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EXPERIMENTAL METHOD FOR DEFINING THE STABILITY LOBE DIAGRAM IN MILLING Č4732 (42CrMo4) STEEL

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Abstract: Self-exciting vibration (chatter) is an unwanted phenomenon that can occur in metal cutting. Self-exciting vibration is a phenomenon that has a negative effect on productivity, leads to accelerated wear or breakage of the tool, and in some cases can lead to breakage of elements of jigs and fixtures or elements of the machine tools. In order to predict and control the process of creating self-excited vibration, different methods have been developed. One way of predicting self-excited vibration is defining stability lobe Diagram, which shows the boundary between stable, conditionally stable and unstable cutting process, whereby combinations of cutting depth, cutting speed, i.e. spindle speed and feed rate are observed. Methods for defining the stability lobe diagram can be analytical, and experimental. This paper shows the experimental method of defining the stability lobe diagram, on machining steel Č4732 (42CrMo4). Metal cutting is carried out on a vertical machining center. The methodology for defining the stability lobe diagram implies that a series of experiments were done, were workpiece surface to be milled is made with a slope of 3°. In this way, when moving the tool, the cutting depth gradually increases until the moment of self-excited vibration occurs. The occurrence of the vibration is registered by measuring the acceleration, where the accelerometer was being mounted on the main spindle carrier, as close as possible to the tool. After the self-excited vibration occurred, which is manifested by a sudden jump of acceleration amplitude, and by the change in the sound, the cutting process is stopped and then the axial depth of the cut at which the vibration occurs determined by the tangent method in Matlab. The obtained stability lobe diagram has two dimensions, which means that all measurements were performed for one, a constant value of feed rate per tooth.
Keywords: milling, self-excited vibration, stability lobe diagram

INTRODUCTION

The emergence of self-excited vibration during the cutting process has long been recognized. Despite, it is still a very current field of research both from the point of view of mathematical modeling and prediction, as well as from the point of view of experimental testing and management of the cutting process. By developing the CNC machine tools and increasing the application of high-speed machining, these problems have become even more pronounced, so the detection and prevention of the emergence of self-excited vibration have become essential for the exploitation of these production systems. This paper presents the method of determining the moment when self-excited vibration emerges during milling, as one of the indicators of dynamic instability of the processing system. The presence of vibration has been determined using modern diagnostic equipment National Instruments, as well as LabView and Matlab software. On the basis of experimentally obtained results, ie experimentally determined the depth of cut in which the self-extracted vibration emerge, the stability lobe diagram has been defined.

During the cutting process, due to insufficient dynamic stiffness of one or more elements of the machine tool system – cutting tool and holder - fixture - workpiece, three types of vibration can occur: free (natural), forced and self-excited vibration.

Free vibration emerges when a mechanical system derived from an equilibrium position is allowed to free oscillate without external influences.

Forced vibration emerge as a result the tendency of some object to force another one into vibrational movement. Free and forced vibration, if known, can be effectively avoided, reduced or removed from the processing process.

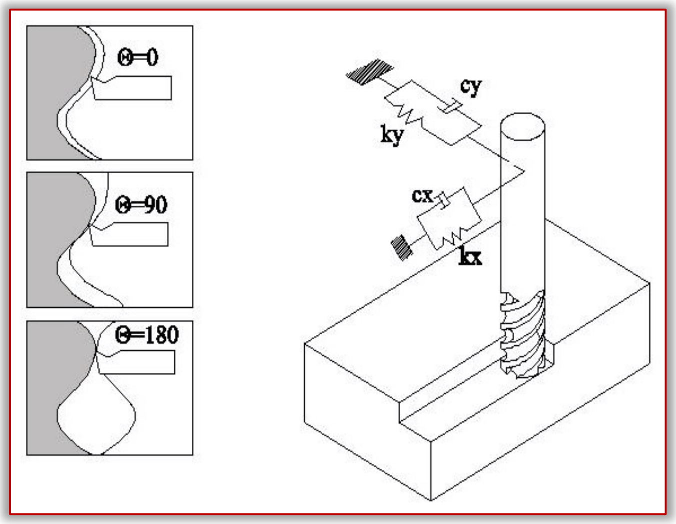

Figure 1. Regenerative chatter in milling. Initial tool deflection copied to workpiece surface is encountered in the next tool revolution

