INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN, 1/2019 (15): 78–83

POWER ANALYSIS OF FORESTRY CUTTERS FOR COMMINUTING OF WOOD WASTE IN POPLAR CLEARINGS. PART 2: POWER PARAMETERS

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ABSTRACT

Forest milling machines have high technological properties but also higher energy consumption and higher power requirements. In the present study, a theoretical analysis is performed to determine the power required for propulsion of specialized forest milling machines used for soil preparation of poplar clearings. For this purpose appropriate analytical dependencies are developed to define the required power of forest milling cutters for comminuting left slash and tree-shrub vegetation in fresh poplar cleaning, and shallow soil tilling. A new formula has been developed for a more complete definition of the power balance equation of forest milling aggregates for soil preparation. A suitable theoretical-experimental model for the determination of dynamic parameters in analytical dependencies is proposed.

Key words: milling brush-cutter, poplar slash, power, resistance.

INTRODUCTION

In recent years, two specialized Prime Tech milling machines have been implemented in our country, in the area of Northwest State Forestry Enterprise, models PT-300 (205 kW) and PT-400 (310 kW), equipped with multi-purpose forest milling cutter FAE 300S-225. This has led to the improvement of the soil preparation quality in poplar clearings and the labor costs reduction in technologies of poplar plantations establishment (Marinov and Jordanova 2017). The high functionality of these machines was used to perform almost all technological operations in the soil preparation process: for comminuting and mulching of left slash and standing wood mass, for grinding of stumps and roots, and for tilling of the soil. From the observations on the work of the two machines, it was found that in clearings with more severe operating conditions (a greater amount of slash and standing wood mass, larger stumps and heavier soil) the milling unit PT-300 has a certain lack of power and experiencing greater difficulty than the more powerful unit PT-400.

The drive power of forest milling cutters depends on technological and kinematic parameters of the milling unit, the type and quantity of the wood materials and soil treated. One of the major factors influencing the power required to drive the forestry cutters is the resistance to cutting wood materials and the rejection of the chips. In specialized literature there is not much research dedicated on the power parameters of forestry cutters, and the published materials are scanty or incomplete (Vinokurov and Eremin 2004, Vinokurov *et al*. 2004). Most research on the power parameters are in the field of agricultural milling machines (Matjashin *et al*. 1988, Shishkov and Daskalov 1989). So far our country a study on the power parameters of forestry cutters was focused in the field of deep tillage in cleaned poplar clearings, in which the stumps and wood waste have been, removed beforehand (Marinov 2017).

The aim of the study is to analyze the power parameters and the power to drive the forestry cutters necessary for comminuting of wood waste, shoots and shrub in poplar clearings and to be developed suitable analytical dependencies. In order to achieve the goal, it is necessary to solve the following tasks: 1/ Development of appropriate analytical dependencies for determination of the power of the forest milling cutters for wood waste comminuting and soil surface tilling; 2/ Defining the full equation of the power balance of the forest milling units for soil preparation poplar clearings; 3/ Development of appropriate mathematical models for defining the dynamic parameters in the proposed analytical dependencies.

METODOLOGY

To perform the study and to establish the power parameters of the milling machine-tractors aggregates the theoretical and comparative analysis methods are applied. To define the analytical dependencies of the power required to drive the forest milling cutters constant and variable parameters is used. For constant parameters are accepted technical and physical characteristics of the studied objects - machinery and working environment. For variables adopt technological and kinematic parameters of the research milling unit. To express the equation of the power balance and the establishment of the dynamic parameters of the research process the results of experimental research of milling unit is used. They are presented in Part 1 "Study of energy intensity". To determine the energy intensity of the milling aggregate, in the same study is used the methods of regression analysis.

RESULTS AND DISCUSSION

POWER TO PROPULSION OF THE FORESTRY MILLING CUTTERS FOR WOOD WASTE COMMINUTING

The necessary power to drive of forestry milling brush-cutters – $N_{фр.д}$ to comminuting left slash and bushes in the forest clearings can be expressed with the equation,

$$N_{фр.д} = N_{пр} + N_{р.д} + N_{о.д}, \quad \textbf{(1)}$$

where $N_{пр}$ is the power of moving forest cutter on the ground;

$N_{р.д}$ – the power for cutting wood;

$N_{о.д}$ – the power to reject the wood chips.

