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ANALYSIS OF THE INFLUENCE OF SELECTED TECHNOLOGICAL PARAMETERS ON THE MAGNITUDE OF VIBRATIONS DURING MATERIAL MACHINING BY MILLING

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Abstract: *With the current development of technology, more and more emphasis is being placed on product quality. Therefore, it is important in machining to continuously take care to reduce the influence of undesirable factors that adversely affect the machining process itself. Vibrations are one of the basic factors influencing the quality of machining. This paper analyzes the issue of vibration during milling. By measuring selected vibration parameters on the spindle head of a universal tool milling machine, information on the process of vibration magnitude in the milling process was obtained using a multiparametric vibration sensor. During machining, the magnitudes of vibration velocity and acceleration are recorded at speed changes of 71 rpm, 90 rpm, and 140 rpm. The measured data are tabulated and displayed in graphical dependencies. They are used to obtain the information needed to develop a proposal for a solution to the mentioned issue, which is the main objective of this research.*
Key words: *Equipment diagnostics, milling, vibration magnitude, speed and vibration acceleration*

Analiza uticaja odabranih tehnoloških parametara na veličinu vibracija prilikom obrade materijala glodanjem. *Uz trenutni razvoj tehnologije, sve se više naglasak stavlja na kvalitetu proizvoda. Stoga je važno u mašinskoj obradi kontinualno voditi računa o smanjenju uticaja nepoželjnih faktora koji štetno utiču na sam proces obrade. Vibracije su jedan od osnovnih faktora koji utiču na kvalitetu obrade. Ovaj rad analizira problematiku vibracija tokom glodanja. Merenjem odabranih parametara vibracija na glavi vretena univerzalne alatne glodalice dobijena je informacija o procesu veličine vibracija u procesu glodanja pomoću multiparametarskog senzora vibracija. Tokom obrade beleže se veličine brzine i ubrzanja vibracija pri promenama brzine od 71 o/min, 90 o/min i 140 o/min. Izmereni podaci su tablični i prikazani u grafičkim zavisnostima. Koriste se za dobijanje informacija potrebnih za izradu predloga rešenja navedenog problema, što je i glavni cilj ovog istraživanja.*
Ključne reči: *Dijagnostika opreme, glodanje, veličina vibracija, brzina i ubrzanje vibracija.*

1. INTRODUCTION

The constant development of production machines and methods of machining materials also requires the development of means for their control and appropriate diagnostics. At present, the industry is concentrating on meeting the increasingly demanding requirements for quality, quantity, and production time [1,2]. In most industries, production in a shorter time (in greater quantity) will affect the quality of the product due to their rapid production and a short time to check the quality [3]. Generally, oscillations occur in the machining process, which is undesirable and cause deterioration in product quality. These mechanical oscillations are also the reason for reducing the service life of the equipment and its components, endangering the safety of its operators and the surrounding area, or economic efficiency and thus competitiveness [4,5]. However, when milling metals, in most cases higher machining speeds result in better part quality and thus shorter production times [6,7]. The resulting quality of components is thus affected by certain phenomena (e.g.: vibration), characteristics (e.g.: rigidity of the SNOP system), and cutting parameters (e.g.: cutting forces), which are an integral part of milling operations [8-10]. Several measures make it possible to prevent machine breakdowns by eliminating harmful influences and thus improving product quality.

Thanks to the ever-improving methods of monitoring and diagnostics of machines and equipment, the optimum technical condition can be achieved by correctly setting the machine's input parameters. In addition to improving product quality, this measure will also ensure a longer machine life and a higher degree of reliability. This will reduce maintenance and repair costs and ensure a high level of economic efficiency.

2. MATERIAL AND METHODOLOGY

2.1. Test sample

During the measurement of vibration magnitude, the material being machined by milling was STN 11 500 grade steel [11]. Grade 11 steel is characterized by the prescribed purity (Sulphur and phosphorus content). Their properties are determined by their carbon content, which does not exceed 0,7 % - the higher the content, the higher the strength and hardness of the steel, but the lower the toughness, tensibility, and plasticity. Steels with good weldability have a carbon content of less than 0,2 %. For deep drawing, the steel must have a carbon content of less than 0,1 %. The chemical composition and mechanical properties are given in Table 1 [10].

chemical properties	
name	value
C	0,07-0,75 %
Si	0,15-0,55 %
Mn	0,4-1,6 %
P	<0,05 %
S	<0,05 %
mechanical properties	
name	value
Yield strength Re	195-637 MPa
Tensile strength Rm	373-980 MPa
Ductility A5	6-31 %
Hardness HBmax	113-290

Table 1. The frequency spectrum of vibration acceleration at point 1 when opening without load

2.2. Methodology of experiments

Experimental analysis of the magnitude of the two basic vibration parameters (magnitude and acceleration) were performed on the spindle head housings of the AVIA FNC 25 universal tool milling machine (Fig. 1). The material was machined by milling with a combination of feed rate (14, 18, 90 mm/min) and spindle speed (71, 90, 140 rpm) separately for the two milling tools used [10].

