INFLUENCE OF VIBRATION MAGNITUDE IN MACHINING OF MATERIALS BY TURNING TECHNOLOGY

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DOI: 10.17973/MMSJ.2021_10_2021118

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The basic task of any prosperous company is to minimize operating costs to a minimum. High-quality maintenance ensures an increase in the operational reliability of the machines. It is important to find a compromise between scheduled maintenance and production process requirements, so resources are spent to optimize the maintenance schedule. This is provided by technical diagnostics, which helps to monitor the technical condition and functional properties of the monitored machine under specified operating conditions. The publication is focused specifically on vibration diagnostics and its use in monitoring the transmission of vibrations during the turning of selected types of materials in the company with a focus on engineering, the ZVL AUTO s.r.o. The scope of research is mainly focused on the monitoring process in order to analyze the magnitude of vibration acceleration at two preselected parts of the machine tool - lathe.

KEYWORDS

Machined material, turning, spindle speed, vibrations, device status observation, signal processing, piezoelectric accelerometer

1 INTRODUCTION

Technical diagnostics is currently classified as an important field, not only in technical applications. One of the most widespread aspect of technical diagnostics is the vibration diagnostics, which is used to evaluate various rotary and other motion components of production machines in which mechanical vibration occurs [Kocman 2001, Lee 2007]. Vibrations serve as a source of information that can be analyzed and then evaluate the technical and operational condition of machines [Tlusty 1999, Modrak 2019, Pavlenko 2020]. In all machining processes, various factors can have both positive but also negative effect. These factors also include vibrations that may be related to the cutting process itself or may be caused by external sources [Cameron 1986]. These vibrations are undesirable and can cause several problems [Panda 2018, Peterka 2020, Sentyakov 2020]. In the first place, they affect the machine itself and thus its service life, tool life and can be a source of excessive noise [Sick 2002, Sidhpura 2012, Bozek 2021]. The second problem is their influence on the quality of the surface that's being machined [Mascenik 2014, Olejarova 2017]. High finishing requirements are placed on the dimensional and geometric accuracy of the workpiece in the finishing stages of operation such as grinding [Murcinkova 2020, Vojtko 2013]. This is where vibrations have a significant impact and it is necessary to locate their sources and, if necessary, take corrective measures to reduce them [Ganovska 2016, Turygin 2018]. In our case, the measurement of the magnitude of vibration acceleration was performed using a piezoelectric accelerometer at predetermined lathe points and machining input parameters. By measurement, frequency spectrums were obtained, which serve as a basis for evaluation and analysis, from which the limit values influencing the machining process on the lathe were determined. Afterwards, it is determined which of the examined speeds is suitable for use in the turning process itself at the measured point of the spindle head and the machining tool.

Thus, the main aim of the paper is to present the research focused on the monitoring process aimed at analysing the magnitude of vibration acceleration at two selected locations of the machine tool - the lathe, particularly on the lathe spindle and the turning knife when machining two types of steel.

2 OBJECT AND THE RESOURCES FOR DIAGNOSTICS

The measurements were performed in the turning workshop of the engineering company ZVL AUTO s.r.o. in Presov, which deals with the production of tapered roller bearings. The experiment was performed with a SUI 40/1500 lathe (Figure 1). It is a universal center lathe, which is still widely used in technical practice due to its reliability. The technical parameters of the used lathe are displayed below in Table 1.

Figure 1. Center lathe SUI 40/1500

Table 1. Technical parameters of the SUI 40/1500 center lathe

Parameter	Value
circulating diameter over bed [mm]	400
distance between points [mm]	1500
circulating diameter over the support [mm]	220
power of main electric motor [kW]	7.5
total weight [kg]	2800

Two types of steel were used for machining: STN 11600 and STN 12050. During machining, steel was removed using a right-hand turning cutting tool of the 20x20 mm type, in which a replaceable cutting plate marked PM 4035 was mounted. The phase constant of 20 mm/min and the removal of 3 mm of material were used during the measurement. Spindle speeds of 280, 350, 560 and 710 rpm were chosen as changing input rates.

