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INFLUENCE OF WOOD CUTTING PROCESS ON NOISE LEVELS GENERATED DURING MILLING

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Summary

Milling is one of the most frequently used technological processes in woodworking industry. At the same time it is characterized by high levels of noise emissions. The aim of the current work was to study the sound pressure level, adjusted to A-weighted curve, generated during the milling process of details from common European beech (Fagus sylvatica L.) wood and depending on the cutting mode conditions. The measurements were carried out at workplace. The greatest influence on the sound pressure level had the feed speed and the rotational speed of the cutting tool. Depending on the cutting mode, the sound pressure level $L_{p(A)}$ *is amended within the range from 77 dB(A) to 89 dB(A). The measurements were performed in accordance with ISO 3744 and ISO 7960.*

Key words: *noise, sound pressure level, wood milling*

INTRODUCTION

It is well known that the noise emission in woodworking and furniture industry is among the highest. Therefore, in order to ensure health and safe working conditions, the noise levels have to be taken into account. Besides having a negative impact on the human health, the noise also accounts for reduced efficiency and concentration of workers and thus appears as an indirect cause for professional disorders and industrial accidents. According to the European Directive 2003/10/EO the upper limit for a workplace noise exposure based on the eight-hour working day is $L_{EX,\,8h}$ = 85 dB(A).

The noise levels generated by the woodworking machine during cutting differ from the noise levels generated by the machine during idling. The main reason for this is the technological noise, resulted from the contact between the workpiece and the cutting tool, which adds to the noise performance of the machine itself. The technological noise levels are influenced by the characteristics of the processed material – wood type, density, moisture content, size of the processing details etc. (HSE, 2009), on one hand and on the other – by the cutting tool operating parameters and construction (HSE, 2009; Svoreň, J., L. Murín, 2009; Vitchev, 2013).

The objectives of the current study was to investigate the influence of the cutting mode conditions on the noise levels in dB(A), generated during the milling process of details from common European beech (Fagus sylvatica L.) wood.

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MATHERIALS AND METHODS

The experiments have been carried out using woodworking spindel moulder machine, type T1002S (ZMM "Stomana" GmbH, Bulgaria) (Fig. 1). The machine was equipped with a two-speed three-phase electric motor with power 3,2/4,0 kW, which through a belt drive provides the following rotational frequency of the working shaft: 3000, 4000, 5000, 6000, 8000 and 10000 min^{-1}.

Figure 1. Woodworking spindel moulder machine, type T1002S with feeder

A cutting tool with an assembled construction for longitudinal plane milling, kindly provided by Metal World – Italy, was used. The main cutting edges of the tool are at 30° relative to the axes of rotation. The technical characteristics of the tool are given in Table 1, where *D* is the diameter of the milling machine, *d* – diameter of the threaded hole, *B* – width of the milling, β – sharpening angle, γ – hook angle, *z* – number of teeth.

Table 1. Technical characteristics of the used cutting tool

General look of the milling cutter	*D* [mm]	*d* [mm]	*B* [mm]	β [°]	γ [°]	*z* [No]
	125	30	50	47	16	4

For the experiments a wood from common European beech (*Fagus sylvatica L.*) with density ρ=690 kg.m^{-3} and moisture content W=12 % was used. The workpieces were with dimensions L x B x H – 1000 x 30 x 50 mm and have been submitted to the cutting tool by a feeder, part of the woodworking milling machine (Fig. 1).

The assessment of the noise levels were based on the sound pressure level adjusted to A – weighted curve, $L_{p(A)}$. The measurement point corresponded to the location of the operator and standing at a distance of 1 m from the edges of the machine, and at a height of 1,5 m from the reverberating floor.

The experiments were conducted in a free sound field using a standardized methodology (Vitchev, 2013).

The actual sound pressure level $L_{p(A)}$, is calculated using the following equation:

$$L_{p(A)} = L'_{p(A)} - K_1 - K_2, dB(A), \tag{1}$$

where:
$L`_{p(A)}$ is the measured sound pressure level, dB(A);
K_1 is a correction coefficient for the background noise, dB(A);
K_2 is a correction coefficient for the test environment, dB (A).

The measurements were performed using precise impulse sound level meter (RFT, Germany) with frequency range of octave bands with nominal mid-band frequencies as follow: 31,5; 63; 125; 250; 500; 1000; 2000; 4000; 8000; 16000; 31500 Hz.

