MONITORING THE CONDITION OF THE SPINDLE OF THE MILLING MACHINE USING VIBRATION

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The goal of this paper is to point out the possibility of occurrence of vibration during milling due to changing depth of removed layer of the material. Growth of values of mechanical vibration in depending on the value of the nominal thickness of the splinter was monitored during changing technological parameters of the milling process due to rotation speed of the engine. The results of the experimental part are values of vibration acceleration amplitude measured by a piezoelectric sensor on the head of the milling machine. Two types of tools have been used for the measurements - a plate and a monolith milling machine and rotation speed and material removal have been changed on the selected device. Based on the analysis of created graphical dependencies a set of new knowledge, conclusions and recommendations is formulated.

KEYWORDS

milling, material processing, mechanical vibration, frequency, frequency spectrum

1 INTRODUCTION

Mechanical vibration occurs by mutual influence of the cutting process and the processing machine. It is caused by a modulation of the static component of the cutting force, which is secured by a changing diameter, respectively a changing depth of the splinter. Change of depth of the splinter is given by change of the relative position of the tool and of the worked piece especially due to vibration of the overall system, specifically machine - tool - work piece [Eynian 2015, Yang 2015]. Thus the cutting process is a source of internal distortion of the system. The occurrence of self-induced vibration is conditioned by the existence of a modulated cutting force, respectively the existence of average depth of the splinter. During milling interrupted cutting occurs with individual blades. The depth of the cut is given by radial depth of the cut [Ford 2014, Oniţă 2014]. During time when none of the blades is cutting, the system is without distortion, but still subdued. Extension of this period could increase the stability of the cutting process. The depth of the splinter during milling is not constant, it is changed depending on the angle of the milling machine, size of the radial depth of the splinter and based on this we know, whether this is uninterrupted or interrupted milling. It is proven that during uninterrupted cut there are greater shocks, which cause greater mechanical vibration of the tool [Kakinuma 2011, Budak 2012, Karagüzel 2016]. During lower depths of the splinter the machine is not popping out of the cut when compared to uninterrupted milling. Popping out of the cut means reducing the distortion period, which has the same effect as shortening the duration of the cut, thus increase of stability during the milling process interrupted cut, change of depth of the splinter during the cut, rotating force and more blades in the cut can have an effect on the occurrence of mechanical vibration [Salokyova 2014, Budak 1995].

Thus the occurrence of self-induced vibration during milling is a factor significantly affecting the performance of the milling machine. In the paper attention is focused on measuring the mechanical vibration on the head of the milling machine by changing selected technological factors, specifically rotation speed of the spindle and depth of the splinter [Bičejová 2013, Panda 2013, Vojtko 2013]. After performing the experiments, original graphical dependencies are created and from the comparison graphs of frequency range covers. The conclusion of the paper proposes knowledge based on evaluating the measurements, which will serve for improving efficiency of the machine operation, reducing failure rate and refining products.

2 RESEARCH METHODOLOGY

A milling-processing tool of the type Zayer 3000 BF 3 has been used for the research in operational conditions. During the processing of steel 1.1213 size of the mechanical vibration is recorded on the head of the milling machine due to change of two factors, namely speed of the head of the spindle and depth of the splinter. These two factors determine to a large extent the character of the occurred vibration signal during processing by milling.

Vibration signal in operational conditions was recorded using a piezoelectric sensor of acceleration, model 4514B-62887 by the Brüel & Kjaer Corporation, which was attached on the head of the spindle using a magnet in the X direction. The X direction is identical with the direction of the milling. Figure 1 depicts the place of mounting the sensor on the head of the spindle.

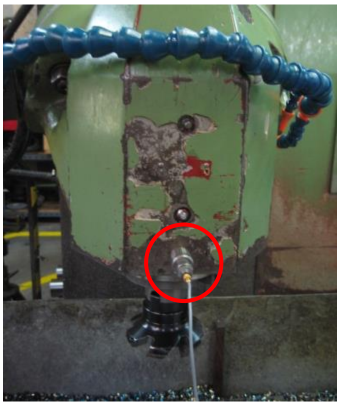

plate milling machine

monolith milling machine

Figure 1. Mounting of the vibration sensor on the head of the spindle of the milling machine

Recorded vibration signal from the sensor is processed using a measuring card NI 9233 of the National Instruments Corporation in the monitoring system SignalExpress and subsequently it is evaluated on a computer in time and frequency domains.

