Improvement of processing operations of cutting work using gasoline-powered tools

A S Chernykh, A I Maksimenkov, V V Abramov¹, I N Troyanov, L D Buhtoyarov, D N Afonichev

Voronezh State University of Forestry and Technologies named after G.F. Morozov,
8 Timiryazeva Street, Voronezh 394087, Russian Federation

¹E-mail: vitali1980a@mail.ru

Abstract. The method of calculation of specific power consumption of the process of cross sawing of wood with fan feed of chain cutting body proposed in the article is a complement to the theory of cutting. The mathematical model developed on its basis allows predicting reliably the energy efficiency of the chainsaw depending on the natural and industrial conditions of its operation. This makes it possible with the help of a computer program to select the optimal combinations of the gasoline-powered saw, the saw bar and the saw chain significantly reducing the specific energy consumption of the process. As a result of the simulation experiment for the logging company Open Company "LK Kedr" (Moscow region, Sergiev Posad) in July 2017, the following two optimal sets were selected: chainsaw Husqvarna 357 + tire "15" + chain 25 RM and chainsaw Stihl S 260 + tire "15" + 26 RM. This made it possible to reduce the specific energy consumption by 9% and 7% in comparison with the previously used at the enterprise option (chainsaw Husqvarna 357 + tire "16" + chain 40 RM).

1. Introduction

The main directions of improvement of logging are in the range of lowering of energy consumption of production processes, growth of labor capacity and reduction of negative ecological consequences to the environment [1]. Improvement of cutting work at the indicated positions can be achieved by identifying of internal reserves to improve efficiency in production based on the creation of automated process control systems [2].

An automated system for making optimal design decisions to improve the performance of processing operations in the cutting area is being developed at Voronezh state forestry engineering university named G. F. Morozov at the department of forestry industry, metrology, standardization and certification. This system has a three-level structure with consistent justification of the optimal set of gasoline-powered tools, technology and organization of labor and parameters of the cutting. The choice of the optimal combination of a chainsaw, a saw bar and a saw chain in the conditions of multivariate of the compared alternatives as well as a large number of natural and industrial factors of influence on the investigated process is assumed at the first level of the system. In this situation it is necessary to use modern methods and means of modeling and optimization of logging operations. Professor A. N. Zaikin [3], which has developed a software package «KoptREG» to improve the quality and efficiency of logging on the basis of their automation, successfully deals with this issue. The economic effect appears here when performing a computer experiment by optimizing the organization of labor. As a result, there is a reduction in the cost of cutting operations to 13.7%,
specific energy consumption to 20.8%, specific labor costs to 36.9%. In his research the author carries out a multilateral assessment of the effectiveness of logging operations by three very important criteria, but does not pay attention to the issue of environmental damage from the ongoing logging. Professor G. F. Hertz [4] eliminates this drawback and develops an integrated criteria of efficiency for the evaluation of logging from an economic, forestry and environmental perspective, but ignores the issue of energy efficiency. Associate professor E. G. Ryzhikova in her studies [5] draws attention to the relevance of energy saving in the logging industry offering her own method of calculating of the energy consumption of a complex of multioperation machines working on the cutting area, taking into account the changing working conditions. At the same time, the methods of assessing the energy efficiency of a chainsaw in different production and environmental conditions still do not exist[6]. It also draws the attention of professor I.V. Grigoriev [7], which elaborates in his studies the methodology of calculating the energy consumption during the cross sawing of wood with chain saw machine. To do this he proposes to use in the calculations of the specific cutting work his experimental dependence of the mutual influence of temperature and humidity of wood on the process.

Thus, the problem of increasing of efficiency of processing operations on the cutting area using gasoline-powered tools based on an integrated assessment of design solutions in the CAD system is relevant [8]. It is important for science and also of practical interest for logging production. In this context, the purpose of research is the development of a mathematical model of the cross sawing wood process to assess the specific energy consumption and the creation of software for science-based selection of the optimal set of gasoline-powered tools in individual forest operating conditions of developed cutting areas on its basis.

2. Methods

Main characteristics of the process of sawing wood with machines with chain cutting body as a rule are obtained during the laboratory or production experiment. That is time-consuming and requires a significant investment on organization of the experiment, as well as on processing of the obtained results [9]. Moreover, a significant number of influence factors and impossibility of imitation of the real process in experimental conditions significantly affect the accuracy and reliability of the obtained results. In such situation is advisable to appeal to simulation methods of production processes [10]. In this connection the mathematical model of the cross-sawing wood process using fan thrust of chain saw apparatus was developed for determination of the specific energy consumption.

