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The methodology for determining of the value of cutting power for cross cuttingon the optimizing sawing machine

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Abstract: *The methodology for determining of the value of cutting power for cross cutting on the optimizing sawing machine***.** In the article the methodology of forecasting the energy effects of the cross-cutting process using the classical method, which takes into account the specific cutting resistance, is presented. The values of cutting power for the cross-cutting process of two types of wood (softwood and hardwood) were forecasted for the optimizing sawing machine with using presented methodology.The cross-cutting process with high values of feed speed was analyzed. The presented methodology allowed us to determine dimensions of the cut workpieces limited by the applied electric motor for both soft and hard wood.

Keywords: cutting power, cross cutting, optimizing crosscut saw

INTRODUCTION

The forecast of the cutting power and analysis of cross-cutting process of wood is the subject of research for many years (Cristovao et al. 2011; Hlásková et al. 2018; Kminiak and Kubš 2016; Krilek et al. 2014; Orlowski et al. 2013). However, the cutting power should be forecasted when designing sawing machines and cutting processes, because it allow to select an electric motor with the appropriate rated power and determine the maximum dimensions of workpiece. Especially, when the processing parameters are significantly different from those commonly used so far. The aim of the paper is to present the methodology for determining of the value of cutting power for cross cutting on the optimizing sawing machine.

MATERIALS

The object of the analysis was the arm of the cutting aggregate L_{ag}= 608 mm length, which was used in optimizing crosscut saw AP-500 by REMA S.A. from Reszel, Poland (Web source 4). The discussed arm of the cutting aggregate was adopted for the analysis of the cross-cutting process with a maximum feed speed $v_{fmax}$of up to 4 m·s^{-1}, because other manufacturers declare carried the cutting process out with such parameters(Web source 5).The model of saw WK 150-2 Leitz company dedicated to cross-cutting of wood at high feed speeds was selected to analysis(Web source 1). The dimensions of the analyzed saw are as follows: saw diameter D_n = 450 mm;kerf width S_t = 4.8 mm; rake angle of the tool γ = 10°; and teeth number z = 138.The electric motor of TAMEL Company type 3SG-112M-2PE was selected for driving the spindle.The motor data for the 50 Hz current frequency is: rated power P_m = 7.5 kW; operating voltage U = 400 V; current intensity I = 13.5 A; rotational speed n_m = 2900 min-1; power factor $cos\varphi$ = 0.9; number of phases - 3; type of work S1; insulation class F, protection class IP 55; mass m_m = 48 kg, engine efficiency, η_m = 0.87 (Web source 2). The value of cutting speed was assumedv_c = 84 m·s^{-1}(Web source 3). From the equation (1) the spindle rotational speed was determined n_s= 3566.9 min^{-1}.

$$n_s = \frac{v_c \cdot 1000 \cdot 60}{\pi \cdot D_n} \quad (1)$$

The transmission ratio of the gears with the toothed belt which is to transfer the drive from the motor to the tool spindle was determined from the equation (2) and the ratioequals $i = 1.2615$.

$$i = \frac{n_s}{n_m \cdot \eta_p} \quad (2)$$

where: η_p – efficiency of gears with toothed belt, $\eta_p = 0.975$.
The available cutting power in the cutting zone was determined from the equation of:

$$P_{Limit} = P_m \cdot \eta_p = 7.313\ [kW] \quad (3)$$

The dimensions of the cross-sections of the cutting material was selected as:minimum height H_{min} = 15 mm, maximum heightH_{max} = 60 mm, minimum widthW_{min} = 30 mm and maximum width W_{max} = 200 mm. The vertical movement of the tool axis was assumedH_s = 150 mm.

METHODOLOGY

Cutting forces were determined with the use of the model, which bases on the specific cutting resistance k_c (Chuchala et al., 2010; Manžos, 1974; Orlicz, 1988).This model is generally used to determine the energy effects of the cutting process (cutting power P_c, cutting force F_c) (equation 5) and is considered as a classic approach(Chuchala et al., 2010; Naylor and Hackney, 2013).

$$P_c = F_c \cdot v_c = k_c \cdot A_{Dav} \cdot v_c = k_c \cdot S_t \cdot h_{av} \cdot v_c\ [W] \quad (5)$$

where: k_c – specific cutting resistance in N·mm^{-2}, P_c – cutting power in W, F_c – cutting force in N; A_{Dav} – average cross-section area of uncut chipin mm^2; v_c– cutting speed in m·s^{-1}; S_t – the kerf width in mm; h_{av} – the average uncut chip thickness in mm.

