EXPERIMENTAL ANALYSIS OF CHARTER VIBRATION ON MICRO MILLING

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Abstract: *In cutting processes it is necessary to study the vibration phenomena which take place and the factors that affect them. In this paper by analyzing the acceleration signals of the machine toolspindle, the influence of chatter vibrations on micro-milling process is examined experimentally. The spindle acceleration was measured with a piezoelectric accelerometer which receives signals in X-Y-Z direction simultaneously. The analog signals were filtered and digitized taking into account the sensitivity factor of the sensorin order to gain the physical size of measurement (g). The acquired accelerationcomponents are subjected to Fourier transformation (FFT) and illustrated in the frequency domain for further analysis.*

1. Introduction

During the cutting process it is very important to know, as precisely as possible, the relationship between the oscillatory behavior of the "Machine Tool- Cutting Tool-Workpiece" system and the cutting conditions such as cutting speed, feed and cutting depth (radial and axial) with the aim of achieving high surface quality. This requirement is even more important when it comes to micro-machining.

The aim of this paper is to study the impact of the chatter vibrations effect on the micro-milling cutting process, the chip formation mechanisms and the surface quality of the workpiece. In order to succeed that, experiments recording the acceleration of the machine toolspindle, were conducted.

In particular, by means of appropriate equipment, the parameters of the cutting process which affect the outcome of the cut, such as the cutting speed, the federate the axial depth of the cut, were studied.

The signals of the measurements, after undergoing the appropriate digital processing, were evaluated in relation to the working conditions, the machining kinematics and the surface quality of the workpiece in order to extract useful information about the cutting mechanism and the impact of the vibrations at the outcome of the cutting process.

The CNC machine tools are more powerful and accurate than the conventional ones. The higher power of the CNC machine tools allows us to perform cutting processes at very high cutting speeds. At the same time, any feed can be elected through a wide range of values to more than one axis, in contrast to conventional machine tools in which the feed is selected between predetermined values. However, the operation of the CNC machine tools at high metal removal rate conditions can lead to rapid tool wear, which results in the tool failure. On the other hand, concerning the high cost of these machine tools, the cutting process should take place under those conditions which ensure their better exploitation.

So, it is crucial to define a group of the optimum cutting conditions, i.e. cutting speed (v_c) and feed speed (f) seeking for the following:

- To avoid rapid development of cutting toolwear

- To ensure dynamic stability of the cutting processwithout side vibration phenomena with anunfavorable impact both on the work piece surfacequality, and the cutting toollife
- To achieve good utilization of the machine tool performance, reducing the processingtime and consequently the production costs

Due to the wide variety of machine tools, cutting tools and workpiece materials it is impossible to define a group of optimal parameters which fits every process. However, it is feasible to determine the best cutting parameters for a specific combination of machine tool, cutting tool and workpiece material.

2. Cutting tools and Workpiece material

The cutting tools which were used have a diameter of 2 mm. They are manufactured by the OSAWA Company. Their type is G2CS4made from tungsten carbide category N with multilayer coating PVD TiN / TiN / TiN, high performance. Due to their excellent abrasion resistance and the fact that they can withstand higher temperatures they are suitable for working with or without lubrication at high cutting speeds.
The material of the workpieces used for the experiments is aluminum alloy of class 7075 T651 (AlZn5.5MgCu).In Figure 2, the composition is shown by weight of the alloy, and a micrograph of a metallographic microscope depicting the crystallographic structure of the material above. There are visible various phases granulation formed (Al-MgZn2, MgSi2, and phase contains Fe). This material hasvery high strength and therefore is used widely in applications in aerospace and in militaryindustry.

Fig.1. The cutting toolused in the experiments

The mechanical properties of the above aluminum alloy are:

- Tensile Strength : 552 MPa
- Yield Strength : 496MPa
- Elongation % : 9

The material hardness was measured at 158 HV.

