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INFLUENCE OF THE CUTTING MODE ON THE NOISE EMISSION LEVEL DURING LONGITUDINAL-PLANNER MILLING OF LINDEN AND BEECH WOOD

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ABSTRACT

The change in noise emissions generated during longitudinal flat milling of solid wood specimens using a knife shaft with spirally arranged flat knives is investigated in the paper. The influence of the feed rate (V_f) and the thickness of the cut-out layer (h) on the change in the A-weighted sound pressure level in dB(A) was determined. For the purpose of the study, specimens from beech and linden wood with widths (B) of 50, 100 and 150 mm were used. Based on the performed measurements, graphical dependencies illustrating the influence of the investigated factors on the noise emission levels were derived. The results confirmed the predicted influence of the feed rate (V_f) on the changes in the noise emission levels as follows: the V_f increased from 88.3 dB(A) to 92 dB(A) during processing beech wood specimens, and from 87.1 dB(A) to 89.9 dB(A) when processing linden wood specimens. Depending on the thickness of the cut-out layer (h), the sound pressure level varies within the range from 90.5 dB(A) to 97.3 dB(A) when processing beech wood specimens and from 86.2 dB(A) to 88.6 dB(A) for linden wood specimens. For the practical applicability of the obtained results and in order to ensure lower noise emission levels consistent with the maximum permissible sanitary and hygienic standard of 85 dB(A), recommendations for the optimal values of the feed rate (V_f) and the thickness of the cut-out layer (h) were made.

Keywords: milling; noise; sound pressure level; beech; linden.

INTRODUCTION

For the current evaluation of modern technological equipment, both technical performance and sound emission levels have to be taken into consideration. Woodworking machines are among the noisiest working machines, primarily due to the mechanical and aerodynamic oscillating processes created by the high rotational speed of their cutting tools (Stasa *et al.*, 2008; Romanchenko, 2010; Junai *et al.*, 2019). Increased noise levels due to the high rotational speed of the cutting head can be compensated by changes in their structure, linear and angular parameters, or by structural changes in the machine itself (Tscheschmedjiev *et al.,* 1988; Svoren, 2011; Kopecký *et al.,* 2012; Gross *et al.*, 2016; Dursan *et al.*, 2018; Vitchev *et al.,* 2018; Ruslyakov, 2021; Vitchev, 2023). The factors influencing the change in noise levels during the processing of wood and wood-based materials generally depend on: (i) the characteristics of the processed materials (type, density, dimensions); (ii) the cutting regime (cutting and feed speeds, thickness of the removed layer, cutting height); (iii) the characteristics of the cutting tool (shape and number of teeth, diameter, cutting angles, type of material from which the teeth are made) (HSE, 2007; HSE, 2009; Mikal, 2016). The ever-increasing quality requirements for the treated surface necessitate the production of woodworking machinery with high-speed cutting tools. However, the speed of these cutting tools is a significant factor influencing the aerodynamic noise level. Aerodynamic noise produced by high-speed milling cutters is a serious environmental concern. Therefore, assessing sound emission levels is of great importance to ensure a working environment that complies with Good Manufacturing Practice (GMP).

Due to the adverse effects of noise on workers' health, the European Directive 2003/10/EC sets the upper safe limit for an eight-hour exposure without the use of personal protective equipment at LEX, 8h = 85 dB(A).

Generated noise can be categorised into idling noise and cutting noise, depending on the working process; each must be assessed and analysed independently.

Due to their diverse applications in furniture and joinery manufacturing, milling machines are among the most widely used in the woodworking and furniture industries. They also belong to the loudest woodworking machinery with *A*-weighted sound pressure levels $L_{p(A)}$ around 100 dB(A) measured in the workplace (HSE, 2007).

The aim of the current study was to investigate the changes in noise emission levels generated during the longitudinal flat milling of specimens from linden (*Tilia* Sp.) and beech *(Fagus sylvatica,* L.) wood using a knife shaft with spirally arranged flat knives. The influence of various factors, including feed rate (V_f), the thickness of the out-cut layer (h) and the width of milling (B) on the generation of noise emission levels was evaluated.

MATERIALS AND METHODS

The experiments were performed using a woodworking planer machine, type Hammer A3-41 (Felder Group, Austria) (Fig. 1) with the following technical characteristics: power P = 4 kW; rotation frequency of the knife shaft n = 5000 min^{-1}; diameter and length of the knife shaft D = 72 mm and L = 400 mm, respectively.

