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VIBRATION DIAGNOSTIC OF A ROTATING MACHINE

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ABSTRACT: The main goal of observing vibrations of rotating parts is to get information on the operational and technical status, with the goal of securing strategic planning and maintenance management. An important part of this process becomes the assessment of the status and progression of vibrations during the use of given machine. It is necessary to bear in mind that vibrations on rotating machines are closely related to dynamic straining parts like e.g. bearings, gears. In the experimental section, sizes of vibration amplitudes have been measured on the head of a pillar drill. During the measurement the tool as well as rotation speed of the devices were changing. The results are processed in table and graphics form. In the conclusion of this paper, recommendations are stated for input factors used for measurement and processing using the drilling technology.
KEYWORDS: Material processing, drilling technology, vibration amplitude, frequency

1. INTRODUCTION

Processing machines using drilling technology and their constant innovation require to a certain degree also the development of means and knowledge for diagnosing their status. When drilling, also when there is no visible mechanical vibration, the cutting force fluctuates constantly. Especially the fluctuation is caused especially by imbalanced attributes of the processed material or unevenness of the processed material [1]. When drilling, there are two types of vibrations observed, namely external and internal. With external vibrations the spindle of the drilling machine vibrates due to vibrations caused by external damage, like e.g. misalignment of the spindle, motor, incorrect setup of the machine and loosening of fastening elements - screws. Internal vibrations occur due to drilling itself. These are caused by a force, through which the work piece affects the drill in opposite direction, speed of the spindle or high feed speed [2, 3]. Except for these types of vibrations, it was proven that during drilling there are also axial, lateral and torsional vibrations. Axial vibrations cause offset, which lead to damage of drills and this also extends the drilling time. Torsional vibrations cause irregular rotation, damage or wear and tear of the material of the drilling machine, which worsens the oscillation and slows down the drilling process itself. Lateral vibrations are caused by collision of the wall with the drill, which causes an opening and eccentricity. These result from the rotation and lead to friction of the entire assembly [4, 5].

Shock in a drilling environment is the sudden input of energy, when the bit or drillstring impacts with the borehole. Vibrations are the response of the bit/drillstring to the shock. Vibration sensors utilize three mutually orthogonal, DC-coupled accelerometers to measure three axes of acceleration. The X-axis measures lateral and radial acceleration of the drillstring. The Y-axis measures lateral and tangential acceleration of the drillstring. The Z-axis measures the longitudinal (axial) acceleration of the drillstring [6, 7]. Therefore, it is necessary to observe excessive shock and vibrations, which can affect given process as well as life expectancy of the machine, wear and tear of the tools, but also individual parts of the device and reliability of the whole operation. The goal of this paper is to add new knowledge based on measurements in the field of mechanical vibration and also to propose correct input technological factors for processing the material steel type 1.1213 using drilling technology.

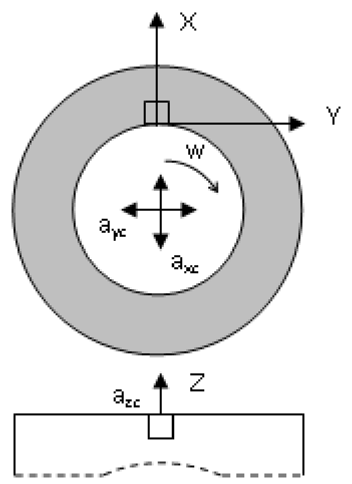

Figure 1. Accelerometer orientations

2. EXPERIMENTAL MEASUREMENT

Based on theoretical knowledge about the technology of drilling, it is possible to identify suitable technological factors for the experiment. Size of the vibrations on the spindle of the drilling machine head was chosen as the research phenomenon. These are defined as the information carrier about the immediate status of the process. Experiments were carried out in operational conditions, from which measured data was recorded to the NI 9233 measuring card [8]. Processing of the signal was carried out using the SignalExpress software. Pillar drill type AB ARBOGA MASKINER BM 2508 was used for material processing. Processing was secured by using spiral drills type HOLEX HSS with diameters ∅ 5 mm, ∅ 10 mm and ∅ 15 mm. Construction non-alloy steel 1. 1213 with a diameter of ∅ 40 mm was used as the experimental material. Technological conditions of the experiment are listed in Table 1. Rotation speed of the spindle head and diameter of the tool were chosen as the variable factors. Sensor for measuring the size of the vibrations was placed based on Figure 2. Sensor of the type 4514B – 62887 was used for data collection.

