

STUDY ON THE INFLUENCE OF CERTAIN FACTORS ON THE SOUND PRESSURE LEVEL GENERATED DURING CUTTING WITH THE CIRCULAR SAW

Pavlin VITCHEV*

Chief assist.Prof.dr.Eng. – University of Forestry
Address: 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
E-mail: p_vitchev@ltu.bg

Dimitar ANGELSKI

Assoc.Prof.dr.Eng. – University of Forestry
Address: 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
E-mail: d.angelski@ltu.bg

Valentin ATANASOV

Chief assist.Prof.dr.Eng. – University of Forestry
Address: 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
E-mail: vatanasov_2000@ltu.bg

Vladimir MIHAILOV

Assist.Prof.Eng. – University of Forestry
Address: 10 Kliment Ohridski Blvd., 1797 Sofia, Bulgaria
E-mail: v.mihailov@ltu.bg

Abstract:

*In the current study, the changes in the sound pressure level (SPL) measured at the workplace and generated by the woodworking sliding table circular saw machine F45 (Altendorf, Germany) were investigated. The influence of the processed wood, in this case, specimens from *Pinus Sylvestris* L. and *Fagus Sylvatica* L., as well as the thickness of the processed material and the rotation frequency of the circular saw on the total level of the generated noise, were evaluated. The influence of the tool overhang effect on the changes of the sound emissions was also measured. The changes in the SPL were measured in octave frequency bands with average frequencies ranging from 63Hz to 16kHz. During the experiments, the characteristics of the sound field were also taken into account. On the basis of the obtained results, graphical relationships between the investigated parameters and the changes in the SPL were derived. The experiments were carried out in compliance with the BDS EN ISO 3744 and BDS ISO 7960.*

Key words: noise; SPL; sound emission; circular saw; scots pine; beech.

INTRODUCTION

It is well known that the machines used in the woodworking and furniture industry, including the circular saw, generate high noise emissions. The high noise emission levels are one of the main risk factors having a negative impact on human health, including noise-induced hearing loss and other diseases (Bresin 1992). In order to ensure a healthy working environment, the upper limit for a workplace noise exposure, based on the eight-hour working day, is determined to be $L_{EX, 8h} = 85\text{dB(A)}$ (European Directive 2003/10/EO).

The main factors influencing the noise levels generated by the circular saw machines are generally derived by the characteristics of: (i) the processed materials – type, length, thickness, humidity, etc.; (ii) the cutting tool – shape and number of teeth, thickness, cutting angles, presence of different sound-absorbing and vibrating cuts on the tool body, etc.; (iii) the cutting mode – feed rate, cutting speed, and others (HSE 2007, HSE 2009).

In the scientific literature, there are various studies investigating the changes in noise emission levels generated by circular saws with different characteristics of the cutting tool as well as the cutting body (Goglia 1999, Hattori 2001, Svoren et al. 2007, Kopecky et al. 2012).

The aim of the current study was to investigate the changes in the sound pressure level, generated by woodworking sliding table circular saw machine in dependence with the following factors: the rotation frequency of the circular saw, the cutting height (the thickness of the processed material) and the tool overhang effect. The influence of the processed wood, in this study, details from Scots pine (*Pinus Sylvestris* L.) and European beech (*Fagus Sylvatica* L.) were also investigated.

* Corresponding author

MATERIALS AND METHODS

The experiments were carried out using woodworking sliding table circular saw machine F45 (Altendorf, Germany) (Fig. 1). The machine was located in the training and production center of the University of Forestry – Sofia on a concrete floor in a room with dimensions, length, width and height, respectively – $L \times B \times H = 24 \times 8 \times 4\text{m}$.



Fig. 1.
Woodworking sliding table circular saw machine F45 (Altendorf, Germany).

