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IMPACT OF ABRASIVE MASS FLOW RATE WHEN PENETRATING INTO A MATERIAL ON ITS VIBRATION

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Preliminary notes

The article deals with the impact of mass flow rate of abrasive in a water jet when penetrating into a material by using the vibration analysis. The vibrations of material were recorded by sensors placed on the experimental material. Values that were studied were amplitude and FFT (Fast Fourier Transform) spectrum of signal. The stainless steel AISI309 was used as the experimental material. Data recorded during the cutting process of the AWJ cutting were analysed by the LabVIEW programming environment. The paper outlines the course of the recorded data and the FFT spectrum of this signal. Presented here is only a part of the basic research focused on the application of vibrations as a feedback for on-line control of abrasive water jet.

Keywords: *abrasive water jet, abrasive mass flow rate, penetration into material, vibration analysis*

Utjecaj brzine abrazivnog masenog protoka na vibracije kod prodiranja u materijal

Prethodno priopćenje

Članak se bavi utjecajem masenog protoka u vodenom mlazu, kada on prodire u materijal, koristeći analizu vibracija. Vibracije materijala zabilježene su senzorima postavljenim na eksperimentalnom materijalu. Veličine koje su proučavane su amplituda i FFT (brza Fourierova transformacija) spektar signala. Kao eksperimentalni materijal korišten je nehrđajući čelik AISI 309. Podaci snimljeni tijekom procesa rezanja mlazom vode analizirani su LabVIEW programskim okruženjem. Nadalje ovdje je opisan tok snimljenih podataka i FFT spektar ovog signala. Izvještaj sadrži djelomični rad temeljnog istraživanja usmjerenog na primjenu vibracija kao povratne informacije za on-line kontrolu abrazivnog vodenog mlaza.

Ključne riječi: *abrazivni vodeni mlaz, abrazivni maseni protok, analiza vibracija, prodiranje u materijal*

1 Introduction
Uvod

The development of new materials with specific features requires the continual technologists' focus on their possibilities of machining. They encounter a need to develop new technologies which are adequate for machining those new materials. The abrasive water jet cutting technology is one of these technologies. The abrasive water jet is currently the most common cutting tool used in special application. It is able to provide cold cutting of all known materials, so there is no thermal degradation of material that appears when using other non – conventional technologies. The tool consists of a mixture of high-pressure water and abrasives that pass through a nozzle, so it is changed to a high velocity water jet with abrasive permeate that is supplied to it [6]. Despite the ongoing investigation of this technology, all the processes involved in material cutting are not yet explained

2 The issue being solved
Rješavani problem

There are two ways of the abrasive water jet impact on material. One of them is a smooth water jet penetration into the material. Second one is the penetration caused by the shock impact of the water jet. This method is used to cut the closed hollow products and also when punching, engraving and milling by the abrasive water jet. During penetration there is a back-flow of the hydro-abrasive mixture. The penetration through the material by the abrasive water jet is shown in Fig. 1. This issue has been studied in more details by Guo and Ramulu. They deal with the impact of abrasive water jet onto the material by an optical method [2]. Their further research focuses on the water jet drilling [3, 4]. The research on the mechanism of penetration is currently carried out by Momber [7], Guo [3] and Hloch [4]. By the use of acoustic emission and vibrations they are trying to get the most detailed and accurate data about this not yet explained removal phenomenon. Despite the great effort of researchers, there are still many unexplained phenomena in this field of research. The vibrations have been rather underused when investigating this technology. More attention of researchers has been paid to acoustic emission emitted by the process. Momber et al. [7] used acoustic emission for online analysis of eroded materials. Foldyna et al. studied the high-pressure systems by using acoustic emission [1]. The authors of this article, Hloch and Valíček dealt in previous works with the impact of factors onto the acoustic pressure level during the abrasive water jet cutting

