Frequency Analysis of Noise at different Milling Parameters of Steel

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The aim of this paper was to experimentally analyse dependency between level of noise in octave band at various standardized central frequencies (31.5, 63, 125, 250, 500,…, 16000 Hz) and different cutting parameters of milling. Based on data from our previous research we analyzed dependency between level of noise in octave band, at standard frequency 500 Hz, and axial and radial depth of cut. In Design-Expert® software we have found adequate models and equations that describes these dependencies. The experimental results obtained can be used for future investigations in this field.

Keywords: Milling, Noise, Frequency analysis

1. INTRODUCTION

In the literature it is usual to compare noise levels in milling process with respect to the spindle speed, feed rate, axial and radial depth of the cut. Purpose of those comparisons is to gain insight in effects of cutting parameters on occurrence of noise and vibrations. [1,2,3]

In addition to measuring noise levels, it is often useful to search characteristic patterns in acoustic spectra of certain technological process (milling, welding, grinding,…).

We have employed the acoustic spectra in analysis of sound emission caused by milling in a series of experiments with different technological parameters.

In [1,2] are explained in detail experiments that were conducted in our previous research. Based on the data obtained in the first set of experiments [1] we have done analysis of level of noise in octave band at different standardized central frequencies.

2. EXPERIMENT

As was mentioned above, in [1,2] are explained in detail experiments that were performed. Here are the most important data. Machine was CHARNOA CNC SYSTEMS (vertical milling machine). We used the milling cutter of diameter of 40 mm and with four APKT inserts and tool holder SANDVIK. For measurements of the sound pressure level (SPL) microphone Bruel & Kjaer 2270 was used. The distance between the centre of the cutter and the microphone was 200 mm. Material of the workpiece was carbon steel S355. The dimensions of the workpiece were: 80x55x55 mm. [1]

In Table 1 are given values of the cutting parameters for each of the experiments of the first set.

Table 1: Values of cutting parameters in first set of experiments [1]

Cutting parameters				
Experiment no.	Axial depth [mm]	Feed rate [mm/min]	Spindle speed [rpm]	Radial depth [mm]
1.1	0.5 – 3	150	800	5
1.2	1	375 - 900	1000	5
1.3	1	300	600 - 1300	5
1.4	1	150	1000	5 - 40

3. FREQUENCY ANALYSIS

In [1] we have done analysis of maximum sound pressure level $L_{F\max}$, dBA and equivalent sound pressure level L_{eq}, dBA on cutting parameters (axial depth of cut, feed rate, spindle speed and radial depth of cut).

There were performed analysis of time variations of sound pressure level. Here, the goal was to do a frequency analysis of noise levels for different cutting parameters.

By frequency analysis of noise levels for all mentioned cutting parameters, it is noticed that the maximum noise level occurs at a frequency of 500 Hz. On Figures 1 and 2 are given values of level of noise in octave band for all standard central frequencies for 8 passes in experiment 1.1. and 1.4.

From the given diagrams it can be clearly seen that the maximum level of noise occurs at a frequency of 500 Hz. The same was obtained for other experiments (1.2, 1.3).

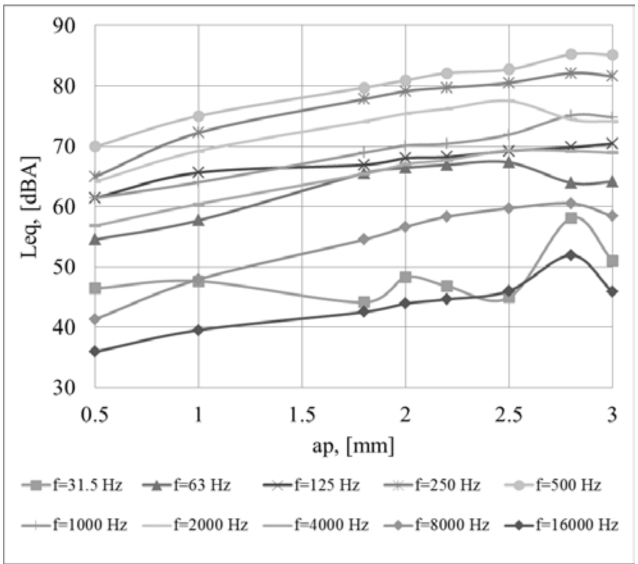

Figure 1: Equivalent sound pressure level at standard central frequencies for 8 pasess in experiment 1.1.

