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ORIGINAL

The optimum log feed speed with bandsaw

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Abstract A method is presented to determine the optimum log feed speed of a bandsaw based on its power consumption. Three timber species—oak, beech and pine—were sawn under real sawing conditions in a mill. The target of the experiment was to find the optimum log feed speed with the following characteristics: Minimum energy consumption per unit volume sawdust produced, maximum filling of saw tooth gullets with sufficiently dense sawdust and desired product quality. The experiment revealed that: (1) there is a crucial sawdust expansion rate in the gullet which is hardly varying among the three species. Its magnitude is 1.7–1.9 times the volume of solid wood. At this sawdust expansion the gullet seems to be fully utilized. (2) There is indeed an optimum log feed speed characterized by minimum energy uptake if related to a unit volume wood converted to sawdust. This value is varying with the cutting height, i.e. wide board products will still require a slower log feed speed, narrow boards a faster one. With the help of an equation, the optimum log feed speed can be quickly established for each board to be cut. (3) By comparing the real log feed speeds with the optimum ones, the utilization of the bandsaw can be judged. The results revealed that the real operation times were about 30 % longer than the machine's optimum, and that an energy saving of about 30 % was possible.

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1 Introduction

In many parts of the world, the majority of sawmills is of small to medium size, seldom cutting more than on average 40,000 m^3 timber per year (Fronius 1989; Hargitai 2003). This implies that the outfit is often slightly aged, and that sophisticated controlling devices such as a log feed speed regulator might not be available. In modern sawmilling practice, the most widely used controller senses the running stability of the saw blade with laser rays while the stem is pushed against it (Myrfield 2004; Alam et al. 2002; Okai et al. 1996; Tanaka and Huang 1995). Less frequently used means are a bandmill calculator (www.woodproductsonlineexpo.com), or theoretical treatises (Wessels 2009). To subsequently equip elderly machines with a sophisticated device is often a matter of economics, and habitually procrastinated in fear of reducing profitability. It can be shown, however, that using data, easily attainable in the mill, can demarcate the desired maximum log feed speed without investing in a high-tech, expensive cruise controller. This practical method–the subject of this paper–harbors a number of immediate advantages: The profitability is improved because the productivity of the machine increases, additionally the energy consumption based on the extent of cut surfaces tends to become a minimum while the dimension accuracy of products remains as set (Okai 2009).

It is postulated that the saw blade is maximally utilized if a tooth gullet, just leaving the timber while sawing, is filled with sufficiently compacted sawdust. Then, this maximum log feed speed is characterized by a minimum of electrical energy consumption based on a unit solid timber volume converted to sawdust. Actually, at a slower log feed speed, the energy needed to convert a unit volume solid wood to sawdust would increase because the average particle size of the sawdust was smaller. With faster feed speed, the energy use would increase because sawdust spills out of the gullet into the slit between the blade and cut surface of timber causing friction and blade vibration. Thus, the optimum log feed speed may be linked to a minimum energy uptake as measured per unit solid wood volume converted to sawdust.

2 Materials and methods

In order to prove the validity of the hypothesis, data have been collected in a mill during real production conditions. A band saw mill has been favored because of its wide spread, and because of the fact that much pertaining research results can be found in the literature. Investigations with regard to frame saws (e.g. Wessels 2009) and circular saws (Lučić et al. 2004) are not less relevant, yet here, focus was put on a bandsaw. As timber material, a conifer and two broad leaved species were selected, specifically Scots pine (*Pinus silvestris,* 12 logs*)*, a European oak (*Quercus* sp., 10 logs) and European beech (*Fagus sylvatica*, 12 logs). The total number of boards sawn was 270, manufactured with 236 cuts.

Prior to the start, the saw blade's profile (pitch, gullet area, saw kerf width) and log data were documented. With these data and the extent of cut surfaces, the dust volume accommodated by one tooth gullet during a passage through the log was calculated. The blade's running speed was derived from the dimensions and the number of revolutions per minute of the driving wheel.

During the experiment, sawdust samples were collected with three goals in mind: first, to be able to link the energy consumption data to the produced sawdust mass. Second, to carry out specific gravity measurement and sawdust compaction experiments in the lab in order to become more precise about the timber mass converted to sawdust, and third, to determine the moisture content of the timber material.

Preliminary sawing runs were carried out to reveal the sawing speed range for the three timber species in which the optimum log feed speed was assumed to lie. Thereupon, the following feed speeds were chosen for the experiment: approximately 20, 30, 40 m/min, and for oak also 50 m/min. A specific device was constructed in order to control the speed of log movement through the machine.

