ANALYSIS OF FREQUENCY CHARACTERISTICS AT SPINDLE OF CNC MACHINING CENTRE

ANDREA CIZIKOVA[1], KATARINA MONKOVA[1], PETER MONKA[1,2], MAREK URBAN[2]

[1]TU Kosice, Faculty of manufacturing technologies with the seat in Presov, Presov, Slovak Republic

[2]University of West Bohemia, Faculty of Mechanical Engineering, Pilsen, Czech Republic

DOI: 10.17973/MMSJ.2016_12_201627

e-mail: katarina.monkova@tuke.sk

The paper deals with an analysis of frequency characteristics scanned at the spindle of CNC machining centre Pinnacle PK-VMC650S. It also points on the early diagnostics necessity of possible sources of unwanted vibrations to predict the behaviour of devices, to find out the life of devices and to improve the quality of machined surface. The method of the planned experiment was used as the research method. The aim of experiments was to measure the frequency characteristics and their effective values. The experimental measures were done at three cutting speeds during the machining, i. e. when the tool was in contact with the workpiece. Measures were processed by means of module NI 9234 software LabVIEW. The experimental measures have shown that the spindle of CNC machine does not show the critical vibrations, and it can be considered acceptable for unrestricted operations.

KEYWORDS

frequency, amplitude, frequency characteristics, machining, analysis

1 INTRODUCTION

Total vibrations represent vibrational energy measured in specific frequency range. "Finding greater value than the normal vibration can be declared that there is "something", what causes these increased values. The vibrations are considered as the best operating parameters according to which it is possible to evaluate the low frequency dynamic conditions, such as unbalance, misalignment, mechanical imposition of will, resonance structures, lack of solid support, a bent shaft, excessive wear of bearings and the like. Vibrations are manifestation of behaviour of mechanical parts for machines that respond to the effects of internal and external forces. Since most failures of mechanical machinery is manifested by excessive vibration, the vibration signals are used as indicators of the mechanical condition of the machine [Krenicky 2008]. Any mechanical failure or defect generates vibrations by its specific way. To be able to determine their causes and choose appropriate steps to rectify this effort is to identify which the "fault type" it is. When analysing vibration signals it is necessary to pay attention to two aspects: amplitude and frequency. Frequency indicates the frequency of the same phenomenon in a given time period, this phenomenon constitutes one vibration cycle. [Baron 2016]

According to the vibration a fault type can be inferred. When it detects a frequency, at which vibration are occurred, it will be obtained a more accurate picture about the cause of the vibration. The amplitude is the size of the vibration signal that is associated with the severity of the failure. Depends on the type of machine and is in relation to the level of the vibration of "good" or a "new" machine"[Valent 2010].

2 METHODS USED IN THE EXPERIMENT

The method of planned experiment was used as the research method. The most appropriate method for the evaluation of the vibration signals in a manner appropriate for their analysis is the method FFT - Fast Fourier Transformation. In mathematical terms, this means that the signal is spread over certain amplitude, which corresponds to different frequency components. The spectrum consists of a chart of amplitude (intensity) of the sinusoidal components depending on the frequency [Valent 2010].

This transformation is used to obtain the spectrum of the signal *f(t)* in the spectrum field *F(ω)* and is defined by the following relation [Valent 2010]:

$$F(\omega)=\int_{-\infty}^{+\infty} f(t)e^{-j\omega t}\,dt. \qquad (1)$$

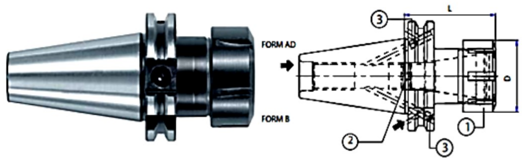
The values of the amplitudes in the individual graphs are shown on the axis "*y*". In the case of the FFT spectrum of is the amplitude expressed in multiples of the gravitational acceleration "g". The value of the gravitational acceleration is 9,81 ms^{-2}. In practice, this means that the values of the amplitudes in the graph must be multiplied with value of the gravitational acceleration that was acquired value of in ms^{-2}. On the axis "*x*" is the frequency with which the basic unit is 1 Hertz. From the point of view of a quantitative evaluation of the amplitudes of the mechanical oscillation is the most important to determine its effective value RMS (Root Mean Square). The effective amount is the derived mathematical way of comparing the energy or power dc or ac power. In the FFT spectrum, it is the square root of the sum of the squares of the instantaneous values [Ungureanu 2011].