The main saw blade of the machine is driven by an electric motor with $N = 5,5\text{kW}$ power. By changing diameter of the pulley of belts', the rotation speed (n) could be adjusted to 3000, 4000 and 5000min^{-1} . During the experiment, the scoring saw was not used. In order to limit the background noise level and to measure only the noise generated by the circular saw machine, the aspiration system as well as the other technological equipment did not work. For the experiment, a circular saw blade (AKE, Germany) was used. Its parameters were adjusted in accordance with the technological equipment and the processed material, namely: diameter $D = 300\text{mm}$; slot width $b = 3.2\text{mm}$; number of teeth $z = 48$; hook angle $\gamma = 15^\circ$; tooth shape W (alternating left and right tilts); tooth material – HW (metal-ceramic solid alloy); maximum rotation speed $n_1 = 6300\text{min}^{-1}$. The experiments were performed with details from Scots pine wood, with moisture content $W_1 = 13\%$ and density $\rho = 490\text{ g/m}^3$; and European beech wood, with moisture content $W_2 = 12\%$ and density $\rho = 690\text{kg/m}^3$. The moisture content and the density of the wood were determined according BDS ISO 3130 and BDS ISO 3131. The changes in the sound pressure level (SPL) were measured at the workplace in octave frequency bands with average frequencies ranging from 63Hz to 16 000Hz and depending on the circular saw rotation speed (n), the cutting height (h) and the tool overhang effect (T). In order to trace the complex influence of the investigated factors on the generated noise levels, a multifactorial planning and a three-factorial regression analysis using G box plan (Box et al.1951, Box et al. 1999) were applied (Vuchkov et al. 1986). During the experiment, the sound pressure level A-weighted was also evaluated. The values of the variable factors are presented in Table 1. The sound pressure level was measured in one point in accordance with BDS ISO 7960.

Table 1

Values of the variable factors of the experiment					
Variables	Coding	Dimension	Minimal value	Average value	Maximal value
Rotation frequency (n)	X_1	min^{-1}	3000	4000	5000
Cutting height (h)	X_2	mm	15	30	45
Tool overhang effect (T)	X_3	mm	7	14	21

In the analyses of the results for the sound pressure level, the effects of background noise and sound field characteristics with corresponding correction coefficients K_1 and K_2 were taken into account and the actual sound pressure level was determined using the following equation:

$$L_p = L_p' - K_1 - K_2 \quad (1)$$

where: L_p is the actual sound pressure level, dB;
 L_p' – the measured sound pressure level, dB;
 K_1 – correction coefficient for the background noise, in the current study $K_1 = 0$, since the difference between the background and the generated noise is more than 15 dB, i.e. $\Delta L > 15\text{dB}$;
 K_2 – correction coefficient for the test environment, in the current study $K_2 = 1,8$, i.e.
 $K_2 < 4$ – the room is suitable for using the method “Measurement in sound-free field”.

The measurements were performed using precise digital sound level meter CEL-620B1 (CASELLA, United Kingdom) (Fig. 2). Before the initiation of the experiments, the entire measurement track had been calibrated, using a standard sound source from the same company.



Fig. 2.
Precise digital sound level meter CEL-620B1 (CASELLA, UK).

The measurements were performed in accordance with BDS EN ISO 3744 and BDS ISO 7960. For the statistical analysis of the data, QstatLab software was used.

RESULTS AND DISCUSSION

Since the noise levels generated during idling and cutting mode of the machine are different, the results obtained from the two different working modes were analyzed independently. Four series of details were processed during the cutting mode of the machine and the analysis of the results took into account the mean sound pressure level values.

The spectral distribution of the sound pressure level during idling and without a cutting tool is presented in Fig. 3.

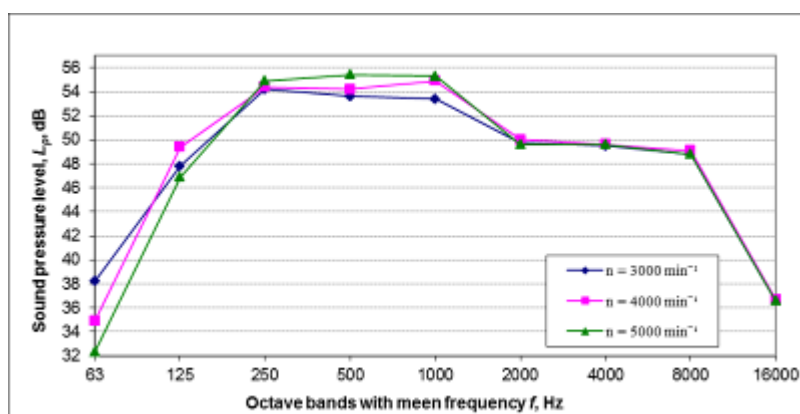


Fig. 3.
Changes in the sound pressure level measured in octave bands at different rotational speeds of the working shaft without a cutting tool.

