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EXPERIMENTAL STUDY AND ASSESSMENT OF THE CAUSES FOR VIBRATIONS IN MACHINING TECHNOLOGY SYSTEMS DURING FACE MILLING OPERATIONS

Danimir Dimov – Student
Department Mechanical and Manufacturing Engineering,
University of Ruse "Angel Kanchev", Ruse, Bulgaria
Phone.: 082 888 653
E-mail: dhdimov88@gmail.com

Assoc. Prof. Dimitar Dimitrov, PhD
Department of Mechanical and Manufacturing Engineering,
University of Ruse "Angel Kanchev", Ruse, Bulgaria
Phone: 082-888 653
E-mail: ddimitrov@uni-ruse.bg

Abstract: *In order to reduce and limit the vibrations caused by physical forces in the processes of machining, the stability of the technology system can be increased by placing additional supports and clamps to better fixate the workpiece. The positions of such fixations must correspond to the system`s own natural frequencies of vibration and oscillation shapes. The application of external forces with frequencies, approaching or equal to those of the system, causes an unwanted phenomenon called resonance. Some workpieces, such as thin-walled beams, are especially susceptible to these vibrations. To know which frequencies can cause mechanical disturbances in the process of machining, we need information about the spectrum of frequencies which the specific tool and operation parameters can induce upon the technology system. The purpose of this study is to determine the spectral characteristics for specific cases of machining through experimentation and analysis.*

Keywords: *Technology, Machining, Metal cutting Milling, Vibrations, Resonance*

INTRODUCTION

A distinct aspect of modern mechanical manufacturing, large or small scale, is the tendency of apllying automation (Penchev M.S., I. Peeva. (1995), (Kostadinov Ch., I. Peeva.) (2017,2019,2020), digital technology and CNC machines. The high economic cost of equipment, combined with the high productivity demand, require a certain efficacy of all processes. It is widely accepted that physical stability is one of the main requirements to a manufacturing process' efficacy. Each system component – machine, device, tool, workpiece, with its own mechanical properties, has an effect on the total stability. (Angelov, Yu. A. 1999,2010), (Bozduganova, V., M. Todorov. (1993), (Enchev PT, YA Angelov. (2004). In the ever developing machining technologies, a main problem concerning efficacy are vibrations of the technology system, caused by the forces of machining. Every technology system has its own vibration frequencies, which depend on the constructional features and mechanical properties of the materials. (Stoyanov Sv., St. Stoyanov. (2011), Stoyanov, S. (2014,2017). External forces, applied with equal to the natural frequencies of the system, can cause resonance. Resonance is related to the amplitude of oscillation of the workpiece and affects the machining process negatively, leading to inconsistent surfaces and dimensions. For that reason, the natural vibration frequencies and amplitudes of the workpiece (and other elements of the system) must be determined, especially in cases of insufficient mechanical stability. Scientific achievements and discoveries, combining fundamental mechanics with computer software-aided modeling and simulation, make the quick application of engineering solutions possible. (Bozduganova, V.,M. Todorov. (1993), (Draganov I. (2016), Draganov I., R. Milkov, A. Pukhlev. (2018), Draganov I., N. Ferdinandov, D. Gospodinov, R. Radev, S. Mileva. (2019), Velchev, D. (2003). Having obtained information about the vibration characteristics of the system, the following steps can be undertaken in order to reduce vibrations: **1)** Dissipation with the help of vibration-absorbing devices, **2)** Avoiding the application of external disturbances with frequencies equal to the natural ones, through altering the machining parameters related to the frequency of the tool striking the workpiece surface. That means how many times the edges of the tool strike the worpiece for a given amount of time. **3)** Increasing the stability of the technology system. To increase the stability of the workpiece itself, additional fixations can be applied at the appropriate areas of deformation (maximum amplitude) in the process of oscillation. (Dimitrov D., I. Georgiev.(2015), (Dimitrov D, N. Nikolov (2019). The latter two solutions aim to reduce the possibility of causing resonance and stabilize the system in its critical areas. That demands information about the frequency characteristics of any external disturbances and of the system itself. Because the frequency spectrum of any technology system is strongly individual and specific, it must be determined for each such system. Determination of the applied forces with a given frequency in advance is only possible through calculations related to the number of cutting edges of the tool and the revolutions per minute. Any other disturbances, which have an effect because of their frequencies, are related to other parameters of the machining process, such as the formation and break-off of chips, and are not analyzed at this point.

