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AN EXPERIMENTAL PLAN FOR NOISE ANALYSIS AND CHATTER DETECTION IN MILLING DEPENDING ON THE CUTTING PARAMETERS

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Abstract – *Improving the performance of cutting operations has led to an increase in noise levels, especially when milling. Main source of noise in milling are self-excited vibrations, i.e. chatter vibrations. In the literature is usual to compare noise level according to the spindle speed, feed per tooth, axial depth of cut and radial depth of cut. Purpose of that comparisons is to gain insight in effect of cutting parameters on occurrence of noise and vibrations. Here are presented plan of experiments and variants of the sample forms for identification of noise generated by chatter vibrations, in dependence of mentioned cutting parameters. That experiments we can use to get conclusions about cutting parameters that causes instability of process trough vibrations and reduce productivity. Based on results obtained it is possible to select cutting parameters which enable us to improve productivity and part quality by avoding unstable regions.*

1. INTRODUCTION

The main goal for manufacturers of machine parts is to produce with as little cost as possible. Manufacturing technologies have advanced significantly, as well as machine tools. Accuracy, flexibility and productivity are constantly increasing in order to satisfy the demands of the market. Current trends, thanks to the advancement of computers and sensors, are focused on on-line monitoring, measurement and control of the process. [1], [3]

Vibrations of machine tools have a big impact in decreasing productivity. Excessive vibrations cause a wear and breakage of tools, poor surface quality, damage of the spindle bearings, waste of energy, excessive noise,... [1]

In metal cutting, there are tree types of mechanical vibrations, which are due to deficiency of mechanical stiffness of system: machine tool, toll holder, cutting tool and workpiece.

These vibrations are:

- Free vibrations,
- Forced vibrations, and
- Self-excited vibrations. [1]

Self-excited vibrations use energy of interaction between cutting tool and workpiece to start and grow during the cutting process. These type of vibrations causes instability and that is the most undesirable type of vibrations. [1]

Chatter in milling can be detected by machine operator who analyzes the sound emited, or by computer application who monitors the milling process sound and analyze the amplitudes and frequencies to identify chatter. [2] In that way, analysing the frequency and amplitude of the sound emited give us a posibility to conclude which characteristics has a sound obtained, generated by chatter vibrations.

In [2] are presented experimental methodology for identification of stability lobes diagram – SLD (Fig. 1), who shows the boundary between chatter-free operations and unstable process, which is obtained as dependence between axial depth of cut and spindle speed. Based on SLDs it is possible to choose a suitable combination of these parameters and prevent the occurrence of chatter vibrations and high noise level. [2] On diagram can be seen that for the certain depths of cut, at any spindle speed cutting process remains stable. Maximum value of depth of cut at which cutting process is always stable is critical depth of cut. That methodology is particularly convenient for smaller companies which does not have enough resources to implement more complicated methods. For more precise SLDs, i.e. for some another combinations of machine, tool holder, tool and workpiece material it is necessary to carry out a large number of experiments. [5], [6]

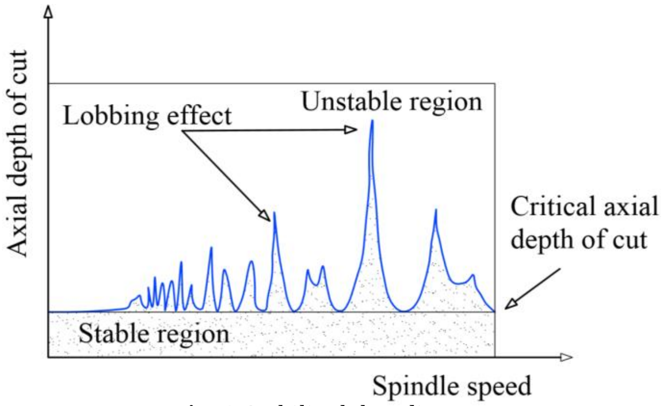

Fig. 1 *Stability lobes diagram*

2. NOISE EMISSION IN MILLING

In face milling, noise can be classified into idling noise and cutting noise. Idling noise consists of aerodynamic noise, noise because of cutter vibration caused by flow of air around the cutter teeth and noise due to rotation of spindle. [4]

In operation of milling, impacts of the cutting edge causes vibrations because of interaction between elements of the system.

