The dependency of energy consumption on cutting angles in the canter chipping process

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KEYWORDS: Canter chipper, Energy consumption, Specific cutting energy, Saw mill chips

SUMMARY: Canter chippers are used in sawmills to reduce the circular cross section of logs to a rectangular shape before sawing. The canter chipper is a conical disc equipped with knives on its periphery. When rotated at high velocity it transforms the outer parts of a log into sawdust and chips. It is important to be able to predict the energy consumption during canting since it is useful to know whether a particular canting strategy can be employed in situations where there is a limit on the power supply. A theoretical model in which energy consumption can be calculated is necessary for such a prediction. Data concerning the specific cutting energy is needed to develop the model for the canting operation.

In this paper the energy consumption during chipping of spruce is determined by using a pilot wood chipper at two different cutting rates and for several cutting angles. The results indicate that the specific energy to cut wood chips increases as the angle between the fibre direction and the cutting plane increases.

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A large amount of lumber is sawn every year worldwide. Given the competitiveness of the market, it is important to make optimal use of the raw material. Thus sawmills produce not only planks and boards but also wood chips from canter chipping that are sold to the pulp and paper industry. It is claimed that in Sweden almost 30% of the wood chips used in pulp production are saw mill chips. Research has focused almost exclusively on the properties of the chips produced.

However, energy consumption in general, and in the canter chipping operation in particular, is an important parameter for the sawmill industry. Yet there has been little research on this field. Energy consumption during operations such as sawing and planing of wood is discussed in Davim (2011). The effect of different operational parameters for a canter chipping process (e.g. the wood species, log diameter and rotational speed) on the size distribution of the wood chips was studied in Hernández and Boulanger (1997), Hernández and Lessard (1997) and Hernández and Quiron (1995).

Some general studies of the production of wood chips for the pulp and paper industry using a disc chipper were carried out by Hartler (Hartler 1986; Hartler 1996). In a very thorough study Kivimaa and Murto (1949) performed experimental studies on the effect of several factors on the chipping of wood. The factors were moisture content, temperature (frozen and unfrozen wood) and knife sharpness. Buchanan and Duchnicki (1963) measured the forces on the chipping tool. The common factor in these studies is that they were performed at low cutting rates. Until recently, there have been few detailed studies of the chipping process under realistic conditions, for example, in regard to cutting rates. Hellström et al. (2011) described a pilot wood chipper in which it is possible to vary a number of process parameters such as cutting rate, chip length, and cutting angles.

Two parameters of particular interest for canter chipping are the cutting angle and the angle defining the conical shape. The cutting angle for a canter chipper can be defined as the spout angle ε in an ordinary disc chipper, ε being the angle between the fibre direction projected on a vertical plane and the cutting plane (see *Fig 1*).

All relevant angles, except the side angle ψ, are defined in *Fig 1,* where ε is the spout angle, α the clearance angle, β the edge angle and λ the complementary angle. The arrow indicates the direction of movement of the knife.

The angle defining the conical shape is comparable to the side angle ψ in a disc chipper, ψ being the angle between the fibre direction projected on a horizontal plane and the cutting plane. *Fig 2* shows a schematic drawing of the geometry of the experimental setup indicating the spout angle ε and the side angle ψ.

In a paper mill wood chipper, the side angle is usually zero, but for canter chippers, due to the conical shape of the disc, the side angle is most often 45°. This can be seen in *Fig 3* (shown by permission of Andritz Iggesund Tools AB).

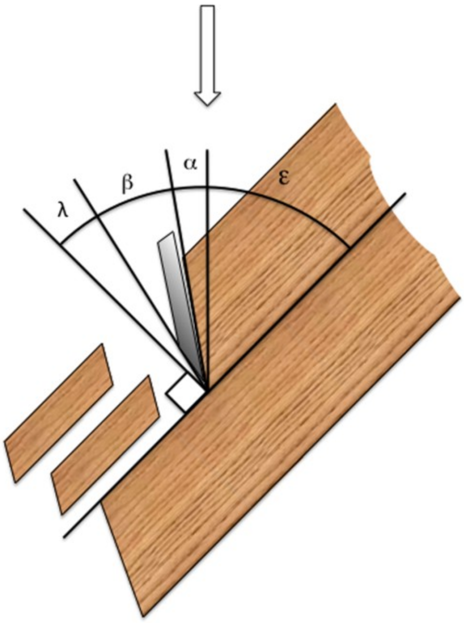

Fig 1. The relevant chipping angles: λ complimentary angle, β edge angle, α clearance angle and ε spout angle.

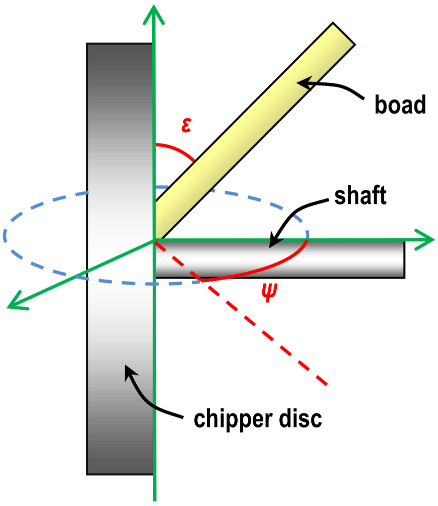

Fig 2. Schematic drawing showing the spout angle ε and the side angle ψ.