Table 1. Measuring conditions

Factors	Experimental range
cutting velocity	0,03 mm/rev
the rpm of spindle	205, 345 and 440 rpm
Type of instrument	type HOLEX HSS ∅ 5 mm, ∅ 10 mm and ∅ 15 mm
Cut material indication	steel 1.1213
Diameter of material	∅ 40 mm

Figure 2. Mounting the vibration sensor

3. TIME PROCESSIONS OF THE VIBRATION SIGNALS

A total of nine time progressions split into three groups have been created. First group designated *A* was made by setting constant factors of the drill ∅ 5 mm and spindle head speed was set to values 205, 345 and 440 rpm. Set B was made by setting the factors of the drill ∅ 10 mm and the variation of the spindle speed remained the same. Setting of the C group was similar to group A and B, with change of the drill value ∅ to 15 mm.

As an example of time progression of the vibration (Figure 3), graphic progression is depicted for the tool with ∅ 5 mm and spindle head speeds 205, 345 and 440 rpm. Measured values in the time range for other used variables of the tool with identical rotations of the spindle were created in the same way.

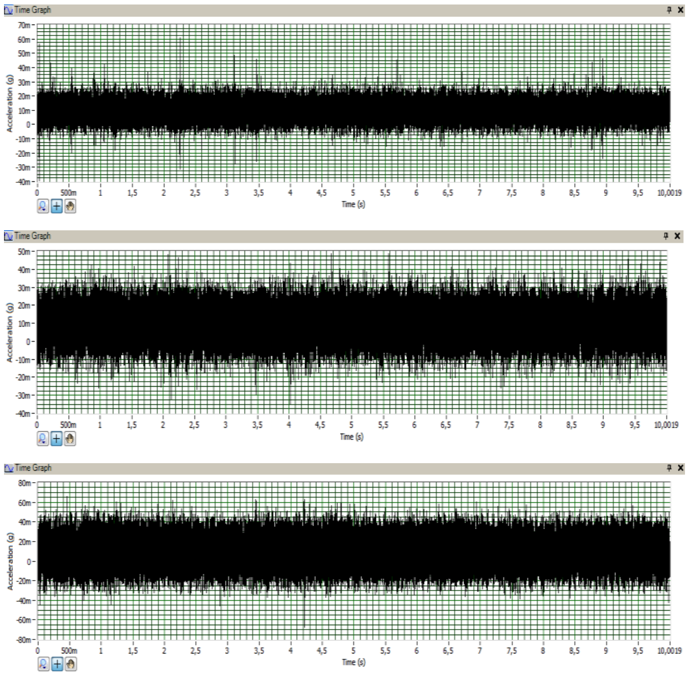

Figure 3. Time procession of signals of the group A

4. FREQUENCY ANALYSIS

The most common form of further signal processing is known as the FFT, or Fast Fourier Transform. This is a method of taking a real-world, time-varying signal and splitting it into components, each with an amplitude, a phase, and a frequency. By associating the frequencies with machine characteristics, and looking at the amplitudes, it is possible to pinpoint troubles very accurately. Since the time progression shows non-periodic progression, section of stable progression of 10 seconds has been selected for the frequency analysis and using FFT a frequency range of 0 - 10 kHz has been generated. Just like in time recording there is a graphical example of depicting frequency ranges for group *A*. Similarly, frequency ranges for sets of measurements of groups B and C have been evaluated.

FFT spectrums for group A show that shape wise similar spectrums are from recordings at spindle speed 205 and 345 rpm. First significant increase of amplitudes can be observed at frequency 400 Hz and 1400 Hz. Highest amplitude was recorded at frequency 1400 Hz and spindle speed 205 rpm with the value 8.76E-7 g. In the following range 5000 Hz through 7000 Hz short increases of amplitudes were recorded. At frequency of 300 Hz great increase of amplitudes was recorded at spindle speed of 345 rpm. Around the frequency 5000 Hz through 7000 Hz similar increase of amplitudes was recorded like at spindle speed 205 and 440 rpm. High amplitudes in low frequency range are observable also in the range corresponding to speed of 440 rom. These are found in frequencies 100 Hz and 700 Hz, where the last peak reached the highest value of amplitudes of 1.37E-5 g.