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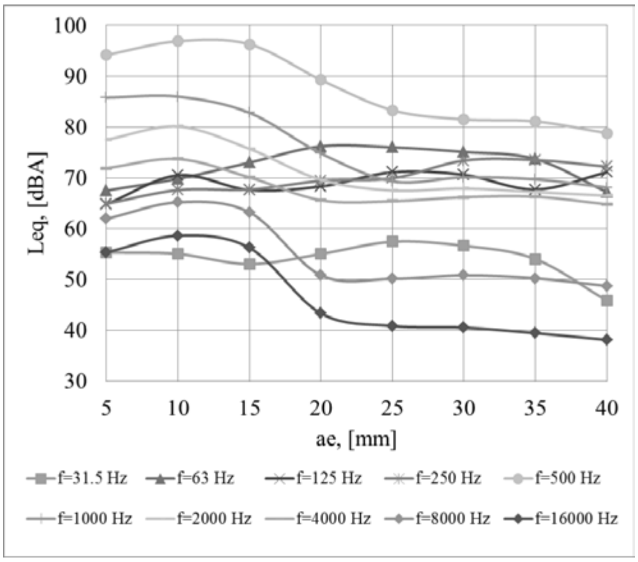

Figure 2: Equivalent sound pressure level at standard central frequencies for 8 pasess in experiment 1.4.

Below we will focus on the frequency of 500 Hz.

On Figures 3 and 4 are given values of noise level at standard central frequency of 500 Hz.

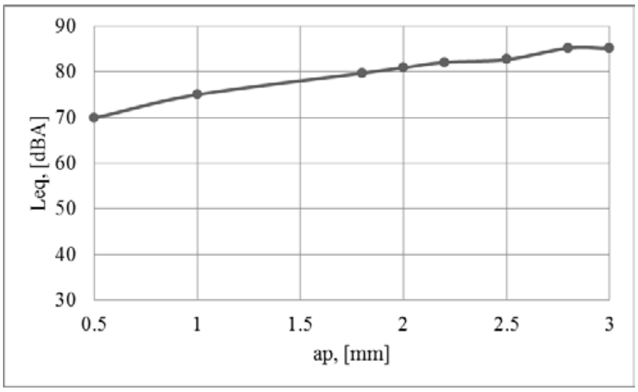

Figure 3: Equivalent sound pressure level at 500 Hz for 8 passes in experiment 1.1.

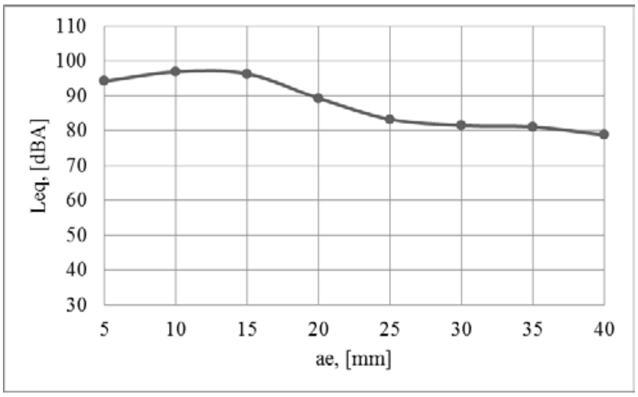

Figure 4: Equivalent sound pressure level at 500 Hz for 8 passes in experiment 1.4.

In Tables 2 and 3 are given values of equivalent sound pressure level at standard frequency of 500 Hz for different values of axial and radial depth of cut (for all 8 passes).