The cutting head consists of 62 segment knives with a side length of 13.8 mm, arranged spirally concerning the axis of rotation of the shaft (Fig. 2).

Fig. 1 Planer machine, type Hammer A3-41 (Felder Group, Austria) – general view.

Fig. 2 Cuter head with segmental knives.

The machine is equipped with a roller feeder (Fig. 3) with a two-speed motor with a power rating of P_1 = 0.75 kW. Thanks to the two engine speeds and the exchange of gears, the feeder provides four possible feed rates (V_f), namely: 4, 8, 11 and 22 m.min^{-1}.


A


B

Fig. 3 Roller Power Feeder: A – general wiue; B – gear.

In the course of the study, specimens from Linden wood (*Tilia* Sp.), with the following characteristics: density $\rho = 530$ kg·m^{-3} and moisture content $W = 11{,}5$ %, and Beech (*Fagus Sylvatica* L.) with the following characteristics: density $\rho = 720$ kg·m^{-3} and moisture content $W = 12$ % were processed. The characteristics of the material used were determined in accordance with the standards BDS ISO 3131 and BDS ISO 3130. The processed specimens were tangentially oriented, with the following dimensions: length (l) of 1000 mm and milling width (B) of 50, 100 and 150 mm. The details were fed automatically by a roller power feeder.

To evaluate the influence of the factors feed rate (V_f) and thickness of the cut-out layer (h) on the roughness of the processed surface, they were changed as follows:

- feed rate V_f – 4, 8, 11 and 22 m·min^{-1} , compliant with the technical specifications of the equipment;
- thickness of the cut-out layer h – 1, 2 and 3 mm.

The machine was placed on a concrete sound-reflecting floor in a parallelepiped-shaped room with dimensions: length, width and height, L x B x H – 10 x 8 x 4 m respectively. During the experiments no other technological machinery worked in the room, which also included the aspiration system.

The noise emission level generated by the tested machine during idling was determined on the basis of the sound pressure level (L_p) in dB, measured in octave bands with geometric mean frequencies from 63 Hz to 16000 Hz. The noise emission level generated during the working mode of the tested machine was determined on the basis of the A-weighted sound pressure level (L_{pA}) in dB(A).

The measuring point was located at a distance of 1 m from the corpus of the machine, corresponding to the operator's position, and was 1.5 m above the sound-reflecting floor.

When determining the actual sound pressure level (L_p and L_{pA}), the influence of the background noise with the correction coefficient K_1 and the influence of the characteristics of the sound field with the correction coefficient K_2 were taken into account, in accordance with BDS EN ISO 3744:2010 in the following the formula:

$$L_{pA} = L'_{pA} - K_1 - K_2 \tag{1}$$

Where: L'_{pA} is the measured sound pressure level;

K_1– the correction coefficient accounting for the influence of the background noise;

K_2– the correction coefficient accounting for the characteristics of the sound field.

Background noise refers to the noise generated by all other internal and external sources, except for the noise produced by the machine under study. To assess its influence, the difference between the sound pressure level from the sound source and the background noise level (ΔL_p) was calculated. In cases where ΔL_p<6 dB, measurements are not recommended as the background noise will have a significant impact on the results. When $6 \leq \Delta L_p \leq 15$, the correction coefficient K_1, which shows the influence of background noise, is necessary to be calculated using the following formula:

$$K_1 = -10lg\left(1 - 10^{-0.1\Delta L_p}\right), dB \quad (2)$$

Where: $\Delta L_p = L'_{pA(ST)} - L_{pA(B)}$;

$L'_{pA(ST)}$ – sound pressure level at the measuring point during operation of the machine;

$L_{pA(B)}$ – background noise sound pressure level.

When ΔL_p>15 dB, the background noise does not affect the measurements because the sound emission of the sound source masks the sound pressure it generates. In this case, K_1 = 0.

The correction coefficient K_2 which shows the characteristics of the sound field, depends on the volume of the room in which the measurements are made, on the sound absorption capacity of its surfaces (walls, floor, ceiling) and on the area of the measuring surface. From a practical point of view, it is most often accepted that the calculation of the correction coefficient K_2 is based on the sound absorption capacity of the room and is calculated using the formula:

$$K_2 = 10lg\left[1 + 4\frac{S}{A}\right] \quad (3)$$

Where: A is the equivalent sound absorbing area of the room, m^2;

S – the area of the measuring surface, m^2.

