EQUIVALENT SOUND PRESSURE LEVELS IN WOODWORKING MILLING MACHINES

Pavlin Vitchev
University of Forestry, Sofia, Bulgaria
e-mail: p_vitchev@abv.bg

ABSTRACT

Equivalent continuous sound pressure level L_{Aeq} is the main variable characterizing the physiological effects of noise on humans. The technological equipment for woodworking and furniture industry includes the woodworking milling machines, which at the same time are characterized with high levels of noise emissions.

The current study investigates the changes in equivalent sound pressure level measured at workplace during milling of details from common beech wood (*Fagus Sylvatika* L). The influence of the construction and rotational speed of the cutting tool have been studied.

It was found that depending on the cutting speed and the construction characteristics of the cutting tool, the equivalent sound pressure level L_{Aeq} for eight hour working day varies from 74 dB(A) to 89 dB(A).

Key words: noise, sound emission, equivalent level, noise during milling.

INTRODUCTION

Some of the noisiest working environments are found in the woodworking industry. This is the result of the technological equipment which in most cases generates high noise emissions. Noise therefore is a common occupational hazard posing a variety of health risks and negative physiological effects on the human organism. For example, short exposure to high noise levels can cause temporary hearing loss, but longer exposures can result in permanent damage. Thus, the control of noise at the workplace is an important factor to reduce the health risk and to ensure safety working environment.

According to the Regulation 6/15.08.2005 of the Ministery of Health and the Ministery of Labor and Social Policy of the Republic of Bulgaria as well as to the European Directive 2003/10/EO the upper limit for a workplace noise exposure based on the eight-hour working day is $L_{EX,\,8\text{h}}$ = 85 dB(A). Noise effects on human health depend as on the intensity, as well as on the exposure duration. Often at a given workplace, depending on the technological process and the characteristics of the given job, a noise with different sound pressure level is generated and its effect on the worker is limited to a certain period of time. For determination of the influence of all different *A*-weighted sound pressure levels, L_{Aeq} in dB(A) “equivalent continuous *A*-weighted sound pressure level” has been introduced. In this case the L_{Aeq} dB(A) defines as a noise level that for a certain time interval (e.g. 8 work hours/day) generates the same sound energy. The L_{Aeq} dB(A) can be regarded as a real criterion for the assessment of the noise influence on the human organism and for the evaluation of the efficacy of the measures taken to reduce the noise at the workplace (Brezin, 1992).

In accordance to this information the objectives of the current study was to evaluate the equivalent sound pressure level generated at workplace for 8-hour work day by a woodworking milling machine, taking into account the type of the cutting tool and its rotational frequency when processing details from common beech (*Fagus Sylvayika* L.).

MATERIALS AND METHODS

The experiments have been carried out using woodworking spindel moulder machine, type T1002S (ZMM “Stomana” GmbH, Bulgaria). For the milling process three cutting tools (Metal World, Italy) with the following parameters: cutting diameter D = 125 mm, milling width B = 50 mm, number of teeth z = 4 have been used.

The first milling tool CH 1 (Fig. 1a) is with a robust construction with welded carbide teeth. The second milling tool CH 2 (Fig. 1b) is with an assembled construction and the cutting edges of the tool are parallel to the axes of rotation. The third milling tool CH 3 (Fig. 3c) is also with an assembled construction, however the cutting edges of the teeth are at 30^0 relative to the axes of rotation.

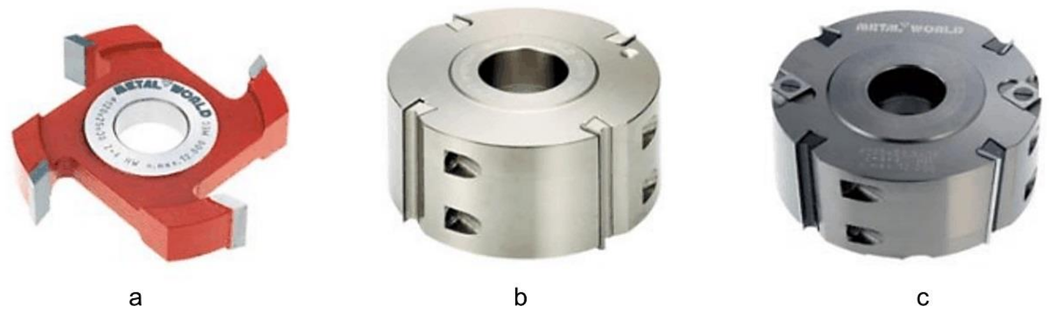

Figure 1: The cutting tools used in the experiment
***a*) with robust construction, *b*) with an assembled construction and the cutting edges parallel to the axes of rotation, *c*) with an assembled construction and cutting edges at 30⁰ relative to the axes of rotation**

The workpieces with dimensions 1000 x 30 x 50 mm have been submitted to the cutting tool by a feeder, at a feed speed U = 3,5 m.min^{-1} and the thickness of the output layer during milling h = 2 mm. The experiments were carried out at different rotational speed of the cutting tools n, 4000, 6000 and 8000 min^{-1}, respectively.