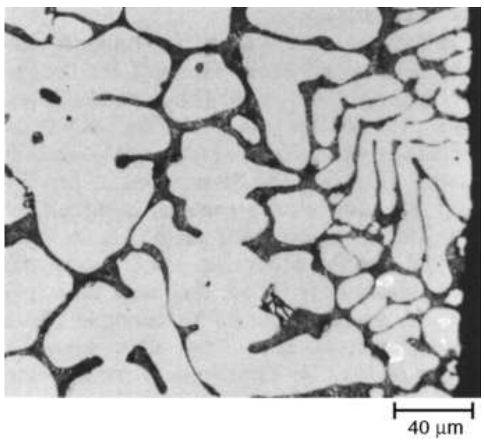

Fig.2. Crystallographic structureof the aluminum alloy used in the experiments

Table 1: Composition by weight of the aluminum alloy used in the experiments (Al 7075 T651)

Alloy element	**Weight %**
Al	87.1 - 91.4
Cr	0.18 - 0.28
Cu	1.2 - 2
Fe	Max 0.5
Mg	2.1 - 2.9
Mn	Max 0.3
Si	Max 0.4
Ti	Max 0.2
Zn	5.1 - 6.1
Other element	Max 0.05
Other element in total	Max 0.15

3. Protocolof Experiments

The procedure of the experiments is typical and is explained below. First of all the workpiece is mountedand fixed on the worktable of the machine tool.

Each workpiece was processed roughing, to achieve the necessary planarity, in order to have the same depth of cut across the cutting surface. For the roughing process a helical milling cutting tool was used with diameter of 40 mm and four cutting flutes, as well as cutting fluid. After that the zero point of the coordinate system onto the work piece is set by means of the CNC machine touch probe. Finally the numerical code of the machining pathsis loaded into the memory (MCU) of the machine tool.Table 2 shows the cutting parameters chosen for the experiments.

The experiments were conducted in the Manufacturing Technology &Production Systems Laboratory of the Technological Education Institute of Central Macedonia, in Serres.

The machine tool is a 5-axis machining center DECKEL MAHO MH600C. The technical specifications of the machine are:

x-travel: 600mm
y,z- travel: 450mm
turning speed range: 20-6300 rpm
feed range: 1-6000 mm/rpm

Table 2: Cutting parameters

Abbre-viation	Parameter	Value
V_c	Cutting speed (m/min)	34,5
F	Feed (mm/min)	220 / 440
F_z	Feed rate (mm/cut)	0,01 / 0,02
a_e	Radial cutting depth(mm)	0,5
a	Axial cutting depth (mm)	0,2 / 0,4 / 0,6
S	Spindle speed (rpm)	5500

4. Equipment

The transducer used to measure the acceleration during the micro-milling process was a Kistlerpiezoelectric accelerometer (type 8692C50) illustrated in Figure 3 with a three channel amplifier (type 5134).

Fig. 3. Acceleration sensor and recording amplifier

5. Acceleration measurementin micro-milling processes

For the evaluation of the cutting tool excitations, produced by the cutting process, the spindle vibrationsare measured. In order to do this, specific experiments were conducted combining the cutting parameters given in Table 1. In these experiments the spindleacceleration is recorded. The purpose of this measurement is to explore the vibration frequencies which affect the cutting process.

The acceleration sensor, presented in section 4, is able to measure the acceleration in three axes (X, Y, Z) simultaneously. It is mounted to the flange of the shaft, so as to receive the vibration excitations directly caused by the tool during the cutting process.

The $A_x$component of the acceleration corresponds to the oscillation of the cutting tool in the direction of the feed and thus is associated with the feed force component (the mark appears in yellow). The $A_y$component of the acceleration corresponds to the oscillation of the tool in the direction of the tool axis and is related to the passive force component (the signal shown in red). Finally, the $A_z$component of the acceleration corresponds to the oscillation of the tool perpendicular to the direction of feed and is connected with the cutting force component (the signal appear in blue).