The equivalent sound absorption area of the room is calculated using the formula:

$$A = \alpha . S_v \quad (4)$$

Where: α is the sound absorption coefficient of the room surfaces using standardized values;

S_v – the total area of the room surfaces (walls, ceiling and floor), m^2.

When K_2 > 4 dB(A), the conditions for a free or approximately free sound field are not met and the measurement results are not accurate (BDS EN ISO 3744).

The sound pressure level was measured with digital precision sound level meter CEL-620B1/K1 (CASELA, Great Britain) with built-in octave frequency filters with geometric mean frequencies from 63 Hz to 16,000 Hz and standard frequency correction characteristics *A*, *B*, *C,* according to accepted international standards which measures sound pressure levels from 20 Hz to 20 kHz.

The tests were performed according to the requirements of BDS EN ISO 3744 and BDS ISO 7960.

RESULTS AND DISCUSSION

Influence of background noise

The measurements of the sound pressure levels show the following results:

• the sound pressure level (L_p) measured in all octave frequencies during idling showed changes from 50 dB to 76 dB. *A*-weighted sound pressure level resulting from the idle mode of the tested machine was 77 dB(A) (see Fig. 4);

• the sound pressure level of the background noise showed changes from 32 dB to 48 dB. *A*-weighted sound pressure level of the background noise was 49 dB(A).

The values obtained showed that the difference between the sound pressure level of the sound source and the background noise, both in the octave frequency band and *A*-weighted, was ΔL_p>15 dB/B(A). Therefore, the background noise did not affect the sound pressure measurements of the studied sound source, i.e., the correction coefficient, which indicates the influence of background noise, was $K_1 = 0$.

Characteristics of the sound field

The machine is placed on a concrete sound-reflecting floor in a room measuring L x B x H – 5 x 4 x 3.6 m. The measuring surface is located 1 m from the base parallelepiped and has the shape of a regular parallelepiped with an area of S = 29 m^2. According to the classification of the type of premises, according to ISO 7960, the room is "*a cuboid room with machines or an industrial room*" with a sound absorption coefficient of its surfaces α = 0.15. After making the calculations using formula (3), it was found that the correction coefficient showing the characteristics of the sound field had a value of K_2 = 2.2.

The values of the coefficients K_1 and K_2 were subtracted from the measured sound pressure level of the tested machine as per formula (1).

Sound pressure level measured during idling

The sound pressure levels generated during the idle mode of the machine are graphically presented in Fig. 4. The results show that the *A*-weighted sound pressure level is 77 dB(A). This is significantly lower than the recommended exposure limit of 85 dB(A)/per 8-hour working day.

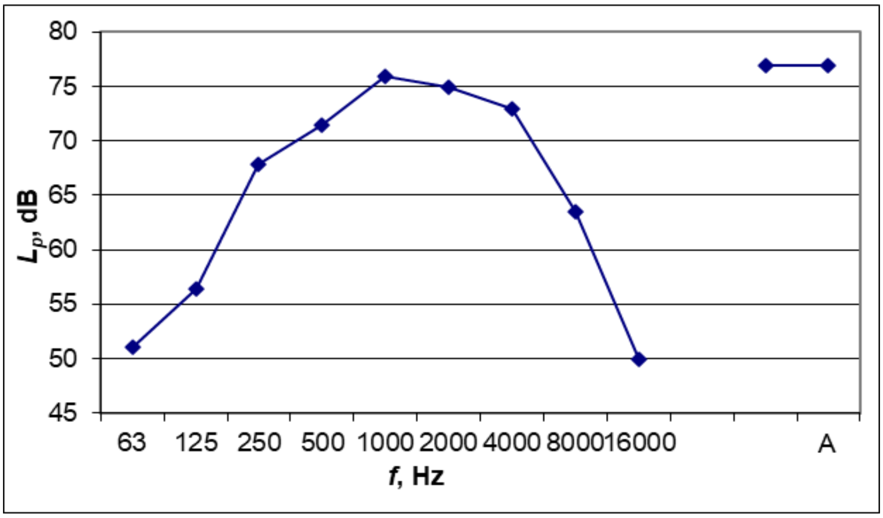

Fig. 4. Sound pressure level in octave frequency bands and *A*-weighted sound pressure level, generated during idling.