In cases where the working body is lowered to the ground, the power to overcome the frictional resistance of the supporting parts on the soil – $N_{пр}$ is expressed by the following formula:

$$N_{пр} = 0{,}001 . m_{фр} . g . f_{фр} . v_р, \text{ kW}, \quad \textbf{(2)}$$

where $m_{фр}$ is the mass of the milling cutter, kg;

g = 9,81 m.s^{-2} – gravity earth acceleration;

$f_{фр}$ = 0.3÷0.7 – friction coefficient of the support parts of milling cutter on the ground;

$v_р$ – the working speed of the milling unit, m.s-^{1};

When the milling machine works only as a brush-cutter (mulcher), and the working and support bodies are lifted above the ground of 2÷5 cm, the friction resistance is negligible – $N_{пр} \approx 0$ and this power can be turned off by formula (1).

The power $N_{р.д}$ for wood cutting with a forestry milling cutter with a drum operating body can be expressed by the following equation:

$$N_{р.д} = 0{,}001 . k_{р.д} . D_{фр.б} . d_с . z_с . \varepsilon . (v_о - v_р), \text{ kW} \quad \textbf{(3)}$$

where $k_{р.д} = (1{,}2÷2{,}1).10^5$ N.m^{-2} is the specific resistance of wood cutting;

$D_{фр.б}$ – milling drum diameter, m;

$d_с$ – the average diameter of the cut stems, m;

z_c – the average number of cut stems in the working range of the milling drum;

ε – the coefficient expressing the non-simultaneous cutting of the working stems in the range of 0.4÷0.5;

v_o – the peripheral cutting speed of the milling drum, m/s;

The peripheral speed of the milling drum – v_o and the average number of cut stems - z_c can be determined by the following dependencies:

$$v_o = \pi \,.\, D_{фр.б} \,.\, n_{фр.б} \quad \textbf{(4)}$$

$$z_c = z_{см} \,.\, B_p \quad \textbf{(5)}$$

where $n_{фр.б}$ is the frequency (revolutions) of the milling drum, s^{-1};

$z_{см}$ – the number of stems per one meter in the treated area, m^{-1};

B_p – the working width of the milling machine, m;

The power required for the rejection of the wood chips and mulching – $N_{о.д}$ by the milling machine working body may be determined by the following equation:

$$\boldsymbol{N_{о.д} = 0,001 \frac{k_{о.д}.m_{о.д}.(v_o - v_p)^2}{2.t}}, \text{ kW}, \quad \textbf{(6)}$$

where $k_{о.д}$ is the dynamic parameter for wood chips rejection;

$t = 1/z_{н.с}.n_{фр.б}$ – the time for feeding the next knife, s;

$z_{н.с}$ – the number of milling cutter knives lying in one plane.

The mass of rejected wood chips within the time – t is determined by the equation:

$$m_{о.д} = \rho_д \,.\, d_{ср} \,.\, z_c \,.\, D_{фр.б}.\, \varepsilon\, (v_o - v_p) \,.\, t, \text{ kg}, \quad \textbf{(7)}$$

where $\rho_д$ is the wood density, $kg.m^{-3}$;

For propulsion of forestry cutters for cutting and shredding wood waste in forest clearings, using the kinematic indicator of milling machines – $\lambda = v_o / v_p$ and making some conversions in the above formulas, the following analytical dependence for determining the required power is obtained:

$$N_{фр.д} = 0{,}001.(\lambda - 1).v_p.\left(k_{р.д}.D_{фр.б}.d_{ср}.z_c.\varepsilon + k_{о.д}.m_{о.д}.v_p \,.\, \frac{(\lambda-1)^2}{2.t}\right), \text{ kW}, \quad \textbf{(8)}$$

POWER TO PROPULSION OF THE FOREST MILLING MACHINES FOR SHALLOW SOIL TILLING

The comminuting of standing and lying wood mass at full soil preparation poplar clearings with multipurpose forestry milling machines, usually is combined with surface soil tilling to 5-10 cm. In this way the wood mass is better comminuted and the resulting wood chips are more homogeneously mixed and absorbed into the soil. Moreover, soil density in the upper layer of poplar floodplain habitats is greater, due to the pressure of the water masses and used heavy logging machinery. The soil's hardness in this layer is within 1.8-2.1 MPa. Pre-processing of this compacted layer reduces the energy intensity of the machine for subsequent deep primary tillage.