The specific cutting resistance k_c consists of the basic specific cutting resistance k_Φ and series of coefficients, which takes into account different conditions from the basic ones (equation 6).

The value of basic specific cutting resistance k_Φ is dependent on the direction of the cutting speed vector with respect to the direction of the wood fibers, and for process cross-cutting of wood is equal to 12 N·mm^{-2} (Orlicz, 1988).Selected values of correction coefficients for the analyzed case are presented in Table 1.

$$k_c = k_\varphi \cdot k_{ws} \cdot k_{MC} \cdot k_{vc} \cdot k_\delta \cdot k_d \quad (6)$$

Values of specific cutting resistance for two types of wood and for the analyzed conditions of cutting process are presented in Table 2.

In accordance with equation (5), the values of the cutting power P_c mainly dependent on the value of the average uncut chip thickness h_{av}, because values of the kerf width S_t , the specific cutting resistance k_c and cutting speed v_c, are constant. The average uncut chip thickness h_{av} was presented in the form of an equation (7):

$$h_{av} = \frac{f_z \cdot B}{t}\ [\text{mm}] \quad (7)$$

where: t – the length of arc on which of the saw has contact with the workpiece (equation 8); f_z – feed per tooth (equation 9); B – width of the cut material in the feed speed direction in mm.

$$t = \frac{\varphi}{360°} \cdot \pi \cdot D_n \text{ [mm]} \tag{8}$$

$$f_z = \frac{1000 \cdot v_f}{n_s \cdot z} \text{ [mm]} \tag{9}$$

φ – the angle of contact the saw with the workpiece called often as on angular width of the cut material (fig. 1), which was calculated with equation:

$$\varphi = \varphi_2 - \varphi_1 \tag{10}$$

where: φ_1 – entrance angle [°], φ_2 – exit angle [°].

Table 1. Values of correction coefficients for the specific cutting resistance for the analyzed conditions of cutting process (Orlicz, 1988; Staniszewska and Zakrzewski, 2010)

Correction coefficient for the specific cutting resistance	Basic conditions		Analyzed conditions	
	Basic parameter	The value of correction coefficient	Basic parameter	The value of correction coefficient
k_{ws}	soft wood (Pine wood – *Pinussylvestris* L.)	1	hard wood (eg. beech – *Fagus sylvatica* L.; oak – *Quercus* L.)	1.85
			soft wood (eg. pine)	1
k_{MC}	dry wood MC = 10÷15 %	1	dry wood MC = 10÷15 %	1
k_{vc}	50 $m \cdot s^{-1}$	1	84 $m \cdot s^{-1}$	1.2
k_δ	60°	1	80°	1.2*
k_d	sharp blade ρ_o= 4÷10 µm	1	tool after 3 hours work	1.1

* value of coefficient which takes into account the transversal direction of wood cutting

k_{ws} – coefficient taking into account the type of Wood, for pine wood $k_{ws}= 1$;
k_{MC} – coefficient taking into account the moisture content of wood;
k_{vc} – coefficient taking into account the cutting speed;
k_δ – coefficient taking into account the cutting angle; coefficientof angleδ_f, often referred to as the cutting angle, which is defined as the sum of the clearance angle α_f and blade angle β_f;
k_d – coefficient taking into account blade wear.

Taking into account the equations 8 and 9, the equation 7 can be presented:

$$h_{av} = \frac{v_f \cdot B}{60 \cdot z \cdot v_c} \cdot \frac{360°}{\varphi} \text{ [mm]} \tag{11}$$

and equation 5 takes the form:

$$P_c = F_{c1} \cdot v_c \cdot z_m = \frac{k_c \cdot S_t \cdot B \cdot v_f}{2} \quad (12)$$

where:

z_m– the number of teeth in contact with the workpiece, taking into account the type of the saw blade,

$$z_m = \frac{\pi \cdot D_n}{2 \cdot P} \cdot \frac{\varphi}{360°} \quad (13)$$

P – angle pitch of saw teeth.