The spectral distribution showed that the emitted sound energy was most pronounced in the low- and mid-frequency regions of the octave bands, with geometric mean frequencies ranging from 500 Hz to 4000 Hz. The peak value of the sound pressure level of

A 76 dB measurement was recorded in an octave frequency band with an average geometric frequency of 1000 Hz.

It is determined that the harmful effect of noise on the human body is most pronounced in octave frequency bands with geometric mean frequencies of 1000 Hz and 2000 Hz; however, under the conditions of this study, the measured values of the sound pressure level are 75 dB and 76 dB, respectively, which is significantly below the recommended hygienic norm of 85 dB(A). The relatively low level of noise generated during idling can be attributed to the geometry of the cutting head and its cutting teeth, which are arranged spirally concerning the rotating axis.

Sound pressure level measured during cutting mode of the machine

In the experiments performed during the cutting mode of the machine, the changes in the *A*-weighted sound pressure level were measured depending on the feed rate (V_f), the thickness of the cut-out layer (h) and the width of milling (B) at the operator's workplace. Specimens from linden and beech wood were processed.

Influence of the feed rate on the sound pressure level

The changes in the sound pressure level (L_{pA}) concerning the feed rate (V_f) at thicknesses of the cut-out layers h = 1 mm, h = 2 mm and h = 3 mm are presented in Fig. 5, 6 and 7, respectively.

The results showed a significant correlation between the feed rate and the levels of the generated noise. In general, the noise emission level increases with the increase in the feed rate. This correlation confirms the results reported by other authors as well (Romanchenko 2010, Vitchev, 2023).

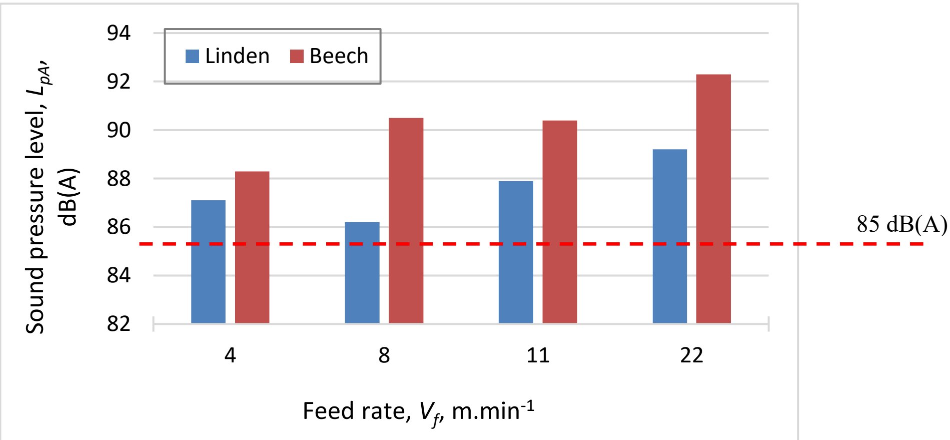

Fig. 5 Changes in the sound pressure level (L_{pA}) in relation to the feed rate (V_f) during milling of specimens from linden and beech wood at thickness of the cut-out layer h = 1 mm.

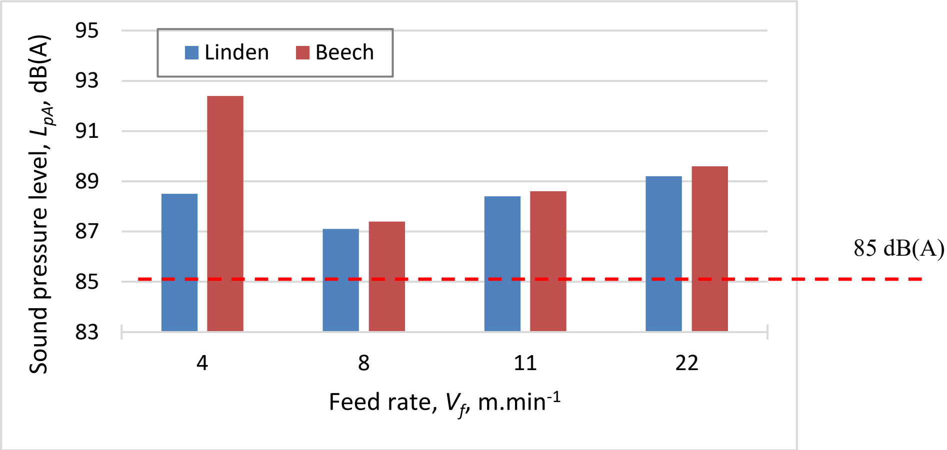

Fig. 6 Changes in the sound pressure level (L_{pA}) in relation to the feed rate (V_f) during milling of specimens from linden and beech wood at thickness of the cut-out layer h = 2 mm.