3 RESEARCH METHODOLOGY

Twelve consecutive measurements have been carried out. Input constant and changing technological and material parameters, under which experiments have been carried out, are listed in the conditions of the measurements in Table 1.

Table 1. Measuring conditions

Factors	**Experimental range**
cutting velocity	150 mm/min
the rpm of spindle	300, 350 a 400 rpm
the reduction of the material	2.7 a 4.8 mm
Milling cutters	plate milling machine R245-080Q27-12M
	monolith milling machine NR TiN 50x36 mm
Cut material indication	1.1213 mechanical characteristics (Rm = 240 – 295 MPa, Re = 490 MPa, HB = 160) chemical characteristics (C 0.53%, Mn 0.5 %, Si 0.25%)
Diameter of material	50 mm

4 ANALYSIS OF THE RESULTS IN THE TIME DOMAIN

Analysis of the results in the time domain consists of evaluation of the measured time progressions of signals, which characterize the basic dimension of vibrations, namely acceleration. Measured values for individual measurements and three examined rotation speeds of the head of the spindle of the milling machine as well as removal of material are listed in graphic form. As an example of time progressions of vibration acceleration is graphically depicted (Figure 2 and 3) the progression for spindle rotation speed 300 rpm with depth of the cut 2.7 and 4.8 mm, with use of both tools (plate and monolith milling machine). Measured values in the time domain have been evaluated in the same way for other examined rotation speeds, namely 350 and 400 rpm with the same cut depth of 2.7 a 4.8 mm with both tools.

Based on graphic dependencies for the progression in the time domain (Fig. 2 and 3) it can be said that the size of the acceleration amplitude is regularly increasing with the increasing depth of the splinter. During processing the amplitudes fluctuate usually non-periodically, but we consider them to be stable. Smaller values of the amplitude values have been recorded for the 2.7 mm depth of the cut went compared with the 4.8 mm depth of the cut during the monitored time progression.

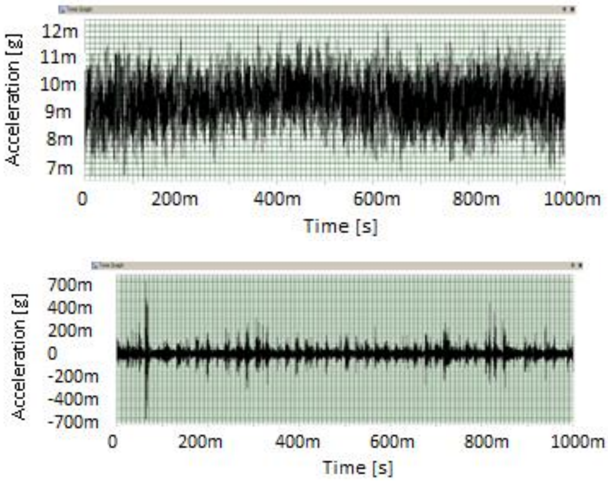

Figure 2. Progression of vibration acceleration depending on time and depth of the cut 2.7 and 4.8 mm and spindle rotation speed 300 rpm under processing by a plate milling machine

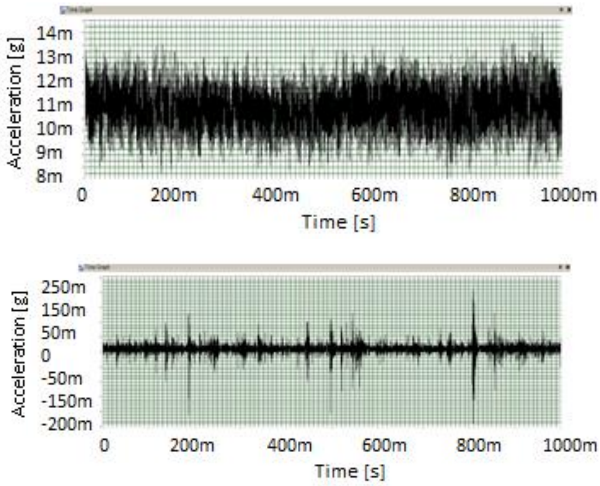

Figure 3. Progression of vibration acceleration depending on time and depth of the cut 2.7 and 4.8 mm and spindle rotation speed 300 rpm under processing by a monolith milling machine

5 ANALYSIS OF THE RESULTS IN THE FREQUENCY RANGE

Vibration signal measured during milling in the time domain is transformed using the quick Fourier transformation to a frequency spectrum in the range 3.0 – 8.0 kHz. Graphic dependencies of the progressions of change of the vibration acceleration amplitude based on frequencies are evaluated together for motor speeds of 300, 350 and 400 rpm.