The measurements were done at a time constant “fast” (F). Before the initiation of the experiments the entire measurement track has been calibrated, using a standard sound source Pistonfon PF 101 with a constant sound pressure level equal to 117,1 dB on $p_0=2.10^{-5}$ Pa at a frequency f = 180 Hz.

The requirements given in BDS EN ISO 3744:2010 and BDS ISO 7960:2005 were strictly followed throughout the experiments.

The cutting mode during milling is characterized primarily by the cutting speed *V*, the feed speed *U* and the thickness of the out-cut layer *h*. The cutting speed *V* is calculated using the following equation (Gochev, 2005):

$$V = \pi.D.n, m.s^{-1} \ (m.min^{-1}), \tag{2}$$

where:
D is the diameter of the cutting tool, m;
n is the rotational frequency of the milling cutting tool, s^{-1} (min^{-1}).

As it is visible from the equation (2), the cutting speed *V* changes with the change of the rotational frequency of the milling cutter *n*.

In order to trace the influence of the cutting mode on the noise levels, generated during milling, a three factor regression analysis described by Vuchkov et al. (1986) was applied. The variable factors include: the rotational frequency of the milling cutting tool *n*, the feed speed *U* and the thickness of the out-cut layer *h*. The levels of the controlled input values in explicit and coded form are given in Table 2. The values are consistent with the most frequently used in practice.

Table 2. Values of the variables n, U and h

Variable	Minimum value		Average value		Maximum value	
	explicit	coded	explicit	coded	explicit	coded
Rotational frequency *n* = x_1 [min^{-1}]	4000	-1	6000	0	8000	1
Feed speed *U* = x_2 [$m.min^{-1}$]	3,5	-1	7	0	10,5	1
Thickness of the out-cut layer *h* = x_3 [mm]	1	-1	2	0	3	1

The sound pressure level measurements, made during the cutting operational mode of the machine were performed in accordance with a preliminary designed matrix B_3 for three factorial experiment plan of G.Box of second order which is shown in Table 3. For the statystical analysis of the data QstatLab softwear was used.

RESULTS AND DISCUSSION

The sound pressure level during the cutting mode of the machine was determined on the basis of three measurements carried out for every single experiment. For data analysis the mean $\overline{L_{p(A)}}$ values were used. For this purpose a correction according the equation (1) was made. The results are presented in Table 4.

Table 3. Planning matrix for three factorial experiment and average sound pressure level values $\overline{L_{p(A)}}$ measured during the cutting mode of the machine

№ exp.	x_1 = n min^{-1}		x_2 = U m.min^{-1}		x_3 = h mm		$\overline{L_{p(A)}}$ dB(A)	№ exp.	x_1 = n min^{-1}		x_2 = U m.min^{-1}		x_3 = h mm		$\overline{L_{p(A)}}$ dB(A)
1	-1	4000	-1	3,5	-1	1	75,23	9	-1	4000	0	7	0	2	79,57
2	-1	4000	-1	3,5	1	3	77,4	10	1	8000	0	7	0	2	85,9
3	-1	4000	1	10,5	-1	1	79,73	11	0	6000	-1	3,5	0	2	81,9
4	-1	4000	1	10,5	1	3	83,57	12	0	6000	1	10,5	0	2	83,23
5	1	6000	-1	3,5	-1	1	83,23	13	0	6000	0	7	-1	1	80,73
6	1	6000	-1	3,5	1	3	84,9	14	0	6000	0	7	1	3	82,73
7	1	6000	1	10,5	-1	1	86,4	15	0	6000	0	7	0	2	80,74
8	1	8000	1	10,5	1	3	90,23								

After the mathematical and statistical analysis of the data, the following regression equation (3) has been derived:

$$\hat{y} = 80{,}743 + 2{,}617x_1 + 2{,}766x_2 + 1{,}533x_3 - 0{,}686x_1x_2 + 0{,}604x_2x_3 - 0{,}811x_1x_3 + 0{,}157x_1^2 + 1{,}572x_2^2 + 1{,}407x_3^2\ , \tag{3}$$

The regression coefficients values are given in Table 4. The correlation coefficient R^2 = 0,97.