Fig. 1. Universal milling machine - AVIA FNC

Two types of tools were used to machine steel (Fig. 2):
– steel insert semi-coarse-toothed milling cutter type N
– milling cutter with interchangeable swivel type VBD inserts

Their basic technical parameters are given in Tab. 2.

N-type steel cutter

Type VBD carbide milling machine

Fig. 2. Types of tools used in material machining

steel inserts semi-coarse-toothed milling cutter type N	
terms	value
diameter	100 mm
height	50 mm
tooth number	10
clamping diameter	32 mm
helix angle	35°
face angle	12°
material	HESSE (i.e., HSS + Co5) - cast milling cutter
milling cutter with interchangeable VBD-type carbide inserts	
terms	value
diameter	125 mm
angle	90°
blade number	10
clamping diameter	40 mm
total height	63 mm
blade VBD height	15,4 mm
screws	M3,5x11/T15

Table 2. Technical parameters of both tools used in steel machining [12]

2.3. Description of the measuring equipment

A multiparametric sensor type CMMS SN: 1210002 from CMMS CHECKER was used to measure the magnitude of vibration. It was mounted horizontally on the measured point by a magnet and the detail of the sensor mounting is shown in Fig. 3. Its technical parameters are given below [10].

– sensitivity: 100 mV/g
– frequency: ±3 dB; 0,7 to 10 000 Hz
– application temperature: -50 to +120 °C

Fig. 3. Detail of the location and attachment of the sensor on the spindle head housing of the milling machine

3. RESULTS AND DISCUSSION

The analysis of the results of the experimental studies was divided into the following phases:

– measured values of vibrations during machining with a steel milling machine,
– measured values of vibrations during machining with a carbide milling machine.

3.1. Measured values of vibrations during machining with a steel milling machine

Table 3 shows a set of measured values of vibration magnitude of two basic parameters - vibration velocity "v" and vibration acceleration "a" depending on the selected technological parameters - feed rate and spindle speed. The graphs in Fig. 4 show the graphical evaluation of the 1-parametric dependencies "v, a - feed rate". These dependencies are shown in the form of clustered graphs in cases where the spindle speed is constant (2 dependencies "v, a - feed rate" are plotted in one graph for three different feed rate values of 14, 18, and 90 mm/min).

input parameter		output parameter	
spindle speed	feed rate	vibration velocity	vibration acceleration
71 rpm	14 mm/min	1,5 mm/s	1,5 g
	18 mm/min	1,1 mm/s	1 g
90 rpm	90 mm/min	2,4 mm/s	1,5 g
	14 mm/min	1,2 mm/s	1,4 g
140 rpm	18 mm/min	1,5 mm/s	2,3 g
	90 mm/min	1,2 mm/s	1,6 g

Table 3. Measured values of vibration magnitude when machining with a steel milling machine

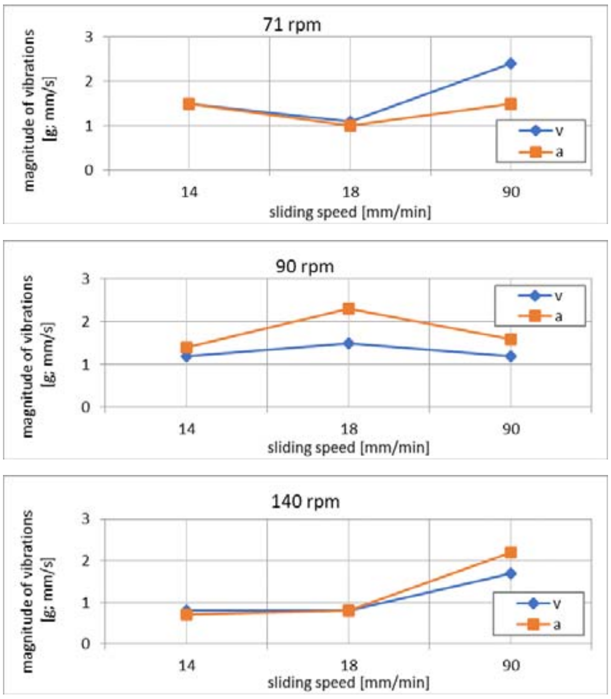


Fig. 4. Graphical representation of the 1-parametric dependence "v, a-displacement" at spindle speeds of 71, 90, and 140 rpm when machining with a steel milling cutter

From the graphical dependence of Fig. 4, where a spindle speed of 71 rpm was used for steel machining, it can be seen that the acceleration curve has a decreasing-increasing tendency. The lowest value of 1 g is measured at a feed rate of 18 mm/min. At a feed rate of 14 mm/min, the graph shows an acceleration of 1.5 g. The same value is measured when the maximum feed rate of 90 mm/min is reached. The vibration velocity has fluctuating values. At the selected feed rate of 14 mm/min, the velocity value is 1,5 mm/s. The lowest speed of 1,1 mm/s is reached at a feed rate of 18 mm/min. Moving to a feed rate of 90 mm/min, the velocity value increases significantly to a maximum level of 2.4 mm/s.