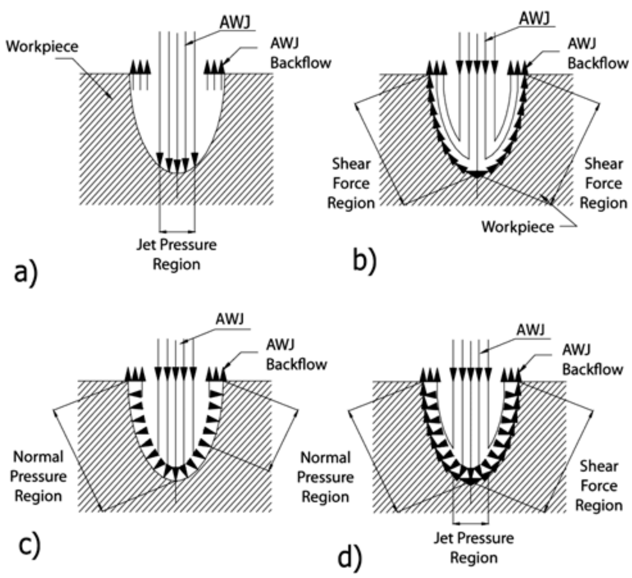

Figure 1 *Penetration caused by the shock impact of the waterjet* [3]
Slika 1. *Prodiranje uzokovano udarcem mlaza vode* [3]

of materials and also elaborated a concept of surface quality prediction for the abrasive water jet cutting process [8]. For the purpose of diagnostics of the technological process of abrasive water jet cutting by vibration analysis [4] a series of experiments was performed.

Table 1 *Experimental conditions*
Tablica 1. *Eksperimentalni uvjeti*

Factors	Experimental range
Pressure *p*/MPa	350
Traverse speed *v*/mm/min	50, 75, 100, 150
Abrasive mass flow rate m_a /g/min	250, 400
Water orifice diameter d_o/mm	0,14
Focusing tube diameter d_f/mm	0,8
Standoff distance *z*/mm	3
Number of passes	1
Angle of attack, φ/°	90
Type of abrasive	Barton Garnet
MESH	80
Material thickness	15 mm
Type of material	AISI 309 – (Cr– Ni oceľ), chemical composition (C 0,20 %, Mn 2%, Si 1 %, Cr 22 – 24 %, Ni 12 −15 %, P 0,045 %, S 0,03 %) mechanical properties (HRB 95, μ = 0,27– 0,3, E = 200 GPa, σ_t = 515 MPa, σ_K = 205 MPa, A = 40 %, Z = 50 %)

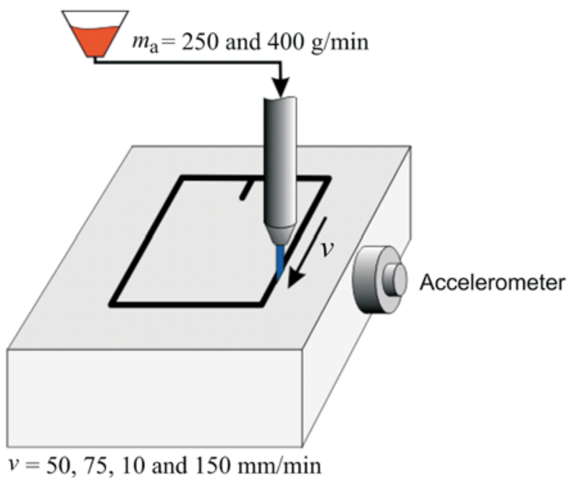

Figure 2 *Cutting of experimental samples of material AISI 309, E = 200 GPa; variable values: v = 50, 75, 100, 150 mm/min; m_a = 250 and 400 g/min; constant values: p = 350 MPa, d_0 = 0,14 mm, d_f = 0,8 mm, z = 3 mm, φ= 90°*
Slika 2. *Rezanje eksperimentalnih uzoraka od materiala AISI 309, E = 200 GPa; promjenjive veličine: v = 50, 75, 100, 150 mm/min; m_a = 250 i 400 g/min; konstantne veličine: p = 350 MPa, d_0 = 0,14 mm, d_f = 0,8 mm, z = 3 mm, φ= 90°*

3 Experimental conditions
Eksperimentalni uvjeti

The material used for experiments was stainless steel AISI 309. The changes in the abrasive mass flow rate and also the traverse speed of the cutting head were examined. The mass flow values were 250 and 400 g/min. The selected traverse speeds of the cutting head were as follows: 50, 75, 100 and 150 mm/min. The technological conditions under which the experiments were carried out and the records detected by the vibration sensor PCB IMI type 607 are shown in Tab. 1. The shape of the experimental samples and the position of the sensors are shown in Fig. 2.

