained. At the same time, on the basis of the nomogram, it is possible to establish the minimum adhesion weight required for the implementation of the technological process under the given operating conditions, which, in turn, is inversely proportional to the share of the transferable weight on the drive wheels, affects the value of the total weight of the machine for collecting logging waste.

Based on the predominant distribution of wheeled forest machines as the base chassis of machines for collecting logging waste, it is recommended to use the BELARUS L82.2 tractors on type I and II soils. On type III soils, depending on the operating conditions, it is possible to use both BELARUS L82.2 and BELARUS L1221, the latter providing a wider range of operating conditions.

The given nomograms are of practical importance, since they provide not only the choice of the parameters of the base chassis for specific operating conditions, but also allow solving the inverse problem, which consists in choosing the conditions and modes of efficient operation of machines for collecting logging waste with various design and layout features.

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