As an example the progression of a change of vibration acceleration amplitude based on frequency is depicted (Fig. 4 and 5) for motor speeds of 300, 350 and 400 rpm and removal of material of 2.7 mm with the use of plate and monolith milling machine. Analogously have been depicted also the graphic dependencies of the vibration acceleration amplitude and vibration frequency for motor speeds of 300, 350 and 400 rpms with depth of the cut 4.8 mm for processing using the plate and the monolith milling machine.

Based on graphic dependencies for the progression in the frequency domain (Fig. 4 and 5) it can be said that during processing using the speed 300 rpms and depth of the cut 2.7 mm using the plate milling machine frequencies have been achieved in the low frequency range of 3.0 kHz – 6.5 kHz. During processing using the monolith-milling machine, increased values were also found in the low frequency range of 3.0 kHz – 5.0 kHz. Frequencies in the range of 6.0 kHz – 8.0 kHz in both cases did not prove any significant dependency on the examined input factors of the experiment.

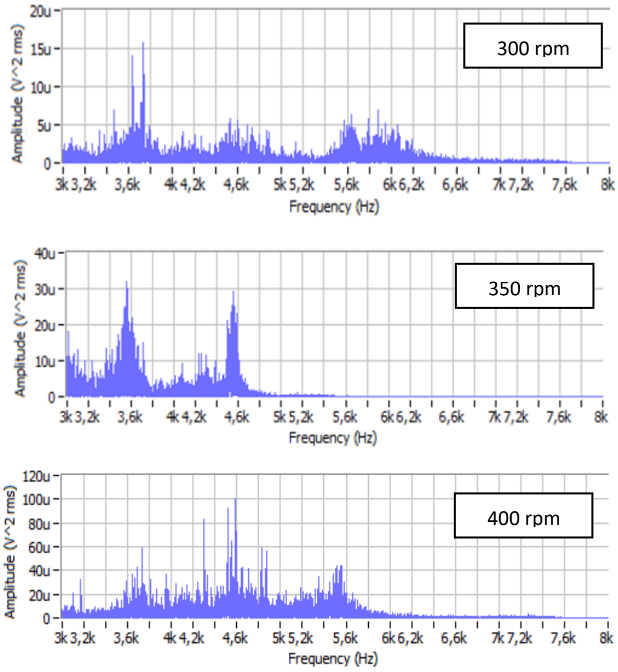

Figure 4. Graphic dependency of the vibration acceleration amplitude on frequency with depth of the cut 2.7 mm for processing using the plate milling machine

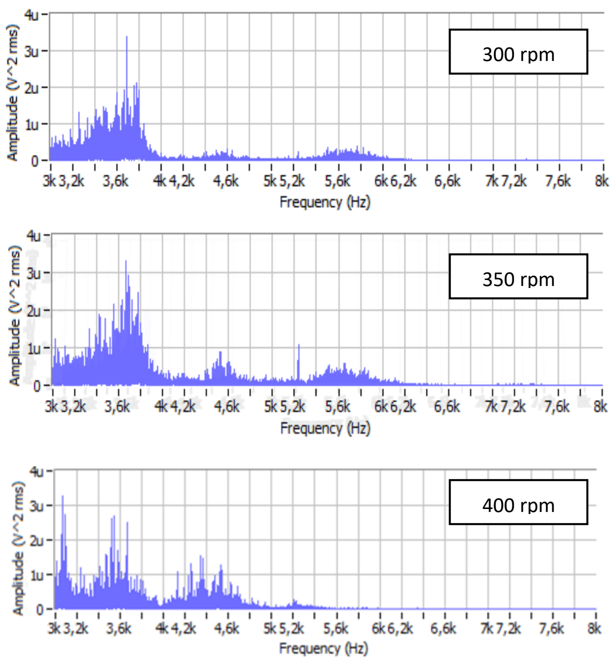

Figure 5. Graphic dependency of the vibration acceleration amplitude on frequency with depth of the cut 2.7 mm for processing using the monolith milling machine