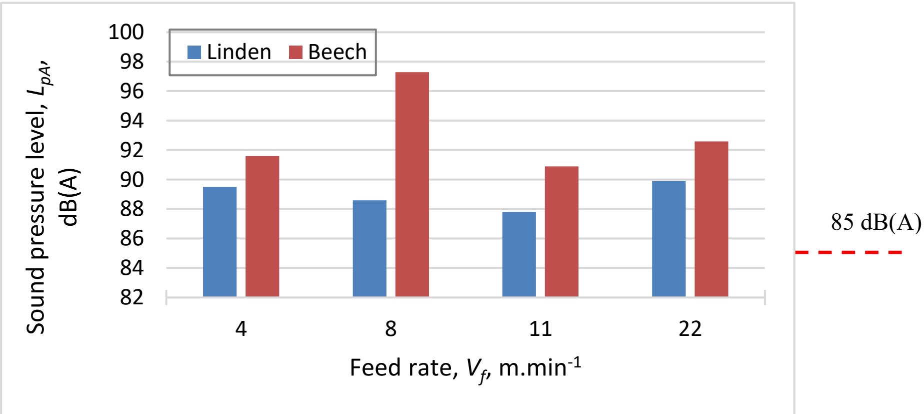

Fig. 7 Changes in the sound pressure level (L_{pA}) in relation to the feed rate (V_f) during milling of specimens from linden and beech wood at thickness of the cut-out layer h = 3 mm.

When comparing the sound pressure levels generated during the processing of specimens from linden and beech wood, it can be concluded that a higher noise level is generated during the processing of beech wood specimens compared to those made of linden wood. This is likely due to the higher density of beech wood compared to linden wood. As is visible from the graphical representation of the results (Figs. 5, 6, and 7), the values of the noise emission levels also differed depending on the different feed rates and thicknesses of the cut-out layer. The results showed that at various feed rates and thicknesses of the cut-out layer, the measured sound pressure level falls within the range of 87 to 95 dB(A).

Influence of the cut-out layer on the sound pressure level

The results of the performed experiments are presented in Fig. 8.

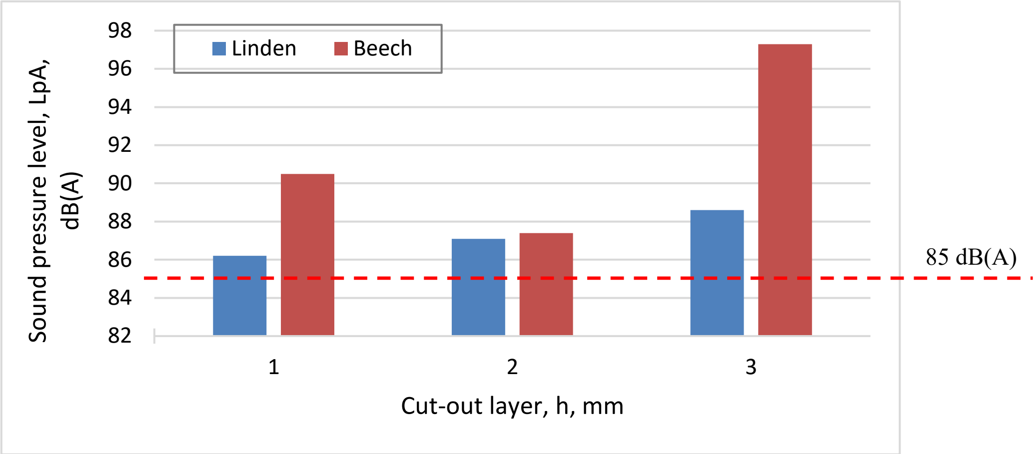

Fig. 8 Changes in the sound pressure level (V_f) in relation to the cut-out layer (h) during milling of specimens from linden and beech wood at feed rate $V_f = 8$ m·min^{-1}.

