Effect of Number of Saw Blade Teeth on Noise Level and Wear of Blade Edges during Cutting of Wood

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The effect of varying the number of saw blade teeth while transversally cutting beech (*Fagus sylvatica* L.) wood on the noise level and saw blade lifetime between two sharpenings was tested. The experiment was carried out with raw beech wood samples with dimensions of 25 x 100 x 1000 mm and circular saw blades with cemented carbide tips (24, 40, and 60 teeth). The saw blade diameters were identical (D = 250 mm), as were the cutting wedge angle geometries (α = 15°, β = 60°, γ = 15°). The saw blades were selected based on commonly used blades (in the Czech Republic and Slovakia) for the transversal cutting of the given wood species. Neither the cutting speed (v_c = 62 m/s) nor the feed force (F_p = 75 N) were changed during the cutting process. The results suggest that the number of saw blade teeth is an important factor that affects the noise level of saw blade during sawing as well as the wear of cutting edge.

Keywords: Noise level; Circular saw blade; Wear of cutting edge; Number of teeth; Beech wood

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INTRODUCTION

Circular saws are used in many different industries for countless applications. As a result of saw usage, an inherent hazard exists to the hearing of workers in the vicinity of the machines, which generate noise of a particularly objectionable quality. Operators of circular saws have an obligation, under law, to take all practicable steps to reduce the noise emissions of these machines through engineering means. Management must also ensure that workers that are not immediately involved in the saw operation are isolated from the hazardous saw noises. Good reductions in noise levels are achievable. On certain saws, the noise level can be reduced to below 85 dB (A); this aids in protecting the operators. On other operations, it is impractical to achieve such reductions, and hearing protection will also have to be worn.

Wood cutting with circular saws plays a very important role in both wood processing and furniture industries (Koch 1985). The most frequently used type of tool for cutting of wood and wood-based materials is, undoubtedly, a circular saw blade (Fig. 1). Blades of this kind are designed for portable circular saws, joinery saw benches, format saws, cutting centers, edgers, and other saw types as well as round timber cutting and firewood cutting circular saws. The greatest advantage of the cutting process with circular saw blades is being able to achieve maximum cutting speed (up to 100 m/s)

(Prokeš 1980; Plester 1985). A circular saw blade without anti-noise grooves was utilized in this study (Fig. 1a).

Moreover, circular saw blade fabrication and maintenance are simple in comparison with other cutting tools (frame saw blade or band saw blade). Additionally, circular saw blade replacement and setup in machines, consisting of the blade setting on the spindle and its locking by a nut, are simple. In most machines, the circular saw blade is fastened between two flanges, whose diameter should be equal to 1/3 of the saw blade diameter. The flanges partially eliminate lateral blade vibrations. No further adjustment of the proper tool in the machine is needed (Lisičan 1988, 1996).

Circular saw blades are always designed for a particular purpose (Fig. 1) (Pabiš 1999; Xu *et al*. 2001). In the wood processing industry, a circular saw machine is very common and is used for longitudinal and transversal cutting of wood and wood-based materials with large surfaces, for timber edging, structural joints, *etc*. (Mikolášik 1981; Buda *et al*. 1983).

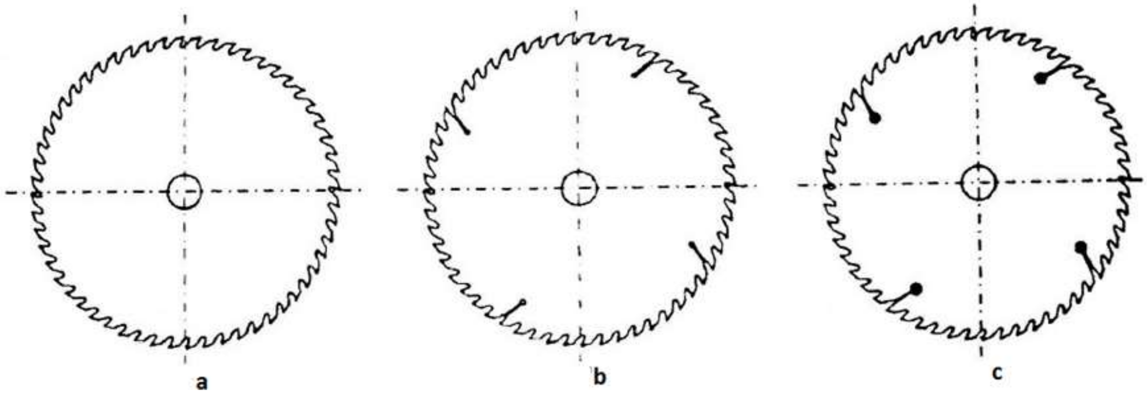

Fig. 1. Different saw blade designs: a) blade without anti-noise groove, b) blade with four grooves around its outer perimeter, and c) blade with copper element inside a groove around its outer perimeter