Table 2. Values of specific cutting resistance for two types of wood and for the analyzed conditions of cutting process

Type of wood	k_Φ basic specific cutting resistance for the transversal direction of wood cutting	$k_{ws} \cdot k_{MC} \cdot k_{vc} \cdot k_\delta \cdot k_d$ ratio of other coefficients	k_c specific cutting resistance
	$N \cdot mm^{-2}$	-	$N \cdot mm^{-2}$
soft wood (eg. pine)	12	1.584	19.01
hard wood (eg. beech, oak)	12	2.93	35.17

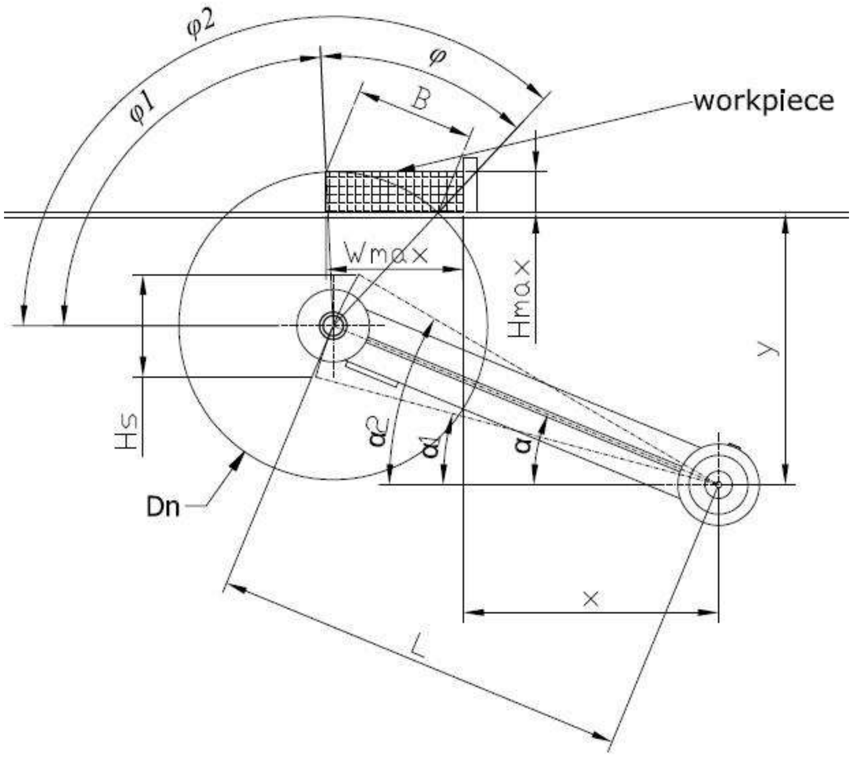

Figure 1. Scheme of the cutting aggregate arm for cross-cutting of wood in position when angle of contact the saw with workpiece φ and the cutting width in feed speed direction B are maximum for selected construction solution, where: α_1 - startangular position of cutting aggregate arm, α_2–end angular position of cutting aggregate arm,α – transitional angular position of cutting aggregate arm, D_n– tool diameter, L – length of arm, H_s - vertical movement of the spindle, x and y - position dimensions of rotation point of arm in relation to workpiece, φ_1 – entrance angle, φ_2 – exit angle, H_{max} and W_{max}–maximum dimensions of the cross-sections of the cutting material.

Equation (12) shows that with constant cutting parameters, cutting power mainly depends on the width cut material in feed speed direction *B*. The position of the axis of rotation of the cutting aggregate arm in relation to the position of the workpiece has been selected so that the angle of contact the saw with workpiece φ and the cutting width in feed speed direction *B* were the smallest (fig. 1). Angular starting position of cutting aggregate arm was assumed on α_1= 15°. The end angular position of the cutting aggregate arm was dependent on the selected vertical movement of the spindle H_s= 150 mm and is equal to α_2= 30,37°. The values of the width of the cut material in the direction of the feed speed *B* were determined graphically for the vertical position of spindle with a step equal to 5 mm (start position 0 mm, end position 150 mm). The value of cutting power $P_c$was determined using equation (12) for each obtained value ofthe width of the cut material in the direction of the feed speed *B*.