The vibration measurement was provided during AWJ cutting of the experimental samples. Data collection was carried by the NI PXI – 1031 measurement system, NI PXI – 6109 for 8 – channel simultaneous collection with a sampling frequency of 30 kHz. Vibrations were recorded by PCB IMI 607 A11 – uniaxial accelerometers. The recorded data were consequently analysed by a tool that was created in the object-oriented programming environment LabVIEW 8.5.

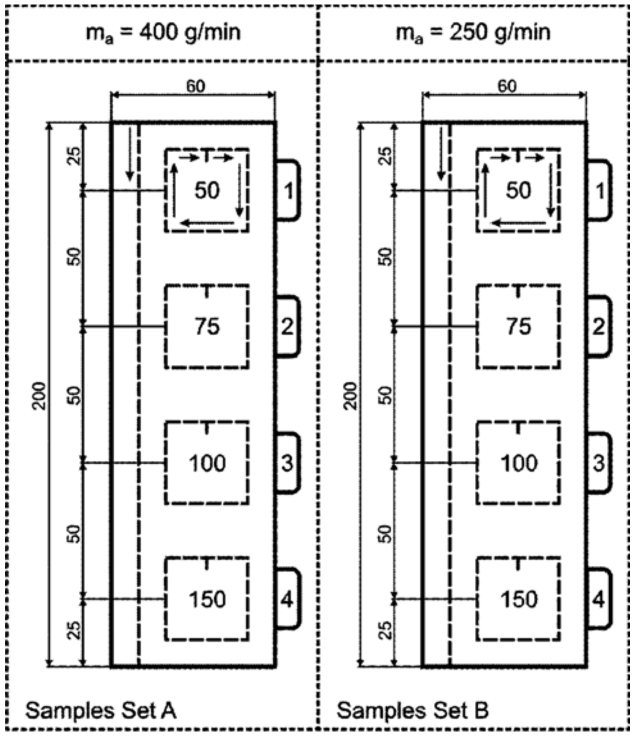

Figure 3 *Sets of experimental cuts produced under conditions – variable values: v = 50, 75, 100 and 150 mm/min; m_a = 250 and 400 g/min; constant values: p = 350 MPa, d_0 = 0,14 mm, d_f = 0,8 mm, z = 3 mm, φ= 90°; material AISI 309, E = 200 GPa*
Slika 3. *Seta eksperimentalnih rezova proizvedenih pod uvjetima – promjenjive veličine: v = 50, 75, 100 i 150 mm/min; m_a = 250 i 400 g/min; constant veličine: p = 350 MPa, d_0 = 0,14 mm, d_f = 0,8 mm, z = 3 mm, φ= 90°; materijal AISI 309, E = 200 GPa*

4 Results and discussion
Rezultati i rasprava

Vibrations were examined during the penetration of the water jet into stainless steel AISI 309. Two values of the abrasive mass flow rate m_a = 250 g/min and m_a = 400 g/min and also four values of the traverse speed of the cutting head *v* were examined as it is shown in Fig. 3. The technological conditions of the experiment are shown in Tab. 1. The time interval of the signals from the sensors was one second. The courses of vibration signals are shown in Fig. 5 and Fig. 6. In Fig. 5 are shown the recorded signals during cutting with the abrasive mass flow rate m_a = 250 g/min. In Fig. 6 are shown the recorded signals during cutting of the samples with the abrasive mass flow rate m_a = 400 g/min. As it can be seen, the signals recorded by the mass flow rate m_a = 400 g/min show