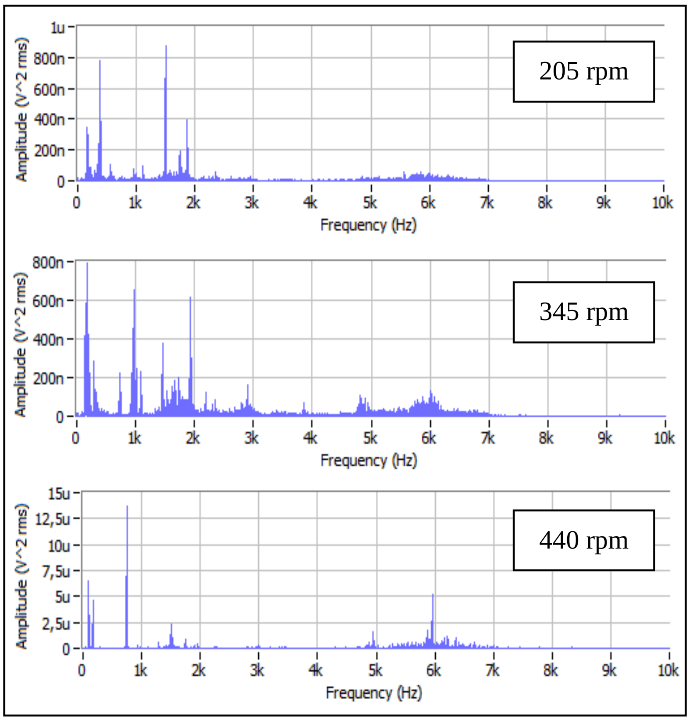

Figure 4. Frequency range for group A

FFT spectrums for group *A* show that shape wise similar spectrums are from recordings at spindle speed 205 and 345 rpm. First significant increase of amplitudes can be observed at frequency 400 Hz and 1400 Hz. Highest amplitude was recorded at frequency 1400 Hz and spindle speed 205 rpm with the value 8.76E-7 g. In the following range 5000 Hz through 7000 Hz short increases of amplitudes were recorded. At frequency of 300 Hz great increase of amplitudes was recorded at spindle speed of 345 rpm. Around the frequency 5000 Hz through 7000 Hz similar increase of amplitudes was recorded like at spindle speed 205 and 440 rpm. High amplitudes in low frequency range are observable also in the range corresponding to speed of 440 rom. These are found in frequencies 100 Hz and 700 Hz, where the last peak reached the highest value of amplitudes of 1.37E-5 g.

5. FREQUENCY ANALYSIS OF THE RMS PARAMETER

Effective value of RMS was chosen as the considered parameter because the FFT spectrum in absolute values is very dense and thus the overlap of individual spectrums for the purpose of comparing does not provide the required information value. The cover method is not suitable since these are not periodic occurrences. The Peak to Peak vibration parameter describes the maximum displacement of amplitudes and neglects lower values. On the other hand, the average of absolute values of amplitudes smoothens extreme values.

Graphs depicted in Figure 5 through 7 depict RMS values dependent on the frequency recorded at variable factors of the spindle speed 205, 345 and 440 rpm and diameter of the drill ∅ 5, 10 and 15 mm individually for individual group A, B and C.