Table 4. Regression coefficients

Coefficient	Coded value	Coefficient	Coded value
b_0	80,743	b_{22}	1,572
b_1	2,617	b_{33}	1,407
b_2	2,766	b_{12}	-0,686
b_3	1,533	b_{23}	0,604
b_{11}	0,157	b_{13}	-0,811

From the regression coefficient values it is evident that feed speed $U=x_2$ with the linear part of the coefficient $b_2=2{,}766$ has the greatest influence on the generated noise during the milling process of details from beech wood. Similar influence on the sound pressure level showed the rotational frequency of the cutting tool $n=x_1$ with linear part of the regression coefficient $b_1=2{,}617$. The linear part of the regression coefficient of the thickness of the out-cut layer is $b_3=1{,}533$. The positive values of the three regression coefficients mean that the sound pressure level, measured at workplace during the cutting mode of the machine is increased with the increase of the values of the tested factors.

The relationship between the investigated factors is the most prominent as it comes to the interaction between the rotational speed of the cutting tool $n=x_1$ and the thickness of the out-cut layer $h=x_3$ which is visible from the regression coefficient $b_{13}=-0{,}811$. The relationship between the factors: rotational speed $n=x_1$ and feed speed $U=x_2$ is nearly equally important as the interaction between the feed speed $U=x_2$ and the out-cut layer $h=x_3$. This is evident by the regression coefficient values relationships: $b_{12}=-0.686$, $b_{23}=0{,}604$ (Table 4).

In Figure 2, the changes of the sound pressure level $L_{p(A)}$, adjusted to A-weighted curve, depending on the feed speed *U*, measured at different out-cut layers *h*, are presented.

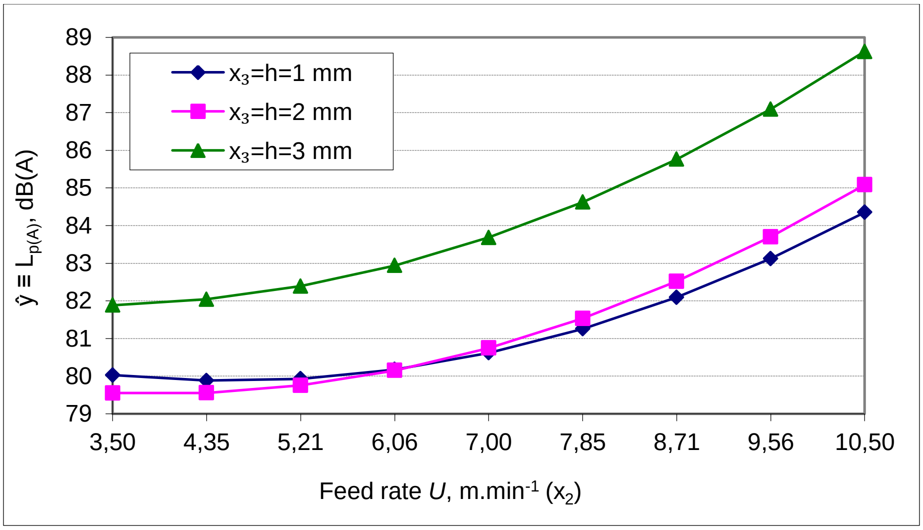

Figure 2. Sound pressure level $L_{p(A)}$ depending on the feed speed U, measured at different out-cut layers h and rotational frequency of the cutting tool $n \equiv x_1=const=6000$ min^{-1}

The results presented in Fig. 2 showed that the sound pressure level $L_{p(A)}$ is incresed with the increase of the feed speed *U*. This relationship is the most prominent at the thickness of the out-cut layer *h*=3 mm where the sound pressure level began to increase with the increase of the feed speed. At feed speed values ranging from U = 3,5 m.min^{-1} to U=7 m.min^{-1} and value of the out-cut layer *h* = 3 mm, the increase of the intensity of the noise level is lower when compared to the feed speed higher than 7 m.min^{-1}.

At thickness of the out-cut layer *h*=1 mm and *h*=2 mm, the sound pressure level was relatively equal and did not change when the feed speed ranges from 3,5 m.min^{-1} to 6,0 m.min^{-1}.

Changes of the sound pressure level, measured during the cutting mode of the machine, depending on the rotational frequency *n* at different feed speeds *U* is depicted in Figure 3.