Self-excited vibration is the most unfavorable type of vibration because the energy for its occurrence and growth of the amplitude receive from the cutting process itself. They can occur as a result of friction during the cutting process, due to thermomechanical effects, or as a consequence of the regenerative effect, i.e. variation the chip thickness during milling, Figure 1.

Self-excited vibration often leads to unstable machining, the so-called chatter. Chatter results in a reduction in the quality of the surface, the appearance of noise, the rapid wear of the cutting tool and in some case machine tool elements damage.

In order to avoid the consequences of self-excited vibration, it is often not possible to use certain cutting regimes during milling. Diagram showing the area of stable and unstable machining is called stability lobe diagrams. In this paper, a stability lobe diagram is formed on the basis of critical cutting depths in which self-excited vibration occur. Stability lobe diagram can be defined as analytically or experimentally.

The analytical model of the prediction of self-excited vibration requires the determination of the transfer function of the mechanical structure of the machine tool, while the experimental testing is reduced to determining the intervals of the individual cutting parameters in which the cutting process is stable.

Influence of self-excited vibration on cutting process stability was examined by Tlusty [1] and Tobias [2]. They provided their research almost simultaneously but in completely separate studies. Tlusty and Tobias proposed methods for analyzing the stability of the cutting process, the influence of the cutting regime, determining the limiting depth of cut and defining a stability lobe diagram.

Altintas [3] and Song [4] using the analytical and experimental approach, consider the influence of a different number of teeth on the appearance of self-excited vibration, cutting thereby the aluminum alloy 7075. They use tools with two angles of the coil. Zataraina [5] provide similar research, considering the influence of the tool coil angle, and cutting aluminum alloy 7075.

Quintana [6] defines the stability lobe diagram in milling experimentally, whereby he cuts the workpiece with an angled work surface. The emergence of self-extracted vibration is determined by recording and analyzing sound emissions, using modern signal processing techniques. Based on FFT sound analysis, the moment of self-excited vibration is detected, which excludes the possibility of an error due to the subjective feeling of the operator.

DESCRIPTION OF EXPERIMENTAL EXAMINATIONS

The experimental examination of the occurrence of self-excited vibration was carried out at the vertical milling center EMCO Concept Mill 450 within the Laboratory for Machine Tools and CIM Systems at the Faculty of Mechanical Engineering, East Sarajevo.

A series of experiments was conducted with a constant value of feed per tooth of 0.02 mm/tooth and variable cutting speed (rpm), ranging from 1000 to 3010 rpm, with an increase of 300 rpm at each subsequent test. The workpiece used in the experiment is made of steel Č4732 (42CrMo4), the shape, and dimensions given in Figure 2. The tool used in the processing is an end mill Φ10, with four teeth and an angle of coil 30°. During the cutting, no cooling agent and lubricating were used.

For each cutting speed, in combination with the calculated feed rate, the depth of cut is continuously increased, until self-excited vibration occurs. During the cutting, vibration amplitude is recorded by the accelerometer, mounted on a housing of the main spindle, as close to the spindle top as possible.

A continuous change in depth of cut is provided by the configuration of the workpiece, ie the inclination of the surface to be cut. Due to the aforementioned change in depth of cut, a very slight increase in the amplitude oscillation of the cutting tool occurs, and at a time when the depth of cut reaches the limit value, a sudden jump of amplitude occurs which indicates the emergence of self-excited vibration.