Procedure for calculating of the energy consumptions presupposes preliminary determination of:

- total energy consumptions;
- duration of clean sawing;
- productivity of clean sawing;
- the actual value power expended for sawing;
- tractive effort, created by the saw chain to overcome the total resistance to sawing;
- the actual value of the cutting force;
- the actual value of the specific cutting work;
- chip thickness when sawing each link;
- admissible federate taking into account the strength constraint of chainsaw bar and drive power.

Specific energy consumptions on 1 m³ of felled wood are determined:

$$E_{sd} = \frac{E_{obs}}{V_{sf}}, \quad (1)$$

where $V_{sf}$ is the average volume of whip, m³; $E_{obs}$ – the total energy consumptions on the process of sawing, kWs. Specific energy consumptions on 1 m² of the area of a kerf:

$$E_{pd} = \frac{E_{obs}}{\pi R^2}, \quad (2)$$

where $R$ is radius of the cross-section of the tree in the plane of cutting, m.
Total energy consumptions for sawing process are determined:

\[ E_{obs} = N_p \cdot t_{c,n}, \]  (3)

where \( N_p \) is the actual value of the power consumed by sawing, W; \( t_{c,n} \) – the duration of clean sawing, s. The actual value of the power used for sawing is determined:

\[ N_p = \frac{z_m \cdot v_c}{\eta_o}, \]  (4)

where \( z_m \) is tractive effort, created by the saw chain to overcome the total resistance to sawing, N; \( v_c \) – speed of saw chain, m/s; \( \eta_o \) is the efficiency of kinematic pair from engine to leading link.

Duration of clean sawing subject to design diagram presented in figure 1 is determined:

\[ t_{c,n} = \frac{t_z}{h_z v_c} \left( \varphi_z - \varphi_s \right) \left( \left( R - x_i \right)^2 + y_0^2 \right)^{1/2} + R, \]  (5)

where \( t_z \) is the chain pitch on opposite planning teeth, m; \( h_z \) – the thickness of the chip removed by the cutting of each tooth, m; \( \varphi_z \) – the rotation angle of the gasoline-powered saw around the chainsaw backstop from the moment of its introduction into the tree trunk to the moment of the chain touch of the object of labor, degree; \( \varphi_s \) – the rotation angle of the gasoline-powered saw around the chainsaw backstop from the moment of the chain touch of the object of labor until the end of the contact, degree; \( x_i \) – the coordinate of the center of rotation of the saw bar around the gasoline-powered saw backstop in X-axis; \( y_0 \) – the coordinate of the center of cross-section of the object of labor in the sawing plane in Y-axis.

The performance of clean sawing is determined:

\[ P_{c,n} = \frac{\pi R^2}{t_{c,n}}. \]  (6)

Tractive effort created by saw chain to overcome the total resistance is determined:

\[ z_m = P_p (1 + a\mu) + 2.08 \left( m_c l_c q \mu + 0.08 z_0 \right), \]  (7)

where \( P_p \) is the actual value of cutting force, N; \( a \) – the coefficient of proportionality between cutting force and feed force; \( \mu \) – friction coefficient of saw chain; \( m_c \) – the mass of running meter, kg; \( l_c \) – total length of saw chain, m; \( q \) – acceleration of gravity, m/s²; \( z_0 \) – the mounting tension of saw chain, N.
Figure 1. Design diagram to determine the geometric parameters of interaction of the chain saw apparatus with a fan thrust and the object of labor in the process of cross-sawing.

Actual value of cutting force is determined:

\[ P_p = k \cdot b \cdot H \cdot \frac{U^*}{v_c}, \]  

(8)

where \( k \) – the actual value of specific cutting work, \( j/m^3 \); \( b \) – the cutting width, m; \( H \) is the average cutting height, m; \( U^* \) was the minimum limitation of the feed speed of the drive power of the saw chain and of the strength of the saw chain of a given structure, that was \( U^* = \min \{ U_m, U_{sp} \} \), m/s.

Actual value of the specific cutting work is determined:

\[ k = \frac{2.65 \cdot 10^5}{(b_a \cdot b_{a3}) a_n a_p a_s}, \]  

(9)
where $a_n$ is the correction factors breed of wood; $a_w$ – correction factor considering humidity of wood; $a_{\rho}$ – the correction factor considering the degree of blunting of the cutting edges of the tooth; $a_t$ – the correction factor considering temperature.

Average cutting height subject to the design diagram presented in figure 2 is determined

$$H = \frac{1}{\pi R^2} \sum_{j=1}^{2\pi R} S_j \bar{H}_j,$$

where $S_j$ is the square of the fragment of sawing $j$, m²; $\bar{H}_j$ is the average height of the saw cut in the fragment of sawing $j$, m.

**Figure 2.** Design diagram to determine the operating characteristics of the process of cross-sawing wood with a fan thrust of the chain saw apparatus on the object of labor.

