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STUDY ON THE NOISE LEVELS GENERATED DURING MILLING OF WOOD FROM *PINUS SILVESTRIS* L.

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ABSTRACT

Wood machining through milling is one of the wide-used cutting processes in woodworking and furniture industry. It is also one of the noisiest, due to the high noise immission levels that often exceed the accepted sanitary standards.

In this work the influence of the feed rate, the speed of the working shaft (or cutting speed) and the thickness of the out cut layer on the noise levels, measured at work place, generated during *Pinus silvestris* L. milling process has been evaluated.

Key words: noise, sound emission, milling noise, milling process

INTRODUCTION

Noise at work is one of the most important factors that are taken into account when safety environment at work is measured. 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).

It is well-known fact that the noise levels exceeding the acceptable sanitary limits pose a variety of health risks and negative physiological effects on the human organism. Therefore the noise levels at work are the main factor which impact on occupational safety and health has to be considered.

The noise generated by a woodworking machine can be aerodynamic, mechanical and technological. The aerodynamic noise is a result of the interaction between the cutting tools of the machine with the surrounding environment. The mechanical noise is due to the vibrations of the machine and the technological noise is a consequence of the cutting process itself. The factors influencing the technological noise levels could be divided into three main groups: factors related to the processing material – wood type, density, moisture content, size of the processing details etc. (HSE, 2009); factors that characterize the cutting tool – operating parameters, construction (HSE, 2009; Vitchev, 2013); factors related to the cutting process – cutting speed, feed speed, cutting height, thickness of the out-cut layer etc.

In the current study experiments were carried out in order to investigate the influence of the feed rate, the speed of the working shaft (or cutting speed) and the thickness of the out-cut layer on the noise immission levels generated during the milling process of wood from Scots pine (*Pinus silvestris* L.).

The experiments were performed under laboratory conditions at the University of Forestry – Sofia.

MATERIALS AND METHODS

The experiments have been carried out using woodworking spindel moulder machine, type T1002S (ZMM “Stomana“ GmbH, Bulgaria). 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}.

A cutting tool with an assembled construction for longitudinal plane milling, kindly provided by Metal World – Italy, was used. 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]**	**Material of the teeth**
	125	30	50	47	16	4	Carbide (HM)

In accordance with the BDS ISO 7960:2005 requirements (chapter D) wood from Scots pine (*Pinus silvestris* L.) with density ρ =490 kg.m^{-3} and moisture content W = 12,7 % was used in the current study. The workpieces with dimensions 1000 x 30 x 50 mm have been submitted to the cutting tool by a feeder, part of the woodworking milling machine and driven by a separate motor.

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

The noise immission level $L`_{P(A)}$ adjusted to A-weighted curve is measured in dB (A) at a measurement point corresponding 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 actual noise immission level adjusted to A – weighted curve, $L_{p(A)}$, is calculated using the following equation:

$$L_{p(A)} = L`_{p(A)} - K_1 - K_2, \text{ dB(A)}, \qquad \mathbf{(1)}$$

where 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. This sound level meter measures both linear sound pressure levels and sound levels, corrected according to the standard frequency characteristics: A, B, C and D weighted curves with a frequency range from 20 to 20 000 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.

In order to trace the influence of the rotational speed (*n)* of the milling cutting tool, of the feed speed (*U*) and of the thickness of the cut-out layer (*h*) (the milling thickness) on the noise immission level, a three factor regression analysis described by Vuchkov et al. (1986) was applied.

Table 2 shows the levels of the input variables in coded and explicit form, as the values are consistent with the most frequently used in practice.

Table 2: Values of the variables *n*, *U* and *h*

Variable	Minimum value		Avarage value		Maximum value	
	explicit	coded	explicit	coded	explicit	coded
Rotational frequence $n = X_1$ [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 cut-out layer $h = X_3$ [mm]	1	-1	2	0	3	1

The measurements 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

After applying the method of regression analysis and statistical analysis of the data we received the following polynomial of second degree:

$$\hat{y} = 85,328 + 2,949.x_1 + 0,534.x_2 + 0,833.x_3 - 0,271.x_1.x_2 - 0,354.x_2.x_3 - 0,354.x_1.x_3 - 0,928x_1^2 - 0,343.x_2^2 - 0,354.x_3^2 \; . \tag{2}$$

Table 3 depicts the average sound pressure level values $(\overline{L_{p\,(A)}})$, calculated on the basis of the results from the performed three factorial experiments and in Table 4 the regression coefficients are given. The correlation coefficient is $R^2 = 0,98417$.