The spout angle will vary within a range determined in part by the arc length of the part of the canter in contact with the log. This is because the knives follow a curved path, causing a variation in the angle between the fibre direction and the cutting direction. Thus to obtain data for a theoretical model describing the canting operation, the energy per unit area of cut surface must be determined for a side angle of 45° and for a range of spout angles. This range can, at least theoretically, be from 0° to 90°. The saw blade seen in *Fig 3* produces a sufficiently smooth surface to the chipped area.

In this paper the main concern is the energy consumption during the chipping part of the canting operation. The pilot wood chipper described in Hellström et al. (2011) was used to determine energy consumption for different process parameters.

Materials and Methods

During canting the externally supplied energy will be consumed by different mechanisms including dry friction, irreversible deformations, the forming of cut surfaces, and crack propagation when a chip is formed. The specific energy can be defined in different ways such as energy per unit volume of chips or energy per unit cut surface. In this study the specific energy is defined as the energy associated with the cutting of one unit of area during chipping. It was determined in two ways. First, the chipper disc was accelerated to a given rotational speed, after which the power was switched off and chipping commenced. When the rotational speed had decreased by approximately 10% of the initial value, the length of the specimen consumed by the chipper was measured. The change in kinetic energy ΔE of the chipper disc is given by

$$\Delta E = \frac{J\left(\omega_f^2 - \omega_0^2\right)}{2} \qquad [1]$$

where J is the mass moment of inertia of the chipper disc, ω_0 is the angular frequency at the instant when the power is switched off, and ω_f represents an approximate drop of

Fig 3. A canter chipper.

10% (i.e. when the chipping is interrupted). The energy G per unit cut area is now calculated as

$$G = \frac{|\Delta E|}{(NA)} \qquad [2]$$

In *Eq 2* the vertical bars denote the absolute value, A is the area created by one cut (i.e. a cut through the whole cross section of the specimen). N is the number of cuts, and was assumed to be the ratio of the total length of the specimen that was transformed into chips and the nominal chip length of 25 mm. Using wood specimens with a rectangular cross section with area A_0, then in general, the cut will have a rhombic shape, the area A of which is given by (in terms of the spout angle ε and the side angle ψ)

$$A = \frac{A_0}{(\sin\varepsilon\cos\psi)} \qquad [3]$$

The reason for choosing only a 10% decrease in the angular frequency during chipping is that if G is dependent on the cutting rate, it would be inappropriate to continue chipping until the chipping disc comes to a complete rest.

Another way to determine G is as follows: the kinetic energy in the chipping disc will decrease by GA for each cut. If it is assumed that one cut is performed for each rotation of the disc, performing n rotations per time unit, then the decrease in kinetic energy per unit time, dE/dt, is given by

$$\frac{dE}{dt} = -GAn \qquad [4]$$

With $n = \omega/(2\pi)$ where, as before, ω is the angular frequency, *Eq 4* will become

$$\frac{dE}{dt} = \frac{-GA\omega}{2\pi} \qquad [5]$$

At some arbitrary angular frequency ω, the change in kinetic energy is given by the right-hand side of *Eq 1* with ω substituted for ω_f. So by differentiation with respect to time, one will obtain

$$\frac{dE}{dt} = J\omega\frac{d\omega}{dt} \qquad [6]$$

Combining *Eq 5* and *Eq 6* gives

$$G = -\frac{2\pi J}{A}\frac{d\omega}{dt} \qquad [7]$$

Fig 4 shows a typical ω versus time t curve (measured using a Leine & Linde AB tachometer, Part No. 516193-04). The slope during the time in which chipping is performed, (i.e. $d\omega/dt$) is negative and constant, as *Eq 7* predicts.

The initial and final angular frequencies ω_0 and ω_f are estimated as shown in *Fig 4*. Comparison between the two methods showed variations in G of approximately 10 to 20%. *Eq 2* was used to evaluate G.

Experimental

For the sake of completeness, two side angles ψ 0° and 45° were tested with spout angles ε equal to 30°, 50°, 70° and 90°. In all tests, β was equal to 34°, α equal to 3° and the nominal chip length was kept at 25 mm. The wood species used in the experiments was Norway spruce (*Picea abies*) with an approximate dry content of 50%.

The tests were carried out using two different values of ω_0, namely 41 and 52 rad/s, corresponding to cutting rates of 20 and 25 m/s. For most combinations of cutting rates, side and spout angles, five trials were carried out.