Table 2: Equivalent sound pressure level at 500 Hz for different values of axial depth of cut

500 Hz								
Pass	1	2	3	4	5	6	7	8
Axial depth [mm]	0.5	1.0	1.8	2.0	2.2	2.5	2.8	3.0
L_{eq} dBA	69.9	75.0	79.7	80.9	82.1	82.7	85.2	85.1

Table 3: Equivalent sound pressure level at 500 Hz for different values of radial depth of cut

500 Hz								
Pass	1	2	3	4	5	6	7	8
Radial depth [mm]	5	10	15	20	25	30	35	40
L_{eq} dBA	94.2	96.9	96.3	89.3	83.3	81.5	81.1	78.8

4. DEPENDENCE BETWEEN LEVEL OF NOISE AND PARAMETERS OF MILLING

In Design-Expert® v.9.0.6.2 software we have entered the data obtained from experiment, in order to find a suitable mathematical model that describes the relationship between level of noise and axial depth of cut, and level of noise and radial depth of cut, at frequency of 500 Hz.

The obtained mathematical model in the form of a polynomial of n-th degree represents the response function.

4.1. Dependence between level of noise and axial depth of cut

Of the mathematical models available has been proposed quadratic model. In Table 4 are given ANOVA analysis of the proposed quadratic model.

After analysis of variance (ANOVA) the adequacy of the proposed mathematical model was confirmed. F value of the model (F=338.71) implies the model is significant and there is only a 0.01% chance that an F-value could occur due to noise. Low probability value (p=0.00000459<0.0500) confirms that the model parameters are also significant. Coefficient of determination (R-squared) and other statistics have good values which confirms the justification for choosing a mathematical model, Table 5.

The final equation of the mathematical model, with real coefficients, which adequately describes the dependence between equivalent sound pressure level, at frequency of 500 Hz, and axial depth of cut is as follows:

$$L_{eq} = 65.47268 + 10.09477 \cdot a_p - 1.17185 \cdot a_p^2 \qquad (1)$$

A graphical representation of the mathematical model described by (1) and the arrangement of the experimental points is given in Figure 5.

Table 4: ANOVA analysis for the quadratic model

ANOVA for Response Surface Quadratic model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	191.2038	2	95.6018777	338.7148	4.59E-06	significant
A-ap	187.3202	1	187.3202349	663.6703	1.65E-06	
A^2	3.883521	1	3.883520509	13.7592	0.013864	
Residual	1.411245	5	0.282248918			
Cor Total	192.615	7				

Table 5: Computational values of statistics for the evaluation of a quadratic model

Std. Dev.	0.531271	R-Squared	0.992673
Mean	80.075	Adj R-Squared	0.989743
C.V. %	0.663467	Pred R-Squared	0.972526
PRESS	5.291962	Adeq Precision	46.05464

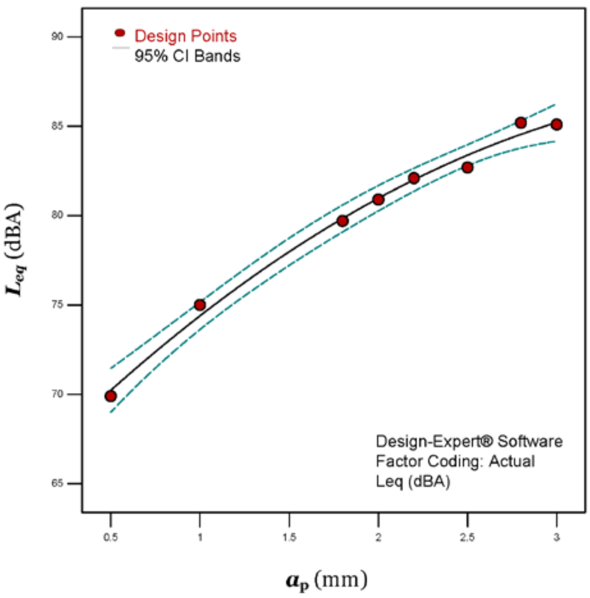

Figure 5: 2D response of the noise level

4.2. Dependence between level of noise and radial depth of cut

Here, of the mathematical models available a sixth degree model is proposed. In Table 6 are given ANOVA analysis of the proposed sixth degree model.