Using a spindle speed of 90 rpm, the graph shows an increase in the acceleration value from 1.4 to 2.3 g in the range of feed rates from 14 to 18 mm/min. When the feed rate was subsequently changed to 90 mm/min, the acceleration level dropped to 1.6 g. The velocity varied less significantly, from a value of 1.2 mm/s at 14 mm/min to a value of 1.5 mm/s at 14 mm/min. The reduction in velocity back to 1.2 mm/s was achieved by changing the feed rate to a level of 90 mm/min.

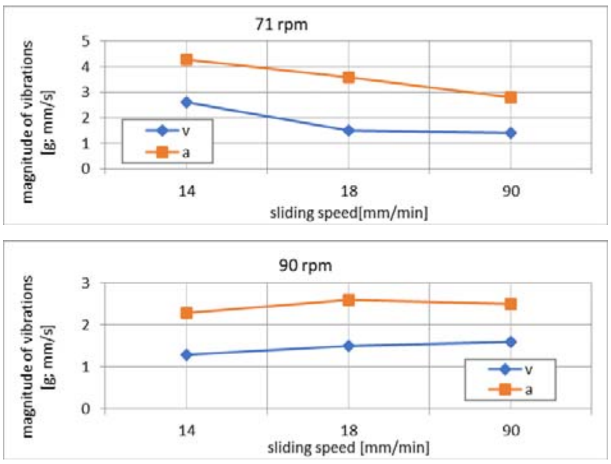
The curve has an increasing character even when machining at a spindle speed of 140 rpm. If at a feed rate of 14 mm/min an acceleration of 0.7 g was measured, the acceleration increased to 0.8 g when the feed rate was changed to 18 mm/min. The highest acceleration value is seen at a 90 mm/min feed rate, namely 2.2 g. The velocity value of 0.8 mm/s was measured equally for both 14 mm/min and 18 mm/min feed. When the maximum feed rate of 90 mm/min was selected, the velocity curve took the value of 1.7 mm/s.

3.2. Measured values of vibrations during machining with a carbide milling machine

Table 4 shows a set of measured values of vibration magnitude of two basic parameters - vibration velocity "v" and vibration acceleration "a" depending on selected technological parameters - feed rate and spindle speed. The graphs in Fig. 5 show the graphical evaluation of the 1-parametric dependencies "v, a - feed rate". These dependencies are shown in the form of clustered graphs in cases where the spindle speed is constant (2 dependencies "v, a - feed rate" are plotted in one graph for three different feed rate values of 14, 18, and 90 mm/min).

input parameter		output parameter	
spindle speed	feed rate	vibration velocity	vibration acceleration
71 rpm	14 mm/min	2,6 mm/s	4,3 g
	18 mm/min	1,5 mm/s	3,6 g
90 rpm	90 mm/min	1,4 mm/s	2,8 g
	14 mm/min	1,3 mm/s	2,3 g
140 rpm	18 mm/min	1,5 mm/s	2,6 g
	90 mm/min	1,6 mm/s	2,5 g

Table 4. Measured values of vibration magnitude during machining with a carbide milling machine



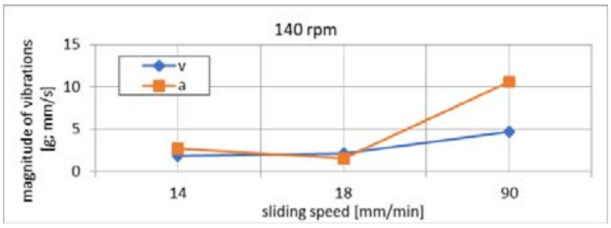


Fig. 5. Graphical representation of the 1-parametric dependence "v, a-displacement" at spindle speeds of 71, 90, and 140 rpm when machining with a carbide milling machine

From the graphical dependence of Fig. 5, where the spindle speed of 71 rpm was used in steel machining, it can be seen that the acceleration curve decreases linearly with an increase in feed rate. The highest acceleration value of 4.3 g was measured at a feed rate of 14 mm/min. At a feed rate of 18 mm/min, the acceleration value dropped to 3.6 g. The acceleration curve reached a minimum at a feed rate of 90 mm/min at 2.8 g. The velocity decreased more significantly at lower feed rates. At a feed rate of 14 mm/min, the vibration velocity was 2.6 mm/s and at a feed rate of 18 mm/m, it was 1.5 mm/s. When the feed rate was changed to 90 mm/min, the velocity dropped to 1.4 mm/s.

