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ASSESSMENT OF NOISE EMISSION LEVEL GENERATED BY A CNC MILLING MACHINE

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ABSTRACT

The current study aims to assess the level of noise emission generated by the CNC milling machine Rover A.3.30 (Biesse, Italy). The change of the *A*-weighted sound pressure level (L_{pA}) measured at the operator's position at idle mode and during milling operations was investigated in relation to cutting tool rotation speed (n) and radial depth of cut (h) when processing particle boards, medium density fiberboards (MDF) and plywood. Sound pressure levels were determined using the precision digital noise meter CEL-620B1 (CASELLA, UK), taking into account the correction coefficients, accounting for the influence of background noises and sound field characteristics. The results show that at idle mode, without movement of the units along the x and y axes, the noise emission level was L_{pA} = 72,6 dB(A), which is significantly below the upper safe limit of 85 dB(A) for eight hours of exposure. It was found that the *A*-weighted sound pressure level during cutting mode changed from 79,5 dB(A) to 85,6 dB(A), depending on the characteristics of the cutting process. The lowest level was registered when processing particle boards, followed by that of processing MDF and the highest level was measured for plywood. On the basis of the performed experiments, graphical dependencies representing the relationship between the different factors were compiled.

Key words: noise, sound pressure level, routing, milling, CNC machine.

INTRODUCTION

Noise is one of the main factors in the work environment which has a negative impact on workers’ health. High levels of noise emissions are a prerequisite for workers’ deteriorating health because they affect the nervous and cardiovascular systems as well as the vestibular apparatus, and in some cases this may lead to permanent disability such as hearing loss (Brezin, 1992; Brezin, 2015; Błasiak, 2015; Antov, 2017).

Safe noise load of workers exposed to noise is specified by EU Directive 2003/10/EC, the upper safe limit for eight hours of exposure being set at $L_{EX,\ 8h}$ = 85 dB(A).

Technological machinery used in woodworking and furniture industry over the years has traditionally been considered one of the noisiest with levels exceeding 90 dB (A). In recent years, however, the industry's efforts to reduce noise levels have been impressive, especially in high-tech and high-performance CNC machines. Factors influencing the change in noise level during processing of wood and wood-based materials generally depend on: (i) the characteristics of the processed materials (type, density, dimensions); (ii) cutting mode (cutting and feeding speeds, thickness of the removed layer, cutting height); (iii) 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; Kminiak, 2023).

The current study aims, through experiments, to investigate the change of sound pressure level measured at the position of an CNC machine operator in relation to cutting tool rotation speed (n) and radial depth of cut (height of cutting) (*h*) when processing particle board, medium density fibreboard (MDF) and plywood workpieces.

MATERIALS AND METHOD OF STUDY

The experiments were performed on the woodworking CNC milling and drilling machine Rover A3.30 (Biesse, Italy) with length, width and height respectively *L* x *B* x *H* = 4900 x 2700 x 2100 mm (Fig. 1). The machine has three interpolated control axes allowing to infinitely adjust the feed speed and change the cutting speed by changing the cutting tool rotation speed (*n*).

Figure 1: CNC milling and drilling center Rover A.3.30 (Biesse, Italy)

In cutting mode particle board, medium density board (MDF) and plywood workpieces with dimensions of 1000 x 100 mm are processed (Fig. 2).

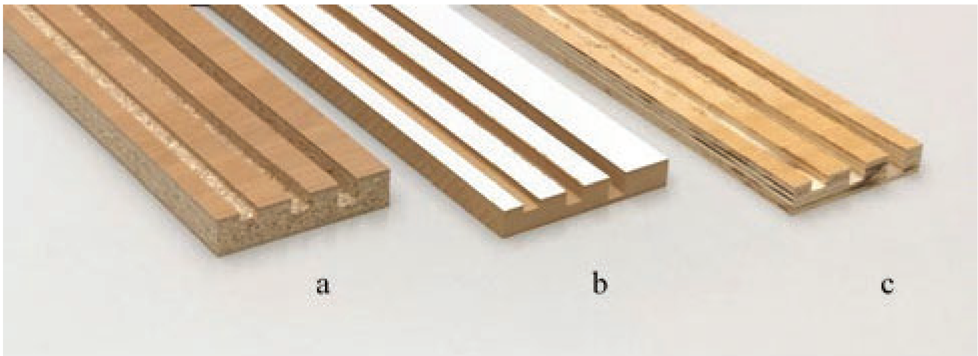

Figure 2: Processed workpieces: a – particle board; b – MDF; c – plywood

With the help of a face milling cutter with a diameter *D* = 12 mm, grooves with depth (*h*) 5, 10 and 15 mm were milled in the workpieces at a tool rotation speed (*n*) of 5000, 10000 and 15000 min^{-1} (Table 1).