RESULTS

The analysis of the cutting power demand for the cross-cutting process of wood showed that values of feed speed, which could be used (table 3) for the assumed maximum cross-section of the workpiece (W200 mm × H60 mm), are much more smaller than the expected maximum value of feed speed,v_{fmax} = 4 m·s^{-1}.The values of cutting power for the cross-cutting process of wood with cross-sectional dimensions W200 mm × H60 mm were forecasted for the determined maximum values of feed speed for two types of wood (soft- and hardwood) (figure 2).

Table 3. The maximum values of feed speed, which enable the sawing of material with a cross-section W200 mm × H60 mm.

Dimensions of the cross-section for sawing workpiece width *W*× height *H*	Type of wood	Maximum value of feed speed v_f
mm ×mm	-	m·s^{-1}
200 × 60	softwood (eg. pine)	0.90
	hardwood (eg. oak)	0.49

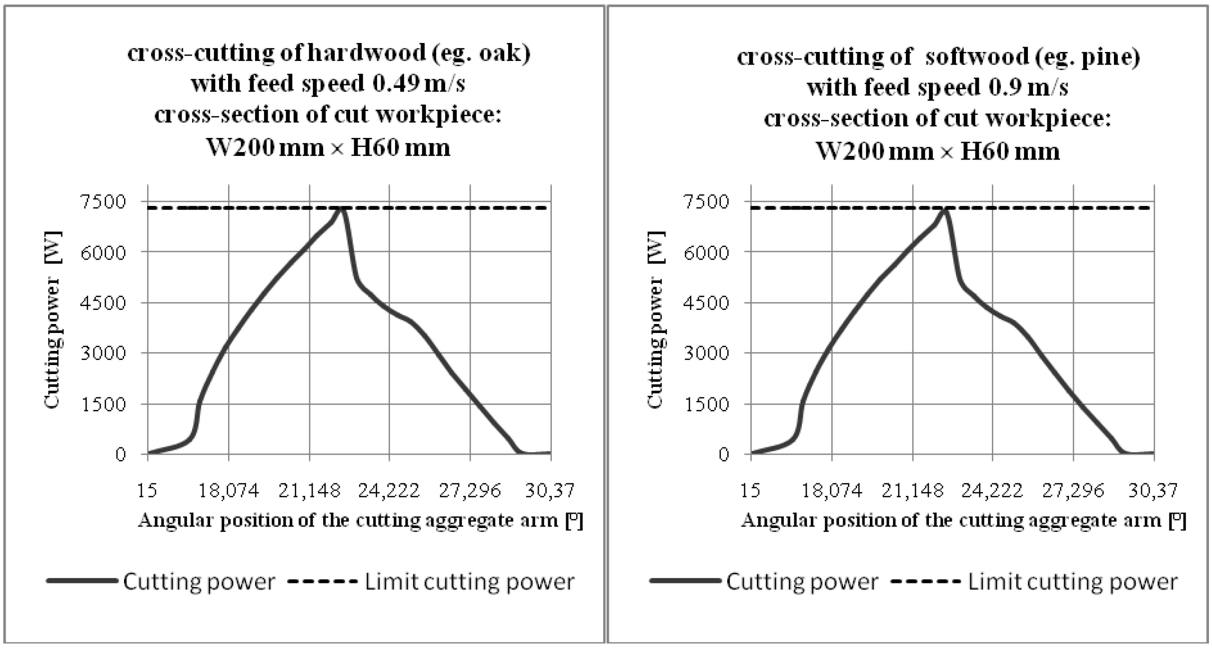

Figure 2. Cutting power for the forecasted cross-cutting process with the maximum analyzed cross-section W200 mm × H60 mm.

The dimensions of the cross-sections of the workpiece, which allow carried the cross-cutting process out with the feed speed v_{fmax} = 4 m·s^{-1}, were determined and are shown in table 4.

While, the forecasted values of cutting power for the cross-cutting process with the feed speed v_{fmax} = 4 m·s^{-1}are shown on figure 3.

Table 4. The maximum dimensions a cross-section of workpiece, which enable the sawing of material with a feed speed4 m·s^{-1}.