After analysis of variance (ANOVA) the adequacy of the proposed mathematical model was confirmed. F value of the model (F=7003.46) implies the model is significant and there is only a 0.91% chance that an F-value could occur due to noise. Low probability value (p=0.009147<0.0500) confirms that the model parameters are also significant. Coefficient of determination (R-squared) and other statistics have good values which confirms the justification for choosing a mathematical model, Table 7.

Table 7: Computational values of statistics for the evaluation of a sixth degree model

Std. Dev.	0.09559	R-Squared	0.999976
Mean	87.675	Adj R-Squared	0.999833
C.V. %	0.109028	Pred R-Squared	0.832819
PRESS	64.19342	Adeq Precision	202.5326

The final equation of the mathematical model, with real coefficients, which adequately describes the dependence between equivalent sound pressure level, at frequency of 500 Hz, and radial depth of cut is as follows:

$$L_{eq} = 124.5 - 14.7371 \cdot a_e + 2.546904 \cdot a_e^2 - 0.19554 \cdot a_e^3 + \ldots$$
$$\ldots + 0.007273 \cdot a_e^4 - 0.00013 \cdot a_e^5 + 8.98 \cdot 10^{-7} \cdot a_e^6 \quad (2)$$

Table 6: ANOVA analysis for the sixth degree model

ANOVA for Response Surface Sixth model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	383.9659	6	63.99431041	7003.459	0.009147	significant
A-ae	59.91608	1	59.91608272	6557.143	0.007861	
A^2	4.83933	1	4.839330035	529.6104	0.027646	
A^3	7.767073	1	7.767073306	850.019	0.021827	
A^4	2.60352	1	2.60351976	284.926	0.037671	
A^5	3.386447	1	3.386446886	370.6086	0.033039	
A^6	1.545606	1	1.545606061	169.1492	0.048853	
Residual	0.009138	1	0.009137529			
Cor Total	383.975	7				

A graphical representation of the mathematical model described by (2) and the arrangement of the experimental points is given in Figure 6.

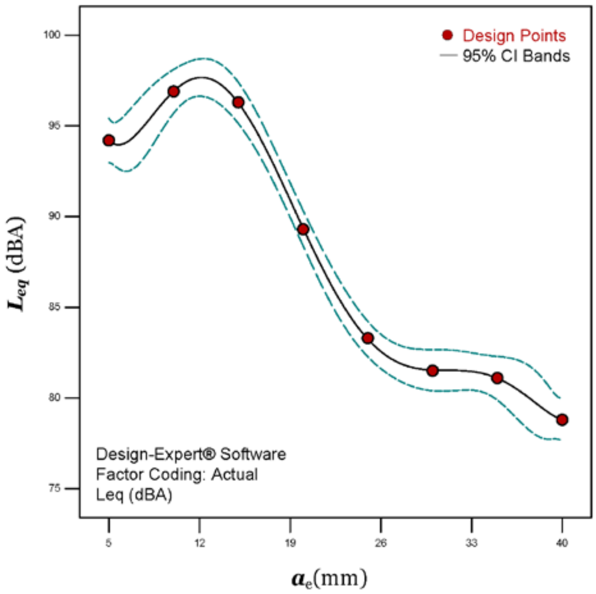

Figure 6: 2D response of the noise level

5. CONCLUSIONS

Measurements of noise reveal the maximum and equivalent values of sound pressure level, allowing studies of the influence of the cutting parameter to the generated noise. [1] In addition to measuring noise levels, it is often useful to search characteristic patterns in acoustic spectra of certain technological process.

The analysis performed in this study have shown that the maximum level of noise occurs at a frequency of 500 Hz for each value of the selected parameters.

Because the maximum noise level is observed at that frequency, we focused our analysis on finding the dependence between level of noise and axial depth of cut, and level of noise and radial depth of cut, at frequency of 500 Hz. Mathematical models that describe these dependencies were found in the software Design-Expert® v.9.0.6.2. By Analysis of variance (ANOVA) adequacy of the proposed mathematical models was confirmed.

More reliable results can certainly be obtained by performing a larger number of experiments.

The described methodology can serve as a basis for further research in this direction.

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