Square of the fragment of sawing $j$ can be defined in the following way

$$S_j = \sum \bar{H}_j,$$

(11)
where \( \sum h_j \) is the average value of the total thickness of the chip, removed by all the teeth when sawing with the simultaneous presence in the kerf of \( n_j \) teeth.

Average value of the total thickness of the chip, removed by all the teeth when sawing with the simultaneous presence in the kerf of \( n_j \) teeth is determined:

\[
\sum h_j = \frac{a'_j a'_{j+1} + b'_j b'_{j+1}}{2}.
\]

(12)

Average height of the kerf in the fragment of sawing \( j \) is determined:

\[
\bar{H}_j = \sqrt{R^2 - [(x_j - R)\sin \varphi_j + y_0]^2}.
\]

(13)

Calculation of the thickness of the chip, removed by the cutting of each tooth is determined

\[
h_c = \frac{4t_i U^*}{v_c}.
\]

(14)

where \( t_i \) is the saw chain step.

Calculation of the allowed value of the feed speed taking into account the power limit of the saw chain drive is determined:

\[
U_{ap} \leq \left[ \frac{N_n [2.08 m \mu q + 0.08 z_0]}{2.65 \cdot 10^3 a_n a_a a_q v_c^{0.33} b^{0.67} H (1 + a \mu)} \right]^{1.5},
\]

(15)

where \( N_n \) is the normal (passport) power of saw chain drive engine.

Allowed value of feed speed taking into account the limit on the strength of the saw chain of a given design

\[
U_{ap} \leq \left[ \frac{z_{pac} - (2.08 m \mu q + 0.08 z_0) - (z_0 + z_0 + z_{dun}) v_c^{0.67} (4t_i)^{0.33}}{2.65 \cdot 10^3 a_n a_a a_q a_i b^{0.67} H (1 + a \mu)} \right]^{1.5},
\]

(16)

where \( z_{pac} \) is the allowed breaking force, \( N; z_0 \) is the tension of saw chain under the action of centrifugal forces, \( N; z_{dun} \) is the dynamic efforts, arising due to the uneven movement of the saw chain links when engaged with the drive sprocket and the guide device, \( N \).

3. Results and discussion

On the basis of the presented mathematical model of the cross-sawing wood process with the chain cutting apparatus software in Delphi environment is created. It allows reliably predict performance of different variants of gasoline-powered tools acquisition in the specified conditions of production and natural environment and justify the optimal combination of gasoline-powered saw, saw bar and saw chain minimizing the specific energy consumption. Block diagram of the computer program algorithm for the justification of the optimal set of gasoline-powered tools is presented in figure 3. The first two blocks of the algorithm include procedures of selecting of the set of gasoline-powered tools. Blocks 3, 4, 5 are used to enter characteristics of natural and production conditions, and also parameters of a chainsaw, a saw bar and a saw chain. Blocks 6, 7, 8 and 9 contain computational procedures of calculation of:

- indicators of the kinematics of the process;
- power parameters of sawing;
- performance and duration of clean sawing; energy performance.

Front-end forms of the computer program «Program of simulation of the process of sawing wood using gasoline-powered tools» to enter source data are presented in figure 4. There you can see 12 compared variants of acquisition of gasoline-powered tools.
Figure 3. Block diagram of the computer program algorithm for the justification of the optimal set of gasoline-powered tools.

Figure 4. Front-end forms of the computer program to enter source data.
The results of the simulation experiment on the example of the logging company "LK Kedr" (Moscow region, Sergiev Posad, July 2017) are shown in figure 5. Chainsaw Husqvarna 357 + tire "15" + chain 25 RM and chainsaw Stihl S 260 + tire "15" + 26 RM were two best options for this enterprise. This made it possible to reduce the specific energy consumption by 9% and 7% in comparison with the previously used option (chainsaw Husqvarna 357 + tire "16" + chain 40 RM).

Figure 5. Front-end forms of the computer program with the results of the simulation experiment.

4. Conclusion

The proposed mathematical apparatus to research the process of sawing wood is sensible to a great variety of acting factors: $N_H, m_c, l_c, z_0, v_c, t_c, a_n, a_v, a_p, a_t, d_{cp}$. Its implementation in software based on simulation using the proposed algorithm allows:

• make a preliminary assessment of saw chain constructions at the stage of sketch design, both by cutting and exploitation properties;

• optimize constructive parameters of chains and other elements of cutting device for the specified combination of the parameters of work;

• choose the best combinations of gasoline-powered tools, chainsaw, chainsaw bar and saw chain from the standpoint of specific energy consumptions.

Developed calculation technique of the specific energy consumption of the process of cross-sawing wood is an essential addition to the cutting theory as fan feed is applied at use of chain cutting body in the great majority of cases. Computer program created on its base gives broad opportunities for
introduction of the obtained results of the research in real production. That has considerable value in the modern conditions of development of logging [10].

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