The maximum analyzed value of feed speed v_f	Type of wood	Dimensions of the cross-section for sawing workpiece width *W*× height *H*
m·s^{-1}	-	mm ×mm
4	softwood (eg. pine)	60 × 25
	hardwood (eg. oak)	30 × 15

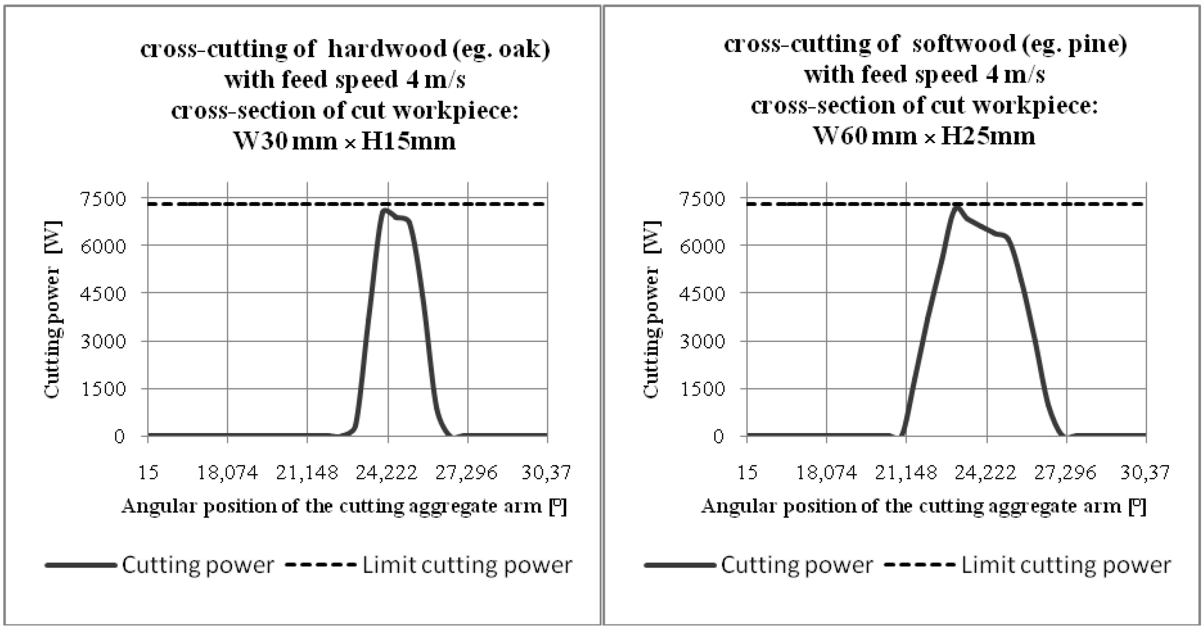

Figure 3. Values of cutting power for the forecasted cross-cutting process with the maximum analyzed value of feed speed, v_f = 4 m·s^{-1}.

CONCLUSIONS

The cross-cutting process of wood with high feed speed (4 m·s^{-1}) generates an extremely high demand for cutting power. This process requires use of an electric motor with rated power higher than Pm = 7.5 kW, which increases the machine's costs.

The cross-cutting process of wood with feed speed (4 m·s^{-1}) can be carried with using the electric motor with rated power Pm = 7.5 kWout, only for small dimensions cross-section of workpiece: soft wood W60 mm ×H25 mm, hardwood W30 mm × H15 mm.

The presented methodology allowed us to determine dimensions of the cut workpieces limited by the applied electric motor for both soft and hard wood.

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Streszczenie: *Metodologia określania wartości mocy skrawania dla przecinania poprzecznego drewna na pilarce optymalizerce.* W artykule zaprezentowano metodologię prognozowania efektów energetycznych procesu poprzecznego przecinania drewna przy zastosowaniu metody klasycznej, która uwzględnia właściwy opór skrawania. Z wykorzystaniem prezentowanej metodyki zaprognozowano wartości mocy skrawania dla procesu przecinania poprzecznego dwóch typów drewna (drewno miękkie oraz drewno twarde) na optymalizerce. Analizy procesupoprzecznego przecinania drewna zostały przeprowadzone dla wysokich wartości prędkości posuwu. Zastosowana metodologia pozwoliła na określenie granicznych przekrojów przecinanego drewna dla zastosowanego silnika dla obydwu rodzajów przecinanego surowca, drewno twarde i miękkie.

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