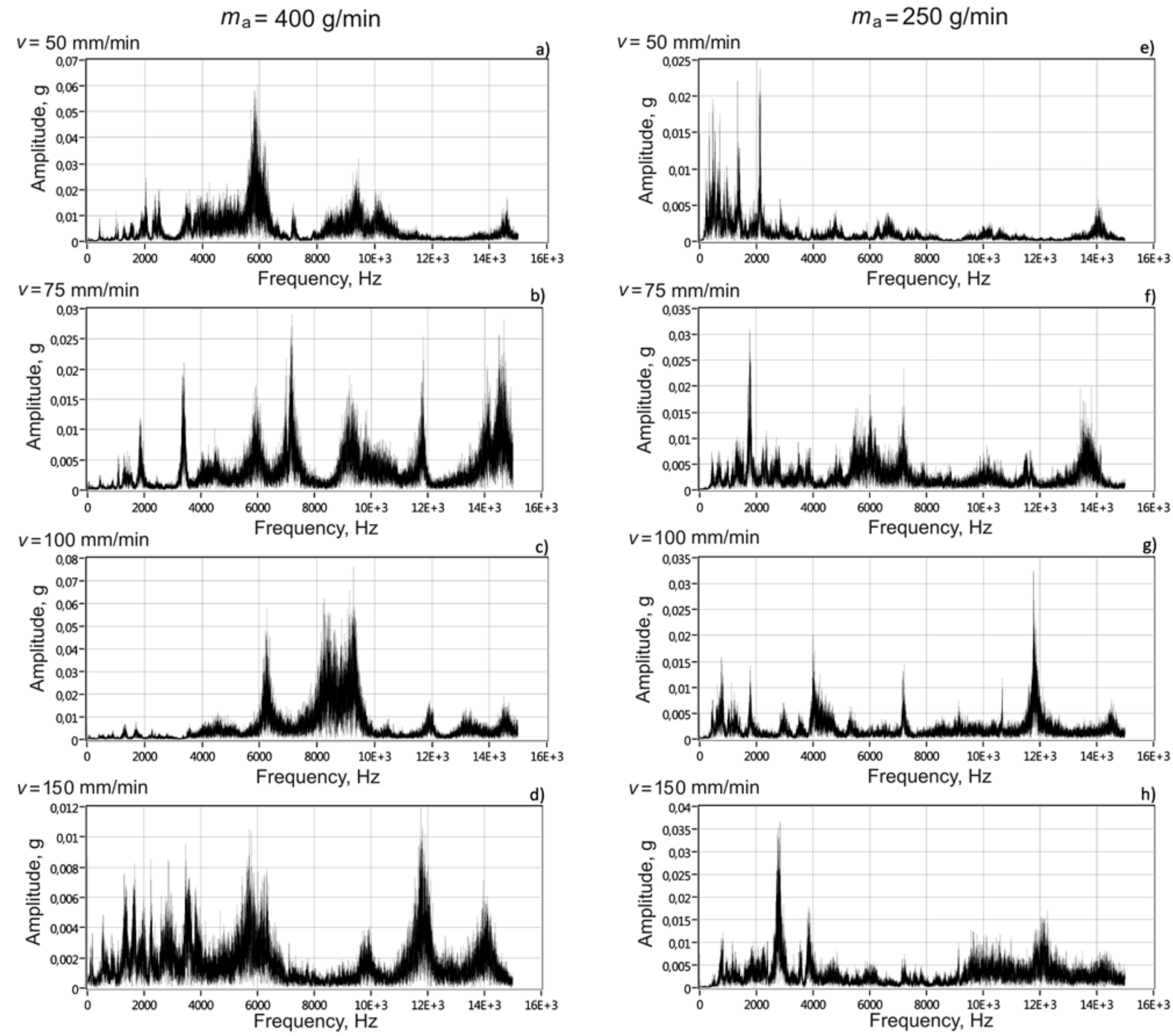

***Figure 4** Spectra of the recorded signals for cutting conditions – variable values: v = 50, 75, 100 and 150 mm/min; m_a = 250 and 400 g/min; constant values: p = 350 MPa, d_0 = 0,14 mm, d_f = 0,8 mm, z = 3 mm, φ = 90°; material AISI 309, E = 200 GPa*