Electrical power consumption was recorded throughout the whole sawing process, and linked to the boards with date and time.

Because of the light variation of the individual cutting height along a board and of the respective power consumption, the data was averaged for each board.

3 Results

Table 1 shows the specific gravity and moisture content of the timber used in the trial. Real sawing environment meant that the material was directly taken from the log yard according to the sawing plan valid for the day. It also meant that a large variation in the data was expected because of the varying storage time in the yard prior to the experiment. Conspicuous was the unusually low moisture content of pine which has obviously been lying longer in the yard than beech or oak. Nevertheless, it was accepted in the experiment.

To start with, the interdependence of log feed speeds and board widths (cutting heights) were determined for all three species.

Figure 1 shows an example for beech, and reveals that the pace of the log speed decreases with growing cutting height. The interdependence roughly respects the dust carrying capacity of the gullet. Fundamentally, the tooth gullet is the measure of the blades sawing potential. For the maximum utilization of sawing capacity of the blade, the gullet must be full of sawdust when it leaves the stem. To produce constantly the same amount of sawdust, the log must move faster with lower cutting height and slower with larger cutting height, respectively, as the figure illustrates.

The optimum log feed speed for the individual cutting height is still unknown here, yet, Fig. 1 indicates that feed speeds for beech under practical sawing conditions range between 15 and 40 m/min for board widths between 0.12 and 0.57 m. Thus, the optimum feed speed is expected to lie in this range or above.

According to the authors hypothesis, the energy needed to slice a board off the trunk must show a minimum at the optimum log feed speed. The electrical energy consumption was registered throughout the whole sawing experiment.

The amount of energy needed to saw a board from the log was calculated from the power readings and the duration of the sawing operation. Divided by the volume of wood sawn to dust the results yield the energy needed to convert a unit volume of solid wood to sawdust. This energy requirement in dependence of the log feed speed is shown in Figs. 2, 3 and 4 for the different timber species.

Table 1 Specific gravity and moisture content of the experimental material

Species	Specific gravity ± confidence limit (kg/m^3)	Moisture content ± confidence limit (%)	Degree of freedom; error probability
Oak, timber	813 ± 9.8	61.0 ± 1.0	19; 0.05
Beech, timber	951 ± 28	52.8 ± 4.0	11; 0.05
Pine, timber	528 ± 37	17.6 ± 0.81	9; 0.05

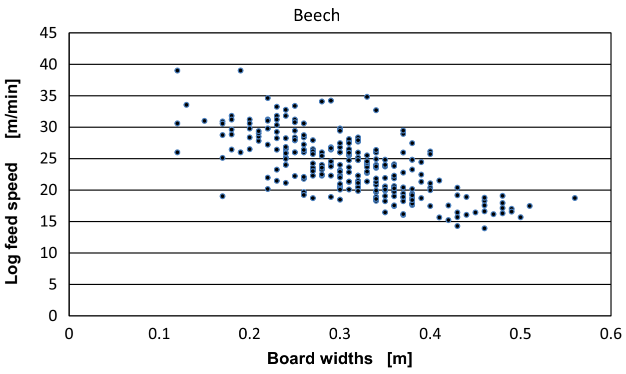

Fig. 1 Dependence of log feed speed on the board width (cutting height) of beech

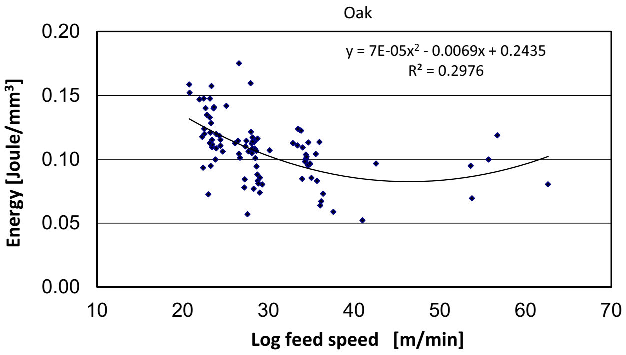

Fig. 2 Energy required converting a unit volume of solid wood to sawdust, and its dependence on the log feed speed. For oak, the optimum log feed speed lies at 47.5 m/min

For a complete energy balance of sawing, the electrical energy needed to move the log carriage ought to be included as well. This was, however, omitted here because the interest was focused solely on the chip forming process.