Table 2. Basic technical parameters of the 4514-B sensor

Parameter	Value
measuring range [$m.s^{-2}$]	50
measurable frequency [kHz]	10
sensor sensitivity [mV/g]	100
impedance [Ω]	20
start-up time [s]	1

A miniature piezoelectric sensor type Bruel & Kjaer 4514-B-001 was used to measure the magnitude of the vibrations. The sensor is calibrated, and its technical parameters are displayed in Table 2.

Data collection was performed using a 4-channel analyser NI 9233 by a company called National Instruments. The technical parameters of the collection card are shown in Table 3.

The LabView SignalExpress software is a tool for collecting, recording, and evaluating data from the field of machine vibration diagnostics. It contains all the functions and tools needed for signal analysis in the interval and frequency domain. In SignalExpress, a steady pace of 20 seconds was selected from a total time record of 120 seconds, and a frequency spectrum in the range of 0 to 10 kHz was generated in increment of 100 Hz using a Fourier transform (FFT).

Table 3. Basic technical parameters of the NI 9233 collection card

Parameter	Value
resolution [bit]	24
dynamic range [dB]	102
input range [V]	± 5
maximum sampling unit	50 measurements per sec
number of analog inputs	4 simultaneous samples

3 IMPLEMENTATION OF THE MEASUREMENT

Before the measurement, it was necessary to determine the spots for mounting the accelerometer, if necessary. A simplified diagram of the machine and the selected spots for mounting the vibration sensor are shown in Figure 2. The accelerometer was attached using a magnet and information on its labelling, scanning direction and sensitivity is displayed in Table 4.

Table 4. Basic technical parameters of the NI 9233 collection card

channel	sensor location	direction of the vibration scan	sensitivity
CH1	spindle head	vertically	100 mV/g
CH2	lathe cutting tool	vertically	100 mV/g

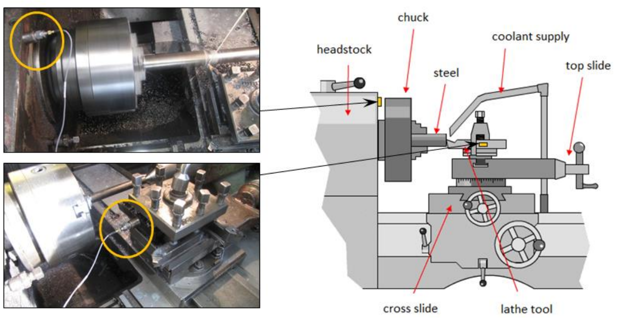

Figure 2. Simplified diagram of the machine with the location of the accelerometers

The evaluation of the measured data from the performed measurements of vibration consisted first of the upload of the measured records, the so-called raw data from the analyser to the computer. Later, data were FFT processed using software SignalExpress. The results are recorded in the form of a frequency spectrum of accelerated vibrations and graphical dependences for predetermined machined steels STN 11600 and STN 12050.

4 EVALUATION OF MEASUREMENTS DURING THE MACHINING OF STEEL STN 11 600

As shown in graph (Figure 3) where the acceleration of vibrations is dependent on the frequency within a range 0 – 10 kHz for the scanning position of the spindle head pointed in the vertical direction while machining at predetermined rotational spindle speeds of 350, 560 and 710 rpm.

As seen in the frequency spectrum, when machining at 350 rpm, a higher vibration of the amplitude can be observed at a speed of 0.7 kHz, where the dominant value of the vibration amplitude is around 2.57 * 10^{-6} g. At a speed of 560 rpm in a rotational frequency of 1.2 kHz, the largest amplitude of vibrations reached the value of 6.35 * 10^{-5} g. Compared to the previously used spindle speed during machining, it can be seen that at 710 rpm the lathe spindle speed is significantly lower, and its highest rate of vibration amplitude is around 1.64 * 10^{-6} g at a frequency of 0.6 kHz.

