WOOD RESEARCH
62 (5): 2017
807-814

IMPACT OF THE SELECTED FACTORS ON THE CUTTING FORCE WHEN USING A CHAINSAW

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(Received February 2017)

ABSTRACT

The paper deals with the calculation and analysis of cutting force and input power when crosscut sawing with a chainsaw. For obtaining and evaluating the results, we have used empirical relationships and the values of appropriate coefficients given by the literature. After the evaluation we have gained the theoretical knowledge of the impact of a tree species and its moisture on cutting force intensity and input power. Tree species have a strong influence on cutting force; the harder the tree species is, the greater cutting force is required. Input cutting power is calculated from the cutting force that is why the impact of a tree species on input power is as big as on cutting force. It has been confirmed that the cutting force and cutting input power are affected by wood moisture content, as well.

KEYWORDS: Cutting force, input cutting power, chainsaw, moisture content.

INTRODUCTION

A chainsaw is a tool commonly used for basic wood processing. The cutting mechanism consists of a saw chain, a guide bar and a drive sprocket. The basic parameters of the cutting mechanism include the type and dimensions of a chain, which determines the dimensions and design of the other parts of the cutting mechanism. Another important parameter of a chain is a tooth pitch; it is half of the distance between its two teeth. (Mikleš and Holík 2005, Mikleš et al. 2011).

Many projects dealing with chainsaws or saw chains (Rottensteiner 2012, Augusta et al. 2001) carry out research on vibrations or possible impact of the temperature of a chain and a guide bar on the efficiency of the chainsaw (Maciak 2009, Stanovský et al. 2012). Such research is very important for health and safety of operators. If we wish to focus on the cutting mechanism and its energy consumption, it is necessary to have deeper knowledge of sawing with a chain saw. In the work which was focused on determination of the impact of the cutting rate and the cutting depth (Otto and Paganini 2015) there was developed a product for attaching a guide bar and a chain to the device driven by an electric motor. A similar product was used in the paper focused on saw chain lubrication (Nordfejll et al. 2007). The solution provides precise setting of selected factors, thereby increasing the quality of results. For comparing and checking coefficients, a similar product shall be used.

Chainsaw

The cutting tool is an endless saw chain consisting of saw teeth, connecting links and drive links (Fig. 1).

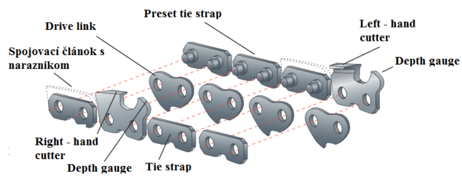

Fig. 1: Parts of a cutter saw chain.

Nowadays, saw chains with cutters are used. A cutter has two plates - the side plate and the top plate. They form a 90-degree angle. The cutter removes a chip of a fixed thickness determined by the difference in height between the depth limiter and the top plate. The peripheral speed of cutter saw chains depends on the type of machine and cutting mechanism 15 to 20 $m \cdot s^{-1}$ (Kováč and Krilek 2012).

Guide bar

A guide bar is the principal component of a chain saw bearing all external loads affecting the chain cutting mechanism when sawing. Increased attention is paid to the shape of the guide bar which has a great impact on the productivity and safety of the whole mechanism. Guide bars consist of four main parts: a mounting section, a top part, a bottom part and a tip. Most bars vary in size and shape and are adapted to their use (Kováč et al. 2013).

The hardness of tree species affects some extent the process of blunting of a tool, thus causing gradual changes in the intensity of cutting force and the necessary input cutting power.

MATERIAL AND METHODS

In this paper we deal with the calculation of the cutting force and cutting power. It is based on empirical relationships. To determine the required parameters such as cutting rate, we have used professional chainsaws; the approximate value is $v = 20\ m \cdot s^{-1}$, the saw kerf height is $H = 300$ mm. The formulas for calculating the cutting force and input power according to Mikleš and Holík 2005 and Mikleš et al 2011 are shown below (Eq. 1 and 2).

The cutting force

$$F_r = k.b.H\frac{v_f}{v} \tag{1}$$

where: *Fr* - cutting force, (N)
k - specific cutting work in crosscut sawing of dry pine (MJ·m^{-3}) (Tab. 1),
b - saw kerf width (m)
H - saw kerf height (m).

Cutting power

$$P_R = k.b.h.v_f \tag{2}$$

where: *Pr* - input cutting power (W)
k - specific cutting work in crosscut sawing of dry pine (MJ·m^{-3}) (Tab. 1)
b - saw kerf width (m)
H - saw kerf height (m).

Coefficient *k* is:

$$k = k_{bor}.K_d.K_w.K_r \tag{3}$$

where: k_{bor} - specific cutting work in cross pine sawing of dry pine (MJ·m^{-3}),
K_d, K_w - correction coefficients representing the impact of tree species and their moisture content,
K_r - correction coefficients representing the impact of blunting.

Specific cutting resistance when sawing is determined empirically (Beňo and Ťavodová 2015).

