

THE ANALYSIS OF THE EFFECT OF SELECTED TECHNOLOGICAL PARAMETERS ON THE VIBRATION PARAMETERS OF THE MACHINED MATERIAL BY PLASMA CUTTING TECHNOLOGY

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ABSTRACT: In plasma arc welding using ultrasound, the ultrasonic vibration acts on the tungsten electrode with the plasma arc and changes its thermal pressure characteristics. It is very important to examine the underlying mechanism of the interaction. In this study, the intention is to analyze and assess the influence of input technological factors on the occurrence and magnitude of mechanical vibration under operating conditions. It analyses the effect of changing the feed rate (200, 700, 1200, and 1700 mm/min) on the plasma machine using two currents (220 and 280 A) on the acceleration amplitude and vibration frequency. From the measured values, graphical dependencies are created and used to compare and evaluate the technical condition of the selected equipment
KEYWORDS: Analysis, experiment, machining, parameter, frequency spectrum, vibration acceleration

1. INTRODUCTION

Plasma is considered to be the fourth state of matter, the first three being solid, liquid and gas. The plasma cutting process is a melting process that uses a stream of ionizing gas blown at high velocity from a torch [1,2]. During this process, an electric arc burns between the electrode (called the cathode) and the workpiece (called the anode) [3]. The plasma beam produced by the blow torch can reach temperatures of around 20 000 °C. That is more than enough to cut metal [4,5]. Industries use this process to cut materials up to 30 mm thick, as it is not economical to cut thicker materials [6]. CNC machine cutters, therefore, combine plasma cutting technology with flame cutting, for example, which enables deeper cuts [7].

During machining, complex processes of mechanical oscillation machine-tool-workpiece are generated. The intensity of the oscillations is sometimes low and has no adverse effect. However, there are cases where the oscillation is very intense and produces an adverse effect in several directions - the tools wear out quickly and the machine wear increases [8,9]. One of the technological input factors examined is speed. It is known that speed has a great influence on the nature of chip formation and build-up. This is because as the cutting speed increases, the temperature at the contact surfaces of the chip, tool, and workpiece, as well as in the shear zone, increases practically linearly [10]. The ultrasonic vibration results in an increase in the electrons' thermal conductivity and reaction thermal conductivity, but leads to a decrease in the electrical conductivity.

This study aims to observe the effect of selected technological factors specifically feed rate and current on the magnitude of vibration under operating conditions. After the experiments are carried out, a set of graphical dependencies and then comparative envelope plots of the frequency spectra will be developed. The thesis concludes by proposing insights from the evaluation of the measurements to be used in the future to make the machine more efficient, reduce failure rates and improve the quality of product surfaces

2. MATERIAL AND METHODOLOGY

Methodology of the experiments:

The experimental measurement of the magnitude of vibration amplitude was carried out on the nozzle head of the HiFocus 280i plasma machine (Figure 1) while machining a pre-selected material type S355J2C with a thickness of 15 mm. This is structural steel suitable for cold forming, whose basic mechanical and chemical properties are listed in Table 1. The material was machined by plasma cutting technology using a combination of parameters namely constant voltage (147 V) and varying parameters of feed rate (200, 700, 1200, and 1700 mm/min) and current (220 and 280 A) with a cutting power of 36 kW. The material was machined with a head type 370.1 [11].

Description of the measuring device:

A Polytec PDV 100 laser vibrometer setup was used to capture the magnitude of the vibration amplitudes during the measurement. The basic technical parameters are given in Table 2. This set-up consists of a vibrometer head mounted on an adjustable tripod. The acceleration of the vibration signal from the sensor is recorded in the data collector and integrated into the vibration signal velocity. The vibration acceleration amplitudes thus recorded in the machining axis are written into the memory of the CompactDAQ NI 9234 measuring device from National Instruments and evaluated in the frequency spectrum using a fast Fourier transform. Its basic technical parameters are given in Table 2. It allows the determination of the frequency of harmonics in the monitored signal. The evaluated signal can then be immediately monitored on a laptop computer using the SignalExpress software [11].

LabView's SignalExpress software system is a tool for collecting, archiving, and evaluating vibration machine diagnostic data. It contains all the functions and tools needed for signal analysis in both time and frequency domains. In SignalExpress, a steady-state waveform 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 with a step of 100 Hz was generated using Fourier transformation

Figure 1. Detail of the HiFocus 280i plasma head

Table 1. Basic material properties of type S355J2C

Chemical Composition	
C Content [%max.]	
≤16	0,23
>16≤40	0,23
> 40	0,24
Element Content by Weight [%max.]	
Si	0,60
Mn	1,70
P	0,035
S	0,035
N	-
Cu	0,6
Mechanical Properties	
Yield Limit Re N/mm^2	355
Tensile Strength Rm N/mm^2	490 - 680

Table 2. Basic technical parameters of the Polytec PDV 100 sensor and the NI 9234 acquisition card