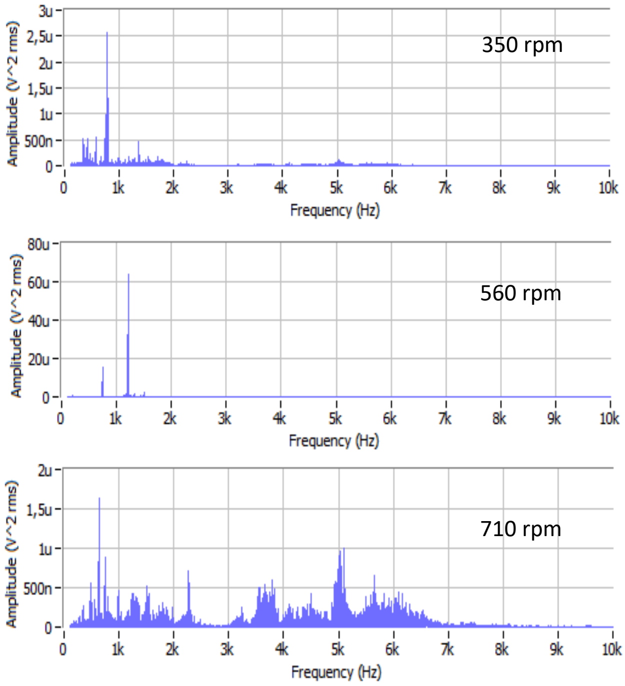

Figure 3. The frequency spectrum of the acceleration of vibrations amplitude at a frequency for individual speeds on the lathe spindle (steel STN 11 600)

The graph in Figure 4 shows the dependence of the vibration acceleration on the frequency in the range 0 - 10 kHz for the scanning point of a turning knife scanned in the vertical direction when machining at a predetermined spindle speed of 350, 560, and 710 rpm.

According to the dependences on the frequency spectrum when machining at 350 rpm, it can be seen that the amplitude of the vibration acceleration is around 5.13 * 10^{-5} g at a speed of about 4.7 kHz. When machining material with both 560 rpm and 710 rpm, the dominant rate reached the amplitude of the vibration acceleration at the same speed, 4.7 kHz. The amplitude of the vibration acceleration when machining the material at 560 rpm is around 1.32 * 10^{-4} g. When machining at 710 rpm, the dominant vibration value was achieved approximately the same as when machining at 560 rpm, namely 1.23 * 10^{-4} g.

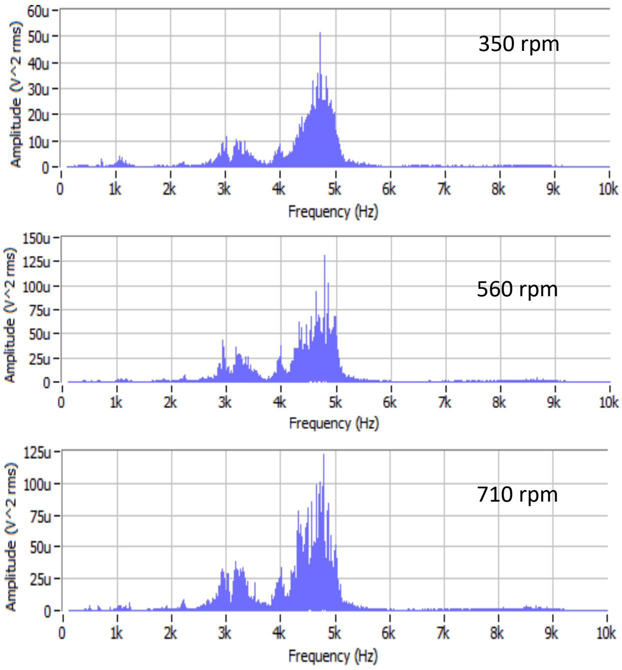

Figure 4. The frequency spectrum of vibration acceleration amplitude at a frequency for individual speeds on a turning knife (steel STN 11 600)

The envelope method was used as an additional step to evaluate the measured values. The envelopes are designed for better overview only in the frequency range of 0 - 7000 Hz, since from the previous observations (in Figures 3 and 4), it can be seen that the dominant rates of the amplitude in vibration acceleration are recorded in this spectrum. The comparison of measured rates consists of the creation of graphical dependences (Figure 5) separately for the selected machining speed and together for the measured points.