6 ANALYSIS OF THE RESULTS USING THE COVER METHOD

Comparison graphs of frequency range covers have been drawn based on individual graphical dependencies of the vibration acceleration amplitude. Fig. 6 depicts the comparison graph of range covers jointly for the tree examined speeds of the spindle with depth of the cut 2.7 mm for processing using the plate milling machine. Similarly a comparison graph has been created (Fig. 7) for the same speed of the spindle and the same tool, but with depth of the cut 4.8 mm. Figure 8 depicts the comparison graph for processing using the monolith milling machine, three speeds of the spindle and depth of the cut. The same input parameters, but with a depth of the cut 4.8 mm are stated in the comparison graph of frequency range in Figure 9.

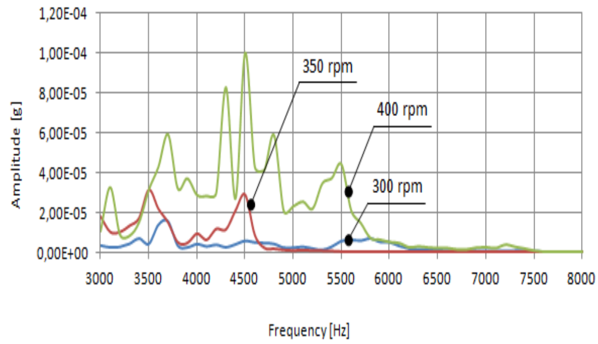

Figure 6. Comparison graph of frequency range covers with material removal of 2.7 mm and rotation speed of the head of the milling machine 300, 350 and 400 rpm for processing using the plate-milling machine

First significant increase of amplitude in the range using the data recorded during the rotation of the spindle of the head of the milling machine at 300 rpm were recorded at the frequency around 3.7 kHz. Another increase of amplitudes occurred at the frequency around 5.5 kHz. This is followed by a range of lower amplitudes. The highest amplitude in the overall frequency range was recorded at the frequency of 3.7 kHz with a value of 1.58E-5 g. Just like in the previous case, also in the case of cover using data recorded during processing at 350 rpm, increased values have been recorded in the frequency range from 3.4 - 4.6 kHz. However significantly increased peaks have been recorded at frequencies 3.5 and 4.5 kHz. Subsequently the amplitudes decreased. The highest value of this cover was recorded at the frequency 4.5 kHz with a value of 2.93E-5 g. The cover corresponds to spindle speed of 400 rpm and as opposed to previous ranges it is different in its middle part. Increased values of the amplitude are found already at the beginning. However further on there is a range of significantly increased amplitudes of 4.3 - 4.8 kHz.

The highest value was recorded also at the frequency of 4.5 kHz with a value of 0.0001 g.

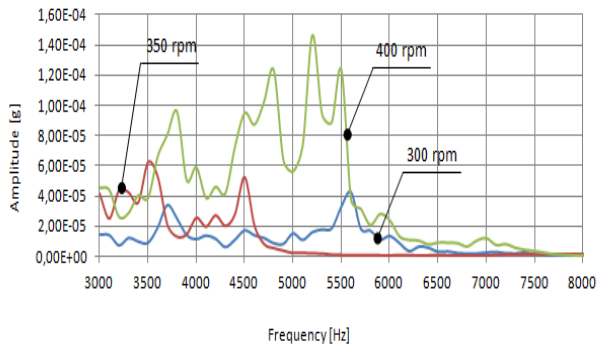

Figure 7. Comparison graph of frequency range covers with material removal of 4.8 mm and speeds of the head of the milling machine of 300, 350 and 400 rpm for processing using the plate-milling machine

The progression of the covers consists of several high peaks spread throughout the entire spectrum, not only in the low frequency range. The first significant peak is found at the frequency of 4.8 kHz. Another peak was recorded at the frequency 5.5 kHz and is followed by one small peak and a short gap, recorded during processing at 400 rpm. In the range corresponding to spindle speed of 350 rpm at frequency of 3.5 kHz amplitudes grow to the maximum value around this range. Subsequent peaks did not exceed this value. Similarly like in previous case also in the range of data recorded at 300 rpm there are significantly increased amplitudes at frequencies 3.7 and 5.6 kHz. The middle part of the spectrum consists of smaller clusters of amplitudes. The highest peak achieved the value of amplitudes 4.27E-5 g at the frequency 5.6 kHz.