During the milling, vibrations are spreading trought the air and create noise that contains information about the milling process. [2]

Noise is directly dependent of vibrations. By analyzing sound emited i.e. its frequency and amplitude, we can see when self-excited vibrations occur and that experimental results can be used to plot the dependence between cutting parameters and level of noise, based on methodology developed in [2].

3. PLAN OF EXPERIMENTAL ANALYSIS

In this section are presented some experiments that can be used to measure sound pressure level (SPL, [dBA]) in dependence of cutting parameters. Equipment that is necessary for those measurements consits of machine (vertical milling machine), milling cutter of proper diameter at each experiment, samples - workpieces with defined shape and dimensions and microphone for measuring SPL. In [4] are proposed that the distance between the centre of the cutter and microphone should be at least 10 times of cutter radius, because the measured values of SPL varies as a function of that distance. In our case distance should be 250 [mm] in first set of experiments, 100 [mm] in second experiment and 110 [mm] in third experiment.

3.1 First set of experiments

First set of experiments consists of measuring SPL when changing cutting parameters (axial depth of cut, feed per revolution, spindle speed and radial depth of cut). In addition to measuring noise, the operator will register when chatter vibrations occur (at which value of the parameter that we change).

In this experiments it is suitably for samples to have quadratic form (Fig. 2).

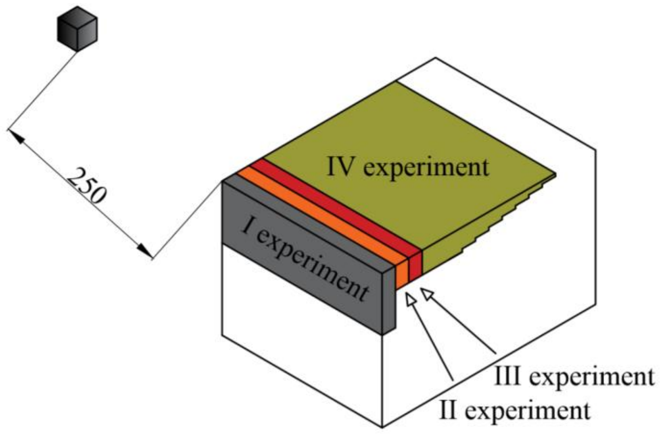

Fig. 2 *Schematic representation of sample form and surfaces obtained by 8 passes in first set of experiments*

In Tables 1-4 can be seen proposed values of cutting parameters we are changing, while the others are constant. The material of workpiece should be carbon steel, and a diameter of the cutter is 50 [mm].

Table 1 *Proposed values of axial depth of cut in first experiment*

FIRST EXPERIMENT								
No.	1	2	3	4	5	6	7	8
Axial depth of cut [mm]	0.5	1.0	1.8	2.5	3.0	3.5	3.8	4.0
SPL [dBA]								

Table 2 *Proposed values of feed per revolution in second experiment*

SECOND EXPERIMENT								
No.	1	2	3	4	5	6	7	8
Feed per revolution [mm/rev]	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
SPL [dBA]								

Table 3 *Proposed values of spindle speed in third experiment*

THIRD EXPERIMENT								
No.	1	2	3	4	5	6	7	8
Spindle speed [rpm]	60	80	100	120	140	160	180	200
SPL [dBA]								

Table 4 *Proposed values of radial depth of cut in fourth experiment*

FOURTH EXPERIMENT								
No.	1	2	3	4	5	6	7	8
Radial depth of cut [mm]	15	20	25	30	35	40	45	50
SPL [dBA]								

In Fig. 3a are shown 8 passes in which diference is in axial depth of cut while other parameters are the same at every pass.