***Slika 4.** Spektri snimljenih signala za uvijete rezanje – promjenjive veličine: v = 50, 75, 100 i 150 mm/min; m_a = 250 i 400 g/min; konstantne veličine: p = 350 MPa, d_0 = 0,14 mm, d_f = 0,8 mm, z = 3 mm, φ = 90°; materijal AISI 309, E = 200 GPa*

a higher amplitude than the signals recorded during cutting with the mass flow rate m_a = 250 g/min. An amplitude of the signal recorded during cutting at the traverse speed v = 150 mm/min shows lower values by using the abrasive mass flow rate m_a = 400 g/min, unlike the other examined traverse speeds. All the signals contain a short section with increased amplitude at the beginning of the signal. This section was created due to vibration of the material at the first contact with the abrasive water jet. From this signal the FFT spectra were obtained. These are shown in Fig. 4. The left side shows the spectra obtained when using higher value of the abrasive mass flow rate. The right side shows the spectra obtained when using lower value of the abrasive mass flow rate. Both in the signal courses and in the FFT spectra, there have been observed higher amplitudes by the abrasive mass flow rate of 400 g/min, except in the case of using the traverse speed of the cutting head v = 150 mm/min. However, there are significant differences within the distribution of maximum amplitudes. When using the abrasive mass flow rate of 400 g/min, there is an increase in the amplitude at a frequency of 6 000 Hz. The maximum values are in a range of frequencies from 6 000 Hz up to 12 000 Hz and at the end of FFT spectrum except in the case of using the traverse speed of 150 mm/min. The frequencies in the frequency range from 6 000 Hz up to 12 000 Hz show decay in amplitudes. When using the abrasive mass flow rate of 250 g/min, the FFT spectra have got significantly different distribution of the maximum amplitudes. These are moved to the top of the spectrum in the range from 0 up to 4 000 Hz. At the traverse speed of the cutting head v = 100 mm/min there has been observed the highest amplitude at the frequency of 12 000 Hz.

5
Conclusion
Zaključak

In this article the vibration signals recorded just during the penetration of the water jet were shown at different input factors such as the traverse speed of the cutting head and the abrasive mass flow rate. After the processing of the recorded data, the authors came to the following conclusions:

The increase in amplitude caused by the first contact of the tool with the material is observed at the beginning of the signal. At the higher abrasive mass flow rate, the higher amplitudes were recorded, as it was expected. Higher