From the graphs, it is visible that the noise emission level increases with the increase in the thickness of the cut-out layer and its values exceed the maximum permissible exposure limit of 85 dB(A)/per 8-hour working day. The peak values of the sound pressure level are measured at the highest thickness of h = 3 mm and amount to 88.6 dB(A) and 97.3 dB(A) for beech and linden, respectively. A similar influence of the thickness of the cut-out layer on the noise emission level was reported in the study of DURCAN et al. (2018), in which the authors report that the noise level at a thickness of 1 mm is 84.25 dB(A) and rises to 90.27 dB(A) at a thickness of 3 m.

Regarding the influence of the processed material on noise emissions, the results align with those presented in Figs. 5, 6, and 7. It is evident that the milling of specimens from beech wood results in the generation of higher sound pressure levels compared to the processing of linden wood specimens. The most significant difference in sound pressure levels between the two wood species used was found at a thickness of the cut-out layer of 1 and 3 mm. At h = 1 mm the measured sound pressure level generated during the milling of linden wood is 86.1 dB(A) and the one generated during the milling of beech wood is 90.3 dB(A). The difference between the two species is about 4 dB(A).

Under the conditions of this study, the optimal thickness of the cut-out layer appears to be h = 2 mm, at which the sound pressure level for linden and beech is 87.1 dB(A) and 87.4 dB(A), respectively. Based on these results, at a thickness of the cut-out layer h = 2 and at feed speed $V_f = 8$ m·min^{-1} , a batter base-forming of the details would be achieved in one go.

Influence of the milling width (B) on the sound pressure level

The results of the performed experiments investigating the influence of the milling width on the sound pressure level, generated during longitudinal flat milling are presented in Fig. 9.

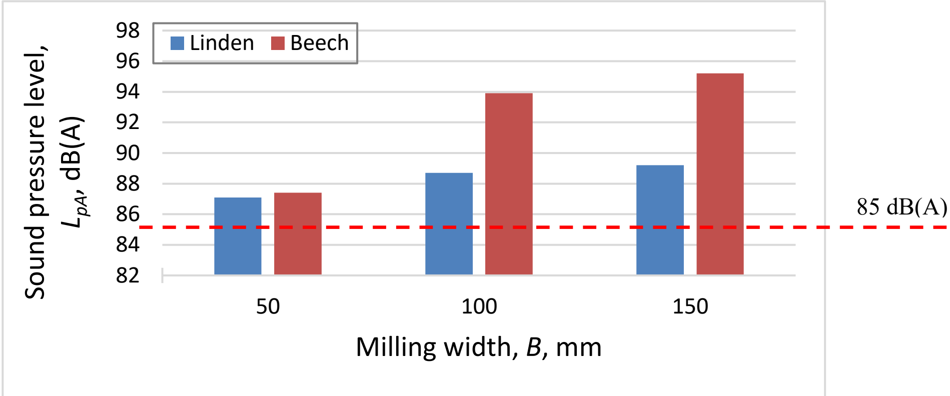

Fig. 9 Changes in the sound pressure level (V_f) in relation to the milling width (*B*) during milling of specimens from linden and beech wood at feed rate V_f = 8 m·min^{-1} and cut-out layer *h* = 2 mm.

From the graphs, it is evident that with an increase in the milling width, i.e., the width of the processed surfaces, the noise emission levels also increase. This increase in the overall sound pressure level is primarily due to the rise in technological noise resulting from the interaction between the cutter head and the workpieces being processed.

The results show that at *B* = 50 mm, the difference in sound pressure levels generated during the milling of linden and beech wood specimens is only 0.3 dB(A). In practice, it can be assumed that they have the same values of L_{pA} = 87.3 dB(A). When increasing the width of the processed surfaces from 50 to 100 mm, a steep increase in the level of generated noise emissions is observed, resulting in 88.7 dB(A) and 93.9 dB(A) when processing linden and beech wood, respectively. With the subsequent increase in milling width to 150 mm, the sound pressure level values are 89.2 dB(A) and 95.2 dB(A) for linden and beech, respectively. Compared to the values generated at *B*=100 mm, this is a relatively small increase. The results also confirm the observation that the type of the processed material has an impact on the generated noise.

Additionally, in this experiment, the noise generated during the processing of specimens from beech wood is greater than that generated by linden wood at all tested milling width values. The influence of the type of processed material and the milling width on the noise emission level is also reported by other authors (Durcan *et al.,* 2018). Their results indicate that as the milling width increases, the generated noise level also increases.