Second experiment (Fig. 3b) represents method for measuring of SPL where at every pass is different feed per revolution.

In third experiment (Fig. 3c) we change spindle speeds.

While in fourth (Fig. 3d) we change radial depth of cut.

In Table 5 are shown cutting parameters which are constant at each pass.

Table 5 *Proposed values of constant cutting parameters in set of experiments*

CUTTING PARAMETERS				
EXPERIMENT	Axial depth of cut [mm]	Feed per revolution [mm/rev]	Spindle speed [rpm]	Radial depth of cut [mm]
1	-	1	100	5
2	1	-	200	5
3	1	0.6	-	5
4	1	0.8	150	-

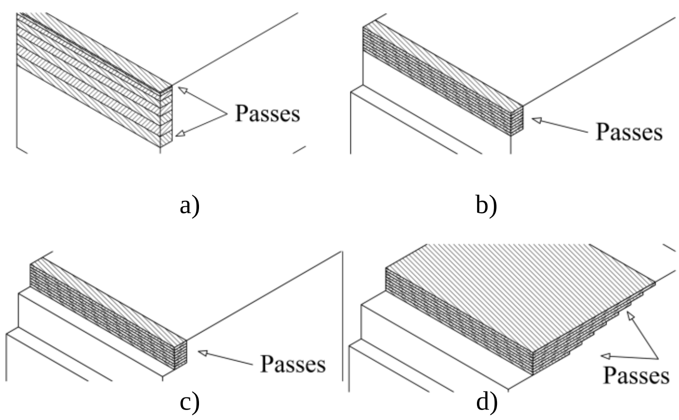

Fig. 3 *Schematic representation of sample forms and 8 passes in set of experiments for measuring SPL*

Purpose of this experiments presented above, is to get conclusions about dependence between noise generated and cutting parameters, and detection of chatter vibrations. Based on this results, we can see which parameters mostly affect the noise level and vibration increase.

3.2 Second experiment

Second type of experiment (Fig. 4) is based on experiments conducted in [2]. In that research, methodology for identifying stability lobes diagram is based on empirical tests where the workpiece has a inclined surface with gradual increase of the axial depth of cut in the feed direction. Axial depth of cut represents ordinate axis (y) of the SLD and spindle speed represents apsics axis (x) which is increased between passes. The cutting process is stopped when the chatter is detected. In that way SLD is physically machined on the workpiece. [2] Measuring noise with a microphone of chatter vibrations, we can take conclusions about level of noise in dependence of spindle speed and axial depth of cut.

In Table 6 are shown cutting parameters in this experiment. There can be seen that axial depth of cut varying from 0 – 3 [mm], and spindle from 80 – 480 [mm] with a step up of 20. Where the diameter of the cutter is 20 [mm], and material of the workpiece is carbon steel.

Table 6 *Cutting parameters*

CUTTING PARAMETERS				
EXPERIMENT	Axial depth of cut [mm]	Spindle speed [rpm]	Feed per revolution [mm/rev]	Radial depth of cut [mm]
	0 - 3	80 - 480	0.8	20

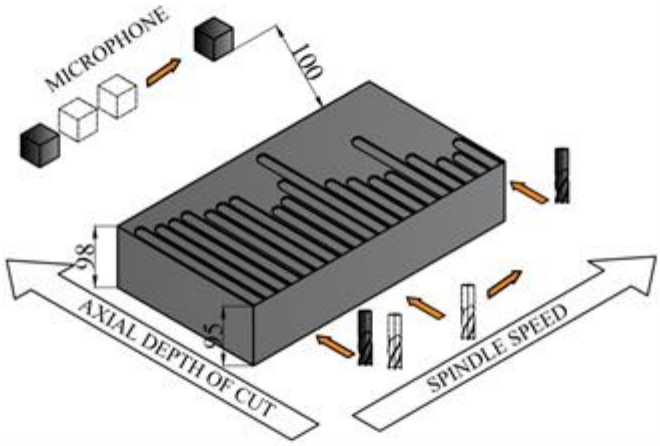

Fig. 4 *Schematic representation of experiment for measuring SPL of chatter vibrations*