The A-weighted sound pressure level $L`_{p(A)}$, was measured in dB(A) at a measurement point corresponding to the location of the operator.

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

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

where: K_1 is a background noise correction coefficient, dB(A);

K_2 is an environmental correction coefficient, dB (A).

The equivalent A-weighted sound pressure level L_{Aeq}, for a given time interval T, split into a number of sub-intervals t_i with an impact sound pressure level L_i has been calculated using the equation (2) (Philipov et al., 1979):

$$L_{Aeq} = \frac{q}{0,3} lg \left[\sum_{i=1}^{n} \frac{t_i}{T} 10^{\frac{0,3L_i}{q}} \right] \text{, dB(A),} \qquad \textbf{(2)}$$

where: q is an equivalent parameter, indicating to what extent the sound increase in dB(A) is compensated by the half decrease of the exposure duration time to a noise with a certain level. In the current study we accepted q = 3, which means that an increase of the noise level by 3 dB(A) would be compensate by a 2 fold decrease of the exposure time;

t_i – the duration of the i-time interval (the impact time of a noise with a sound pressure level L_i), min;

$T = \sum_{i=1}^{n} t_i$ – the whole noise impact interval, min;

L_i – the sound pressure level at the *i*-time interval, dB(A);

n – number of the intervals with different noise levels.

It is well-known that the noise levels, generated by the woodworking milling machines vary, as the noise levels during idling differ significantly from those during the cutting mode of the mill.

The refore the *A*-weighted sound pressure level during idling – L_{pA1} as well as the *A*-weighted sound pressure level during cutting – L_{pA2} has to be measured.

On the basis of the observations made during the production process, as well as taking into account the opinion of the experts in this field it was determined that between 30 % to 50 % of the total working time of the milling machines is under idling. The duration of this time depends on the technological operation, the organization of the technological process and the professional qualification of the operator.

In the current study a conditional operating mode of the machine, for which average working time under idling was 40 % of the total working time, has been accepted.

In order to evaluate the total equivalent continuous *A*-weighted sound pressure level for 8 hours, using the woodworking spindel moulder machine, type T1002S, we have accepted that the whole noise impact interval *T* = 480 min is consisted of the following intervals: t_1 = 40 %. T = 192 min – the time of the machine working under idling; t_2 = 60 %. T = 288 min – the time of the cutting mode of the machine.

At equivalent parameter *q* = 3, the partial equivalent sound pressure levels L_{eq}^{1} and L_{eq}^{2} for evaluating the time interval t_1 and t_2, respectively are calculated using the equation (3):

$$\boldsymbol{L_{eq}^{i}} = \frac{3}{0,3}\,\boldsymbol{lg}\left[\frac{t_i}{T}\,10^{\frac{0,3L_i}{3}}\right] = \boldsymbol{10lg}\left[\frac{t_i}{T}.\frac{L_i}{10}\right] = \boldsymbol{10lg}\,\frac{t_i}{T} + \boldsymbol{L_i},\ \text{dB (A)}, \qquad \textbf{(3)}$$

where t_i is the duration of the *i*-time interval, min;

T – the whole noise impact interval, min;

L_i – the sound pressure level at the *i*-time interval, dB(A);

The equivalent continuous *A*-weighted sound level for the whole time interval of 8 hours, $L_{Aeq(8h)}$ has been calculated by logarithmic addition of the L_{Aeq}^{i} using the following equation (4) (Bruel & Kjaer, 2001):

$$L_{Aeq(8h)} = 10lg\left(10^{0,1L_{Aeq}^{1}} + 10^{0,1L_{Aeq}^{2}}\right),\ \text{dB(A)}, \qquad \textbf{(4)}$$

where: L_{Aeq}^{1} is the partial equivalent *A*-weighted sound pressure, measured at the workplace during idling, dB(A);

L_{Aeq}^{2} is the partial equivalent *A*-weighted sound pressure, measured at the workplace during cutting mode of the machine, dB(A);

The measurements were performed using precise impulse sound level meter (RFT, Germany) with built in standard frequency characteristics A, B, C and D with a frequency range from 20 Hz to 20 kHz. 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 (RFT, Germany).