Fig. 4. Experimental log acceleration device to the shaft of the machine tool during the milling micromachining.

In order to record the cutting tool acceleration signals in micro-milling an appropriate codewas developed in graphical programming language "LabView". The code realizes the acquisition of the three signals, one for each acceleration component. All the signals are digitized and normalized to the physical size of measurement (g) taking into account the sensitivity of the sensor.

The signals of the accelerationcomponents are subjected to Fast Fourier Transformation (FFT) and illustrated in the frequency domain. Finally, the digitized signals are stored in the computer for further evaluation by implementing low-pass filteringwith MatLab software. The acceleration signals were acquired with a sampling frequency of 50 KHz and for each measurement were obtained 1000 values (sample size). This means that for each measurement the signal duration amounts to 0,02 sec.

6. Acceleration measurement results in micro-milling processes

The most representative results from the evaluationof the acceleration measurements on the machine toolspindle in micro-milling processare presented. The following figures show the acceleration components in the directions X, Y, Z, measured at the lower bearing housing of the spindle, in the frequency range (0-25 kHz).

It should be mentioned that the optimal response of theused accelerometer is limited to the frequency range 0-6 kHz.Beyond this frequency, the accelerometer's sensitivity is reduced and the measurement is not accurate.

The measurements have been takenunder various cutting parameters: cutting depth 0,2-0,4-0,6 mm, feedrate: 0,01-0,02 mm/cut, constituting 6 different combinations of cutting conditions(see Table 3).

Table 3: Cutting parameters

	1	**2**	**3**	**4**	**5**	**6**
a (mm)	0,2	0,2	0,4	0,4	0,6	0,6
F_z(mm/cut)	0,01	0,02	0,01	0,02	0,01	0,02

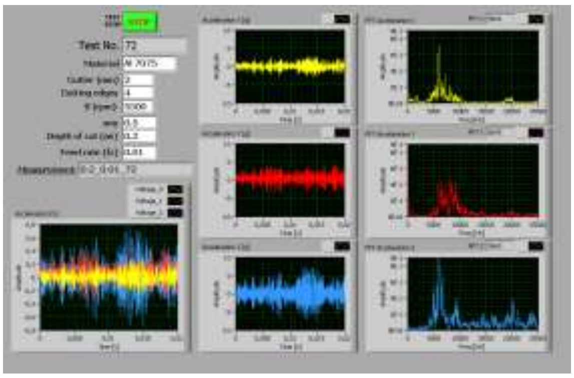

Fig. 5. Acceleration measurement (Cutting depth 0,2 mm, feed 0,01 mm/cut)

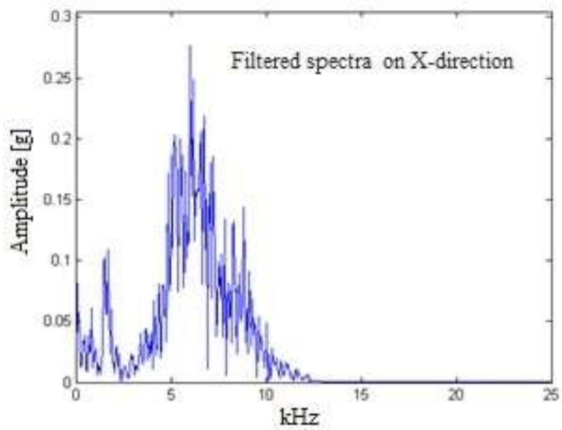

Fig. 6a: Corresponding spectra of the acceleration signals on X-direction for a=0,2 mm, Fz=0,01 mm/cut.