From the spectral distribution of the sound energy, presented in Fig. 3, it is visible that the sound pressure level, generated during idling without a mounted cutting tool, is significantly lower in the low frequency domain and most pronounced in the medium frequency domain - octagonal bands with geometric frequencies of 250, 500 and 1000Hz. During the cutting mode of the machine with a mounted cutting tool, a maximum sound pressure level was reached as follows: at rotation speed of the working shaft $n = 3000\text{min}^{-1}$, the noise level is 53,4dB; at $n = 4000$ and $n = 5000\text{min}^{-1}$, the noise level of 55dB was achieved. In the high frequency domain, the sound pressure level decreased in comparison with the medium frequency domain and it is equal at the three rotation frequencies of the working shaft.

The spectral distribution of the sound pressure level generated during cutting with a cutting tool is presented in Fig. 4.

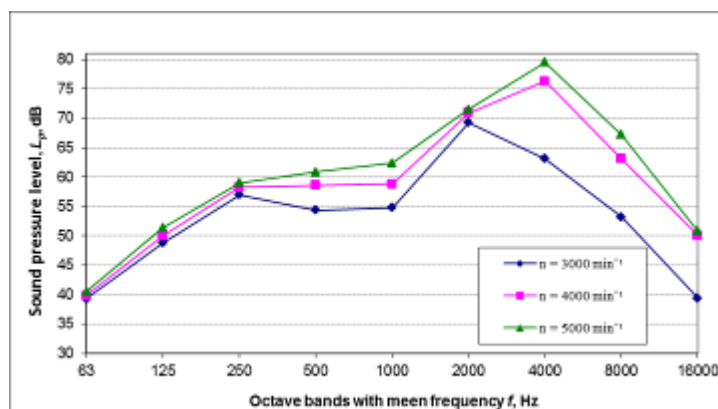


Fig. 4.

Changes in the sound pressure level measured in octave bands at different rotational speeds of the working shaft with a mounted circular saw blade.

The mounting of the cutting tool resulted in an increased sound pressure level and significantly changed the spectral distribution of the sound energy, as shown in Fig. 4. Throughout the studied frequency range ($63 \div 16000\text{Hz}$), it is observed that with the increase of the speed of the work shaft the level of the generated noise increased as well. At rotation speed of the circular saw blade $n = 3000\text{min}^{-1}$, the maximal level of the sound pressure level in octave bands with average frequency of 2000 Hz is 69,3dB. At rotation speed of the circular saw blade $n = 4000$ and $n = 5000\text{min}^{-1}$, the maximal sound pressure levels in octave bands with average frequency $f = 4000\text{Hz}$ are 76,3dB and 79,5dB, respectively. When comparing the results in Fig. 3 and Fig. 4, it can be concluded that the mounted circular saw blade led to an increase in the levels of the generated noise, which is due to the additional aerodynamic noise generated by the rotation of the cutting tool.

The values of the evaluated A-weighted sound pressure level are presented in Table 2.

Table 2

A-weighted sound pressure level measured at the workplace during idling with mounted circular saw blade with diameter $D = 300\text{mm}$

Rotation frequency of the saw blade, n , min^{-1}	A-weighted sound pressure level, dB(A)
3000	70,9
4000	77,8
5000	80,3

It is visible that in the idling mode of the machine with mounted circular saw blade with diameter $D = 300\text{mm}$, the sound pressure level is below the sanitary standard of 85dB(A). The highest measured sound pressure level of 80,3 dB(A) has been generated at maximal rotation speed of the cutting toll $n = 5000\text{min}^{-1}$.

The changes in the A-weighted sound pressure level, generated at rotation frequency of the saw blade $n = 4000\text{min}^{-1}$ and the tool overhang effect $T = 14\text{mm}$, depending on the cutting height during the processing of the details from the two wood types, are presented in Fig. 5.