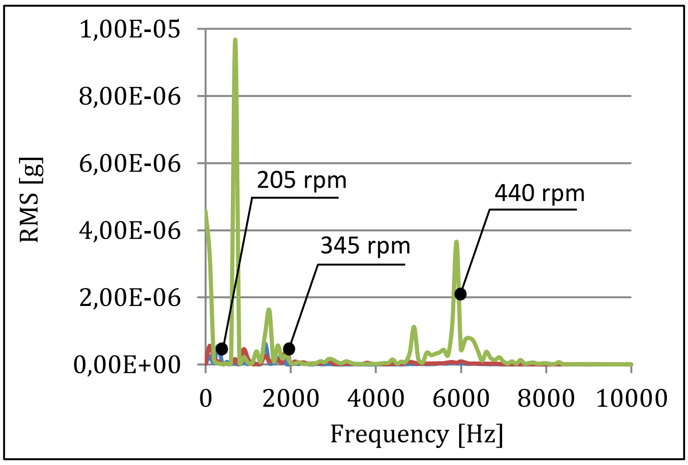

Figure 5. RMS value dependent on the frequency for group A

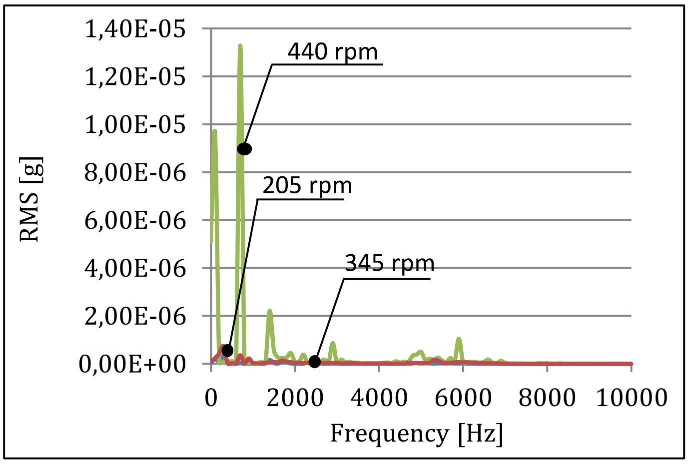

Figure 6. RMS value dependent on the frequency for group B

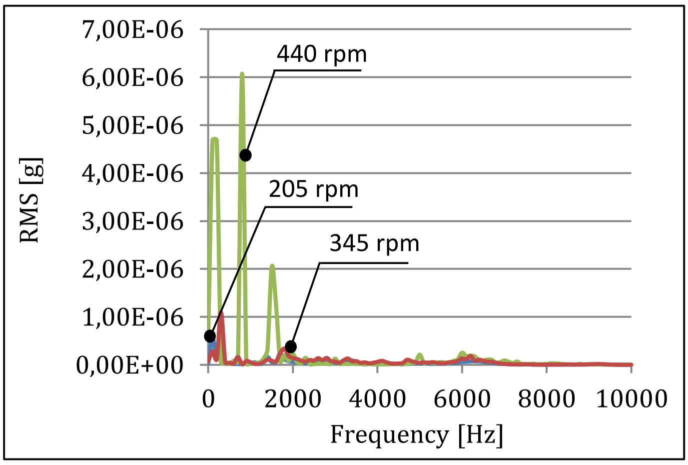

Figure 7. RMS value dependent on the frequency for group C

The graph of values acquired when setting the factors of the spindle speed to 205, 345 and 440 rpm with diameter of the drill 5 mm (Figure 5) it is clear that the curve corresponding to the highest rotation speed used for processing shows significantly higher value at low frequencies. Around the frequency 5000 Hz through 7000 Hz there are again more dominant peaks of the curve at speed of 400 rpm. Curves corresponding to spindle speed 205 and 345 rpm have approximately the same progression. Peaks of these curves are slightly shifted to lower frequency values. Similar trend is recorded also in Figure 6. This presents data at the same spindle speeds with change of the drill diameter of 10 mm. Just like in previous case also here RMS values corresponding to speed of 440 rpm are the highest, the peaks of which were recorded in lower values of the frequency. Curve values for speeds of 205 and 345 rpm have again approximately the same progression. Graphical depiction in Figure 7 describes the development of RMS values with the same setting of factors with the exception of drill diameter. This factor was changed to the value of 15 mm. Peaks of curves when processing by three different spindle speeds are recorded at lower frequency values. Curve of the spindle speed of 400 rpm shows significantly higher values at frequencies 200 Hz, 800 Hz and 1700 Hz.

6. COMPARISON OF THE RMS PARAMETER

As already mentioned, the main observed parameter of vibrations is the effective value of RMS. This parameter was used for the analysis of the vibration signal that has been paid more attention. When processing the signal different values of this parameter were recorded. Figure 8 graphically depicts RMS values for all examined groups A, B a C.

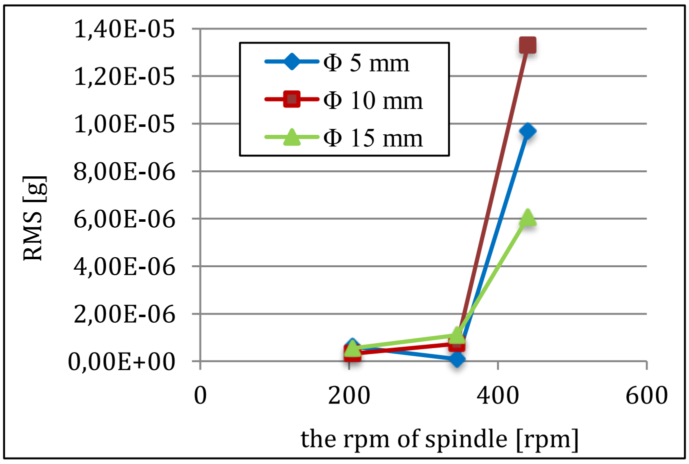

Figure 8. Dependency of the RMS values on spindle speeds when processing at different diameters of the drill

Highest RMS value equalling to 1.33E-5 was recorded at setting of input factors of spindle speed to 440 rpm with drill diameter 10 mm. A slightly lower value of 9.69E-6 was recorded at setting of the same spindle speed, but the difference was in using the diameter of the drill of 5 mm. The lowest value of 6.07E-6 was recorded at speed 440 rpm and drill diameter of 15 mm. The smoothest progression had curves with three different diameters of drills and processing speed 205 and 345 rpm. Progressions of individual curves in this diameter are similar.