During the process of cutting wood and wood-based materials with circular saws (CS), two simultaneous interactions occur: the main rotational movement of the saw blade (SB), and a linear shift of the blade (Beljo-Lučić and Goglia 2001). The saw blade cutting edge moves at a constant cutting speed (v_c) following a circular trajectory. During the cutting process, the SB rotational movement and linear velocity of feed (v_f) create a cycloid trajectory. The cutting speed (v_c) is several times greater than the value of v_f. Therefore, for cutting kinematics analyses, a part of the kerf in the wood is deemed a circular arc (Cho and Mote 1979).

Another factor is the critical rotational speed of circular saw blade. This speed represents the maximum rotation speed in which at circular saw blade sustained in a stable phase. After exceeding of this critical speed, the circular saw blade cannot resist transversal forces and becomes unstable, which is manifested, among other things, by increasing the vibrations and noise level (Taki *et al*. 1975; Kimura *et al.* 1976; Hattori and Noguchi 1992; Beljo-Lučić and Goglia 2001; Schajer and Wang 2002; Orlowski 2005, 2007; Kopecký and Rousek 2012).

Knowledge of the blade interaction phenomena is very important for optimizing the machining process. The proper cutting process depends on various factors that strongly affect such outputs as machined surface quality, cutting process energy, and noise level (Prokeš 1982).

Most studies of parameters influencing cutting forces and power requirements have been conducted at constant wood moisture (Konishi 1972; Steward 1984; Aquilera and Martin 2001; Bučar and Bučar 2002).

The cutting process noise level does not affect the process that generates chips, but it significantly affects staff health and safety. There is therefore a need to eliminate any potential risk to which the employees are exposed. The knowledge of mutual interactions of the mentioned factors and the proper cutting process constitutes an effort to approximate optimum outcomes while keeping process costs low and maximizing efficiency, purposefulness, and economy concerns while simultaneously observing occupational health and safety (OHS) at work rules (Mikleš *et al*. 2010).

In the past, the wood processing industry has disregarded the fact that increasing the machine running speed and the mechanization of the operation increase the noise level (Wasielewski and Orlowski 2002; Chen and Chang 2012). Also, an acoustically improper design of the external walls of production halls makes the noise level increase. Until recently, tool design was primarily based on performance and the machined surface quality. However, the fact that the tool is the primary source of noise has been neglected (Prokeš 1985; Cheng *et al*. 1998).

Changes in the blade body resonance can be achieved through proper design, thereby affecting its noise level and noise frequency. Saw blade design aims to reduce noise levels using various shapes of grooves, both peripheral and within the inner section. The groove diversity affects the blade strength parameters to maintain stability and safety during cutting.

Trim saws belong to the group of machines with the maximum noise level, at approximately 100 to 110 dB (A). Examples of trim saws include strippers, band saws, and four-siders. As far as the physiological impact of noise on humans, it is known that after long-term exposure in an environment with a noise level of approximately 85 to 110 dB (A), an individual will likely suffer hearing loss (Janoušek 2005; Žiaran 2005).

The aim of this work was to determine the influence of number of teeth of circular saw blades on noise level during transversally cutting of beech wood. The transversal cutting was carried out with circular saw blades at firm cutting speed (v_c = 62 m/s) and feed force (F_p = 75 N).

EXPERIMENTAL

Materials

Samples of European beech (*Fagus sylvatica* L.) from the Poľana region, east of Zvolen, Slovakia, were used for the experiment. Radial-sawn samples (Fig. 2) were made from beech timber 30 mm thick, with various widths. Samples were selected to have minimal knots and similar annual ring slopes. After cutting and length shortening, the boards were dried and conditioned to 12 ± 2% moisture content under the following conditions: relative humidity (ϕ) = 65 ± 3% and temperature (t) = 20 ± 2 ºC, thereby being ready for further equalizing, thickening, and shortening processes. Test samples (60 to 80 pieces) were cut into dimensions of 25 × 100 × 1,000 mm (thickness, width, and length). The number of test samples was specified in accordance with the tool edge lifetime. The test sample dimensions for the experiment were designed with respect to the function of the machinery and cutting conditions in a manner allowing data collection regarding edge blunting while cutting the test samples.