EXPOSITION

Description of the experiment and expected results

Apllying the forementioned solutions requires an understanding of the amplitude-frequency characteristics of the specific machining process. As was already explained, that can only be achieved through numerical analysis of the frequency of the incisions that the tool's cutting edges perform into the workpiece. Another step in determining these characteristics is analysis through means of experimentation. The obtained data must be reliable and repeatable, so that it may be significant.

The experiment aims to answer the following questions: **1)** Is there any sort of repeatability in the frequency spectrum of the technology system for every set of equal conditions, but different instances, or is it variable and undetermined, and **2)** What impact do the number of the tool's cutting teeth and machining parameters have on the frequency spectrum and could they be altered to reduce vibrations.

The experimental set-up (Fig. 1) consists of a CNC machine, a test workpiece, an accelerometer and a PC. The solid steel test workpiece is fixed to the machine's work table and the accelerometer is attached to it. The PC with the appropriate software allows us to vusialize the measurements and data regarding the vibrations, detected with the accelerometer. The test workpiece is fixed with two clamps in a holding device, which is attached to the work table. The used tools are two different mill heads, which have respectively 7 and 8 cutting edges and external diameters of respectively 80 and 100 milimeters. Seperate sets of tests were conducted with each tool.

The expected results are that the frequency spectrum of vibration of the technology system is repeatable and that it does not vary unexplainably, and that vibrations with certain frequencies are related to the rpm and amount of cutting teeth of the tool.

Pos. 1 – Work table

Pos. 2 – Accelerometer, attached to test piece 3 and connected to PC 6

Pos. 3 – Solid steel test workpiece, fixed to the work table 1

Pos. 4 – CNC machine – 5-axis mill

Pos. 5 – Machining tool – mill head

Pos. 6 – PC with appropriate software loaded – Soundcard Scope (Soundcard Oscilloscope)

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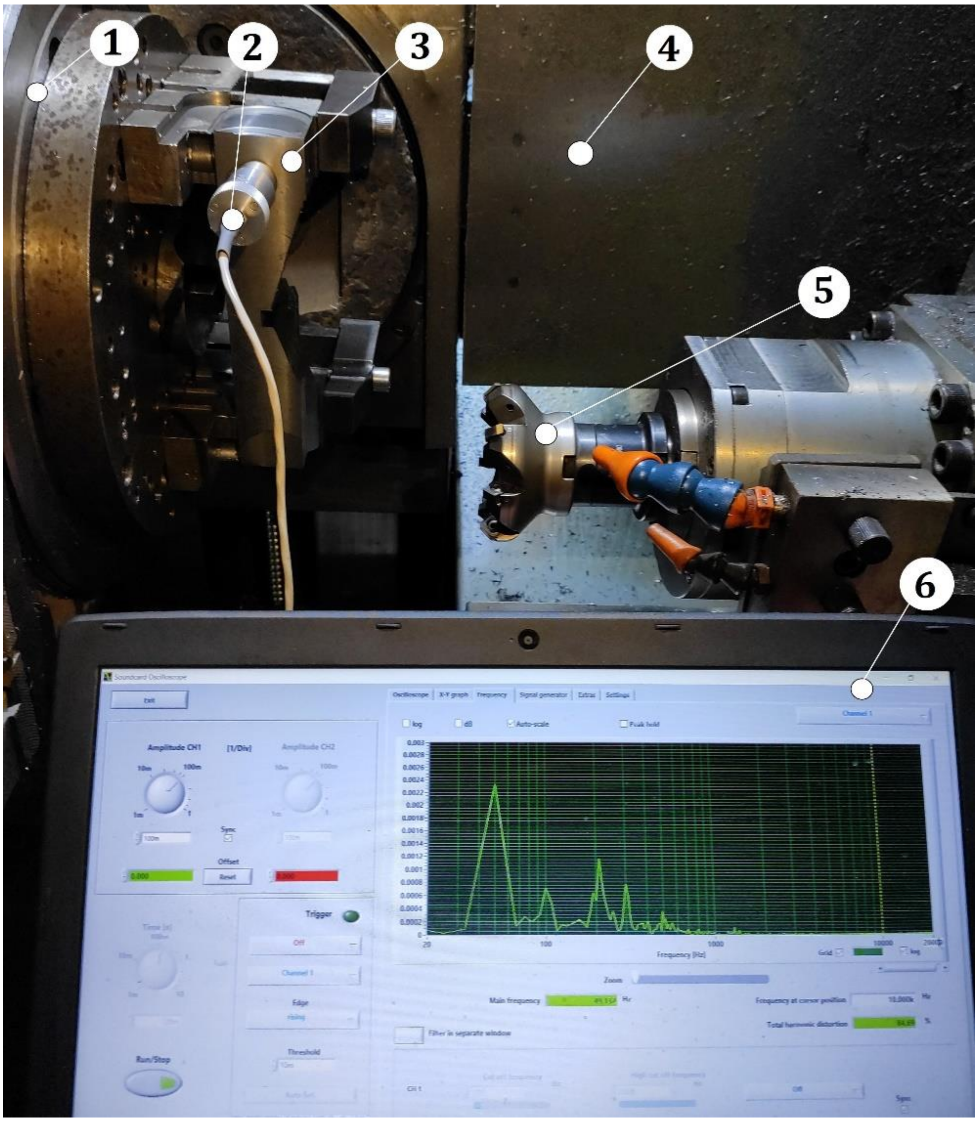