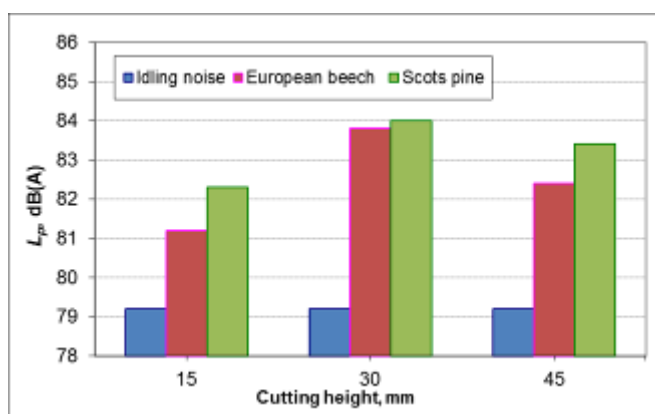


Fig. 5.
Changes in the A-weighted sound pressure level, generated at $n = 4000\text{min}^{-1}$, $T = 14\text{mm}$, and depending on wood species and the cutting height of the circular saw.

It is visible that the sound pressure level generated during cutting mode of the machine is significantly higher compared to those generated during idling. The increase in the noise emission is due to the technological noise which is a result of the interaction of the circular saw blade with the processed material. It has to be noted that when compared to the idling mode, the noise levels, generated during processing of wood details from Scots pine and European beech, are higher by 4dB(A) and by 3dB(A), respectively. All results presented in Fig. 5 are below the sanitary standard of 85dB(A).

Results from the three-factorial experiment

As a result of the three-factorial experiment and application of the regression analysis, the equations (2) and (3) were derived. The latter is used to determine the expected sound pressure level that would be generated during processing of details from European beech (2) and Scots pine (3):

$$Y_{\text{beech}} = 83,2 + 3,547.X_1 + 0,737.X_3 - 0,948.X_1^2 + 0,402.X_3^2 - 0,134.X_2.X_3 \quad (2)$$

$$Y_{\text{pine}} = 84,032 + 3,510.X_1 + 1,080.X_3 - 1,012.X_1^2 + 0,637.X_3^2 - 0,463.X_2.X_3 \quad (3)$$

where: $X_1 = n$ is the speed of rotation frequency of the circular saw blade, coded;
 $X_2 = h$ – cutting height, coded;
 $X_3 = T$ – tool overhang effect, coded.

Some of the regression coefficients are of zero value, therefore they are excluded from the regression equations (2) and (3) presented above.

From the values of the regression coefficients in both equations, it is confirmed that the rotational speed of the circular saw has the greatest influence on the sound pressure level. The regression coefficients of 3,547 and 3,51 for beech and pine wood, respectively, were calculated. The cutting height (the thickness of the workpiece) is the second most important factor, followed by the tool overhang effect.

Fig. 6 and Fig. 7 depict the influence of the rotational speed of the saw blade on the changes in the A-weighted sound pressure level, as a result of the complex influence of the three tested factors during processing of details from European beech and Scots pine wood. During processing of details from European beech wood, the A-weighted sound pressure level changes from 78,7dB(A) at rotational speed of the circular saw blade $n = 3000\text{min}^{-1}$ to 85,8dB(A) at rotational speed $n = 5000\text{min}^{-1}$. The sanitary norm of 85dB(A) is reached at rotational speed $n = 4\,600\text{min}^{-1}$.

During processing of details from Scots pine wood, the A-weighted sound pressure level changes from 79,51dB(A) to 86,53dB(A). The sanitary norm is reached at $n = 4\,250\text{min}^{-1}$.

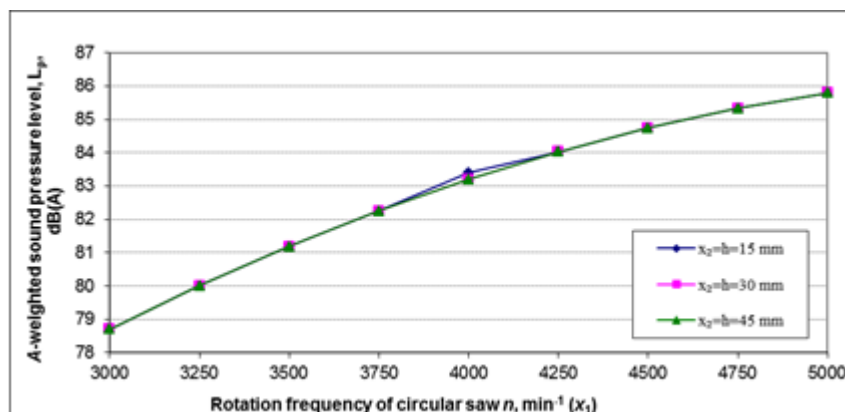


Fig. 6.

