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The original method of cutting power forecasting while wood sawing

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Abstract: *The original method of cutting power forecasting while wood sawing.* In the classical approach, energetic effects of wood sawing process (cutting forces and cutting power) are generally calculated on the basis of the specific cutting resistance. On the other hand, cutting forces (power) could be considered from a point of view of modern fracture mechanics. Forecasting of the shear plane angle for the cutting models, which include fracture toughness in addition to plasticity and friction, broaden possibilities of energetic effects modelling of the sawing process even for small values of the uncut chip. The mentioned model is useful for estimation of energetic effects of sawing of every kinematics. However, for band saws and circular sawing machines the chip acceleration power variation as a function of mass flow and tool velocity ought to be included in analysis of sawing at larger cutting speeds.

Keywords: wood sawing, cutting power, fracture mechanics

INTRODUCTION

In the classical approach energetic effects (cutting forces and cutting power) of wood sawing process are generally calculated on the basis of the specific cutting resistance k_c (cutting force per unit area of cut) [1, 2], which in the case of wood cutting is the function of the following factors: wood species, cutting direction angle (cutting edge position in relation to wood grains), moisture content, wood temperature, tooth geometry, tooth dullness, chip thickness and some others which are less important [3, 4]. Many of those traditional models are empirical and based upon limited information employing blades having standard thickness kerfs. Moreover, for each type of sawing kinematics different values of specific cutting resistance k_c have to be applied [4]. On the other hand, cutting forces (power) could be considered from a point of view of modern fracture mechanics [5]. Atkins's ideas [5] can be also applied in analyses of sawing processes in which the offcut formation by shear occurs, e.g. in the real sawing process on a sash gang saw with the method based on the macro-mechanics [6–9].

In this paper we are going to prove that cutting power models which are based on modern fracture mechanics are useful for estimation of energetic effects of sawing on sash gang saws and band sawing machines. However, it should be emphasised, that very promising results have been obtained also in the case of cutting power estimation for circular sawing machines [9].

Nomenclature

f_z – feed per tooth (uncut chip thickness h), m
k_c – specific cutting resistance (cutting force per unit area of cut), MPa
$\dot{m}$ – represents the mass of wood (chips) evacuated in a certain period of time at the certain cutting tool velocity v_c (cutting speed), kgs^{-1}
v_c – cutting speed, ms^{-1}
v_f – feed speed, ms^{-1}
w – the width of orthogonal cut equal to S_t (overall set, kerf), m
F_c – cutting force per one tooth during the working stroke, N
H_p – workpiece height (cutting depth), m
P_{cw} – mean cutting power during the cutting stroke, W

P_{ca} – chip acceleration power, W
R –specific work of surface separation or formation (fracture toughness), Jm^{-2}
S_t – overall set, theoretical kerf, m
β_μ – friction angle given by $\tan^{-1}\mu = \beta_\mu$, rad
γ – the shear strain along the shear plane
γ_f – rake angle, rad
μ – friction coefficient
ρ – density of sawn wood, kgm^{-3}
τ_γ – the shear yield stress, Pa
Q_{shear} – the friction correction
Φ_c - shear angle, rad or deg

THEORETICAL BACKGROUND

Making an assumption that cutting force F_c acting in the middle of the cutting edge is an equilibrium of forces related to the direction of primary motion for a single saw tooth the mechanical process of material separation from the sawn workpiece, i.e. chip formation, can be described by the example of an orthogonal process (two dimensional deformation) [10].

According to Atkins [5] and Orlowski [10], furthermore, taking into account that the chips have to be accelerated to the same velocity as the cutting tool velocity v_c [5, 11], mean cutting power for one saw blade during the cutting stroke on a sash gang saw, and during cutting on a bandsaw machine, because their sawing kinematics (chip formation) resemblance [3, 4, 10], has the following mathematical formula [9, 10]:

$$\overline{P}_{cw} = \sum F_c v_c + P_{ac} = \left[\text{Ent}\left(\frac{H_P}{P}\right) \cdot \frac{\tau_\gamma S_t \gamma}{Q_{shear}} v_c f_z + \text{Ent}\left(\frac{H_P}{P}\right) \cdot \frac{R S_t}{Q_{shear}} v_c \right] + P_{ac} \qquad (1)$$

where: $\text{Ent}\left(\frac{H_P}{P}\right)$ is a number of teeth being in the contact with the kerf (integral).