Table 3: Planning matrix for three factorial experiment and average sound pressure level values $(\overline{L_{p\,(A)}})$

№ 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	78,07	8	1	8000	1	10,5	1	3	86,73
2	-1	4000	-1	3,5	1	3	81,23	9	-1	4000	0	7	0	2	81,73
3	-1	4000	1	10,5	-1	1	80,57	10	1	8000	0	7	0	2	87,07
4	-1	4000	1	10,5	1	3	81,57	11	0	6000	-1	3,5	0	2	84,07
5	1	6000	-1	3,5	-1	1	85,73	12	0	6000	1	10,5	0	2	85,90
6	1	6000	-1	3,5	1	3	86,73	13	0	6000	0	7	-1	1	83,23
7	1	6000	1	10,5	-1	1	86,40	14	0	6000	0	7	1	3	86,07

Table 4: Regression coefficients

Coefficient	Coded values	Coefficient	Coded values
b_1	2,949	b_{33}	- 0,678
b_2	0,534	b_{12}	- 0,271

b_3	0,833	b_{23}	- 0,354
b_{11}	- 0,928	b_{13}	- 0,354
b_{22}	- 0,343		

From the results given in Table 4 is clear that the rotational of the cutting tool (n) has the greatest influence on the noise level. The linear part of this factor was positive (b_1=2,949), i.e. the generated noise level is increased with the increase of the rotational frequency of the cutting tool. The regression coefficient of the rotation of the milling cutter was negative (b_{11}= -0,928), i.e. the higher the rotating frequency the higher the noise level (Fig. 1). This could be explained by the increased levels of the aerodynamic noise resulted from the increased rotational speed of the cutting tool.

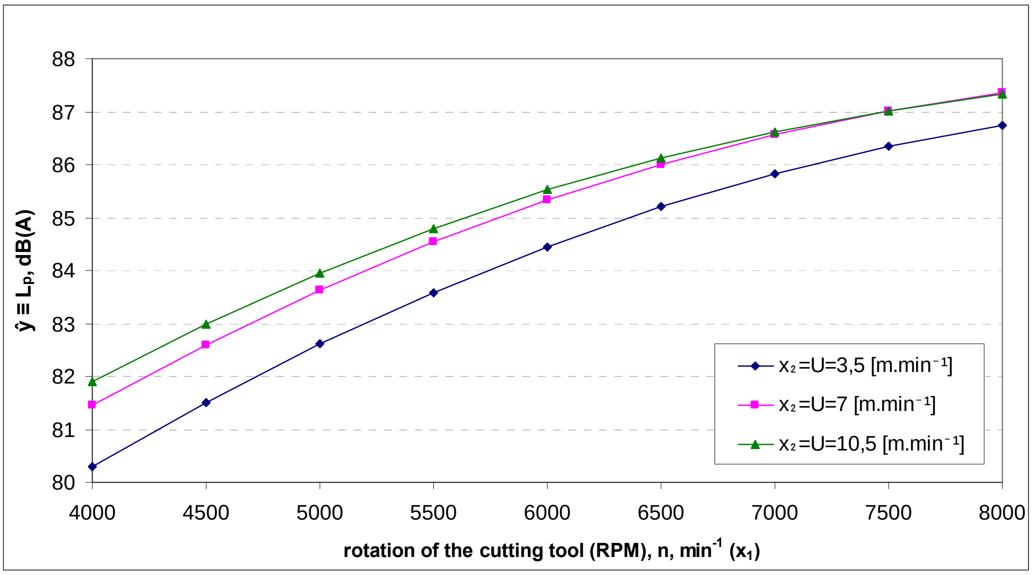

Figure 1: Relationship between the rotation of the milling machine and the noise levels measured at different feed speeds and thickness of the out-cut layer h≡x_3=const=2 mm