When crosscut sawing, specific cutting work is decreasing with increasing saw kerf. This occurs because a large part of the cutting force is consumed to cut fibres. The cutting resistance changes insignificantly with increasing saw kerf width; however, the force needed for cutting undercut fibres increases proportionally with the saw kerf width. (Lisičan 1996, Štollmann and Slugeň 2009)

The values of specific cutting work kbor for dry pine when cutting with sharp saw chains are in Tab. 1.

Tab. 1: Values of specific cutting work for different types of chains kbor (Mikleš and Holík 2005).

Saw kerf width (mm)	Feed per tooth f_z (mm)					
	1	0.7	0.4	0.3	0.2	0.1
	Specific cutting work k_{bor} (MJ·m^{-3})					
8	13.0	16.6	19.6	20.6	22.5	29.3
12	11.6	13.0	16.6	17.6	19.6	25.4
18	10.2	11.6	13.6	15.2	17.6	21.5

Tab. 1 shows the effect of the size of the saw kerf and the feed per tooth on the specific cutting work kbor. Specific cutting work is decreasing with growing saw kerf width as well as with increasing feed per tooth. Correction coefficient Kd represents the impact of the hardness of tree species shown in Tab. 2 depending on the tree species.

Tab. 2: Correction coefficient representing the impact of tree species Kd (Mikleš and Holík, 2005).

Tree species	K_d	Tree species	K_d
Linden	0.80	Larch	1.10
Aspen	0.85	Birch	1.20 ÷ 1.30
Spruce	0.9 ÷ 1.0	Beech	1.30 ÷ 1.50
Pine	1.00	Oak	1.50 ÷ 1.60
Alder	1.0 ÷ 1.05	Ash	1.50 ÷ 2.00

The resultant cutting force may also be affected by the coefficient representing the time after sharpening the chains, but that is ignored and a new chain is considered.

RESULTS

The results are based on the technical knowledge of crosscut sawing with a chainsaw. To obtain the results, we used empirical relationships to find out the impact of tree species and moisture on the cutting force and cutting power.

Fig. 3 shows the impact of moisture on the cutting force. As it can be seen in the graph, the cutting force at the humidity of 35÷50% is lower than at the humidity of 15÷20% due to the weighting value for given moisture content (Tab. 3).

Tab. 3: Correction coefficient representing the impact of moisture Kw (Mikleš and Holík 2005).

Absolute moisture content w_{abs} (%)	K_w	Absolute moisture content w_{abs} (%)	K_w
8 ÷ 10	0.90	100 ÷ 150	1.10
15 ÷ 20	1.00	150 and more	1.15
35 ÷ 50	0.95		

The final values were statistically evaluated by ANOVA in the STATISTICA software. The values of the resultant cutting force and input power are shown in Tabs. 4 and 5.

Tab. 4: Final values of the cutting force.

Tree species	Moisture content w_{abs} (%)				
	8÷10	15 ÷ 20	35÷50	100 ÷ 150	150 and more
	Cutting force F_r (N)				
Oak	153.855	170.951	162.403	188.046	196.593
Pine	102.570	113.967	108.269	125.364	131.062
Spruce	92.313	102.570	97.442	112.827	117.956
Beech	133.341	148.157	140.749	162.973	170.381
Ash	205.141	227.934	216.537	250.727	262.124

Tab. 5: Final values of the cutting input power.

Tree species	Moisture content wabs (%)				
	8÷10	15 ÷ 20	35÷50	100 ÷ 150	150 and more
	Cutting input power P_r (W)				
Oak	3111.696	3457.440	3284.568	3803.184	3976.056
Pine	2074.464	2304.960	2189.712	2535.456	2650.704
Spruce	1867.018	2074.464	1970.741	2281.910	2385.634
Beech	2696.803	2996.448	2846.626	3296.093	3445.915
Ash	4148.928	4609.920	4379.424	5070.912	5301.408

The analysis shows that the intensity of the cutting force and input cutting power depends on the tree species and its moisture content (Figs. 2, 3).

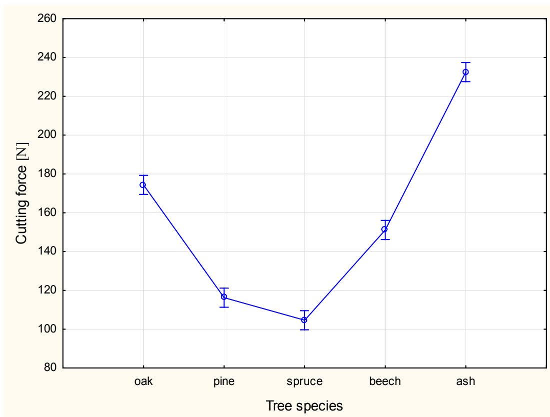

Fig. 2: Impact of tree species on the resultant cutting force.