Figures 2, 3 and 4 confirm the hypothesis as formulated in the introduction. The vertical axis represents the energy needed to convert a unit volume solid wood to sawdust. The horizontal axis shows the three feed speeds (four for oak) as selected for the experiment. Although the actual feed speed was always accurately determined, the machine operator could keep the desired pace imprecisely only. Actually, for the proof of the hypothesis, this inaccuracy was rather advantageous: it has slightly spread the influencing variable (log feed speed). The Figures prove that the energy needed to convert 1 mm^3 solid wood to sawdust sinks with all three timber species from a starting level along the horizontal axis to a minimum, and then rises again.

The mean curve is shown for oak solely with the purpose to visualize the trend hidden in the data, and also to calculate the minimum position on the horizontal axis. It is otherwise not used later.

With oak, the minimum energy level is 0.05 J/mm^3 and appears at a feed speed of approx. 47.5 m/min. With beech, these values are 0.065 J/mm^3 at 40 m/min, and with pine 0.065 J/mm^3 at 34 m/min.

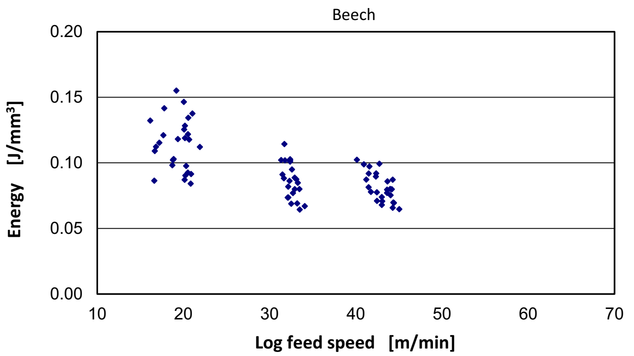

Fig. 3 Energy required converting a unit volume of solid wood to sawdust, and its dependence on the log feed speed. For beech, the optimum log feed speed lies at approx. 40 m/min

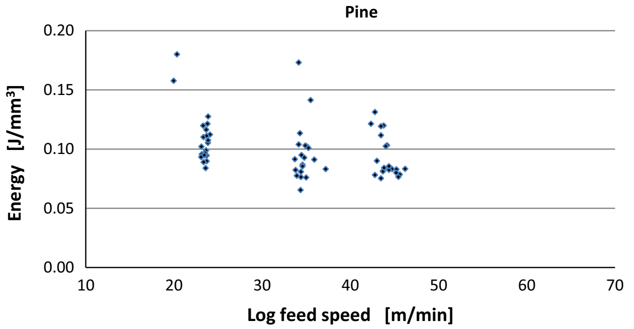

Fig. 4 Energy required converting a unit volume of solid wood to sawdust, and its dependence on the log feed speed. For pine, the optimum log feed speed lies at approx. 34 m/min

The interpretation of Figs. 2, 3 and 4 is not straight forward. The elongated data cloud shows the energy consumption with different sawing runs. On the cloud top, boards with small widths are located. As one moves down the cloud, board widths increase, accompanied by falling energy requirement. As from a certain board width the energy rises again. This U-turn shaped data dispersal is also characteristic to the data clouds associated with higher log feed speeds. At the turning points, however, the board widths become smaller with increasing log feed speeds indicating that this data triplet (optimum feed speed, cutting height and minimum energy requirement per unit wood volume converted to sawdust volume) may be inherently interdependent what seems to be controlled by another factor in the background—the sawdust expansion rate. This shall be discussed in the next chapter.

4 Discussion

Feed speeds at the minimum energy data excellently lend themselves to estimate the expansion rate of sawdust.

Actually, the dust density crucially determines the production performance of a saw blade. In the saw kerf, solid timber is being converted to sawdust. While the tooth cuts through the timber, dust is increasingly compacted as the gullet gets filled up. The final ratio of the sawdust mass to the same mass of solid wood (denoted further as *c*) at the moment when the saw tooth just leaves the timber may range between 1.5 and 5 (Barker 2006).

In order to shed light on the compressibility of sawdust collected during the experiment, samples were subjected to compression tests. To this end, a heavy duty steel cylinder with a piston was used. The cylinder, filled with a known mass of sawdust, was placed in a standard testing machine. The force applied on the piston and the distance of its movement could be precisely recorded. The volume compaction of the dust was calculated and plotted against the force applied. The lines presented in Fig. 5 denote the mean value of six tests for each species.

The tests show smoothly collapsing sawdust under compression without any notch, not even at $c \approx 1$ where the dust density reaches that of solid wood. Sawdust reveals plastic behavior if compressed, exhibiting some difference with respect to species. Similar dust comportment can be expected in the gullet as well.