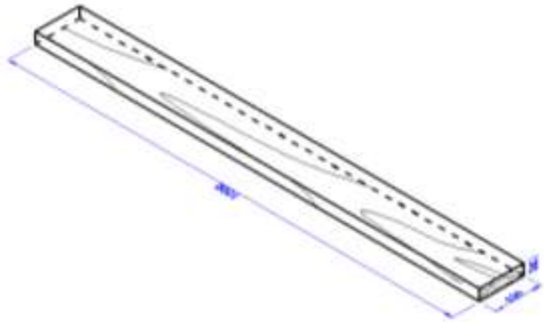

Fig. 2. An overview of cross-sections of wood types

The boards were cut with a sliding mitre saw, GCM 10S PROFESSIONAL (Robert Bosch GmbH, Germany). See Table 1 for saw technical parameters.

Table 1. Mitre Saw Parameters

Bosch GCM 10S Professional	Parameters
Tool input (W)	1,800
Idle rotational frequency (min^{-1})	4,700
Cutting capacity at 45° chamfer (mm)	87 x 216
Cutting capacity at 45° declivity (mm)	53 x 305
Chamfer adjustable angle left / right (°)	52/62
Declivity adjustable angle left (°)	47
Saw blade maximum diameter (mm)	254
Flange diameter (mm)	75
Mounting hole diameter (mm)	30

Three PREMIUM (EXTOL, Czech Republic) circular saw blades, with diameter 250 mm and thickness 2.2 mm, with cemented carbide tips were used for transversal cutting of the beech samples. The cemented carbide edge lifetime is 30 to 50 times longer than that made of tool steel.

Methods

A digital noise meter SL - 4011 (Lutron Electronic Enterprise Co., Taiwan) was used to measure noise levels. The circular saw blade noise level was determined in accordance with ISO 9612 (2009). The proper measurement of the noise level during the transversal cutting process was carried out at idle state and load running (*i.e.*, cutting). The noise meter was placed on an insulated tripod 100 cm from the measured blade and 150 cm above the floor in the operator's workplace (Fig. 3). The measurement within the required noise exposure value of the running machine was ensured by means of measurement automatic mode setup on the noise meter. This value falls within the "Upper Operative Value of Exposure" inside the L_{AEX}, (L_{AEX} - normalized level of noise exposure) value of 80 to 137 dB (A) for 8 h. Sign "(A)" means A-weighting which is defined in the International standard IEC 61672 (2003) relating to the measurement of sound pressure level. A-weighting is applied to instrument-measured sound levels in an effort to determine the relative loudness perceived by the human ear.

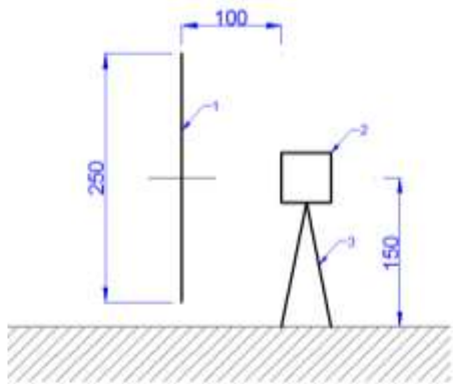

Fig. 3. Illustration of saw blade noise level measurement: (1) circular saw blade, (2) noise level meter, and (3) tripod

Once the electric motor was switched on, the shaft with the attached circular saw blade was started. The measured noise values were evaluated using ANOVA analysis, mainly by Fisher's F-test, in STATISTICA 12 software (Statsoft Inc., USA).

The cutting edge loss (wear) between two sharpenings was considered the blade lifetime index. Such loss reached its maximum value when the wood burned during the cutting. A digital microscope DMBA 210 PC/∞ (Motic, China) with built-in camera was used to evaluate the wear of the cutting edge. On each circular saw blade, the certain number of saw teeth, having approximately the same initial blunting, were selected and marked (6 teeth for 24-teeth, 10 teeth for 40-teeth and 15 teeth for 60-teeth circular saw blade, respectively). After the cutting, marked teeth were measured again in order to detect blunting, and of these values, the average value was calculated. The number of cuts identifies the amount of cuts made with the saw tool without showing wear signs. During this phase, the tool does not require treatment of the edge (tool edge lifetime between two sharpenings). Once the edge lifetime was exceeded, the wear increase in time was significant and not adequate for saw performance.