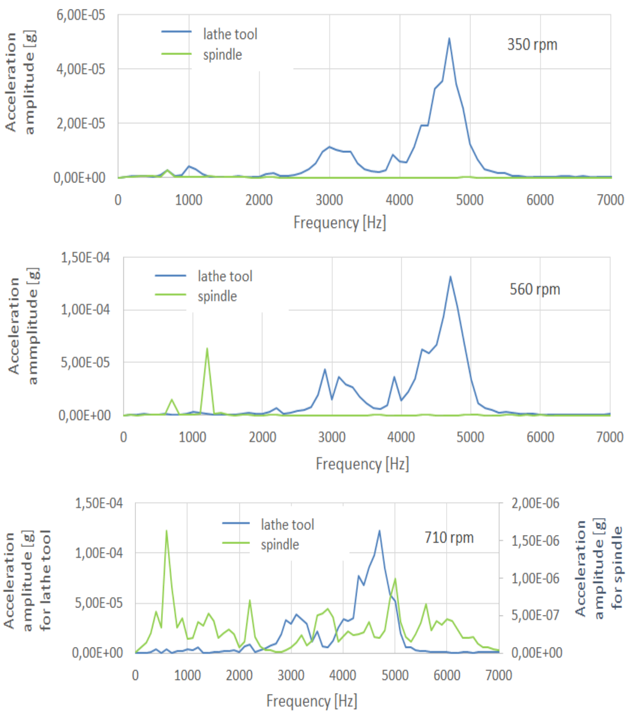

Figure 5. Comparing the graphs of envelopes in a frequency spectrum in steel machining 11 600

It was expected that the vibrations would be greater at the measured location - a turning knife (cutting tool), this was confirmed even after the evaluation of graphical dependencies from the envelopes. The amplitude of the vibration acceleration occurs at this measured spot in all measurements at a frequency speed of 4700 Hz. When machining at 350 rpm on a turning knife, the rate of this amplitude is 19.96 times higher than on the lathes spindle head. At 560 rpm, the rate of the vibration acceleration amplitude on the cutting tool is 2.07 times higher than on the spindle. Finally, at 710 rpm, the amplitude is 75 times higher than on the spindle.

5 EVALUATION OF MEASUREMENTS WHEN MACHINING STEELS STN 12 050

The graph in Figure 6 shows the dependence of the vibration acceleration on the frequency in the range of 0 - 10 kHz for the scanning position on the spindle head pointed in a vertical direction when machining at predetermined spindle speeds of 350, 560 and 710 rpm.

From the frequency spectrum, when machining with a speed of 350 rpm, a higher amplitude of vibrations can be seen at a speed of 0.9 kHz, where the dominant value of the vibration amplitude is around the value of 1.72 * 10^{-4} g. At speeds of 560 rpm also at a speed of 0.9 kHz, the largest amplitude of vibrations reached a rate of 7.74 * 10^{-5} g. Compared to the previously used rotational speed with spindle during machining, it can be seen that at 710 rpm the lathe spindle speed is significantly lower and its largest rate of vibration amplitude is around 9.57 * 10^{-5} g at a frequency of 1.9 kHz.

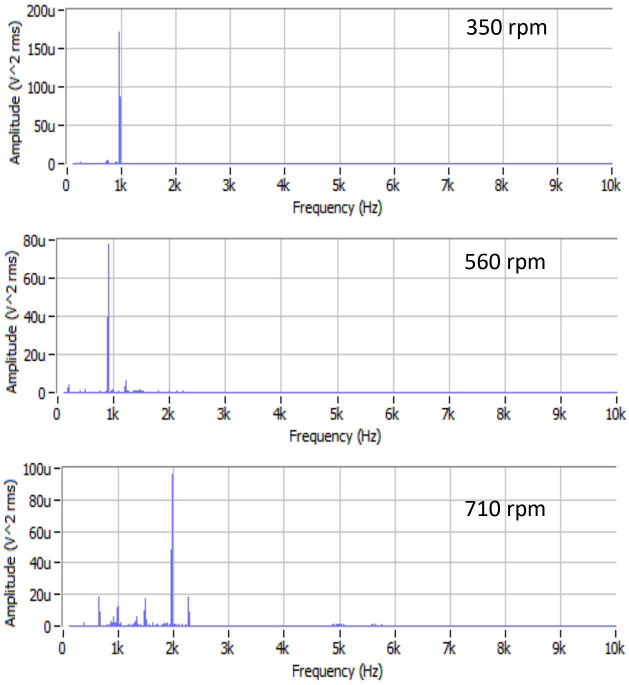

Figure 6. The frequency spectrum of the amplitude of vibration acceleration at a frequency for individual speeds on the lathe spindle (steel STN 12 050)