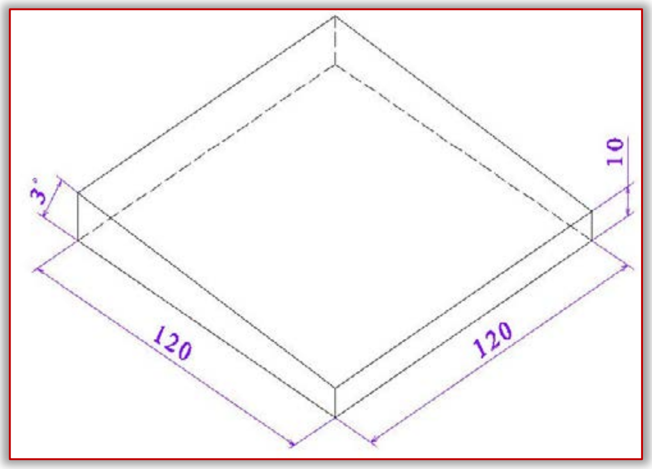

Figure 2. Shape and dimension of workpiece used for the experiment

The vibration parameter directly measured by the contact method is acceleration, using the National Instruments instrumentation. The instrumentation consists of the National Instruments cDAQ 9172 chassis (Figure 5a) and the NI 9233 analog card with four analog inputs of ± 5 V voltage range and a maximum channel selection speed of 50 kS / s (kilo samples per second). Accelerometer METRIX Instruments sensitivity 100mV / g with piezo-ceramics is placed on the main spindle carrier using a magnetic holder, as close as possible to the tool. For acquiring data, the graphical programming language LabVIEW was used, and for processing the results by the tangent method the Matlab software.

It should also be noted that when limiting value of depth of cut was determined using collected data, the absolute value of the vibration amplitude is not taken into account because it is not relevant for determining the moment when self-excited vibration occurs. This moment, in addition to the sudden vibration amplitude jump, is characterized by a change in surface quality, as well as the appearance of intensive sound, which is an indicator that the machine works with an unfavorable cutting regime.

REVIEW OF THE OBTAINED RESULTS

At the appearance of sound, the operator stops the feed movement of the tool. Dept of cut (axial) is subsequently determined using the tangent method, Figure 3.

Figure 4 shows the stability lobe diagram obtained by experiment. Table 1 shows the cutting regime, the cutting speed and the feed rate in mm / min. In the Y column path length of the tool in the Y-axis direction until the moment of self-excited vibration occurs was given.

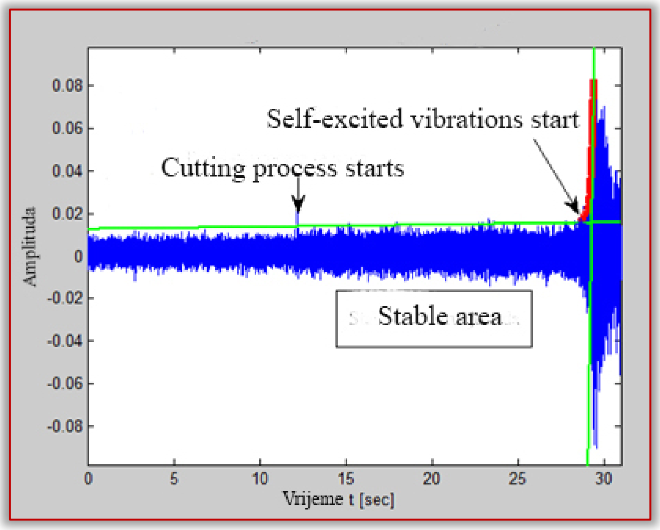

Figure 3. The amplitude of vibration in time domain and occurrence of self-excited vibration