Changes in the A-weighted sound pressure level depending on the rotational speed of the saw blade during processing details from European beech wood at different cutting heights.

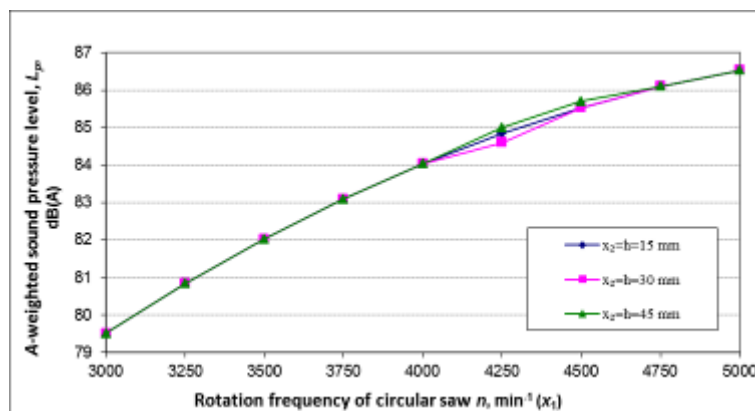


Fig. 7.

Changes in the A-weighted sound pressure level depending on the rotational speed of the saw blade during processing details from Scots pine wood at different cutting heights.

The influence of the tool overhang effect during processing of details from European beech and Scots pine wood is presented in Fig. 8 and Fig. 9, respectively. From the results it can be concluded that the increase in the tool overhang effect led to an increase in the sound pressure level, as a result of an increase in the aerodynamic noise. When the tool overhang is increased from 7mm to 14mm, the noise level increased by around 0,5dB(A). At $T = 21$ mm the noise level increased by 1dB(A), when compared to $T = 14$ mm, and by 1,5dB(A), when compared to $T = 7$ mm.

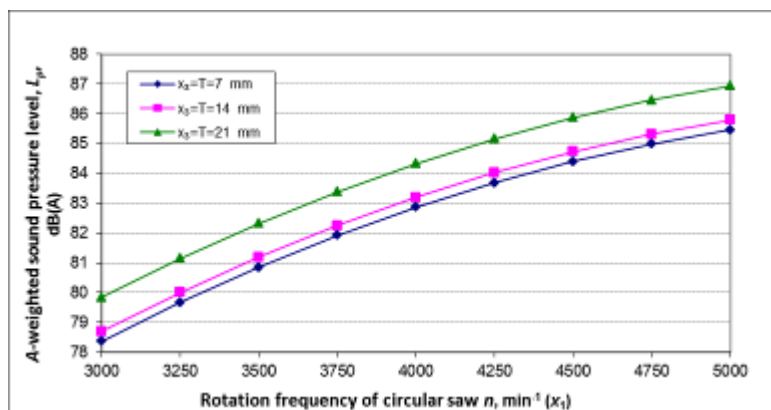


Fig.8.

Changes in the A-weighted sound pressure level depending on the rotational speed of the saw blade during processing details from European beech wood at different tool overhang effects.

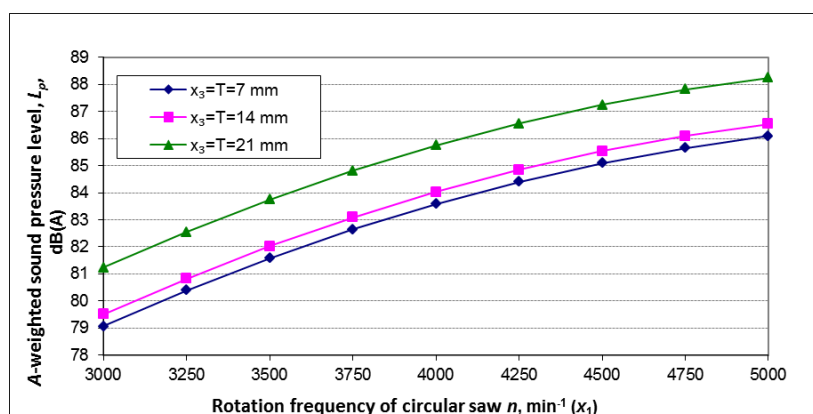


Fig. 9.