The results presented in Fig. 1 show that at the three tested feed speeds the noise level increased with the increase of the rotational frequency of the milling machine. The noise levels measured at the three different feed speeds were below the sanitary level of 85 dB (A) only when the rotational speed was up to 5500 min^{-1}. At speeds of rotation from 6500min^{-1} to 8000 min^{-1} there was no significant difference in the generated noise levels, measured at high feed speeds (U=7 $m.min^{-1}$ and U=10,5$m.min^{-1}$). It also has to be noted that at the three feed speeds there was a similar pattern of increase in the intensity of the generated noise. However, in the range of 4000 min^{-1} - 6000 min^{-1} the noise level enhanced more intensively when compared to the higher rotational frequencies. For the whole covered range of rotational frequencies of the milling machine, from 4000 min^{-1} to 8000 min^{-1} and milling thickness h = 2 mm, the lowest noise level was measured at the lowest feed speed (U=3,5 $m.min^{-1}$). At rotations above 7000 min^{-1} the level of the generated noise was equal for the feed speeds of U=7 $m.min^{-1}$ and U=10,5 $m.min^{-1}$. For the all three feed speeds the noise level reached its peak at the maximum rotation of the cutting tool, as follow: at U=3,5 m.min^{-1}, L_{pA}=86,74 dB(A); at U=7 m.min^{-1}, L_{pA}=87,35 dB(A); at U=10,5 m.min^{-1}, L_{pA}=87,33 dB(A). Since the feed speed, given in equation (2) was negative (b_{22}=-0,343), the higher the feed speed the lower the intensity with which the level of the generated noise is increased. This relationship is shown in Fig. 2.

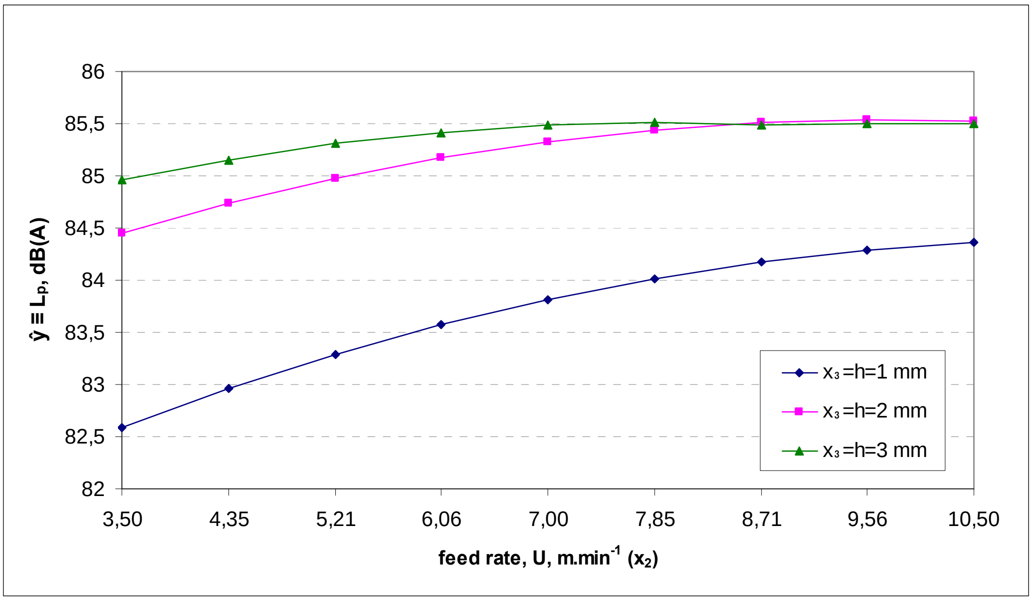

Figure 2: Relationship between the feed speed and the noise level measured at different thickness of out-cut layer and rotations of the milling machine n ≡ x_1 = const = 6000 min^{-1}

For all feed speeds in the tested interval U∈(3,5÷10,5) m.min^{-1} the noise levels were under the sanitary standard of 85 dB (A) and the lowest noise level was generated at the thickness of the out-cut layer h = 1mm. At higher values of the thickness of the out-cut layer (h = 2 mm and h = 3 mm) the noise levels were within the sanitary standard range only at the lowest feed speed of U = 3,5 m.min^{-1}. When the feed speed was over 4 m.min^{-1} the noise level, measured for both out-cut layers thickness was above the sanitary standard. The increase of the intensity of the noise level was higher at thickness h = 2 mm and speed feed up to 7 m.min^{-1}, compared to speed feed from 7 m.min^{-1} to 8,7 m.min^{-1}. With a speed feed over 8,7 m.min^{-1} and a rotation of the milling machine n = 6000 min^{-1} the noise levels reached a steady state and were approximately the same at thickness of the out-cut layer h = 2 mm and h = 3 mm.