The effective value can be expressed by the following relation [Blata 2011]:

$$RMS=\sqrt{\frac{1}{T}\int_{0}^{T} x^2(t)dt}. \qquad (2)$$

3 CONDITIONS OF EXPERIMENTS

For the purpose of the experiment the CNC machining centre Pinnacle PK-VMC650S with an output of 22 kW was used. It is located at Faculty of Manufacturing Technologies with the seat in Presov. The drill cutter KENNAMETAL UEDE1000A3AS was used as a tool. The vibrations were scanned at the spindle of the CNC machine that it is shown in Figure 1.



	Code N.	Description	ISO	ER	D	L
STANDARD	*214-31211	TC30H55ER16	30	16	32	55
	*214-31212	TC30H55ER25	30	25	42	55
	*214-31228	TC30H60ER32	30	32	50	60
	214-31362	TC40H70ER16 AD+B	40	16	32	70
	214-31329	TC40H70ER25 AD+B	40	25	42	70
	214-31331	TC40H70ER32 AD+B	40	32	50	70
	214-31333	TC40H70ER40 AD+B	40	40	63	70
	214-31341	TC50H70ER25 AD+B	50	25	42	70
	214-31335	TC50H70ER32 AD+B	50	32	50	70
	214-31338	TC50H80ER40 AD+B	50	40	63	80

Figure 1. Taper of spindle according to DIN 69871

As the machined workpiece, the block with dimensions 150 x 150 x 40 mm was used. Material of the workpiece was structural steel 14 220. The cutting path is presented in Figure 2, where labels II. ÷ IV. indicate the individual parts of tool path.

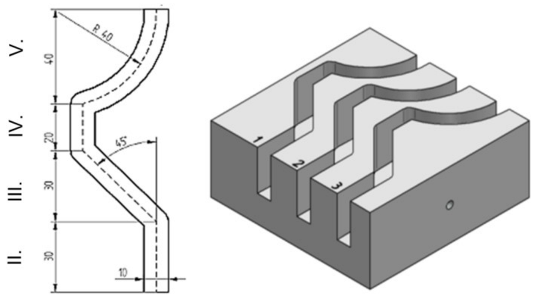


Figure 2. The cutting path with the block of workpiece

For every cutting speed ten measures were carried out. Measures were observed by means of accelerometer PCB Piezotronics 607A11 (shown in Figure 3). The signal was transformed by means of Module NI 9234 and measured data were processed in software LabVIEW. Sampling frequency was 51 200 Hz. The capture of individual time slots was recorded after 1 second.

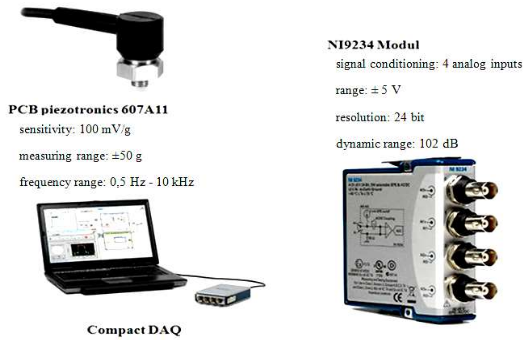


Figure 3. The measuring instruments

The experimental measurements were done at three cutting speeds, as it is listed in Table 1.

Table 1. Basic data of experimental measurements

No	Cutting speed [m/min]	Speed [rpm]	Feed speed [mm/min]	Feed [mm/rev]	Cutting depth [mm]	Diameter of milling cutter [mm]
1	100	3200	384			
2	125	4000	480	0,12	5	10
3	150	4700	570			

4 DESCRIPTION OF EXPERIMENTS

The time of the measurements at every of the three cutting speeds was divided into five sectors depending on the tool motion. The first phase of the measures I. is the time when the tool is not in contact with the workpiece (the tool makes a feed motion). Next parts II. – IV. were monitored during the machining and the labels II. – IV. correspond to individual parts of manufacturing path shown in Figure 1.