The relative volume of sawdust *c* in the gullet can be calculated from data available in a mill, using Eq. (1) below (for a more elaborate presentation see Bariska and Pásztory 2011). An example is computed for beech:

$$c = (V_b \times A \times k)/(p \times H \times k \times V_l) \tag{1}$$

where: V_b is the blade running speed (42 m/sec), *A* the gullet area (384 mm^2), *k* saw kerf width (2.8 mm)—dropping out of the equation, *p* tooth pitch (45 mm), *H* board width (cutting height = 0.3 m), and V_l the log feed speed which can be found e.g. in Fig. 1 (in this example 24 m/min). Solved for the above data, the value of *c* is:

$$c = (42\ \text{m/s} * 60\ \text{s/min} \times 0.000384\ \text{m}^2)/(0.045\ \text{m} \times 0.3\ \text{m} \times 24\ \text{m/min}) = 2.99$$

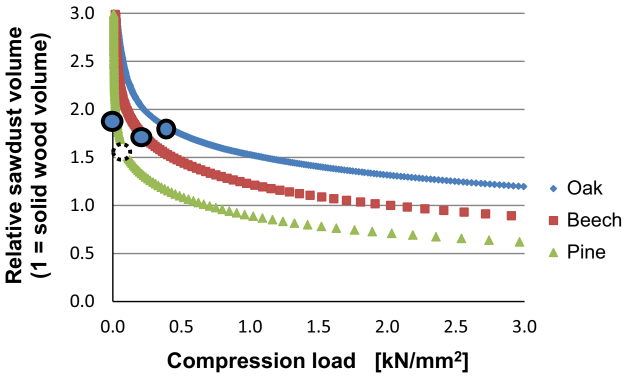

Fig. 5 Volume change of sawdust under compression, measured for the three timber species

Table 2 Summary of essential results

Species	Minimum work (J/mm^3)	Optimum log feed speed (m/min)	Sawdust expansion value	Mean board width (m)
Oak	0.050	47.5	1.8	27.7
Beech	0.065	40	1.7	25.5
Pine	0.065	34	1.9	21.3

The dust expansion in the gullet at the minimum energy consumption was calculated to be 1.8 for oak, 1.7 for beech, and 1.9 for pine. These values are also marked in Fig. 5. It should be noted that the *c* value of pine seems to be somewhat too high. Based on the specific gravity of pine, the optimum *c* value ought to lie where the dotted circle is drawn. Pine was sawn, however, with extreme low moisture content, and accordingly, the dust might have acquired enhanced resistance against compaction (Lučić et al. 2004).

Judged by their values, the sawdust expansion data of the three species are quite similar. One can argue that the physical space of the gullets is a constant that constrains the accommodated dust volume (here to 1,075 mm^3), further that the density of the wood substance is approximately a constant (about 1.53 g/cm^3), limiting the dust‘s final density. These two factors together with the forces in action may determine the order of magnitude for the sawdust expansion rate (volume of sawdust over volume of solid wood with the same mass). Particle size distribution and moisture content of the dust may, however, differ from one species to the other causing the observed disparities. Though, reports also state that the geometric shape of tooth and gullet play a role in the configuration of sawdust particle size as well (Očkajová et al. 2006). Table 2 summarizes the essential results.

With all data on hand, an equation can be presented for the three species in Table 3 which computes the optimum log feed velocity (V_{OLF}). When above discussed Eq. (1) is rearranged and the acquired constants inserted, the working Eq. (2) appears:

$$\mathbf{V}_{OLF} = (V_b \times A)/(p \times H \times c) = \text{coefficient} \times \text{cutting height} \tag{2}$$

$$= \left(42[m/\sec] \times 60[\sec/\min] \times 0.000384\left[m^2\right]\right) / (0.045[m] \times H[m] \times 1.7 - 1.9)$$

= e.g. for oak $V_{OLFS} = 11.95/H$ (m/min)

The optimum log feed speed will still vary with each individual board width in order to maintain a constant

Table 3 Working equations for the optimum log feed speeds of the three timber species

Species	Equations
Oak	$V_{\mathrm{OptimumLogFeed}}[\mathrm{m/min}] = 11.95\ [\mathrm{m^2/min}]/\mathrm{Cutting\ Height}\ [\mathrm{m}]$
Beech	$V_{\mathrm{OLF}}[\mathrm{m/min}] = 11.32\ [\mathrm{m^2/min}]/\mathrm{H}\ [\mathrm{m}]$
Pine	$V_{\mathrm{OLF}}[\mathrm{m/min}] = 12.65\ [\mathrm{m^2/min}]/\mathrm{H}\ [\mathrm{m}]$