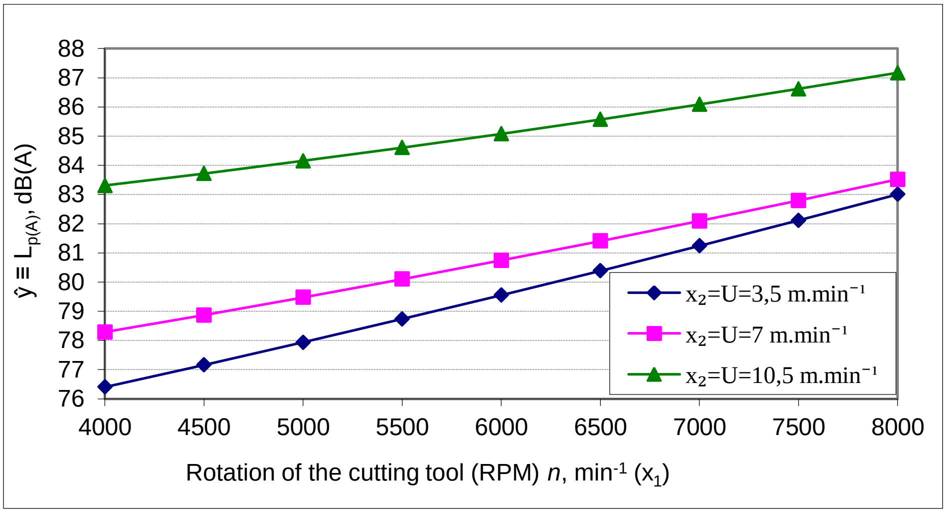

Figure 3. Sound pressure level $L_{p(A)}$ depending on the rotational frequency of the cutting tool n, measured at different feed speeds U and the thickness of the out-cut layer $h \equiv x_3 = const = 2$ mm

At all tested rotational frequencies of the working shaft, the highest noise levels were measured at feed speed *U*=10,5 m.min^{-1}. The noise levels were within the sanitary range when measured at feed speed of 10,5 m.min^{-1} and rotational frequency *n* up to 5500 min^{-1}. The noise level increased with the increase of the rotational frequency, as at *n*=8000 min^{-1} the noise level measured is 87,1 dB(A).

At feed speed *U*=3,5 m.min^{-1} and *U*=7 m.min^{-1} the sound pressure level is below the sanitary standard of 85 dB(A). At rotational frequencies of the working shaft *n*, ranging from 4000 min^{-1} to 6500 min^{-1}

At rotational frequency of the working shaft *n* ranging from 4000 min^{-1} to 6500 min^{-1} a difference in the noise levels between the two lower feed speeds was observed. This difference decreases with an increase of the rotational speed and at *n*=8000 min^{-1} the sound pressure levels at *U*=3,5 m.min^{-1} и *U*=7 m.min^{-1} were nearly equal (Fig. 3).

For the three feed speeds the increase of the intensity of the noise level is higher at the loewest feed speed *U*=3,5 m.min^{-1}, as the level changed from 76,4 dB(A) at *n*=4000 min^{-1} to 82 dB(A) at n=8000 min^{-1}, i.e. the increase is by 5,6 dB(A). The intensity of the noise level decreased with the increase of the feed speed. At feed speed *U*=10,5 m.min^{-1} the level of the sound energy is changed from 83 dB(A) at n = 4000 min^{-1} to 87 dB(A) at n = 8000 min^{-1}, i.e. the change is by 4 dB(A).

CONCLUSION

On the basis of the current study that investigated the noise immission levels, measured during the milling process of details from common European beech (Fagus sylvatica L.) wood, the following conclusions can be made:

The highest influence on the sound pressure level, measured at the workplace and adjusted to A-weighted curve, showed the feed speed U and the rotational frequency of the cutting tool n, followed by the thickness of the out-cut layer h.

For the whole examined range of the feed speed from 3,50 m.min^{-1} to 10,5 m.min^{-1}, the highest noise level was measured at the thickness of the out-cut layer h=3 mm. At feed speed up to 8 m.min^{-1} the noise levels were within the sanitary standard range of 85 dB(A). With the increase of the feed speed from 8 m.min^{-1} to 10,5 m.min^{-1} the sound pressure level increased from 85 dB(A) to 88,6 dB(A), i.e. the noise level was increased by 3,6 dB(A) which accounts for more than two times larger noise immission. At lower values of the thickness out-cut layer (h=1 mm and h=2 mm) the sound pressure level is within the sanitary range standards for the whole range of the feed speed (Fig. 2).

At rotational speed of the cutting tool up to 6000 min^{-1} the noise immission level is within the sanitary range standards for the three investigated feed speeds.

Regarding the noise immission levels, produced during the milling process of the details from common European beech wood, the following optimal values of the tested factors are recommended: feed speed U - up to 8 m.min^{-1}; cutting speed V – up to 40 m/s; thickness of the out-cut layer h – up to 3 mm.

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