The graph in Figure 7 shows the dependence of the vibration acceleration on the frequency in the range of 0 - 10 kHz for the scanning spot on the turning knife scanned in a vertical direction when machining at predetermined spindle speeds of 350, 560, and 710 rpm.

According to the dependences on the frequency spectrum when machining at 350 rpm, it can be seen that the amplitude of the vibration acceleration is around 3.10 * 10^{-5} g at a speed of about 2.4 kHz. The amplitude of the vibration acceleration when machining the material at 560 rpm is around 3.17 * 10^{-5} g at a frequency of 2.6 kHz. When machining at 710 rpm, the dominant vibration rate was achieved approximately the same as when machining at 560 rpm, and that is 4.21 * 10^{-5} g at a speed of 4.7 kHz.

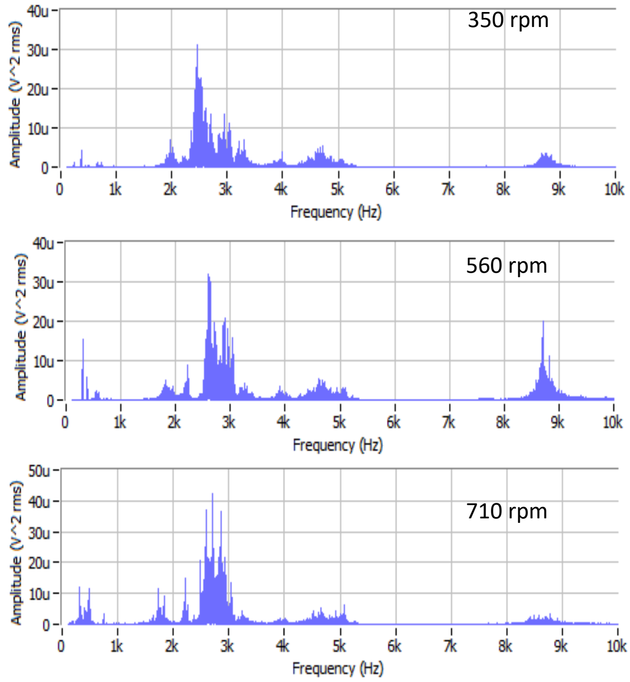

Figure 7. The frequency spectrum of vibration acceleration amplitude at a frequency for individual speeds on a turning knife (steel STN 12 050)

Similar to the machining of STN 11 600 material, the envelope method was also used to compare the measurement results in the machining of STN 12 050 steel. Envelopes are formed only in the frequency range of 0 - 5000 Hz, since from the previous observations in Figures 6 and 7, it can be seen that the dominant rates of the amplitude of the vibration acceleration are recorded in this spectrum. The comparison of the measured rates consists of the creation of graphical dependences (Figure 8) separately for the selected machining rotational speed and together for the measured spots.