All the experiments were carried out in compliance with the acting normative documents (EN ISO 3744:2010; BDS ISO 7960:2007)

RESULTS AND DISCUSSION

The measured sound pressure level L_{p1} and L_{p2}, the calculated partial equivalent sound pressure levels L^1_{eq} and L^2_{eq} as well as the equivalent continuous sound pressure level $L_{Aeq(8h)}$, measured under idling and cutting mode of the machine for the three used cutting tools (CH 1, CH 2 and CH 3) are shown in Table 1.

The analysis of the results showed that the equivalent continuous sound pressure level, measured at workplace was influenced by the work mode of the machine, the construction of the cutting toll and its rotational frequency.

The influence of the construction of the cutting tools (CH 1, CH 2 and CH 3) and the different rotational frequencies of the working shaft on the equivalent *A*-weighted noise level $L_{Aeq(8h)}$ is given in Figure 2. From the graphical distribution of the equivalent sound pressure level it is visible that at rotational frequencies 4000 min^{-1} and 6000 min^{-1} of the working shaft the noise at workplace was under the sanitary norm of 85 dB(A) for all three used cutting tools.

Table 1: Equivalent *A*-weighted sound pressure level for 8 hours workday L_{Aeq}, measured at the workplace equipped with the cutting tools CH 1, CH 2 and CH 3

Cutting tool CH 1

		Sound pressure level L_p, measured at workplace, dB(A)						Calculated equivalent continuous sound pressure level
		Idling			Cutting mode			
n, min^{-1}	T, min	t_1, min	Lp_1	L^1_{Aeq}	t_2, min	Lp_2	L^2_{Aeq}	**$L_{Aeq(8h)}$, dB(A)**
4000	480	192	64,4	60,42	288	81,57	79,35	**79,41**
6000	480	192	74,4	70,42	288	87,23	85,01	**85,16**
8000	480	192	81,4	77,42	288	90,57	88,35	**88,69**

Cutting tool CH 2

		Sound pressure level L_p, measured at workplace, dB(A)						Calculated equivalent continuous sound pressure level
		Idling			Cutting mode			
n, min^{-1}	T, min	t_1, min	Lp_1	L^1_{Aeq}	t_2, min	Lp_2	L^2_{Aeq}	**$L_{Aeq(8h)}$, dB(A)**
4000	480	192	64,4	60,42	288	76,57	74,35	**74,52**
6000	480	192	74,4	70,42	288	79,73	77,51	**78,29**
8000	480	192	81,4	77,42	288	85,07	82,85	**83,95**

Cutting tool CH 3

		Sound pressure level L_p, measured at workplace, dB(A)						Calculated equivalent continuous sound pressure level
		Idling			Cutting mode			
n, min^{-1}	T, min	t_1, min	Lp_1	L^1_{Aeq}	t_2, min	Lp_2	L^2_{Aeq}	**$L_{Aeq(8h)}$, dB(A)**
4000	480	192	61,4	57,42	288	75,23	73,01	**73,13**
6000	480	192	68,4	60,42	288	81,9	79,68	**79,81**
8000	480	192	74,4	70,42	288	84,9	82,68	**82,93**