In second-time time period the straight path with length of 30 *mm* has been machined. The third period describes the course of vibration during slant path milling. The fourth section describes the period of the vibration acceleration at the straight path with length of 20 *mm* machining. The fifth part shows the time course of acceleration of vibrations during milling radius.

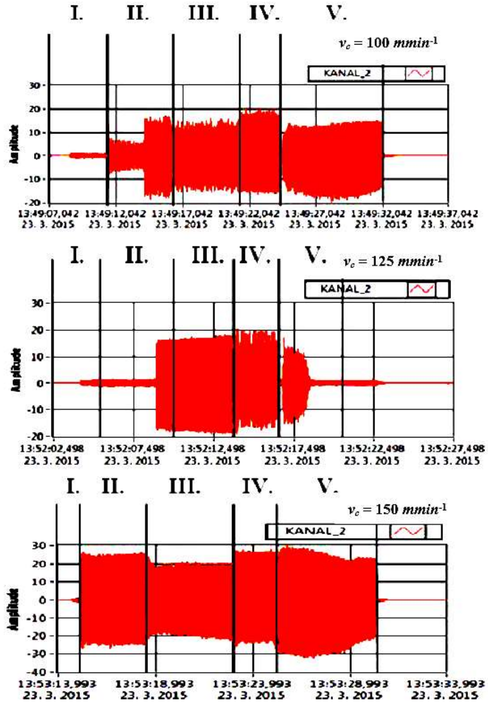


Figure 4. Vibrations at the individual cutting speeds

For deeper analysis, it was selected second time period II., where it was possible to see major changes in amplitude during the vibration, while other sections are observable small changes. The course of the vibrations at the other section has a more stable course. Therefore, within time period II. (at each cutting speed), three smaller periods of time were selected for analysis. Summary of the values in selected three time periods at individual cutting speeds is shown in Table 2. These three periods are labelled A, B and C. Measured amplitudes of vibrations depending on frequency are presented in Figures 5 – 7 with.

Table 2. Summary of the data in selected three time periods at individual cutting speeds

Part of machined path		**II.** (machining of the straight path with length 30 mm)					
Sampling frequency		51,2 kHz (51200 samples)					
The selected analysed time periods		**A**		**B**		**C**	
Cutting speed (m/min) **100**	time	4,4 s	4,6 s	6,65 s	6,85 s	8,9 s	9,1 s
	samples	225280	235520	340480	350720	455680	465920
	time/samples	0,2/10240		0,2/10240		0,2/10240	
	RMS	0,452519		0,305919		1,6708	
Cutting speed (m/min) **125**	time	3,5 s	3,7 s	5,475 s	5,675 s	7,45 s	7,65 s
	samples	179200	189440	280320	290560	381440	391680
	time/samples	0,2/10240		0,2/10240		0,2/10240	
	RMS	0,19663		0,185233		1,52018	
Cutting speed (m/min) **150**	time	1,15 s	1,35 s	2,85 s	3,05 s	4,55 s	4,75 s
	samples	58880	69120	145920	156160	232960	243200
	time/samples	0,2/10240		0,2/10240		0,2/10240	
	RMS	2,30314		2,10439		1,92066	

In the II. phase of the machining, where the motion of the mill cutter was straight and the cutting speed was 100 $mmin^{-1}$, the highest values of amplitude were recorded in periods A and B at a frequency of 825 Hz (in time period A it was 0,1185 g and in B period the value of amplitude was of 0,1066 g). In time-period C the maximum amplitude of 0,7534 g was observed at frequency of 840 Hz. (Figure 5)