Formulae for the shear strain along the shear plane γ, Q_{shear} the friction correction and the shear angle Φ_c which defines the orientation of the shear plane with respect to cut surface, which were presented in works [6, 7, 9, 10], are as follows:

$$\gamma = \frac{\cos\gamma_f}{\cos(\Phi_c - \gamma_f)\sin\Phi_c} \qquad (2)$$

$$Q_{shear} = [1 - (\sin\beta_\mu \sin\Phi_c / \cos(\beta - \gamma_f)\cos(\Phi_c - \gamma_f))] \qquad (3)$$

$$\left[1 - \frac{\sin\beta_\mu \sin\Phi_c}{\cos(\beta_\mu - \gamma_f)\cdot\cos(\Phi_c - \gamma_f)}\right]\cdot\left[\frac{1}{\cos^2(\Phi_c - \gamma_f)} - \frac{1}{\sin^2\Phi_c}\right] =$$
$$= -\left[\cot\Phi_c + \tan(\Phi_c - \gamma_f) + Z\right]\cdot\left[\frac{\sin\beta_\mu}{\cos(\beta_\mu - \gamma_f)}\left\{\frac{\cos\Phi_c}{\cos(\Phi_c - \gamma_f)} + \frac{\sin\Phi_c \sin(\Phi_c - \gamma_f)}{\cos^2(\Phi_c - \gamma_f)}\right\}\right] \qquad (4)$$

in which $Z = \frac{R}{\tau_\gamma \cdot f_z}$ is the parameter which makes Φ_c material dependent. It ought to be emphasised that Φ_c may be merely found numerically [6].

The chip acceleration power P_{ac} variation as a function of mass flow and tool velocity is given by:

$$P_{ac} = \dot{m} v_c^2 \quad (5)$$

and $\dot{m}$ which represents the mass of wood (chips) evacuated in a certain period of time at the certain cutting tool velocity v_c (cutting speed) can be calculated as follows:

$$\dot{m} = H_P S_t v_f \rho \quad (6)$$

Moreover, it should be stressed, that in these analyses it was assumed that the power P_{ac} is not a function of the number of working teeth [11].

THE CASE STUDY

Predictions of cutting powers have been made for the case of sawing on two kinds of basic sawing machines such as the sash gang saw (HDN, f. EWD) and the band sawing machine (EB 1800, f. EWD), which are used in Polish sawmills. The basic sawing machines data and cutting parameters for which computations were done are shown in Table 1. Computations were carried out in each case study for one saw blade. The raw material was pine wood (*Pinus sylvestris* L.) of depth of cut equal to H_p (Table 1) derived from the Baltic Natural Forest Region in Poland. The raw material indispensable data for computation such as: fracture toughness R = 840 Jm^{-2} and the shear stress τ_γ = 22636 kPa was determined according to the methodology described in the works [7, 10]. The latter tests of raw material data determination were carried out on the sash gang saw PRW15M [10] with stellite tipped saw blades with a kerf equal to S_t = 2 mm. The average density of samples was ρ = 525 kgm^{-3}, at moisture content MC 8.5–12%. A value of friction coefficient μ = 0.6 for dry pine wood was assumed. The chip acceleration power P_{ac} variation was estimated for each kind of sawing kinematics for depth of cut equal to H_p = 100 mm.

Table 1. Tool and machine tool data

Parameter	Sash gang saw HDN (f. EWD)	Bandsawing machine EB 1800 (f. EWD)
H_p [mm]	140	140
S_t [mm]	4.0	3.1
P [mm]	25	50
γ_f [°]	14	28
z [–]	32	217
v_c [m/s]	6.4	35
v_f [m/min] ([m/s])	0–15 (0–0.25)	40–70 (0.67–1.167)
$f_z = h$ [mm]	0–1.953	0.95–1.67
P_{EM} [kW]	160	4×110

a) b)

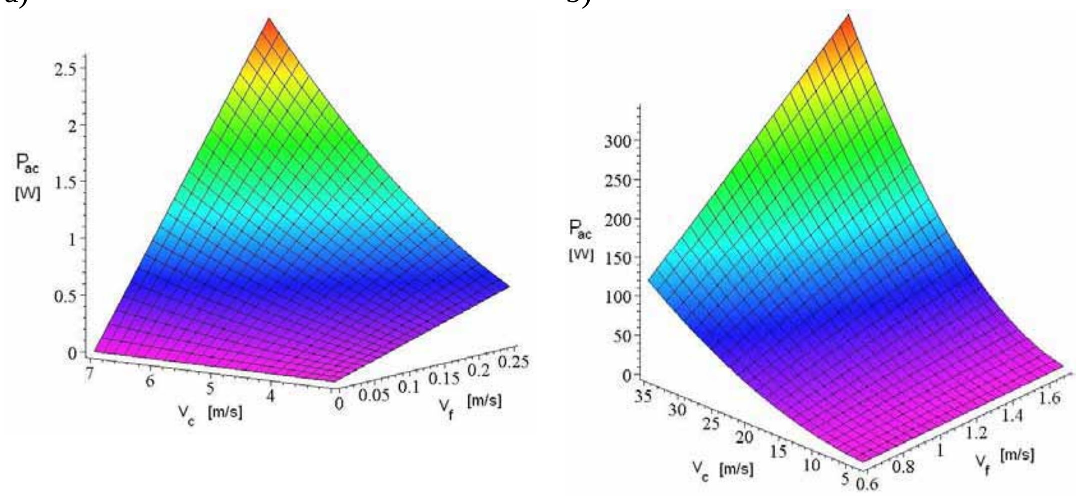

Fig. 1. Predictions of chip acceleration power variation P_{ac} as a function of cutting speed v_c and feed speed v_f for sawing of the pine workpiece of 100 mm in height with one saw blade on sash gang saw HDN (a) and band sawing machine EB 1800 (b)