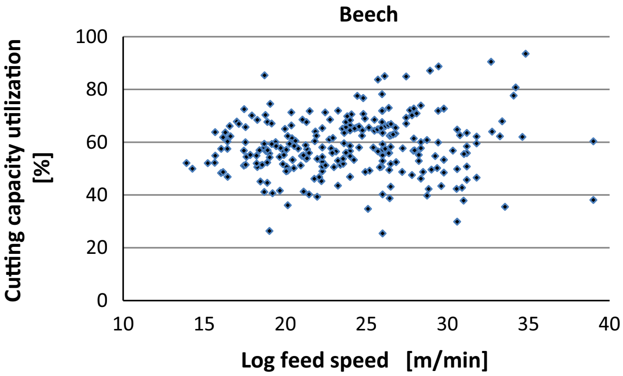

Fig. 6 Cutting capacity utilization of bandsaw, calculated for beech data, used in Fig. 1

gullet filling, yet, the performance of the machine shall significantly improve.

The constants in the working equations of Table 3 seem to be strikingly similar though determined for three distinctly different timber species. For lack of sufficient amount of data, minimum values were targeted only, no statistical analysis could be carried out. In order to overcome this difficulty other saw blade profiles need to be included in future investigations.

With the help of these data the extent of utilization of the bandsaw under real milling conditions can be judged. Figure 6 shows results for beech as an example. Data used to construct Fig. 1 were recalculated in order to compare the real feed speeds with the optimum sawing velocities. According to Fig. 6, none of the sawing runs exploited the machine's full sawing potential. At the bottom of the data cloud, one can find the smaller cutting heights meaning that narrow boards are manufactured with notoriously slow log feed speeds. Larger cutting heights utilize the cutting potential better, yet, there is still plenty of space for improvement.

If the machine's customary production regime is compared with the optimum setting, possible savings become obvious. Table 4 shows the extent of time and energy utilization of the machine.

In Table 4, the values calculated for the pure sawing times are presented. Yet, logs need to be retrieved for producing the next board. The carriage return and log positioning take about as much time as the sawing process itself–according to Ištvanić et al. (2009) at least 40 % of the processing time. Therefore, the calculated savings might be halved. The possible increment of the production rate and the possible reduction rate of power consumption both lie around 30 %, a significant improvement potential.

Table 4 Actually utilized sawing potential of bandsaw and energy consumption at optimum feed speed, as calculated for the pure sawing time

Timber species	Optimum log feed speeds in relation to real feed speeds (%) mean ± confidence limits	Energy consumption at optimum log speed in relation to actual energy use (%) mean ± confidence limits	(Degree of freedom, probability of error)
Oak	67 ± 3.6	51 ± 2.6	(94, 0.05)
Beech	59 ± 5.1	72 ± 3.4	(76, 0.05)
Pine	54 ± 5.5	68 ± 12	(63, 0.05)

5 Conclusion

The experiment demonstrates that data, gathered during daily sawmilling practice under real life conditions, can reveal profound insight into the sawing process. It will provide some useful understanding of the chip formation which is at the heart of the production process.

To find the optimum log feed speed for a machine some investigative works are needed. It implies that during normal production routines, a team would collect data such as timber species, log length, board width (cutting height), time—for identification—and duration of sawing and power consumption also with time and duration. Log feed speed ought to be varied according to judgment of the team leader (slow, medium and fast) for all log dimensions. Thereafter, the real log feed speed must be calculated for each board, and plotted against the energy consumption data to locate the optimum log sawing speed. The sawdust volume per cut board needs to be known as well. To make use of this method thereafter, a simple computing program is required to obtain the optimum log feed speed in dependence of the cutting height.

The data presented here might be characteristic for the specific bandsaw investigated. Yet, the data has proven the validity of the hypothesis that cutting with the optimum log feed speed can save energy, and that the sawing procedure may be accelerated. It implies, of course that experiments need to be carried out for the headrig of each production line.

Whether the mill shall execute this fine-tuning investigation on its own or with the help of consultants is irrelevant because the results speak for themselves. The savings would write off the costs fairly quickly, and would secure enhanced profitability thereafter.

Further experiments would reveal whether the conspicuous constancy of the sawdust expansion rate is a timber property, a machine characteristic or just an incidence.

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