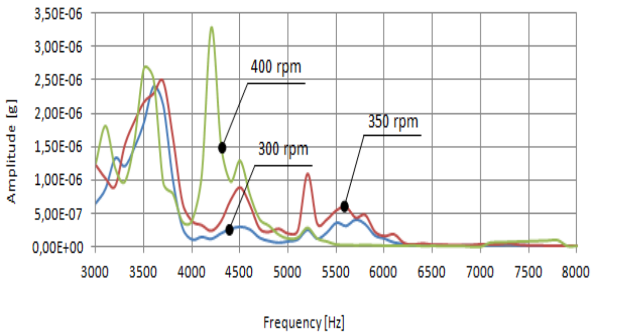

Figure 8. Comparison graph of frequency range covers with material removal of 2.7 mm and speed of the head of the milling machine of 300, 350 and 400 rpm for processing using the monolith milling machine

As opposed to previous progressions of recorded values these progressions have almost an identical shape, with the exception of a significant peak when processing at 400 rpm, where the highest value of the amplitude was recorded, specifically 3.29E-6 g. In the range between 3.3 - 3.9 kHz there is a cluster of amplitudes in the shape of a hill when processing at all chosen speeds of the spindle of the head of the milling machine. In the high frequency range, when processing at 300 and 350 rpm low values of amplitude have been subsequently recorded. The highest values of the range for 300 rpm were recorded in the frequency of 3.6 kHz with a value of 2.4E-6 g and at speed of 350 rpm the peak was achieved at the frequency of 3.7 kHz with a value of 2.48E-6 g.

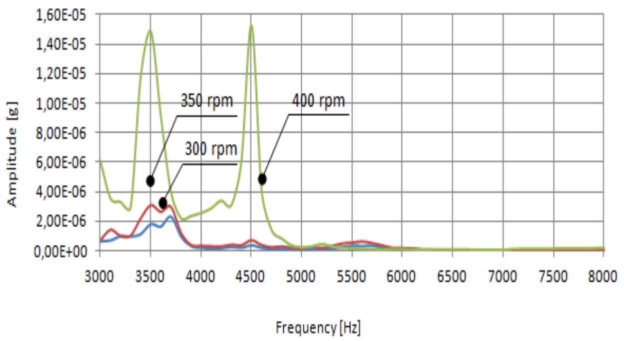

Figure 9. Comparison graph of frequency range covers with material removal of 4.8 mm and speeds of the head of the milling machine of 300, 350 and 400 rpms for processing using the monolith-milling machine

As to the shape, the most similar are the covers for records obtained for speeds of the head of the milling machine of 300 and 350 rpm. First major increase of amplitudes can be observed in the frequency range from 3.5 - 4.5 kHz at speed of the spindle of 400 rpm when compared with speeds of 300 and 350 rpm. In this range the highest recorded value of the vibration amplitude was 1.53E-5 g. The lowest value of the vibration amplitude was recorded at 300 rpm. In the range from 3.3 to 3.8 kHz short increases of the amplitude have been recorded up to 0.84E-6 g.

7 PRESUMED DIRECTION OF THE RESEARCH OF THIS ISSUE

Knowledge gained from the measurement can be used in classic operations using milling technology, but especially when setting up the output technological parameters, which were used for the measurement. Using the frequency analysis increase of values of vibration amplitudes have been determined in the low and medium frequency range, specifically from 3.0 kHz to 6.2 kHz of the overall observed spectrum of 3.0 kHz through 8.0 kHz and for changing speed of the spindle of 300, 350 and 400 rpm. Using this knowledge it is possible to detect changes in the system of processing, like interruption of the rotation of the spindle. Using the results acquired through individual measurements recommendations for this operation can be created, where the experiments have been carried out - when using lower rotation speeds we reduce the duration of interruptions, increase the life-span of the device and increase the economic efficiency of the operation. It can also be said that greater values of the amplitudes were recorded at curves corresponding to speed of 400 rpm. Therefore it is recommended to use for the input parameters lower speeds of processing of 300 and 350 rpm.

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