RESULTS AND DISCUSSION

In figure 1, the chip acceleration power P_{ac} variations as a function of feed speed v_f and cutting speed v_c for the sash gang saw HDN (fig. 1a) and the bandsawing machine EB1800 (fig. 1b) for the cutting processes with one saw blade while sawing dry pine wood for depth of cut equal to H_p = 100 mm are presented. For the examined sash gang saw a maximum value of the chip acceleration power P_{ac} equals to ≅ 2.5 W. Thus, in those machine tools where cutting speeds and feed speeds are rather small if compared with band saws (fig. 1b) and circular saws [9], chip momentum may be disregarded, the same as in the case of metal cutting where it is customarily ignored [5]. In case of the bandsawing machine the chip acceleration power P_{ac} is several hundred larger in comparison with the sash gang saw.

Comparison of predictions of cutting powers obtained with the use of cutting models that include work of separation in addition to plasticity and friction, and chip acceleration power variation (a maximum value of P_{ac} added) in the case of dry pine sawing with one saw blade for two examined typical sawing machines are shown in fig. 2.

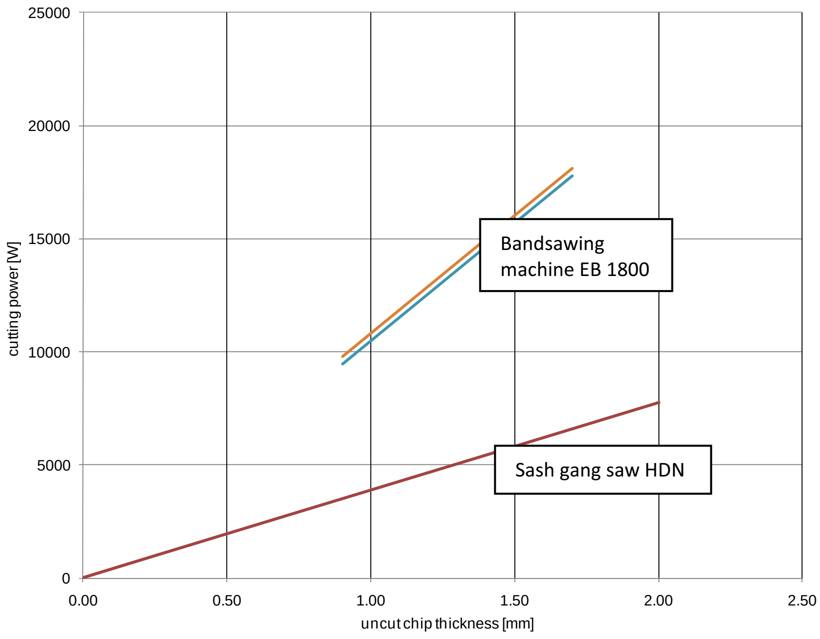

Fig.2. Comparison of predictions of cutting powers obtained with the use of cutting models that include work of separation in addition to plasticity and friction (lower lines), with chip acceleration power variation added (upper line in case of bandsawing machine) while sawing dry pine with one saw blade

Obtained values for those machines seem to be reasonable if compared to the power P_{EM} of installed electric motors (Table 1), and also they are in conformity with values calculated with the use of empirical calculation models. Furthermore, they proved that predictions of cutting powers obtained with the use of cutting models that include work of separation in addition to plasticity and friction together with the chip acceleration power variation could be a useful tool for estimation of energetic effects of sawing for different types of sawing machines.

CONCLUSIONS

The conducted analyses of cutting power forecasting with the use of the novel models that include work of separation in addition to plasticity and friction corroborated their versatility and revealed the usefulness for different types of sawing machines. Moreover, in the estimation of cutting power for sash gang saws chip momentum may be disregarded. On the other hand, in case of cutting on band sawing machines the chip acceleration power P_{ac} has to be taken into account. Eventually, it ought to be emphasised that in that kind of approach only

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Streszczenie: *Oryginalna metoda prognozowania mocy skrawania podczas przecinania drewna piłami.* Efekty energetyczne procesu przecinania drewna piłami (siły skrawania i moc skrawania) przy klasycznym podejściu do zagadnienia są określane na podstawie wartości właściwego powierzchniowego oporu skrawania. Z drugiej strony siły skrawania można rozważać z punktu widzenia współczesnej mechaniki pękania. Prognozowanie wartości kąta ścinania z zastosowaniem modeli uwzględniających wiązkość materiału obrabianego, ścinanie w płaszczyźnie ścinania i tarcie na powierzchni natarcia rozszerza możliwości modelowania (przewidywania) efektów energetycznych przecinania nawet dla małych wartości grubości warstwy skrawanej. Wspomniany model jest przydatny do szacowania mocy skrawania dla każdej znanej kinematyki przecinania. Jednakże, przy prognozowaniu mocy skrawania dla pilarek taśmowych i tarczowych, z uwagi na duże wartości prędkości skrawania, należy dodatkowo w modelowaniu uwzględniać moc niezbędną na przyspieszenie wiórów, która jest funkcją strumienia masy wiórów i prędkości skrawania narzędzia.

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