Changes in the A-weighted sound pressure level depending on the rotational speed of the saw blade during processing details from Scots pine wood at different tool overhang effects.

CONCLUSIONS

From the results of the current study, it can be concluded that the sound pressure level measured at the workplace and generated by woodworking sliding table circular saw machine depended on the characteristics of the processed wood material and on the working mode, alike. The maximal noise level of 55 dB generated during idling and without mounted cutting tool was achieved at maximal rotation speed of the working shaft at $n = 5000 \text{min}^{-1}$. The noise level generated during idling and with mounted circular saw blade ($D = 300 \text{mm}$, $z = 48$ teeth) was measured to be 79,5dB. The results showed that the noise levels are higher during processing of details from Scots pine wood in comparison to European beech wood. The difference is about 2dB(A) at different working modes. Among the evaluated factors, the greatest influence on the sound pressure level was exerted by the rotation speed of the cutting tool. During processing the details from European beech wood with circular saw blade with diameter $D = 300 \text{mm}$ and teeth number $z = 48$, the sanitary norm was achieved at rotation speed $n = 4600 \text{min}^{-1}$, while during processing the details from Scots pine wood – at $n = 4250 \text{min}^{-1}$.

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REFERENCES

- BDS EN ISO 3744 (2010) Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Engineering methods for an essentially free field over a reflecting plane.
- BDS ISO 7960 (2005) Airborne noise emitted by machine tools – Operating conditions for woodworking machines.
- BDS ISO 3130 (1999) Wood – Determination of moisture content for physical and mechanical tests.
- BDS ISO 3131 (1999) Wood – Determination of density for physical and mechanical tests.
- Box GEP, Wilson KB (1951) On the experimental attainment of optimum conditions. Journal of the Royal Statistical Society, Series B13:1-45.
- Box GEP, Liu PYT (1999) Statistics as a catalyst to learning by scientific method. Part I - an example, Journal of Quality Technology 31:1-15.
- Brezin V (1992) Occupation and safety in woodworking. Zemizdat, 215 p. (in Bulgarian).
- Directive 2003/10/EC of the European Parliament and of the Council of 6 February 2003 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise) (Seventeenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). Available at: <http://eur-lex.europa.eu/legalcontent/EN/TXT/?uri=CELEX:32003L0010>.

Goglia V (1999) Some possibilities of reducing circular saw idling noise. Proceedings of 14th International Wood Machining Seminar, Volume 2, 12-19 September, Paris, France, pp. 345-353.

Hattori N (2001) Suppression of the whistling noise in circular saws using commercially – available damping metal. Holz als Roh – und Werkstoff, 59:394-398.

Health and Safety Executive (HSE) (2007) Noise at woodworking machines. Leaflet WIS13, HSE books 2007.

Health and Safety Executive (HSE) (2009) Noise at woodworking machines, Woodworking Information Sheet No 13.

Kopecky Z, Rousek M, Vesely P, Svoren J, Karolczak P (2012) Effect of irregular tooth pitch on the noise level of circular saw-blade. Proceedings of the 8th International Science Conference Chip and Chipless Woodworking Processes, 11-13 September, Zvolen, Slovakia, pp. 155-159.

Svoren J, Nascak L (2007) Effect of compression slots, copper corks in the body of a circular saw blade and unbalanced pitch of several teeth on noise level of circular saws in cutting process. Proceedings of the 2nd International Science Conference Woodworking Technique, 11-15 September, Zalesina, Croatia, pp. 311-317.

Vuchkov I, Stoianov S (1986) Mathematical modelling and optimizing of technological objects. Tehnika, 341 p. (in Bulgarian).