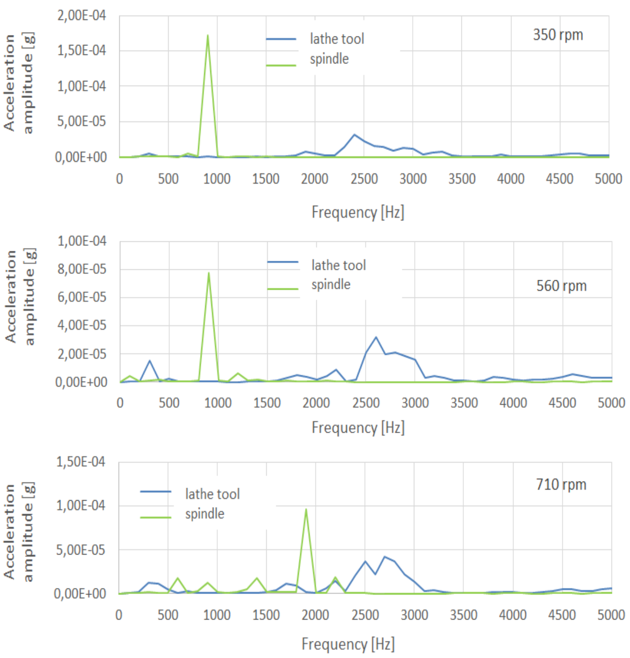

Figure 8. Comparing envelope graphs of the frequency spectrum in steel machining 12 050

As in the previous evaluation when machining STN 11 600 steel, it was expected that even when machining STN 12 050 steel, the vibrations would be greater at the measured point - the turning knife. This was also confirmed from the evaluation of the envelopes. When machining at 350 rpm on a turning knife, the rate of this amplitude is 5.54 times higher than on the lathe spindle head. At 560 rpm, the rate of the vibration acceleration amplitude on the knife is 2.44 times higher than on the spindle. Finally, at 710 rpm, the amplitude is 2.27 times higher than on the spindle.

The amplitude of the vibration acceleration is smaller on the lathe spindle head during both machining operations, because the vibrations are transmitted to the tailstock and to the face plate located on the lathe spindle. It should also be noted that the lathe spindle was located further away from the turning point and is also more rigid than the machining tool itself.

6 EVALUATION OF THE MEASUREMENTS

The evaluation of the measurement was performed according to the Czech standard norm CSN ISO 20 0065, which stipulates the methods and conditions of measurement, such as the place of measurement and the direction of vibration scanning. It also determines the limit rates, effective rates of deflection, speed and acceleration of vibrations in metal machine tools. These rates were also compared with the documentation for the lathe, about the rates of the magnitude of vibrations affecting the operation of the device. The rates influencing (red) or not influencing (green) the operation of the lathe are given in Table 5.

Table 5. Table for dominant measured values of vibration acceleration

Steel STN	measured point					
	lathe spindle			turning knife		
	spindle speed					
	350 rpm	560rpm	710 rpm	350 rpm	560rpm	710 rpm
11 600	2.57 $x10^{-6}$	6.35 $x10^{-5}$	1.64 $x10^{-6}$	5.13 $x10^{-5}$	1.32 $x10^{-4}$	1.23 $x10^{-4}$
12 050	1.72 $x10^{-4}$	7.74 $x10^{-4}$	9.57 $x10^{-5}$	3.10 $x10^{-5}$	3.17 $x10^{-5}$	4.21 $x10^{-5}$

7 CONCLUSION

The demand for highly reliable and precise machining processes is constantly rising and therefore the turning process must be ever more intelligent. The growing shortage of professionals has accelerated the need to modify the turning process towards greater autonomy. For this reason, and because of the elimination of previously investigated influences, such as machining parameters, it is recommended to secure the machine with a diagnostic and measuring system.

Each machine tool has several natural frequencies, so-called resonant frequencies. Resonance occurs when the frequency of the excitation forces is equal to the frequencies of its own oscillations. If excessive vibration amplitude occurs at a certain frequency during turning, it is necessary to solve the problem, for example by changing the chip depth reduction or by changing the spindle speed.

It is also necessary, for turning to be performed at lower speeds than critical or to overcome the critical speed range quickly and turning at supercritical speeds. The operation of the machine in the area of resonance not only deteriorates the quality of the machined surface but above all reduces the reliability and service life of tools and the machine several times, where a failure can subsequently occur.

The measured values of vibrations and their comparison from individual measurements are recorded in the frequency spectra and compared in graphs.

To conclude, in the paper, frequency analysis methods were used to identify vibrational behaviour related to the machining of the two types of steel. The results may be used for optimization of the process parameters in order to provide satisfactory quality of the products and to enhance service life of the machining instrumentation.

ACKNOWLEDGMENTS

This work was supported by the Slovak Ministry of Education within project VEGA No. 1/0823/21 and by the Slovak Research and Development Agency under contract No. APVV-18-0316.

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