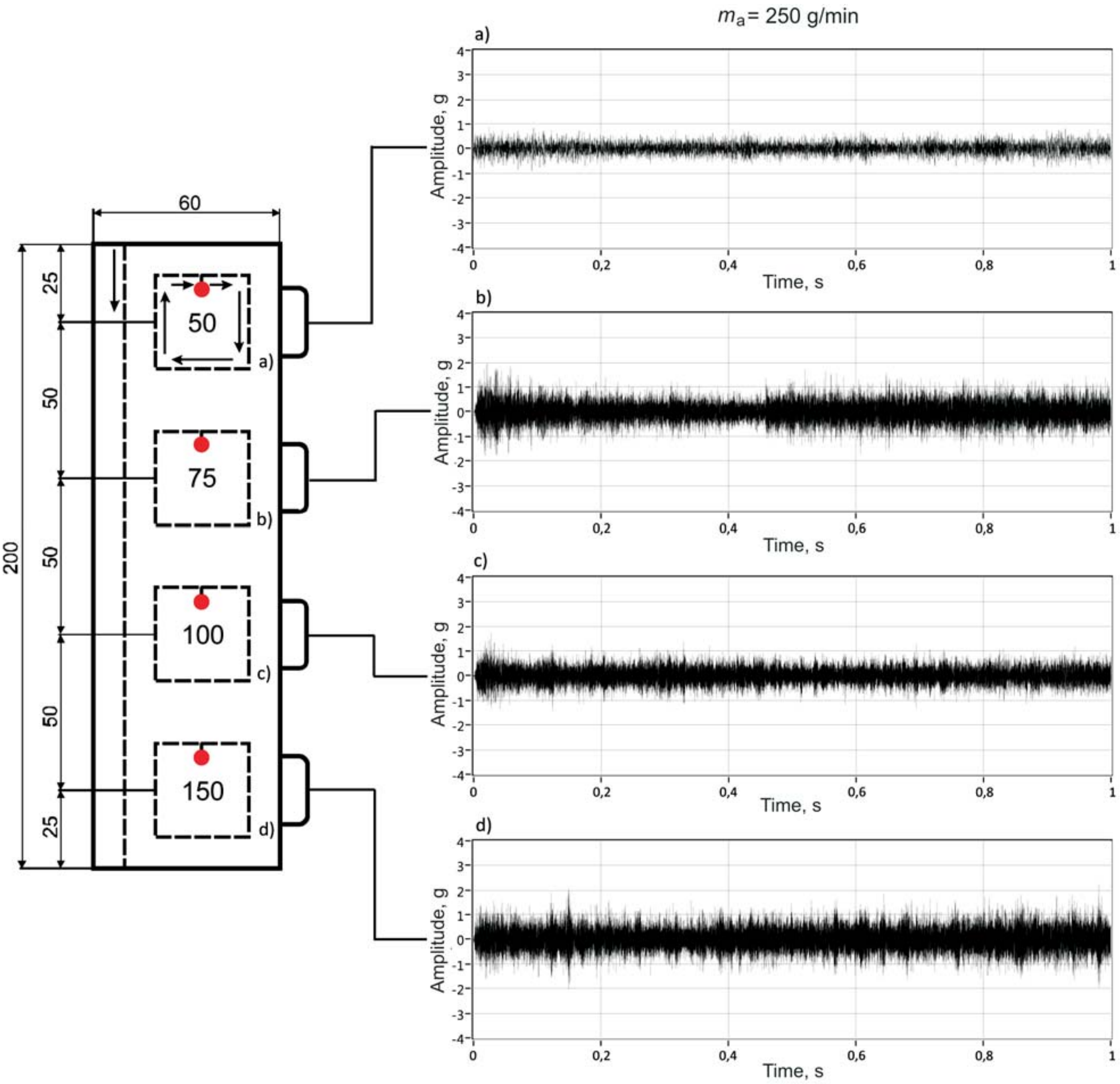

Figure 5 *Record of the signals recorded when using the abrasive mass flow rate of* m_a *= 250 g/min, a) v = 50 mm/min, b) v = 75 mm/min, c) v = 100 mm/min, d) v = 150 mm/min, p = 350 MPa,* d_0 *= 0,14 mm,* d_f *= 0,8 mm, z = 3 mm, φ = 90°; material AISI 309, E = 200 GPa*
Slika 5. *Zapis signala snimljen kada se koristiti abrazivni maseni protok* m_a *= 250 g/min, a) v = 50 mm/min, b) v = 75 mm/min, c) v = 100 mm/min, d) v = 150 mm/min, p = 350 MPa,* d_0 *= 0,14 mm,* d_f *= 0,8 mm, z = 3 mm, φ = 90°; materijal AISI 309, E = 200 GPa*

amplitudes in the FFT spectra were also recorded.

The distribution of the maximum amplitudes within the FFT spectra was concentrated at the frequencies up to 5 000 Hz, when using the lower value of the abrasive mass flow rate. When using the higher value of the abrasive mass flow rate, the maximum amplitudes were distributed in the middle of the frequency spectrum. We can claim that the higher value of the abrasive mass flow rate moves the distribution of the maximum amplitudes into the middle of the frequency spectrum.

This study penetration of the material is part of a larger vibration analysis AWJ cutting process. The aim of this analysis is to optimize input factors. It is also necessary to carry out detailed studies in relation to the vibrations generated by surface roughness.