Fig. 1 – Experimental setup

Experimental conditions

The tests have been conducted in a certain order. The required information is about the frequencies of vibration in the process of cutting (machining), and also in resting conditions, the so called 'dry run'. First, measurments were made at dry run at 250 rpm, than 500, 1000 and 2000 rpm. That means that the series of tests was conducted in the absence of contact between the tool and the workpiece – no cutting is being executed, so no forces are transferred from the tool to the workpiece. These frequencies of rotation fall into both rpm bands which the machine's gearbox has.

The next set of test was conducted in the process of machining – the tool is in contact with the workpiece and actual processes of cutting are applied. So at each of those four rotary frequencies (250, 500, 100, 2000 rpm) 5 tests (measurments) were performed at dry run and 5 more in cutting conditions. This series of tests was conducted using a 7-edge tool. Apart from them, the same sets of 5 measurments were taken when using an 8-edge tool at 500 rpm. That allows us to compare the vibration frequencies induced by each of those tools.

In order to grant repeatability and reliability of the results, all other conditions remained constant or (some) were changed according to certain principles. The depth of cut in all instances was a=0,4 mm. The work path of the tool was y=60 mm in length. The feed was related to the rpm (frequency of rotation-s) in each case – at s=250 rpm, f=175 mm/min. At s=500 rpm, f=350 mm/min. At s=1000 rpm, f=700 mm/min. At s=2000 rpm, s=1400 mm/min. These values of feed rates were calculated from the equation:

$$f = f_z * z * s \text{ , [mm/min]}$$

where f – minute feed, f_z – feed per tooth, z – number of teeth, s – rpm.

Feed per tooth was f_z=0,1 mm for each case.

With the parameters feed per tooth and depth of cut kept constant for each instance, equal conditions are insured. The only parameter used as a variable is the frequency of rotation.

Results and interpretation

As a result of the experiment and with the help of the mentioned software, the following diagrams of the frequency spectra were created.