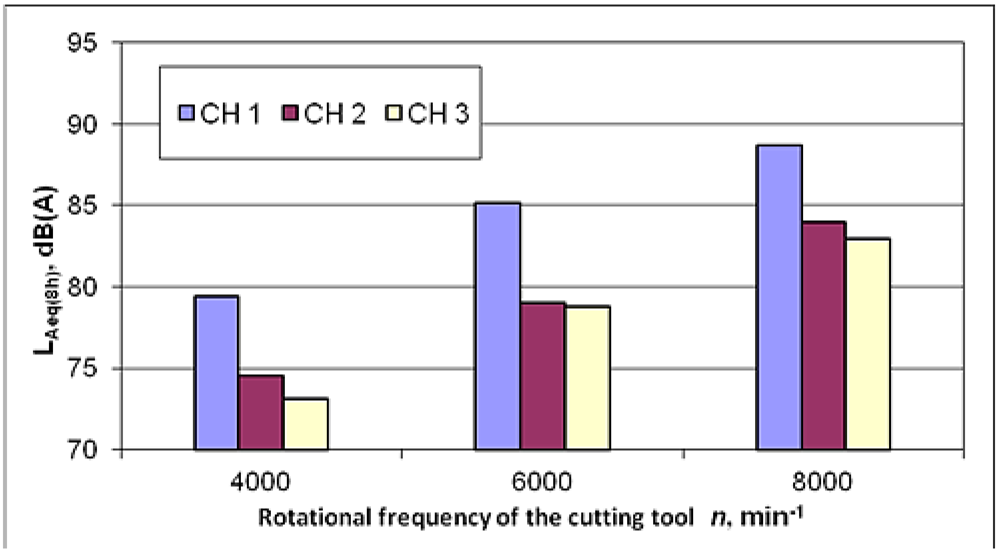

Figure 2: Equivalent *A*-weighted sound pressure level $L_{Aeq(8h)}$ measured during milling of workpieces from common beech using cutting tools CH 1, CH 2 and CH 3 at different rotational frequencies of the working shaft

It is notable that the use of the cutting tool CH 1 at rotational frequency n = 8000 min^{-1} generated equivalent continuous sound pressure level of 88,69 dB(A) which exceeds the accepted sanitary standard s. However, the values of the equivalent continuous sound pressure level are below the accepted sanitary standards for all three rotational frequencies of the shaft when the cutting tools CH 2 and CH 3 have been used. These results can be explained by the "enveloped" construction of the body of the cutting tools CH 2 and CH 3. As a result of its construction properties of the cutting tool CH 1 there are sort of "pockets" formed in the cutting body which are responsible for twisting of the air flow and as a consequence, increase the aerodynamic noise. Lower noise level, by 0,5 dB(A), emitted by CH 3 in comparison to CH 2 are due to the cutting edges of the tools inclined toward the axes of rotation. Thus the air flow meets the cutting edge gradually which allows the compressed air to move along the cutting edge.

In order to evaluate the time needed to reach the safe sound levels based on an 8-hour workday using cutting tool CH 1, the prognostic equivalent sound pressure level L^{j}_{Aeq}, has been calculated for different time intervals. The results are given in Table 2.

Table 2: Prognostic equivalent A-weighted sound pressure level – L^{j}_{Aeq} at workplace calculated for certain time intervals for 8-hours workday, using the cutting tool CH 1 for milling work pieces of common beech.

Rotational frequency of the cutter, n [min^{-1}]	Exposure duration [min]							
	60	120	180	240	300	360	420	480
	L^{j}_{Aeq} [dB(A)]							
4000	70,38	73,39	75,15	76,40	77,37	78,16	78,83	79,41
6000	76,13	79,14	80,90	82,15	83,12	83,91	84,58	85,16
8000	79,66	82,67	84,43	85,68	86,65	87,44	88,11	88,69

From the results in Table 2 is visible that when the rotational frequency of the cutting tool CH 1 is n = 8000 min^{-1}, the accepted sanitary value of 85 dB(A) would be reached at exposure duration of 205 minutes. Therefore, in order not to exceed the sanitary standard of 85 dB(A) for 8-hour workday, the operator has to be moved for the remaining time to a workplace with sound pressure level lower than 70 dB(A).

CONCLUSION

Under the conditions of this study and on the basis of the results obtained, the following conclusions can be made:

1. The equivalent continuous A-weighted sound pressure level, evaluated at workplace is an important parameter characterizing the noise impact on the operator in the woodworking industry
2. Decreasing the rotational frequency of the cutting tool results in a decrease in the equivalent sound pressure level. For the milling machine that we used, the rotational frequency n = 6000 min^{-1} of the working shaft is optimal;
3. The use of a cutting tool with the cutting edges of the teeth situated at a certain angle to the axes of rotation reduced the equivalent sound pressure level, as at rotational frequency up to 8000 min^{-1} the equivalent sound pressure level is within the sanitary standard of 85 dB(A);
4. The applied methodology ensures relatively quick and easy calculation of the equivalent continuous sound pressure level for a certain time interval at a certain working mode of the machine. The measurement equipment consisted only of a sound meter, which is another advantage of the method;
5. The method described for the evaluation of the equivalent sound pressure level, generated by woodworking machineries, as well as the results presented for the woodworking spindle moulder machine can also be implemented for the calcuation of the equivalent soumd pressure levels at the early stage of the design and engineering of woodworking workhouses.

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