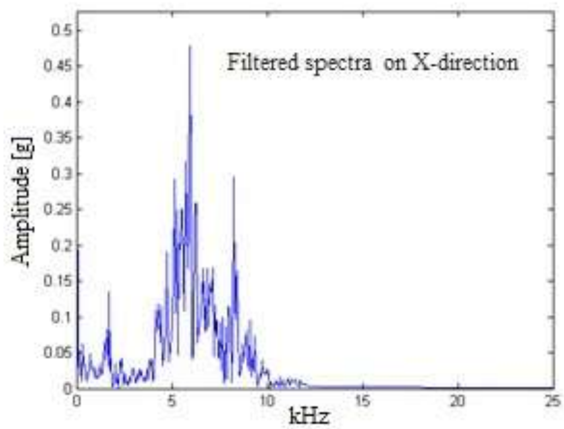

Fig. 6b: Corresponding spectra of the acceleration signals on X-direction for a=0,2 mm, Fz=0,02 mm/cut.

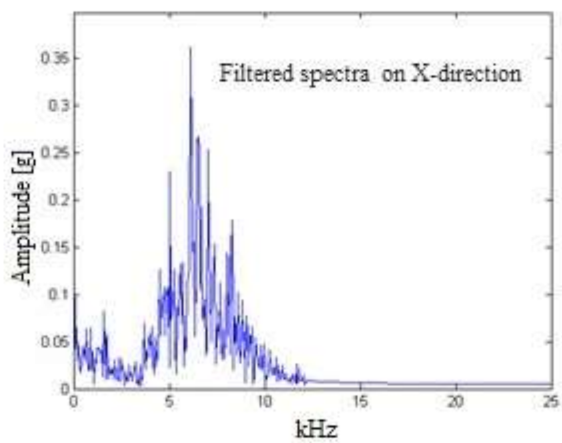

Fig. 6c: Corresponding spectra of the acceleration signals on X-direction for a=0,4 mm, Fz=0,01 mm/cut.

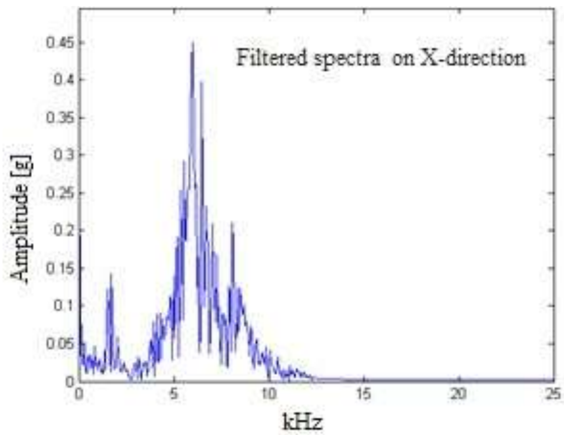

Fig. 6d: Corresponding spectra of the acceleration signals on X-direction for a=0,4 mm, Fz=0,02 mm/cut.

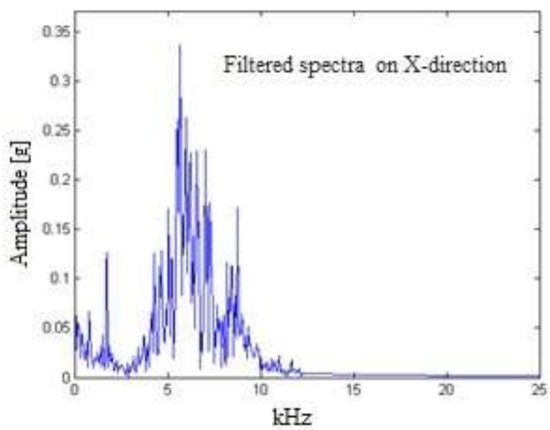

Fig. 6e: Corresponding spectra of the acceleration signals on X-direction for a=0,6 mm, Fz=0,01 mm/cut.