To determine the power required to drive the mills for the surface treatment of soil –- $N_{фр.п}$, following formula can be used:

$$N_{фр.п} = N_{пр} + N_{рп} + N_{оп} \quad \textbf{(9)}$$

where $N_{рп}$ is the power of cutting the soil;

$N_{оп}$ – the power for rejection of the cut soil particles;

$N_{пр}$ – the power to overcome the resistance to movement forestry milling cutter on surface of the ground, defined by equation (2).

The power to cut the soil can be expressed by the following equation,

$$Npn = 0{,}001 \,.\, kn.\, kб \,.\, a \,.\, B \,.\, (vo - vp), \text{ kW}, \quad \textbf{(10)}$$

where $k_п$ is the specific resistance to cutting the soil, N.m^{-2};

$k_б$ – the coefficient expressing the working width of the knives relative to the working width of the milling cutter, $k_б = z_н \,.\, b_z / B$;

B – the working width of the milling machine, m;

a – the depth of tillage, m;

$z_н$ – the number of knives.

The power required to reject the cut soil particles from the milling machine working body – $N_{оп}$ can be expresses by the formula,

$$\boldsymbol{N_{оп} = 0,001 \frac{k_{о.п}.m_п.(v_o - v_r)^2}{2.t}}, \text{ kW}, \quad \textbf{(11)}$$

where $k_{о.п}$ is the dynamic parameter for soil particles rejection;

$m_{о.п}$ – the mass of soil particles rejected by the milling machine for a time - t, kg.

The soil particles mass rejected by the milling machine for the time - t is defined by formula:

$$m_{о.п} = \rho_п \,.\, k_б.\, a.\, B \,.\, (v_о - v_р) \,.\, t, \text{ kg}, \quad \textbf{(12)}$$

where $\rho_п$ is the soil density, kg.m^{-3}.

To define the required power of the forest milling cutters for shallow soil tilling - $N_{фр.п}$, by doing some transformations in the above formulas and using the kinematic indicator of the milling machines - λ, the following analytical dependence is proposed:

$$N_{фр.п} = 0,001.v_р \left[m_{фр} \,.\, g \,.\, f + k_п.k_b a.B.(\lambda - 1) + k_{о.п}.m_{о.п} \frac{(\lambda-1)^2}{2t} v_p\right], \text{ kW}, \quad \textbf{(13)}$$

POWER TO PROPULSION OF THE FOREST MULTI-PURPOSE MILLING MACHINES FOR WOOD WASTE COMMINUTING AND SHALLOW SOIL TILLING

The power to propulsion the forestry multi-purpose milling machines can be determine by the sum of two formulas (8) and (13). For define of necessary power to drive the forest milling machines to comminuting of the wood waste and shallow soil tillage the following analytical equation is proposed:

$$N_{г.фр} = \frac{0,001}{\eta_{тр}.\eta_{с.пр}} v_р \left\{m_{фр} \,.\, g \,.\, f + (\lambda - 1).\left[k_п.k_b.a.B + k_{р.д}.D_{фр.б}.d_{ср}.z_c.\varepsilon + (k_{о.п}.m_{о.п} + k_{о.д}.m_{о.д}) \frac{(\lambda-1)^2}{2.t} v_p\right]\right\}, kW \quad (14)$$

where $\eta_{тр}$ is efficiency of the towing machine transmission;

$\eta_{с.пр}$ – efficiency of the power transmission of the milling machine.

Several parametric coefficients are involved in the proposed formula (14). They can be varied within a narrower or wider range. From their proper interpretation the accuracy of results will greatly depend.

Various methods are used to measure the power of milling machines. They are based on direct laboratory tests or indirect experimental methods. Laboratory methods are more precise but require special measuring equipment and appropriate conditions. Indirect methods are based on the use of appropriate physical indicators, that can be measured relatively easily and with which power to be calculated. As such an indicator in the present work is used "the energy intensity of the milling cutter", defined as the relative fuel consumption. Energy intensity can be determined under real operating conditions based on operational performance and fuel consumption. Subject to certain experimental conditions, this method can provide good results.