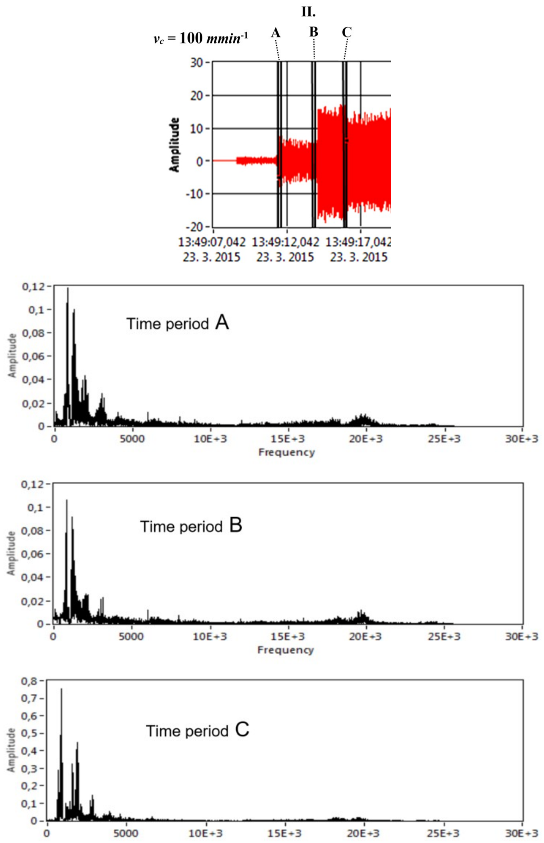


Figure 5. FFT spectra in individual analysed time periods A, B, C at the cutting speed 100 mmin^{-1}

FFT spectra in individual analysed time periods A, B, C at the cutting speed v_c = 125 *mmin*$^{-1}$ are shown in Figure 6.

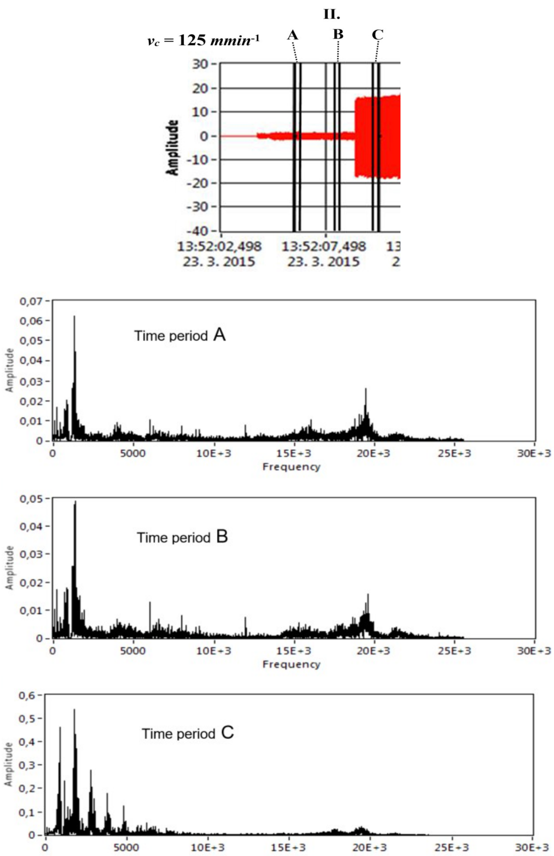


Figure 6. FFT spectra in individual analysed time periods A, B, C at the cutting speed 125 mmin^{-1}

The highest values of amplitude spectrum were recorded at frequency 1250 Hz. In the process of milling simulation, it is recorded spectra similarity which was initially characterized by a small set of values visible amplitude at frequencies between 100 Hz - 4100 Hz with a gradual increase amplitude values.

FFT spectra in individual analysed time periods A, B, C at the cutting speed v_c = 125 *mmin*$^{-1}$ are shown in Figure 7.