RESULTS AND DISCUSSION

Based on the comparison of the results measured for the individual blades (Fig. 4) with teeth numbers of 24, 40, and 60, it is clear that the highest noise levels occurred for the 24-teeth circular saw blade. There were no significant differences in noise level differences for sawing with the 40- and 60-teeth blades up to 6,400 cuts. For these two blade types, a statistically significant difference was seen at 6,400 or more cuts.

At the beginning of the measurements for the 24-teeth blade, the idle run noise value was 95.5 dB (A). The average first cut noise level was 97.9 dB (A), whereas, at the end of cutting, the average noise level was 105.9 dB (A). This represents a statistically significant increase in the noise level. The noise level increased exponentially from 0 to 3,000 cuts. Subsequently, the noise level did not change, as shown in the linear portion of the diagram from 3,000 to 6,600 cuts, after which it increased exponentially up to 7,600 cuts. The cutting of wood with this saw blade was stopped at 7,600 cuts because the beech wood samples were burning and blade re-sharpening was necessary. At this number, the difference in the average noise level values between the first and the last cut was 8 dB. As the cutting edge withdrew, the cutting was stopped for the individual blades at the mentioned number of cuts.

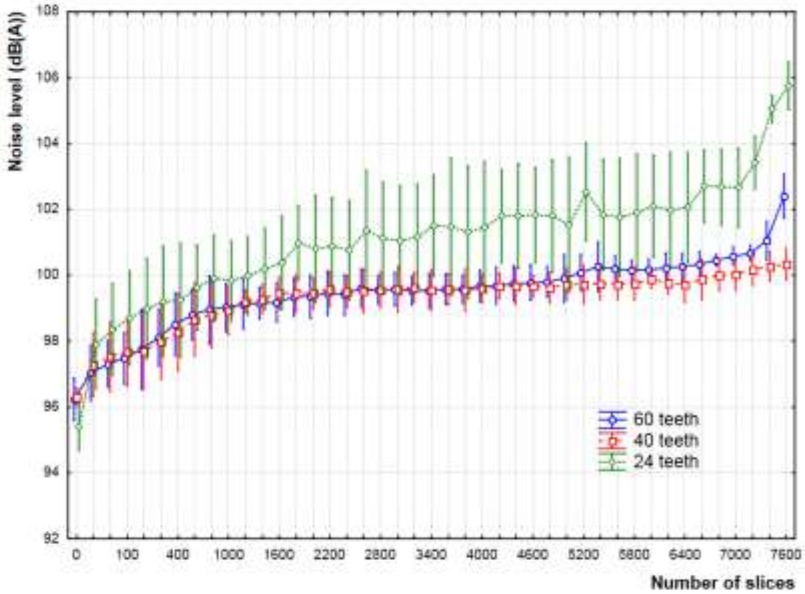

Fig. 4. Measured saw blade noise level course as a function of the number of cuts for circular saw blades with various numbers of teeth

At the beginning of the measurements for the 40-teeth blade, the idle run noise value was 96.3 dB (A). The average first cut noise level was 97.3 dB (A), whereas at the end of cutting, the average noise level was 105.1 dB (A). This represents an important difference. The noise level increased exponentially from 0 to 1,600 cuts. Subsequently, it became linear approaching 6,000 cuts. A statistically significant increase was apparent from 6,200 to 11,600 cuts, afterwards increasing exponentially up to 12,200 cuts. The saw blade cutting was stopped at 12,200 cuts because the beech wood samples were burning. At this number, the difference in average noise level values between the first and last cut was 7.8 dB (A).

At the beginning of the measurements for the 60-teeth blade, the idle run noise value was 96.2 dB (A). The first cut average noise level was 97.0 dB (A), whereas, at the end of cutting, the average noise level was 104.2 dB (A). This represents a statistically significant difference. The noise level increased exponentially from 0 to 2,800 cuts. Subsequently, the noise level did not significantly change up to 7,000 cuts and then increased exponentially up to 8,050 cuts. Cutting with this saw blade was stopped at 8,500 cuts. At this number, the difference in the average noise level between the first and the last cut was 7.2 dB (A).

In our experiment, we investigated the noise level by using a circular saw blade without anti-noise grooves, while the majority of previously published work, such Droba as Svoreň (2012), Beljo-Lučić and Goglia (2001), as well as Cho and Mote (1979), focused on circular saw blades with these anti-noise-grooves. They found that the average noise level, during a transverse sawing, is in the range from 93 dB to 104 dB. Results obtained by our experiment are also within this range.