CONCLUSIONS

Based on the results obtained under the conditions of this study, the following conclusions can be drawn:

- The sound pressure level generated during the idle mode of the woodworking planner machine with spirally arranged flat knives amounts to 77 dB(A), which is significantly below the recommended exposure limit of 85 dB(A) for an 8-hour working day.
- The highest values, amounting to 88.6 dB(A) and 97.3 dB(A) for beech and linden wood, respectively, were measured at a feed rate *of Vf* = 8 m/min and a thickness of the cut-out layer *of h* = 3 mm.

The results of this study were compared with the sound pressure levels provided by the manufacturer of the same machine but using straight, flat knives. The values are 89.3 dB(A) during idle and 100.0 dB(A) during cutting mode of the machine.

Based on this comparison, one of the most significant advantages of the woodworking planner machine with spirally arranged flat knives is the decrease in the aerodynamic noise, as witnessed by the lower noise emission levels during idling. This construction, however, does not significantly affect the noise generated during cutting. Therefore, attempting to mitigate noise emissions solely by modifying the cutting shaft design is insufficient. In this sense, the use of additional personal protective equipment, such as helmet earmuffs, as well as reducing exposure to the nose by decreasing the time spent at the machine, should be recommended to the machine's operators.

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 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.

BDS ISO 7960:2007 Airborne noise emitted by machine tools. Operating conditions for woodworking machines.

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: https://eur-lex.europa.eu/eli/dir/2003/10/oj/eng.

Durcan, F., Burdurlu, E., 2018. Effects of some machining parameters on noise level in planing of some wood materials. BioResources 13(2): 2702-2714, ISSN: 1930-2126, https://doi.org/10.15376/biores.13.2.2702-2714

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.

Gross, L., Heisel U., 2016. Parameters influencing the noise emission of planing machines, Journal of Environmental Science and Engineering A 5, pp. 102-108. https://doi.org/10.17265/2162-5298/2016.02.007

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

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

HSE., 1998. Health and Safety Executive Buying new machinery: A short guide to the law and some information on what to do for anyone buying new machinery for use at work, Leaflet INDG271.

Junai, P., Travnicek, P., Ruzbarsky, J., Kopecky, Z., Solar, A., 2019. Nooise emissions of older woodworking machines at parallel operation process, MM Science Journal, pp. 2832-2838. https://doi.org/10.17973/MMSJ.2019_03_201870

Kopecký, Z., Rousek, M., Veselý, P., Svoreň, J., Karolczak, P., 2012. Effect of irregular tooth pitch on the noise level of circular saw-blade, Chip and Chipless Woodworking, 8 (1):155-159.

Mika1, D., Józwik, J., 2016. Normative measurements of noise at CNC machines work stations. Advances in Science and Technology 30 (10): 138-143, https://doi.org/10.12913/22998624/63387

Romanchenko, M. K., 2010. Reduction of Noise and Vibration in Woodworking, Russian Engineering Research, 30 (11): 1188-1189.

Ruslyakov, D., 2021. Acoustic models of the main sources of noise of multi-spindle drilling woodworking machine. Akustika, Volume 39: 4-17. https://doi.org/10.36336/akustika20213910

Stasa, J., Skele, A., Pagasts, I., 2008. Dynamics of noise caused by woodworking machinery. Proceeding of 7th International scientific conference – Engineering for rural development, Jelgava, Latvia, May 29-30: 290-295.

Svoren, J., 2011. Vplyv polohy kompenzačných drážok, medených nitov v tele pílového kotúča a nerovnomerného rozstupu zubov na kritické otáčky [The influence of the position of compensation grooves, copper rivets in the saw blade body and uneven tooth spacing on critical speeds]. Acta facultatis technicae, XVI, 2011 (1): 125-132.

Tscheschmedjiev A., Dinkov, B., Brezin, W., 1985. Abhangigkeit des Schalldruckpegels von der Drehzahlfrequenz rotierenden Messerwellen, Mobel und Wohnraum, 1985, 8:245-250.

Vitchev P., Angelski, D., Atanasov, D., Mihailov, V., 2018. Study on the influence of certain factors on the sound pressure level generated during cutting with the circular saw. Proligno 14(4): 65-72, Online ISSN 2069-7430, ISSN-L 1841-4737.

Vitchev, P., 2023. Assessment of noise emission level generated by a CNC milling machine. Science Journal Innovations in Forest Industry and Engineering Design, 24(2): 78-85, ISBN: 1314-6149.

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