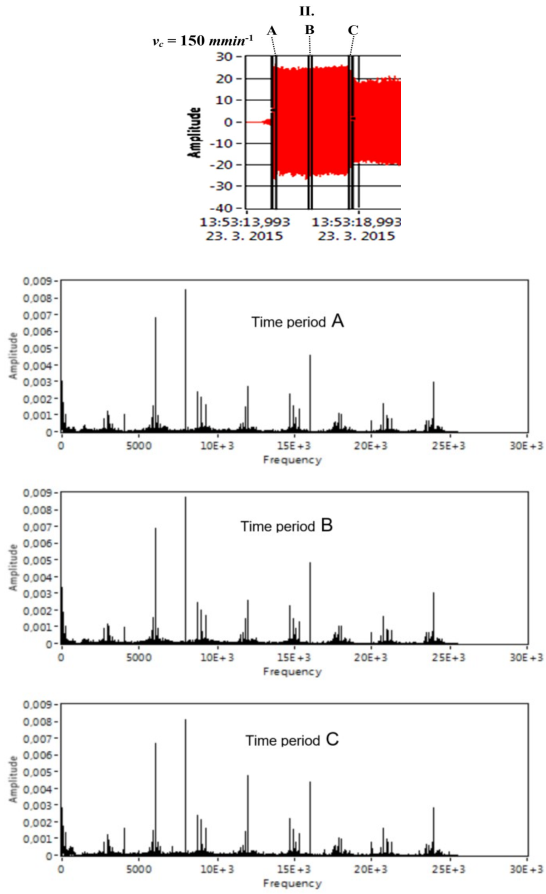


Figure 7. FFT spectra in individual analysed time periods A, B, C at the cutting speed 150 mmin^{-1}

. A similar course of the FFT spectrum than in other cutting speed v_c = 150 *mmin*$^{-1}$ occurs at the last speed and wherein the first section is recorded acceleration amplitude high values, which are in the range of 650 Hz - 1900 Hz. The sharp drop FFT amplitude values caused settled instrument occurs in FFT spectrum of the second section. Consequence of the decrease may be several factors that influenced the measurements, for example performance CNC machine. In the third section, the FFT spectrums are similar to previous sections analysed. As well as in the latter case, in all three sections of the recorded FFT spectra are similar. Start spectra showed a high amplitude value, then a rapid fall off a sharp downturn. High amplitude value may be due to an increase in speed and increase in feed speed in the simulation of the milling process. The cause of the decline and subsequent attenuation of the completion of the whole process simulation of the milling process. In each spectrum, the process is repeated. The highest value 0,7007 g of the amplitude is recorded at the frequency of 6000 Hz

5 EVALUATION AND CONCLUSION

By means of frequency analysis can be achieved early identification of technical conditions of components or mechanical systems. The main task is to identify the nascent fault, locate the place of its occurrence and to predict the time of failure occurrence. Diagnostics of failures of the machines serves as a tool to facilitate their faults, to avoid financial losses, unexpected downtime, and improve reliability. To proper diagnosis of machinery must be approached comprehensively and have available as much information as possible about their diagnosis. Incompleteness of information may result in the erroneous decision of the human factor. In the last period of great development in diagnosis has contributed to the improvement of the accuracy and its implementation in practice. Appropriate and efficient deployment of technical diagnostics and maintenance is an integral part of a competitive and prosperous company. It is necessary to realize that to a large extent this has an impact also on the protection of the health and life of a person. It is currently in the engineering enterprises frequent phenomenon an effort to save finances. The correct application of technical diagnostics it is possible these funds achieve.

The impact of vibrations performed in given conditions was analysed on the basis of the description of evaluation criteria for assessing the severity of vibrations on CNC machine. The criterion of vibration is assessed on the basis of the ISO 10816, according to the second class arising from the performance of the machine. [Krehel 2009] One of the assessment criteria is the size of the observed broadband vibrations, the second is the change in the size, regardless of their increasing or decreasing. Figure 8 shows the effective values of RMS in individual sectors measured at various cutting speeds.

As it was expected, the measured RMS values were lower when the milling cutter worked outside the machined workpiece in comparison with values measured during the machining process. The smallest effective values of RMS were achieved at cutting speed v_c = 125 *mm/min* measured at the spindle when the tool was not in contact with the workpiece and the maximum values of RMS were achieved during the machining with the cutting speed v_c = 150 *mm/min*.