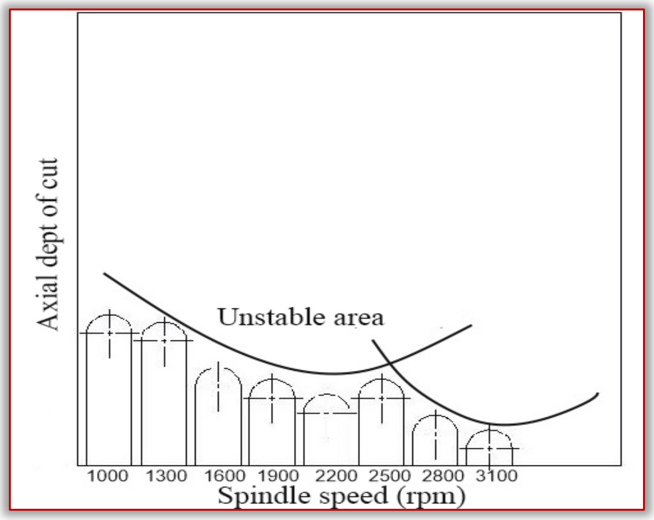

Figure 4. Experimentally defined stability lobe diagram

With each new passage of the tool, cutting speed increases, Figure 5. Accordingly, the velocity of the auxiliary movement is calculated, so that the feed rate per tooth has a constant value of 0.02 mm/tooth.

Table 1. Cutting regime and obtained results

No	Cutting speed (rpm)	Feed rate (mm/min)	Y (mm)	Limiting depth of cut (mm)
1	1000	80	40	2.1
2	1300	100	38	2
3	1600	130	26	1.4
4	1900	150	22.9	1.2
5	2200	180	19	1
6	2500	200	22.9	1.2
7	2800	224	13.3	0.7
8	3100	250	9.54	0.5

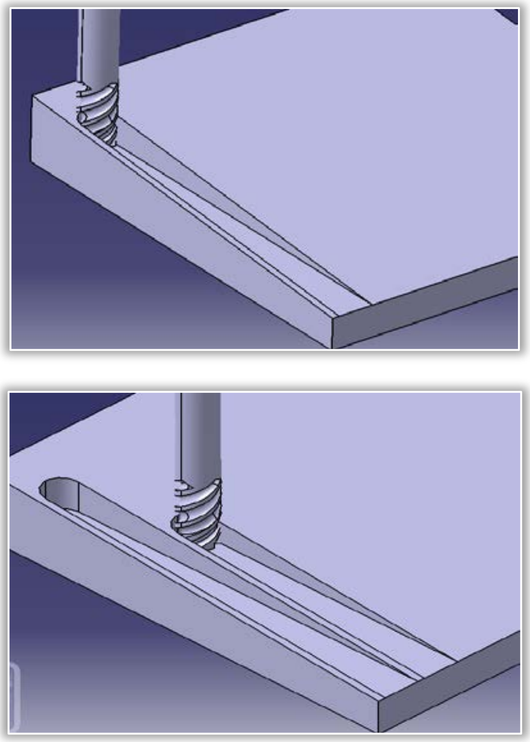

Figure 5. Schematic representation of the experiment

CONCLUSIONS

A stability lobe diagram, as a boundary between a stable and unstable cutting process, is a function of the cutting regimes, the cutting speed, feed rate, and the axial depth of cut. This paper shows a simple experimental method for defining the stability lobe diagram in milling. The boundary between a stable and unstable milling process can be experimentally determined by using data acquisition systems to measure the amplitude of vibration in the time domain, and then using the method of "tangents", to process obtained data, which is presented in this paper.

Also, the depth of cut at which self-excited vibration occurs can be determined by measuring the axial cutting depth on the workpiece itself. Due to the fact that results depend on the subjective feeling of the operator (as to the timing of stopping feed movement), this is considered to be the less favorable method.

The presented methodology is suitable for determining the stability lobe diagram for slot milling, where the width of the cut is equal to the tool diameter, and radial immersion is 100%.

Note:

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