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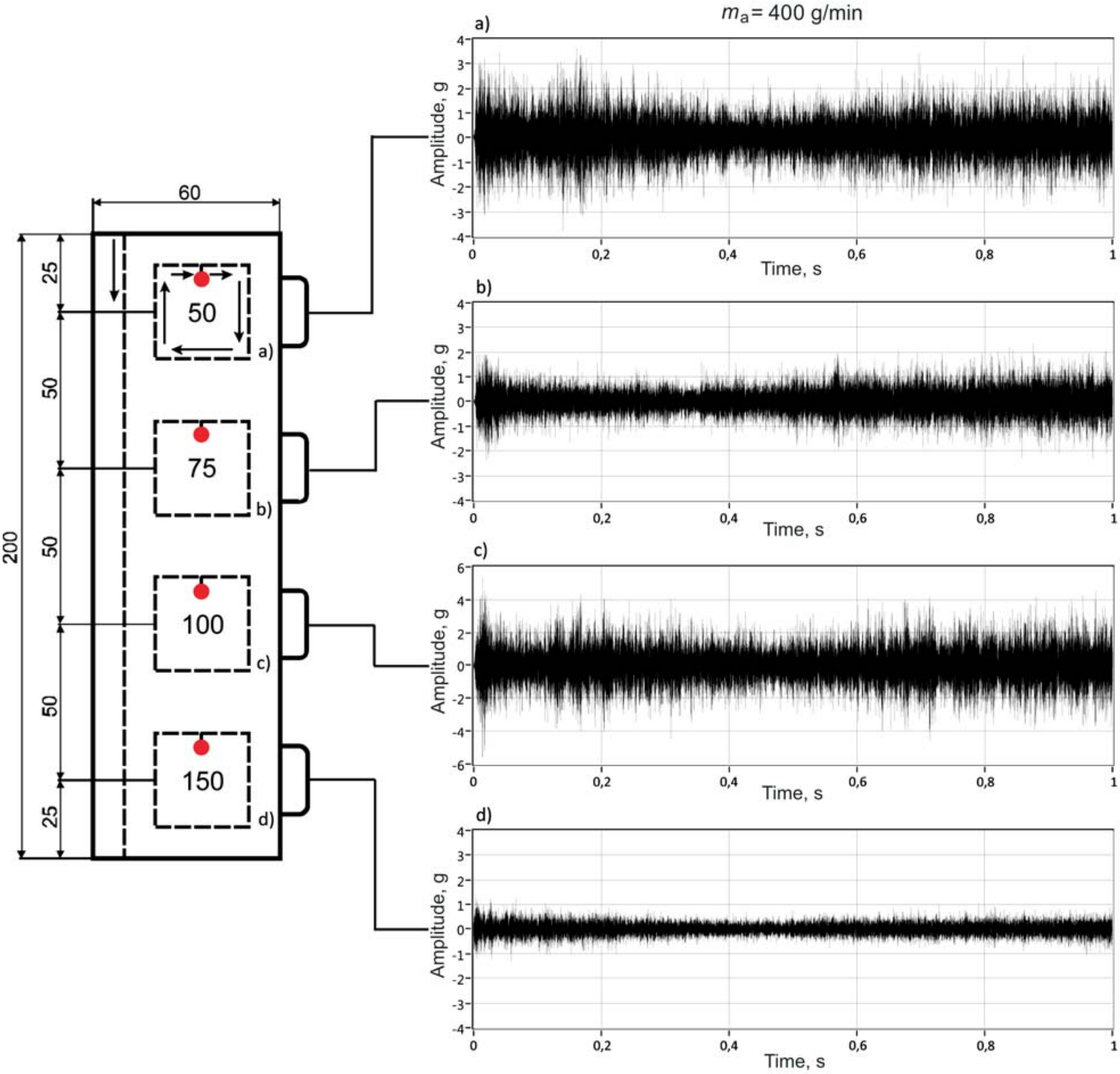

Figure 6 *Record of the signals recorded when using the abrasive mass flow rate of* m_a *= 400 g/min, a) v = 50 mm/min, b) v = 75 mm/min, c) v = 100 mm/min, d) v = 150 mm/min, p = 350 MPa,* d_0 *= 0,14 mm,* d_f *= 0,8 mm, z = 3 mm, φ = 90°; material AISI 309, E = 200 GPa*
Slika 6. *Zapis signala snimljen kada se koristiti abrazivni maseni protok* m_a *= 400 g/min, a) v = 50 mm/min, b) v = 75 mm/min, c) v = 100 mm/min, d) v = 150 mm/min, p = 350 MPa,* d_0 *= 0,14 mm,* d_f *= 0,8 mm, z = 3 mm, φ = 90°; materijal AISI 309, E = 200 GPa*

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