Table 1: Conditions under which sound pressure levels were measured

Processed material	Particle board	MDF	Plywood
Workpiece dimensions [mm]		1000 x 100	
Radial depth of cut (h) [mm]	5	10	15
Cutter diameter [mm]		12	
Cutter rotation speed (n) [min^{-1}]	5000	1000	15000
Feed rate V_f [m.min^{-1}]		6	
Cutting tool material		PCD	

The machine is placed on a concrete sound-reflecting floor in a room with the shape of a parallelepiped with dimensions: length, width and height, L_1 x B_1 x H_1 – 24 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 as a result of the operation 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 at a distance of 1 m from the base parallelepiped, corresponding to the operator's position, and was 1.5 m above the sound-reflecting floor (Fig. 3). The workpieces were placed on the machine table in the area near the control panel (near the measuring point).

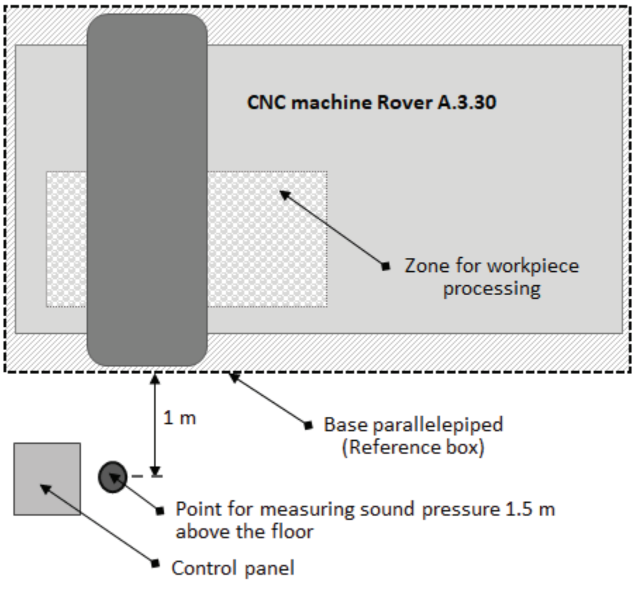

Figure 3: Diagram showing measuring point position and zone for workpiece processing

When determining the actual sound pressure level (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 the following way:

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

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 is the noise from all other internal and external sources, with the exception of noise from the machine under study. To assess its influence, the difference (ΔL_p) between the sound pressure level from the sound source and the background noise level was calculated. In case of ΔL_p<6 dB, measurements are not recommended as the background noise will have a significant impact on the results. When $6 \le \Delta L_p \le 15$, it is necessary to calculate the correction coefficient K_1 which shows the influence of background noise in the following way:

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

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.

In case of ΔL_p>15 dB the background noise does not affect the measurements as the sound pressure it generates is masked by the sound emission of the sound source. 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:

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

where

A is the equivalent sound absorbing area of the room, m2;

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

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

$$\boldsymbol{A = \alpha . S_v} \qquad \textbf{(4)}$$

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 free or approximately free sound field are not fulfilled and the results of the measurements are not correct (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. Prior to the measurements the device was calibrated by means of an acoustic calibrator of the same company with a constant sound pressure level of 114 dB, $p_0 = 2.10^{-5}$ N.m^2 at a frequency f = 180 Hz.

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

RESULTS

Influence of background noise

The measurements made showed that the sound pressure levels were as follows:

- *A*-weighted sound pressure level resulting from the idle mode of the tested CNC machine was 71 dB(A);

- *A*-weighted sound pressure level of the background noise was 52 dB(A).

The values obtained showed that the difference between the sound pressure levels of the sound source and the background noise was $\Delta L_p > 15$ dB(A). Therefore, the background noise did not affect the sound pressure measurements of the studied sound source, i.e. the correction coefficient showing 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* - 9 x 10 x 3.6 m. The measuring surface is 1 m from the base parallelepiped and has the shape of a regular parallelepiped with an area of $S = 85.15$ 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 $K_2 = 2{,}6$.

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

Sound pressure level in idle mode of the machine

The generated sound pressure level as a result of the operation of the machine without cutting is graphically presented in Fig. 4.

The results clearly show that the values of the sound pressure level in octave frequency bands and the *A*-weighted sound pressure level were significantly lower than the maximum permissible safety and health norm of 85 dB.