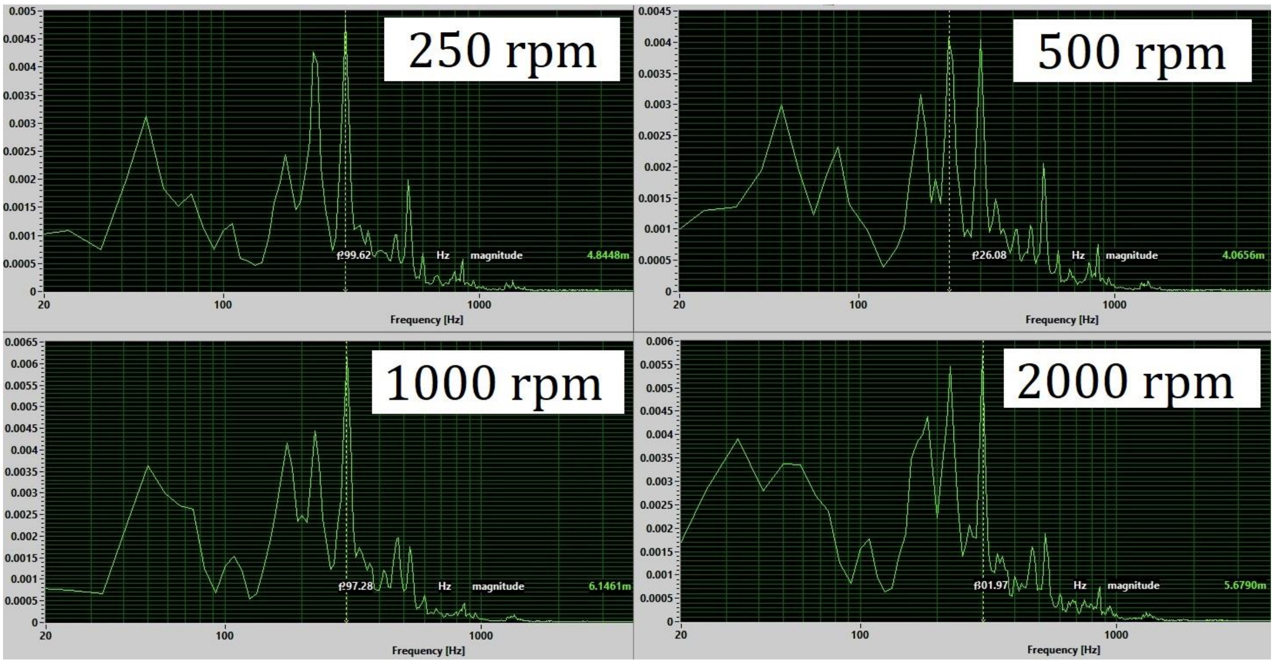

Fig. 2 – Comparison of frequency spectra at dry run

Fig. 2 shows the frequency spectrum of each of the 4 chosen rpm cases at dry run - 250, 500, 1000 and 2000 rpm. As expected, these 4 charts do not have significant differences. The maximum amplitudes (vertical axis) are related to the same frequencies (horizontal axis) in all cases. The peaks can be assumed equal in number aswell.

It can be concluded that the frequency spectrum in resting conditions does not change unexpectedly. It cannot be predetermined accurately, but the revolutions per minute by themselves do not have a significant effect upon it. In equal conditions the natural frequency range remains constant enough for the purposes of machining.

On Fig.3 we see a comparison between the frequencies of oscillation in working conditions – actual forces of machining (cutting) apply. Again, in the same rpm range, the frequency spectra are very similar. The maximum amplitude peak is around 1040 Hz in all cases. Above that frequency a subsidence of the vibrations follows. The other peaks are also similar.