Figure 3 shows the relationship between the rotation of the milling cutting tool and the noise levels measured at different thickness of the out-cut layer. Similarly to the results shown in Figure 1, the generated noise levels, measured at the three out-cut layers thickness (h = 1 mm, h = 2 mm и h = 3 mm) increased with the increase of the rotational speed of the cutting tool.

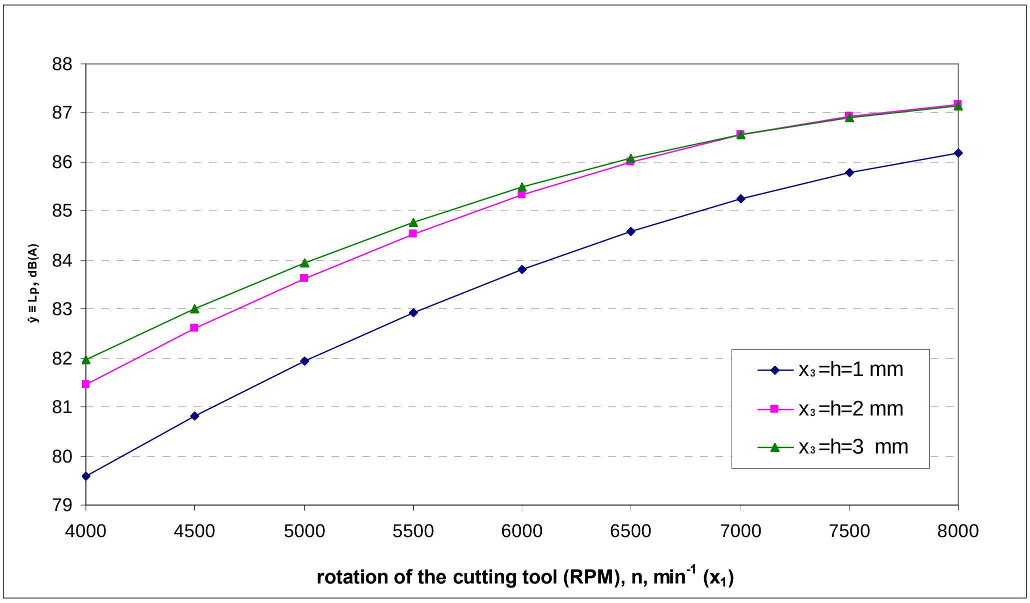

Figure 3: Relationship between the rotations of the milling machine and the noise levels measured at different thickness of the out-cut layer and speed feed U ≡ x_2 = const = 7,5 m.min^{-1}

At thickness of the out-cut layer h = 1 mm and rotational speed up to 6700 min^{-1} the generated noise levels were within the accepted sanitary standards. At thickness of the out-cut layer h = 2 mm and h=3 mm, the generated noise levels were within the accepted sanitary standards only when the rotational speed of the cutting tool was up to 5500 min^{-1}. When the rotation speed of the cutting tool exceeded 6500 min^{-1}, the generated noise levels were equal for both thickness of the out-cut layers (h = 2 mm and h = 3 mm).

CONCLUSION

On the basis of the current study that investigated the noise levels, measured at workplace during milling of wood from Scots pine (*Pinus Sylvestris* L.) the following conclusions can be made:

Among the investigated factors the rotation of the milling cutting tool exerted the highest influence on the generated noise levels. The noise level generated by the cutting tool with diameter D = 125 mm were within the sanitary standard range when the rotational frequency was up to 5500 min^{-1}. At the same rotational frequency of the cutting tool the noise level increased as the feed speed increased. Among the all factors tested the thickness of the out-cut layers had the slightest effect on the noise immission levels.

For the whole examined range of rotational frequencies $n \in (4000 \div 8000)$ min^{-1} and at speed feed U = 7 m.min^{-1} the lowest noise level was detected at thickness of h=1 mm. In comparison, at thickness of the out-cut layers of h = 2 mm and h = 3 mm the noise level was significantly higher (see Fig. 3) and at rotational frequency of the tool over 6500 min^{-1} the noise level was equal for the both thickness levels (h = 2 mm and h = 3 mm).

Regarding the results of our study, the influence of the investigated factors: rotation of the milling cutting tool, feed speed and thickness of the out-cut layer have to be taken into account when the cutting process is planned. This is important as for the technological process itself, as well as for reducing the noise immission levels in order to ensure healthy and safe work conditions at the workplace.

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