7. SIGNIFICANCE OF FACTORS

To determine the effect of individual input factors (spindle speed and drill diameter) the DOE method was used for measured parameters of RMS vibrations. Standard design of the experiment was implemented with the examined number of factors of two and number of levels of three. Spindle speeds of 205, 345 and 440 rpm and diameter of the drill with levels of 5, 10 and 15 mm were used as examined factors. Table 2 contains measured values from performed measurement. The highest diameter value of output $\bar{Y}$ was achieved at E6 (1.33E-05 g).

Table 2. Nut with real values of factors and measured RMS parameter of vibrations

		nut with real values		measured values
		diameter of drill [mm]	the rpm of spindle [rpm]	RMS [g]
order	experiment	A	B	$\bar{Y}$
1	E1	700	220	0.012623
2	E2	700	240	0.010594644
3	E3	700	260	0.016859436
4	E4	1200	220	0.015372158
5	E5	1200	240	0.032987347
6	E6	1200	260	0.026373604
7	E7	1700	220	0.009203673
8	E8	1700	240	0.002095446
9	E9	1700	260	0.018513003

Analysis of the main effect of individual factors is listed in Table 3. Individual values A1, A2, A3, B1, B2 and B3 are variable values from the diameter of the resulting value $\bar{Y}$, in which given parameter was found. So for:

- A1 these are experiment values, where parameter A had value of 5 so E1, E2, E3
- A2 these are experiment values, where parameter A had value of 10 so E4, E5, E6
- A3 these are experiment values, where parameter A had value of 15 so E7, E8, E9
- B1 these are experiment values, where parameter B had value of 205 so E1, E4, E7
- B2 these are experiment values, where parameter B had value of 345 so E2, E5, E8

– B3 these are experiment values, where parameter B had value of 440 so E3, E6, E9

Table 3. Main effects of factors on output Ȳ

		A	B	Ȳ
A1	A=5	3.47E-06		3.60967E-06
A2	A=10	4.79E-06		
A3	A=15	2.58E-06		
B1	B=205		4.99E-07	
B2	B=345		6.43E-07	
B3	B=440		9.69E-06	3.60967E-06

The greatest effect of factors on the RMS was recorded by the factor spindle head speed. Significance level was not exceeded by the factor drill diameter. As shown in Figure 9 the greatest effect on the RMS value of vibrations has the upper level of the B factor, so spindle head speed of 440 rpm. Certain effect is also recorded for the middle and lower level of the factor B. A certain lower effect on the size of the RMS vibrations has the second observed factor, namely the diameter of the tool in the medium and upper level A.

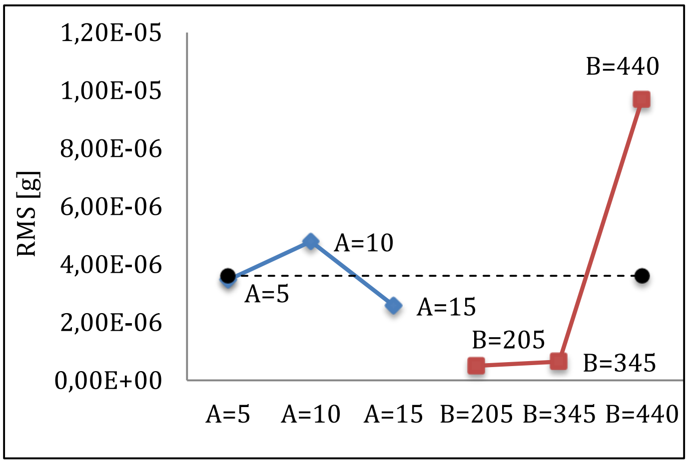

Figure 9. Main effect of individual factors and their levels on output Y

8. CONCLUSION

Using the measurement effect and significance of two selected processing factors were observed - rotation speed of the spindle head and diameter of the tool, which affect the size of the vibration amplitude of the head of the pillar drill. Experimental measurement confirmed the different significance of observed factors affecting the size of the vibrations. Based on acquired data, it is possible to optimize the conditions in the drilling process, which will secure higher productivity, reliability and longevity of given device. Specific measurements show that the best results when processing steel 1.1213 were achieved using the tool with a diameter of 15 mm under lower spindle head speeds. It is necessary to add that conditions under which individual measurements were carried out were adapted to the processing material. Therefore, it is not possible to generalize this knowledge or results for processing of different types of materials using the drilling technology.

9. ACKNOWLEDGEMENTS

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