The spectral distribution showed that the sound energy was most pronounced in an octave frequency band with an average geometric frequency of 1000 Hz, in which the sound pressures at the individual rotation speeds of the milling cutter were as follows:at $n = 5000$ min^{-1},L_p = 64 dB; at n = 10000 min^{-1}, L_p = 65,5 dB; at n = 15000 min^{-1}, L_p = 67,8 dB. The results confirm the assumption that by increasing the cutting tool rotation speed, the level of noise emission increases as a result of the increased level of aerodynamic noise.

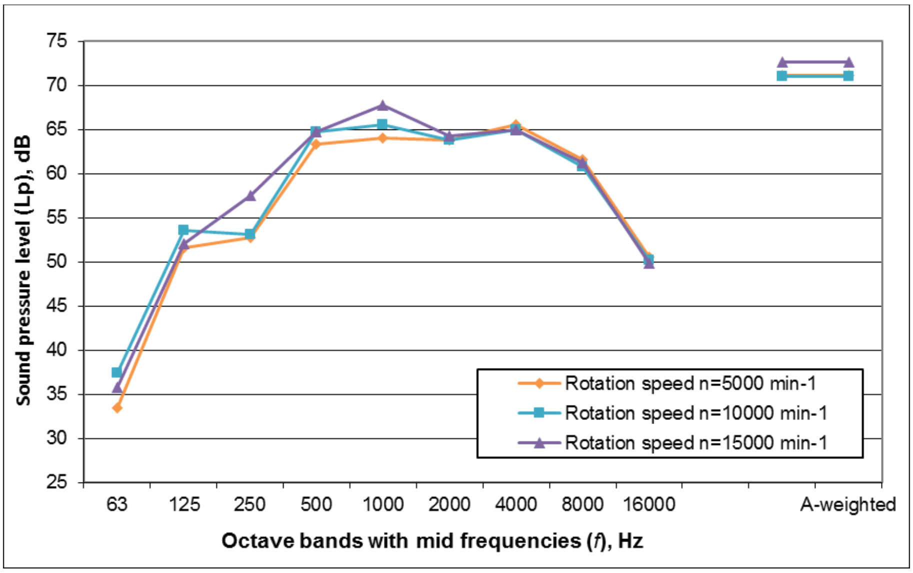

Figure 4: Sound pressure level (L_p) in octave frequency bands which is frequency weighted along curve *A* (L_{pA}) at different speeds of the electric spindle during operation of the machine without cutting

Sound pressure level during cutting operations of machine (in operational mode)

The first series of experiments, performed during cutting, evaluated the change of *A*-weighted sound pressure level L_{pA} in relation to cutting tool rotation speed (n) at radial depth of cut h = 10 mm and feed rate $V_f = 6$ m/min. The results are presented graphically in Fig. 5.

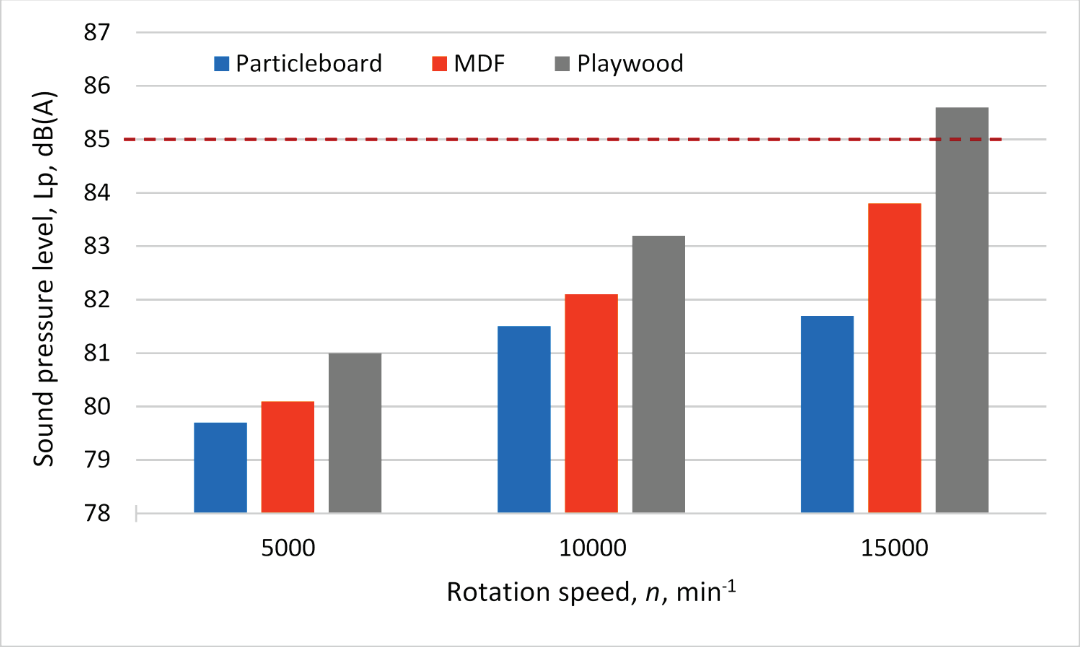

Figure 5: Change of sound pressure level (L_{pA}) in relation to cutting tool rotation speed (n) at milling depth h = 10 mm and feed rate V_f = 6 m/min.