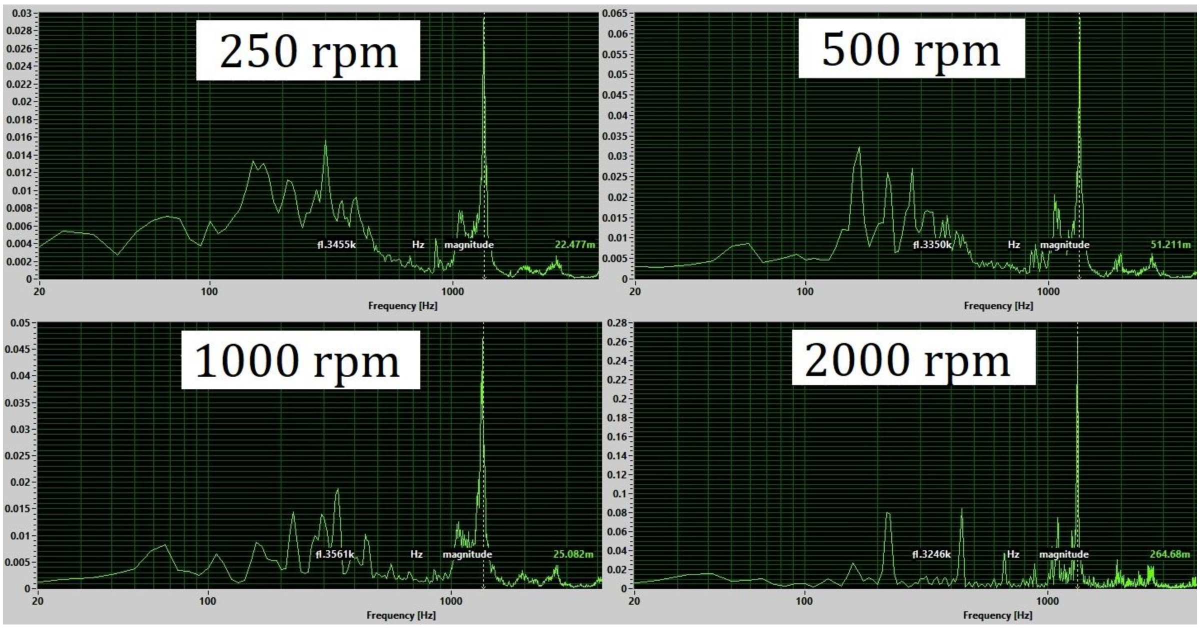

Fig. 3 – Comparison of frequency spectra in working conditions

Determination of critical frequencies

Ctitical frequencies are those, which pose a risk of developing resonance when paired with their equal counterparts from the natural frequency spectrum of the system. In other words, when an external frequency becomes equal to one of the natural frequencies, the amplitudes of both combine and cause a strong vibration with a high resulting amplitude. When the workpiece (or other system components) vibrates that strongly, the process of machining is highly impaired.

When working with a given multi-toothed tool, as a result of the tool's rotation, the teeth strike the workpiece with a specific frequency. That frequency can be calculated as:

$$f = \frac{s*z}{60},\ [Hz] \qquad (2)$$

where f – frequency,

s – revolutions per minute,

z – number of teeth of the tool

That is how we can determine the frequency of strikes of the teeth on the workpiece surface for every chosen number of teeth and rpm.

Knowing that frequency, through consultation with the technology system's natural spectrum, resonance could be avoided. That can most easily be done through altering the externally applied critical frequency, through changes in the two studied machining parameters – rpm and number of teeth.

On Fig.4 One can see a rise in the amplitude at frequency around 70 Hz when working with an 8-tooth tool and 500 rpm. Through the equation (2) we can work out that at that rpm and number of teeth, the frequency of striking is $f = \frac{500*8}{60}$ = 66,7 Hz. The chart shows this very frequency has a local maximum amplitude, although in the low range of up to 0,03.

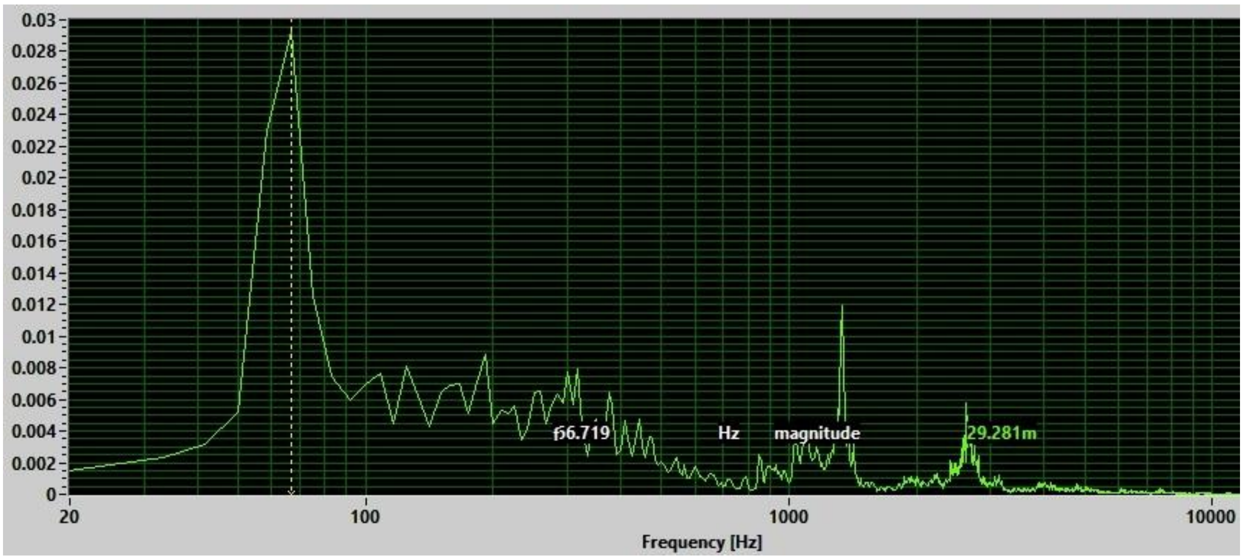

Fig. 4 – Frequency spectrum of vibration when using an 8-tooth tool, 500 rpm

CONCLUSION

The carried out experimental study confirms the direct relationship between the generated frequencies and applied external disturbances as a function of the periodic striking (incisions) of the tool's cutting edges, with its momentary rpm, onto the workpiece.

Changing the frequency of rotation (rpm) of the mill-head tool does not affect the resulting frequency characteristic significantly, but only the amplitudes of certain frequencies.

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