The cross section of the specimen was 100 by 50 mm^2 for all cases where ψ was equal to 0° and for the case ψ = 45°, ε = 90°. Due to the limited length of the chipping knife, the cross section had to be reduced to 37 by 37 mm^2 (shown in *Fig 5*) for the case ψ = 45° and ε = 30°. A cross section of 50 by 50 mm^2 was used for the cases $\psi = 45°$, $\varepsilon = 50°$ and $\psi = 45°$, $\varepsilon = 70°$.

Results and Discussions

Fig 6 and *Fig 7* show the specific cutting energy (determined using *Eq 2*) versus the spout angle for side angles 0° and 45° at cutting rates of 20 and 25 m/s. The vertical bars represent ± one standard deviation.

Based on the results for the case ψ = 0°, one would expect that the cutting energy for the case ψ = 45° should be an increasing function of ε. However, the energy at ε = 30° is higher than at 50°. It was observed that for this particular case a large proportion of the chips were not completely separated and large aggregates of chips were formed. It might be that the fibre bridging involved here may be responsible for the larger energy dissipation.

When the cutting rate was increased to 25 m/s (*Fig 7.*) almost no aggregates of chips were formed. The curve for side angle 45° proves to be an increasing function of ε. At the side angle of 0°, the scatter for ε = 90° was very large. This could be because there is no well-defined fracture process in this case; probably some combination of cutting and crushing is involved.

Another reason for the observed scatter might be that there was no self-feeding of the specimen into the chipper (i.e. the specimen had to be manually pushed through).This might have caused additional (and not well-defined) dissipation of energy through the friction between the specimen and chipper disc.

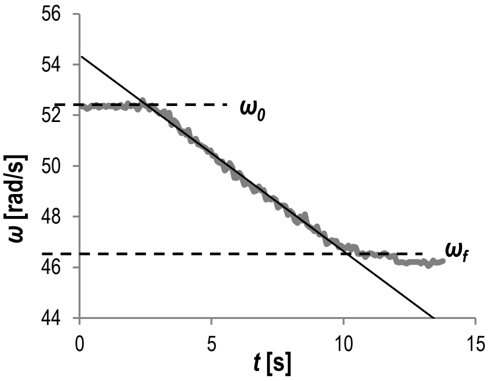

Fig 4. Angular frequency vs. time in a chipping experiment for side angle 45°, spout angle 50°, and chip length 25 mm. ω_0 and ω_f are the initial and final angular frequency respectively.

Fig 5. The wood chipper with a sample inserted.

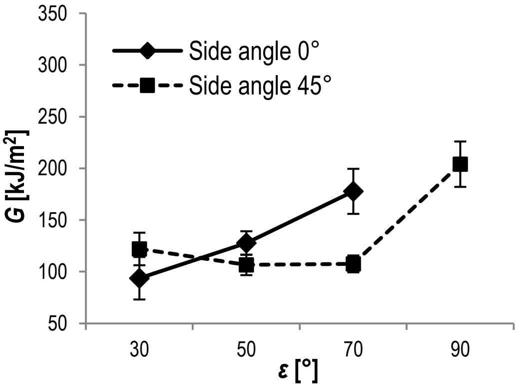

Fig 6. Specific cutting energy vs. the spout angle for cutting rate 20 m/s.

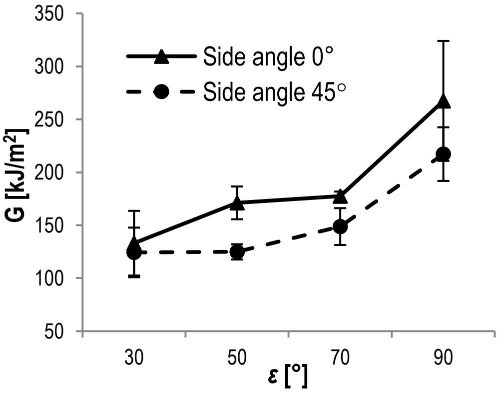

Fig 7. Specific cutting energy vs. the spout angle for cutting rate 25 m/s.

In Hellström et al. (2011) the specific cutting energy for the case $\varepsilon = 30°$, $\psi = 0°$ and cutting rate 20 m/s was determined (in a slightly different way) to be 93 kJ/m^2. It can be seen that this agrees with the corresponding value given in *Fig 6.,* which lends some confidence to the results presented here.

Conclusions

Measurements of the specific cutting energy during chipping were made with the aim of developing a theoretical model to estimate the energy consumption for a given canting strategy. This was done for a range of spout angles $30° \leq \varepsilon \leq 90°$and for side angles 0° and 45°, where 0° corresponds to a cylindrical canter chipper and 45° to a conical chipper.

At a cutting rate of 20 m/s and a side angle of 45°, the specific cutting energy vs. the spout angle was not a monotonically increasing function. This was found to be due to the formation of clusters of chips. When the cutting rate was increased to 25 m/s this behaviour disappeared, so that the specific cutting energy increases with spout angle, as expected.

The theoretical model to be developed will use the results for the 45° side angle shown in *Fig 7*. Depending on the canting strategy, different spout angles and areas will be involved. The relationship between the specific cutting energy and the spout angle will be one necessary ingredient when calculating the required power.

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