An increase in the noise emissions were observed with an increase in the tool speed. The sound pressure level varied from 79.5 dB(A) when processing particle board with rotation speed n = 5000 min^{-1} to 85.6 dB(A) when processing plywood with rotation speed n = 15000 min^{-1}. The maximum permissible safety and health norm was exceeded by 0.6 dB (A) only in the latter case.

In the second series of measurements the influence of the radial depth of cut (h) on the change of the sound pressure level at cutting tool rotation speed n = 10000 min^{-1} and feed rate $V_f = 6$ m/min was observed (Fig. 6). The results clearly confirmed the influence of the radial depth of cut on noise emission level. The sound pressure level increases by an increase of the radial depth of cut; however at a cutting tool rotation speed of n = 10000 min^{-1} it did not exceed the safe upper limit of 85 dB(A) for 8 hours/day for the maximum radial depth of cut of h = 15 mm.

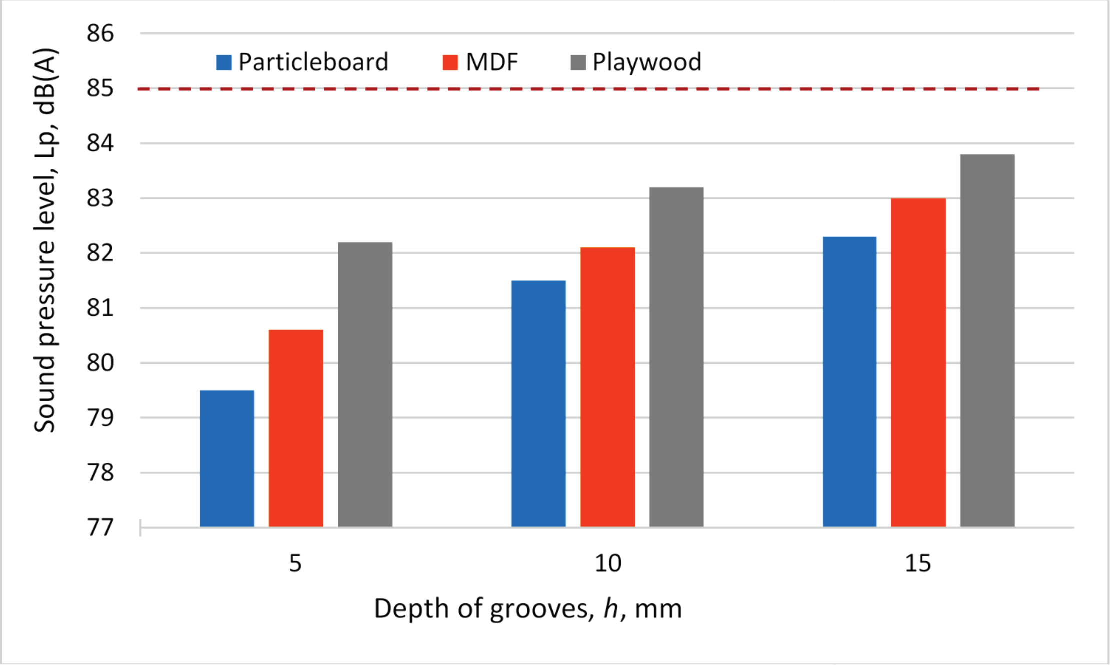

Figure 6: Change of sound pressure level (L_{pA}) in relation to radial depth of cut (h) at the cutting tool rotation speed n = 10000 min^{-1} and the feed rate V_f = 6 m/min

The graphical dependences in Fig. 5 and Fig. 6 also show the influence of the processed material on the change of noise emission level. It is visible that the lowest sound pressure level was measured when processing chipboard workpieces, followed by MDF and plywood workpieces.

CONCLUSION

Based on the results obtained under the conditions of this study, it could be concluded that the sound emission level does not exceed the maximum permissible health and safety norm of 85 dB(A) for 8 hours/day. The obtained results confirm the trend and efforts of the industry in reducing the noise emission levels of machines for processing wood and wood-based materials.

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