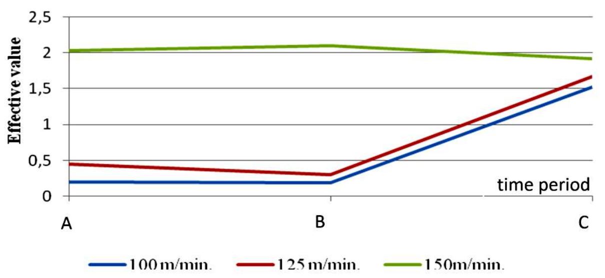


Figure 8. The effective values of RMS in individual measured sectors at various cutting speeds

The experimental measures have shown that the spindle of CNC machine does not show the critical vibrations, and it can be considered acceptable for unrestricted operation. However, on a closer look, the precise diagnosis of a fault must convert several measurements and share them among themselves to compare and examine. The courses of both measurements are significantly affected by external factors, e.g. other sources of vibrations in the object, the ambient temperature, the mounting of the sensor to the measured object and the like. It is therefore very important to these factors to minimise, to achieve the accurate determination of the technical condition of the equipment. More results obtained by diagnosis of the spindle on the CNC machining centre will be published in other blog posts.

ACKNOWLEDGMENTS

The paper was published thanks to the grants VEGA 1/0614/15; KEGA 087TUKE-4/2015; KEGA 013TUKE-4/2014 with direct support of Ministry of Education of the Slovak Republic and thanks to project ED2.1.00/03.0093 - Regional Technological Institute - RTI covered by the European Regional Development Fund and the state budget of the Czech Republic.

REFERENCES

[Baron 2016] Baron, P. et al. Proposal of the knowledge application environment of calculating operational parameters for conventional machining technology, Key Engineering Materials, Vol. 669, 2016, p. 95-102

[Blata 2011] Blata, J. Methods of technical diagnostics. Ostrava: VSB-TU. Ostrava, 2011. ISBN 978-80-248-2735-3

[Jaksch 2011] Jaksch, I. Technical diagnostics. Liberec: Technical University in Liberec. Liberec, 2011.

[Krehel 2009] Krehel, R. et al. Mathematical model of technological processes with prediction of operating determining value, Acta Technica Corviniensis: Bulletin of Engineering, Vol. 2/4, 2009, pp. 39- 42

[Krenicky 2008] Krenicky, T. Methods and means of eliminating sources of vibration for die casting machines. Technological Engineering, Vol. 5, No.2, pp. 58-59. ISSN 1336-5967

[Matus 2012] Matus, G. Time window for frequency analysis using smooth functions. Brno: VUT. Brno, 2012.

[Ondrouch 2011] Ondrouch, J. and Podesva, J. Technical vibration. Ostrava: VSB-TU. Ostrava, 2011.

[Ungureanu 2011] Ungureanu, N. et al. Contributions regarding, the mining drilling tribo-system, Archives of mining sciences, Vol. 56/3, 2011, pp. 527-535.

[Valent 2010] Valent, O. et al. Condition Monitoring and Maintenance Systems, 2010, Prague [online]. [30.04.2016]. <cmms.cz/archiv-clanku/doc_download/3-technicka-diagnostika-i.html>

CONTACTS:

Eng. MSc. Andrea Cizikova
Assoc. Prof. Eng. MSc. Katarina Monkova, PhD.
Technical University of Kosice
Faculty of manufacturing technologies
Department of technological systems design
Sturova 31, 080 01, Presov, Slovak Republic
a.cizikova87@gmail.com

katarina.monkova@tuke.sk

Prof. Eng. MSc. Peter Monka, PhD.
Technical University of Kosice
Faculty of manufacturing technologies
Sturova 31, 080 01, Presov, Slovak Republic
University of West Bohemia, Faculty of Mechanical Engineering
Univerzitni 22, 360 14 Pilsen, Czech Republic
peter.monka@tuke.sk

Eng. MSc. Marek Urban
University of West Bohemia, Faculty of Mechanical Engineering
Department of Machining Technology
Univerzitni 22, 360 14 Pilsen, Czech Republic
maarc@kto.zcu