POWER BALANCE OF FOREST MILLING AGGREGATES

The power costs of energetic machines to overcome the different resistances during operation process of technological machines is expressed by the power balance equation. Using some results from our previous studies on forest cutters (Marinov 2017), and apply the regression models of formula (3) and formula (6) from the experimental study in Part 1: „Energy Intensity“, to determine the full power to drive the forest milling units to wood waste comminuting in poplar clearings, following analytical formula is proposed:

$$N_{фр} = G_0 \frac{3.6.B_p.v_p.\gamma_{д.г}}{k_{дв}.g_e}\eta_{тр}(1-\delta) - 0{,}001.m_{ем}.g.f.v_p, \text{ kW}, \quad \textbf{(15)}$$

where G_o is the relative fuel consumption, which is determined by regression models in formulas (3) and (6) in Part 1, as function of $y_3 = f(x_1,x_2)$, l.dka^{-1};

g_e – specific fuel consumption of the engine, g_e = 225 g.[kW.h]$^{-1}$;

γ – fuel density, kg.m^{-3};

$\eta_{тр}$ = 0,85 – efficiency of the PT-400 towing machine transmission;

$m_{ем}$ = 18,330 kg – operating mass of PT-400 towing machine;

f = 0,10÷0,12 – resistance coefficient of self-propulsion the towing machine;

δ – slipping coefficient of the towing machine;

$k_{дв}$ – power utilization factor of the engine.

By equalizing the two sides of equations (14) and (15) and some transformations are made in them, to express the power balance of forest milling aggregates, the following full equation is proposed:

$$\left[G_o \frac{3{,}6.B.\gamma_g}{0.001.k_{дв}.g_e}\eta_{тр}(1-\delta) - m_{ем}g.f\right]\eta_{тр}.\eta_{с.пр} - m_{фр}.g.f = (\lambda-1)\left[k_{п}.k_b.a.B + k_{р.д}.D_{фр.б}.d_{ср}.z_c.\varepsilon + (k_{о.п}.m_{о.п} + k_{о.д}.m_{о.д})\frac{(\lambda-1)^2}{2.t}v_p\right] \quad (16)$$

In cases where the relative fuel consumption an experimental way G_o is determined, the formula (16) of the power balance of the forest milling aggregates is a suitable theoretical-experimental model for determining the dynamic parameters – $k_{о.п}$ и $k_{о.д}$. The dynamic parameters established in this way can be used with sufficient precision in the proposed analytical dependencies (8), (13) и (14) for calculating the forestry cutters power for wood waste comminuting in poplar clearings.

CONCLUSION

The forestry milling units must have sufficient power for the more complete comminuting of left slash and wood mass in poplar clearings. The power to drive forestry milling brush-cutters at established speed regimes depends on the amount and size of wood waste and available standing vegetation, of the number and diameter of the stumps, and the mechanical composition of the soil and the depth of tilling.

In this study an analysis of performance and power parameters of forest mills to clean the poplar clearings from left slash, shoots and bushes, with wood mass corresponding to 1st и 2nd category clearings. For this purpose, the wood mass is comminuted in place and at the same time a shallow soil tilling is carried out to 5-10 cm. The following conclusions can be drawn from the study:

1. Appropriate analytical dependencies to determine the required power of forest milling cutters for comminuting of wood waste, shoots and shrubs

in fresh poplar clearings, with simultaneous shallow soil tilling was defined.

2. A new formula for a more complete definition of the power balance equation of forest milling aggregates for soil preparation was established.
3. A suitable theoretical-experimental model for determine the dynamic parameters in analytical dependencies was proposed.

The obtained results of the study have a scientific and scientifically applied contribution in the field of theory, design and operation of the forest milling machines.

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UNIVERSITY OF FORESTRY

International Scientific Journal

INNOVATON IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

Volume VIII Issue 1 Year 2019

ISSN 1314-6149 e-ISSN 2367-6663

UNIVERSITY OF FORESTRY
FACULTY OF FOREST INDUSTRY

INNOVATION IN WOODWORKING INDUSTRY AND ENGINEERING DESIGN

1/2019

INNO vol. VIII Sofia

ISSN 1314-6149
e-ISSN 2367-6663

Indexed with and included in CABI

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