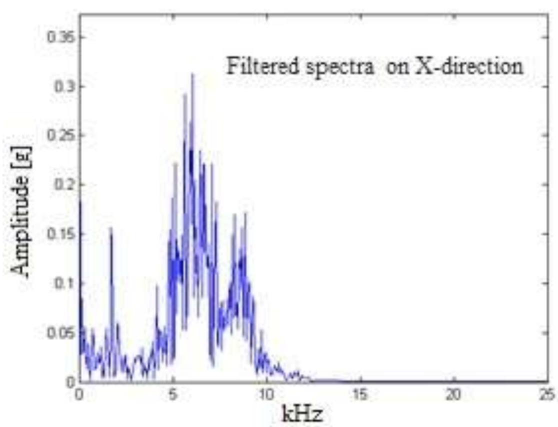

Fig. 6f: Corresponding spectra of the acceleration signals on X-direction for a=0,6 mm, Fz=0,02 mm/cut.

Figure 7 shows the value of the amplitude on X-direction for each combination of cutting parameters

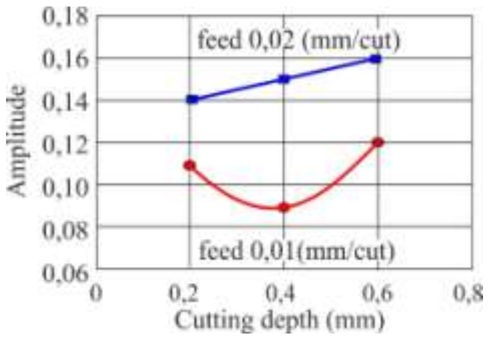

Fig. 7: Amplitude on X-direction for each combination of cutting parameters

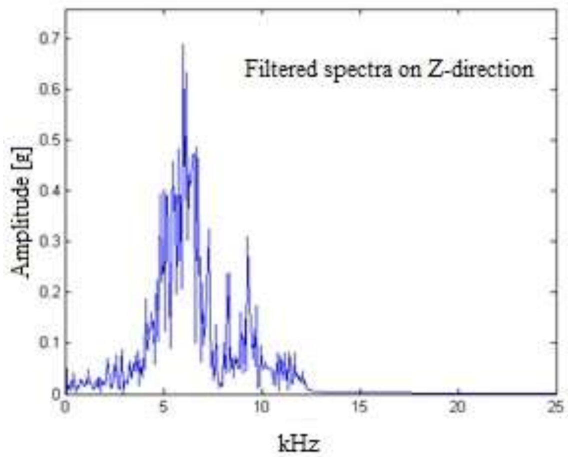

Fig. 8a: Corresponding spectra of the acceleration signals on Z-direction for a=0,2 mm, Fz=0,01 mm/cut.

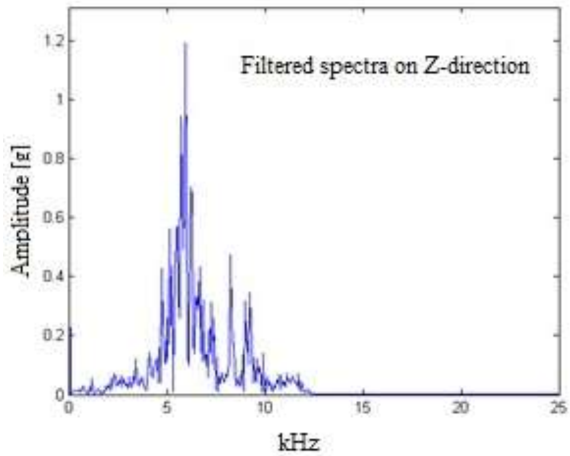

Fig. 8b: Corresponding spectra of the acceleration signals on Z-direction for a=0,2 mm, Fz=0,02 mm/cut.