Badida *et al*. (2010) explored the occupational environmental noise level for material cutting with circular saws. Their findings confirmed our results. The saw blade, despite its anti-noise modifications and other measures, will exhibit a noise level exceeding the L_{AEX} upper operative exposure value of 85 dB (A) for 8 h. Therefore, measures should be adopted to protect hearing pursuant to the Directive of the European Parliament and of the Council No. 2003/10/ES. Authors Heisel and Kuolt (2004) also reached this conclusion.

As shown in Fig. 5, the blade with the longest cutting ability, *i.e.*, the longest edge lifetime, was the 40-teeth circular saw blade. Paradoxically, the 60-teeth circular saw blade exhibited less cuts although its blunting was higher than that of the 40-teeth blade. Low blunting of the 60-teeth circular saw blade can be explained by the fact that blades with higher number of teeth (*i.e.*, with smaller gap between teeth) are used for thin materials (with a minimum of 1 tooth in engagement). Generally, the following rule applies: for harder materials, the saw blade should contain a greater number of teeth. This is because with greater number of teeth and cutting speed, the cut becomes more accurate and cleaner.

Unambiguously, the shortest lifetime and greatest wear were seen in the 24-teeth circular saw blade. This finding can be explained because circular saw blades with smaller numbers of teeth (*i.e*., with a greater gap between teeth) are used mostly for thicker materials (with a maximum of 4 teeth in engagement), and for longitudinal cutting of softwood species.

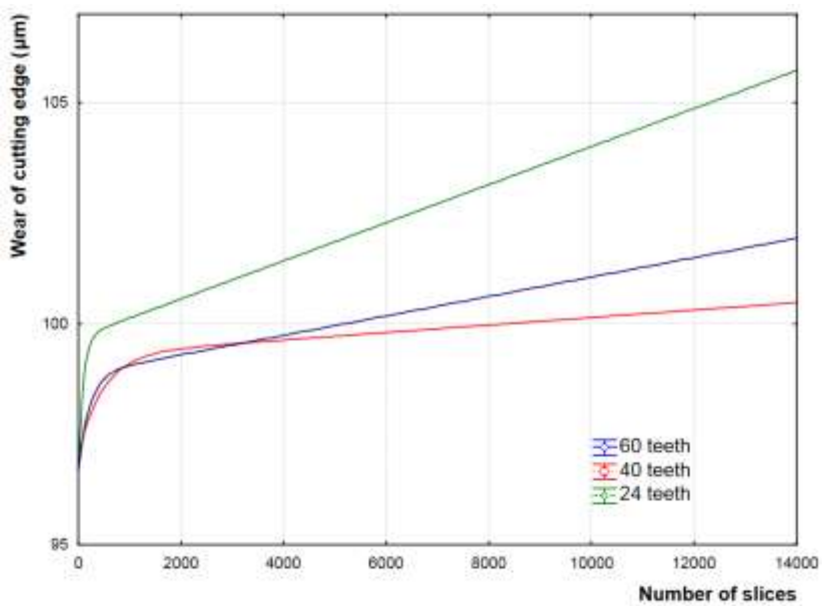

Fig. 5. Wear of cutting edge as a function of the number of cuts and various numbers of teeth

Therefore, the 40-teeth circular saw blade was the best for the process of beech wood transversal cutting on a crosscut miter saw. This saw blade provides the best relationship between blunting and lifetime.

Pernica and Rousek (2001) reported that circular saw blade with number of teeth 60 has about 10% greater durability than saw blade with 72 teeth. Even our results confirm the fact that the circular saw blade with a lower number of teeth (40) has about 35% greater durability than saw blade with 60 teeth.

CONCLUSIONS

1. Based on the results, the influence of the number of saw blade teeth on the noise level during sawing can be deemed statistically significant. It was found that for saw blades with fewer teeth, the noise values were greater.
2. For saw blades with 40 and 60 teeth, no significant difference in the measured noise level was shown. The difference increased after 6,400 cuts, as the difference in the measured noise level values increased with increasing number of cuts.
3. Concerning edge lifetime, the blade with the fewest number of teeth had a substantially shorter lifetime. This was evident in the blade blunting and formation of burnt areas on the cut surfaces. The longest edge lifetime was found for the 40-teeth saw blade. For this saw blade, the burnt areas caused by the blunting started to appear after the 12,200th cut. In the case of the 60-teeth blade, no burnt areas appeared after 8,000 cuts to the degree that they appeared with the 24-teeth blade. However, tool blunting resulted in an increase of both cutting shift and cutting resistance values.

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