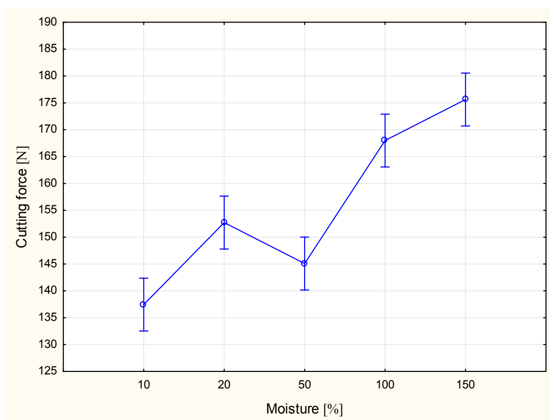

Fig. 3: Impact of moisture on the resultant cutting force.

The input cutting power is calculated from the cutting force that is why the curves of the graphs are identical, and it can be concluded that the selected factors have as much impact on the cutting force as on the input power (Figs. 4, 5). The harder the tree species, the greater cutting force is required for sawing. Based on 2 - factor analysis, it can be estimated that the impact of moisture is not as significant as of tree species.

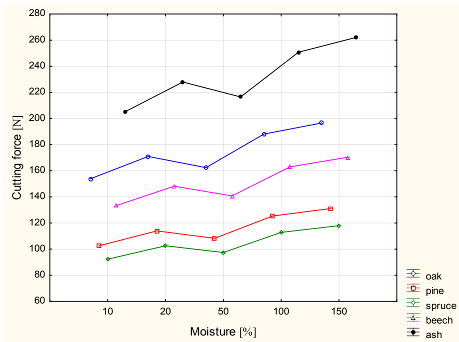

Fig. 4: Interaction of tree species and moisture affecting the resultant cutting force.

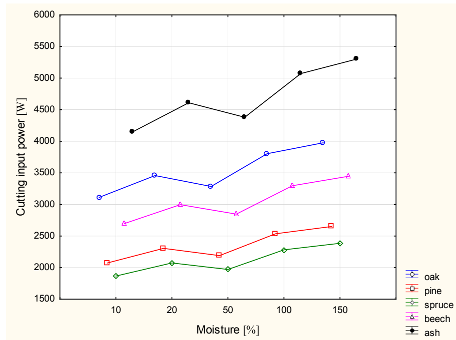

Fig. 5: Interaction of tree species and moisture affecting the cutting input power.

More intensive cutting force is required for the tree species such as oak and ash trees which are harder, hence the conclusion that tree species have a considerable influence on the cutting force. Moisture also has a marked effect on the cutting force but not as much as tree species.

DISCUSSION

Through the inclusion of workpiece moisture content and density, an accurate regression model can be created for the prediction of saw-chain cutting forces that accounts for the inherent heterogeneity of wood mechanical properties. Over the range of workpiece moisture content measured in the study by Otto and Paganini 2015, increasing moisture content was found to cause chain force, cutting force, and feed force to increase for all but the smallest depth–of-cut, with the effect being greatest at high depths-of-cut. At the smallest depth-of-cut, increasing moisture content caused chain force and feed force to increase. There were used samples of douglas fir. The samples were in the shape of rectangle with dimensions 90 x 140 mm and a length of 0.75 m. The moisture of samples was from 12% to 24.8% and density was from 500 kg·m^{-3} to 695 kg.m^{-3}.

Maciak (2015) used samples of pine trees with an absolute moisture content 9.7% and 12.9%. On the basis of results there was shown that high feed speed needs high cutting force.

Moisture and density can be in the correlation with mechanical properties (Kretschmann 2010). Except this fact, Chuchala et al. (2014) explain changes of a cutting force regarding to the density in two different depths of cutting. These results are supported by the meaning of interaction between physical properties and a depth of cutting.

In the mentioned studies (Otto and Paganini 2015, Maciak 2015), the experiments were held in the laboratory conditions with the samples which moisture was up to 25%. The results of these experiments show the influence of the given parameters on the cutting force. In this work we deal with the theoretical definition of the cutting force on the basis of chosen parameters such as moisture and tree species (i.e. physical properties). The model of the cutting force by Atkins (2009) shows theoretical basics for existence of interactions where physical properties have lower influence on cutting force when sawing small chips.

CONCLUSIONS

The paper is focused on the impact of selected factors on the cutting force and input cutting power. To understand the process of sawing, we described the basic parts of the chainsaw mechanism. Empirical relationships were used for calculating the cutting force and input cutting power. In the formulas, the impact of tree species and moisture are specified as correction coefficients K_d and K_w. The results regarding cutting force and input cutting power are shown in Tabs. 4, 5 and will be used in the implementation of the measurements of the energy consumption of the chainsaw cutting mechanism. Statistical analysis provided graphs which clearly show the impact of tree species and moisture on the cutting force and input power. Based on the results and analyses it can be concluded that both factors have an influence on the cutting force as well as cutting input power, tree species having greater impact than moisture.

ACKNOWLEDGEMENT

The paper was written within the project: VEGA 1/0826/15 „Research into the cutting mechanisms within wood processing".

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