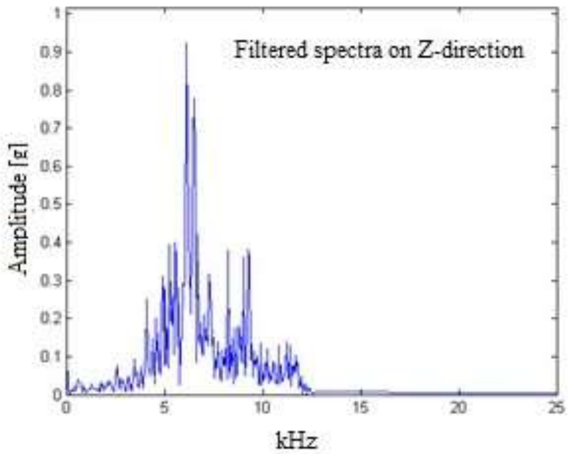

Fig. 8c: Corresponding spectra of the acceleration signals on Z-direction for a=0,4 mm, Fz=0,01 mm/cut.

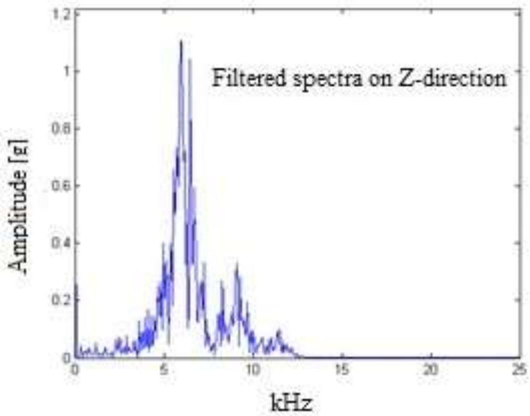

Fig. 8d: Corresponding spectra of the acceleration signals on Z-direction for a=0,4 mm, Fz=0,02 mm/cut.

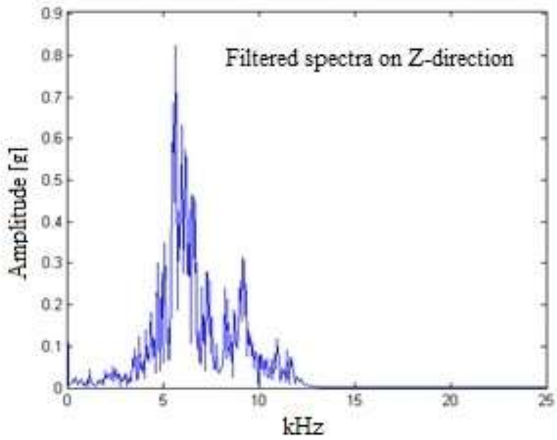

Fig. 8e: Corresponding spectra of the acceleration signals on Z-direction for a=0,6 mm, Fz=0,01 mm/cut.

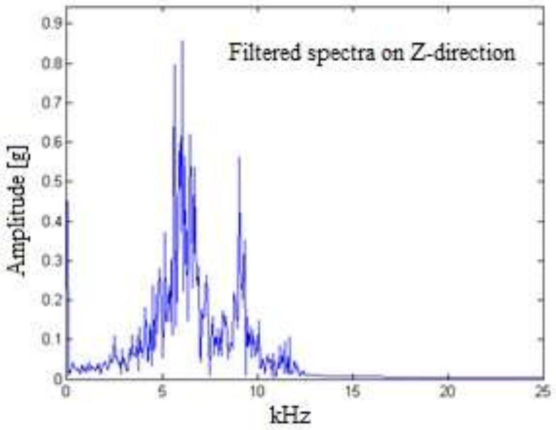

Fig. 8f: Corresponding spectra of the acceleration signals on Z-direction for a=0,6 mm, Fz=0,02 mm/cut.

7. Conclusions

In machining processes it is crucial to determine the optimal cutting parameters in order to avoid the chatter vibration effect which can harm not only the cutting tool but also the surface quality of the workpiece.

In this paper, an effort to indentifythe optimal cutting parameters in micro-millingprocess is presented. For this scope vibration analysis of the cutting tool during the machining process under various cutting conditions is performed.

Based on the experimental results important conclusions can be drawn. The peak at 1400Hz, shown in Figure 6, appears only on X-direction, the direction of the tool feed, because of the chatter vibration effect near the eigenfrequency of the tool (1440 Hz).

Bibliography

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