3.3 Third experiment

In third experiment, proposed here, aim is to obtaine the level of noise in dependence of radial depth of cut (a_e) which is increasing linearly from 0 to 20 [mm] that is the diameter of the cutter, (Fig. 5). As it is used the SLD where we can see dependence between spindle speed and axial depth of cut, also SLD can be obtained by ploting the values of radial depth of cut. Material of the sample form is carbon steel.

In Table 7 are given cutting parameters in this experiment.

Table 7 *Cutting parameters*

CUTTING PARAMETERS				
EXPERIMENT	Radial depth of cut [mm]	Axial depth of cut [mm]	Feed per revolution [mm/rev]	Spindle speed [rpm]
	0 - 20	1	0.8	100

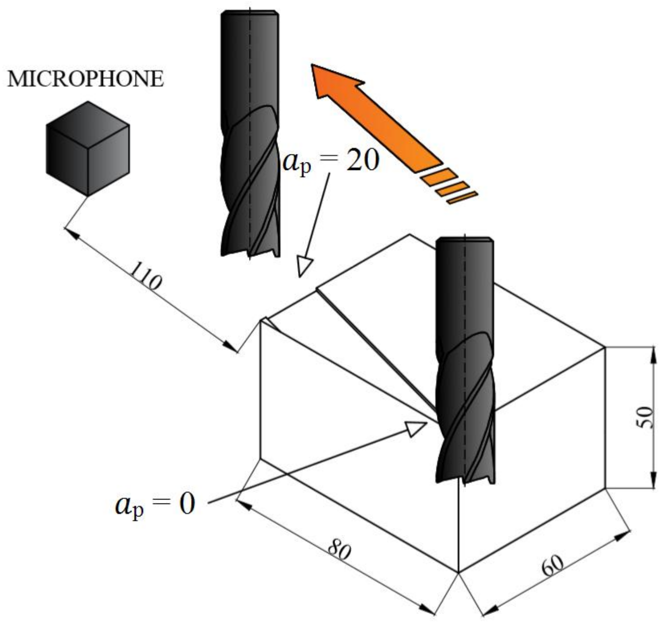

Fig. 5 *Schematic representation of experiment for measuring SPL at variating radial depth of cut*

4. CONCLUSIONS

In today industry, vibrations is the main problem, especially in process of high speed milling. Researchers have dealt with problem of vibrations as the main cause of noise, especially chatter vibrations. Measurements of noise levels can be used to capture frequencies and amplitudes at which chatter vibrations occur. It allows us to make the process of cutting stable (without chatter), by customizing the cutting parameters. In this paper are proposed three diferent types of experiments to measure noise level, i.e. SPL generated and detection of chatter vibrations. In first we measure SPL in dependence of cutting parameters and detect when vibrations occur, second measures noise induced by chatter vibrations and analyzes its frequency and amplitude. In third experiment idea is to see how noise changes with radial depth of cut that increases linearly. Generally, the aim of this three types of experiments is to determine the dependence between diferent cutting parameters of milling and noise and vibrations, with the aim of determining stable regions of cutting process. Results that would be obtained can be used for furher investigations of that dependence. Based on obtained results we can conclude which parameters is most critical and adjust them to avoid high level of noise during process of milling in practical application. This plan of experiments is only initial step in our further research in this field. Next step would be some other experiments that should be conducted with diferent types of material, cutter, parameters of the process (cutting parameters), using of accelerometers for determining vibrations, etc.

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