The graphical dependence using a spindle speed of 90 rpm shows an increase in acceleration value at feed rates of 14 and 18 mm/min. At a feed rate of 14 mm/min, the acceleration value is 2,3 g. When the feed rate was changed to 18 mm/min, the acceleration was equal to 2,6 g. When the maximum feed rate was selected, the acceleration decreased to 2.5 g. The vibration rate increased as the feed rate increased. At a feed rate of 14 mm/min, the velocity was 1.3 mm/s. Increasing the feed rate to 18 mm/min increased the velocity value to 1.5 mm/s. The highest speed value of 2.6 mm/s was obtained at a feed rate setting of 90 mm/min.

The curve has a decreasing-increasing tendency when machining at a spindle speed of 140 rpm. At a feed rate of 14 mm/min, an acceleration value of 2.7 g was measured. When the feed rate was changed to 18 mm/min, the acceleration value dropped to 1.5 g. At a maximum feed rate of 90 mm/min, the acceleration value rose sharply to 10.6 g. The evolution of the velocity curve is almost linearly increasing. By setting the feed rate to 14 mm/min, a velocity of 1.8 mm/s was measured. When the feed rate was changed to 18 mm/min, the velocity value increased to 2.1 mm/s. The highest velocity of 4.7 mm/s was reached by the vibration at the maximum feed rate of 90 mm/min.

4. RECOMMENDATIONS FOR VIBRATION VALUES

The recommended values of technological parameters for achieving the minimum and maximum experimentally measured vibration values - vibration velocity and acceleration are listed in Tab. 5.

	tool type	output parameter	technological parameters	
			spindle speed	feed rate
for minimum experimental measured values	steel milling machine	vibration velocity v – 0,8 mm/s	140 rpm	14 and 18 mm/min
		vibration acceleration a – 0,7 g	140 rpm	14 mm/min
for maximum experimental measured values	steel milling machine	vibration velocity v – 2,4 mm/s	71 rpm	90 mm/min
		vibration acceleration a – 2,3 g	90 rpm	18 mm/min
for minimum experimental measured values	carbide milling machine	vibration velocity v – 1,3 mm/s	90 rpm	14 mm/min
		vibration acceleration a – 1,5 g	140 rpm	18 mm/min
for maximum experimental measured values	carbide milling machine	vibration velocity v – 4,7 mm/s	140 rpm	90 mm/min
		vibration acceleration a – 10,6 g	140 rpm	90 mm/min

Table 5. Recommended values of technological parameters for achieving minimum and maximum experimentally measured vibration values

5. CONCLUSION

The paper deals with the investigation of the influence of two selected technological parameters (spindle speed and feed rate) on the vibration parameters (velocity and acceleration) of a sample of steel grade STN 11 500 in a production system with milling technology. The results presented are valid for the exact experimental conditions described in the paper. The obtained results of measurements and analyses allowed us to draw the following conclusions:

- with increasing feed rate, an increase in the observed vibration parameters was expected, but this was not confirmed for all speed changes.
- when using a steel milling machine and setting the spindle speed to 71 rpm, it is most suitable to machine the selected material at a feed rate of 18 mm/min where the vibration magnitudes reached the following values vibration rate of 1.1 mm/s and acceleration of 1 g. By changing the speed to 90 rpm, the lowest vibration values were measured at a feed rate of 14 mm/min. The vibration velocity and acceleration were 1,2 mm/s and 1,4 g respectively. By setting the maximum speed to 140 rpm, machining with the steel cutter was most effective at a feed rate of 14 mm/min, when the speed value was only 0.8 mm/s and the acceleration was 0.7 g.
- in the case of the use of a carbide milling machine at 71 rpm, the lowest values of the measured quantities were obtained by selecting a maximum feed rate of 90 mm/min. The vibration velocity reached 1.4 mm/s and the acceleration 2.8 g. Increasing the speed to 90 rpm resulted in the most effective values of 1.3 mm/s vibration velocity and 2.3 g acceleration

being achieved by selecting a feed rate of 14 mm/min. Moving to 140 rpm, the lowest vibration velocity of 1.3 mm/s was measured at 14 mm/min and the acceleration of 1.5 g was measured at 18 mm/min.

The results of the experimental studies presented in this paper do not exhaust all the related issues of the problems of investigating the influence of selected technological parameters in terms of vibration magnitude. Therefore, it is necessary to continue this interesting and promising research, especially in the context of optimization of processes used in milling technologies for industrial applications. The directions for the development of this paper could be, for example, to research other types of steel. Research the dependencies of other types of milling tools. Extend the research of selected technological parameters over wider ranges of their values.

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