Polytec PDV 100 sensor	
Name	Value
Frequency spectrum	0,5 - 22 kHz
Number of measuring ranges	3
Laser working distance	0,1-30 m
Working temperature	+5 ... +40 °C
NI 9234 Acquisition Card	
Name	Value
Resolution	24
Dynamic range	102
Input range	± 5
Maximum sampling rate	50 measurements per second
Number of analog inputs	4 simultaneous samples

3. RESULTS AND DISCUSSION IN THE TIME DOMAIN

The analysis of the vibration signal measured on the diagnosed machine in the time domain consists of the evaluation of the measured time waveforms of the signals characterizing the magnitude of the vibration and therefore the acceleration. From the signal waveforms, the immediate, mean, and effective values of the signal can be easily determined. The time-domain analysis is suitable and can be used especially when there is a single or at least a predominant source of vibration. If this is not the case, information may be lost in the noise of the vibration signals from other sources, and thus locating the cause of the excessive vibration is very difficult. In our case, no such problem occurred.

As an example, the time history of vibration acceleration is graphically shown in Figure 2 for a feed rate of 200 mm/min and a current of 220 and 280 A. Similarly, the vibration acceleration time histories for the other investigated feed rates of 700, 1200, and 1700 mm/min and for currents of 220 and 280 A have been graphed in this way.

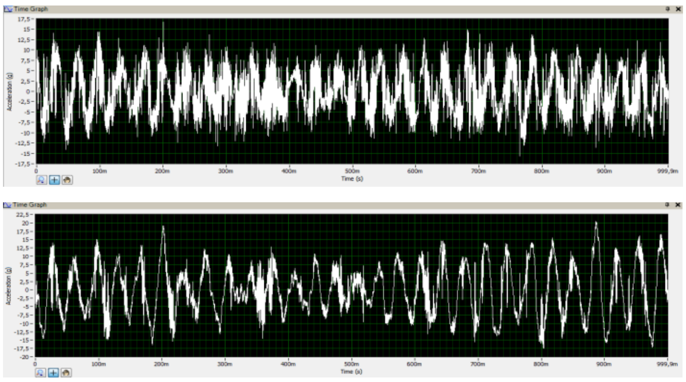

Figure 2. Vibration time history at a feed rate of 200 mm/min and a current of 220 and 280 A

From the graphical dependencies (Figure 2), we can conclude that the amplitudes increase regularly with increasing currents. The amplitudes fluctuate mostly non-periodically during machining, but we consider them stable. From the time waveform recording taken with 220 A current, smaller amplitudes were observed compared to the recording with 280 A current.

4. RESULTS AND DISCUSSION IN THE FREQUENCY DOMAIN

Frequency analysis allows accurate identification of the individual causes of oscillations. It eliminates the disadvantages of time-domain analysis, or in other words, it localizes the fault occurring in the individual parts of the diagnosed machine. Frequency analysis is determined by the amplitude spectrum - amplitude spectral density and phase spectrum. Since the time recording shows a non-periodic waveform for the frequency analysis, a part of the steady-state waveform of 10 seconds was selected and a frequency band in the range of 0 - 10.0 kHz was generated using FFT. Similar to the time recording, a graphical example of the representation of the frequency spectra for a feed rate of 200 mm/min with a current of 220 and 280 A is given (Figure 3). Similarly, the frequency spectra for the other feed rates and currents were evaluated.

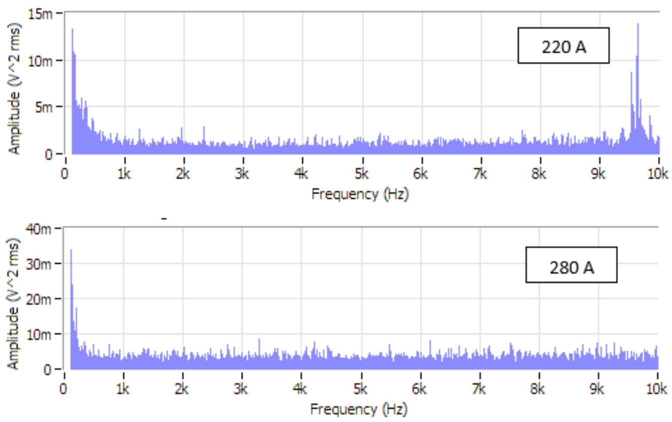

Figure 3. Frequency spectra of vibration acceleration amplitude at frequencies when machining at a feed rate of 200 mm/min for currents of 220 and 280 A

From the waveforms of the frequency spectra, it can be stated that for all machining operations, the maximum frequencies included frequencies in the range of 100 Hz - 700 Hz. Overall, frequencies in the range 1.0 kHz - 10.0 kHz showed no significant dependence on the experiment input factors investigated.

5. RESULTS AND DISCUSSION FROM THE FREQUENCY ANALYSIS OF THE RMS PARAMETER

Since the FFT spectra from the absolute acceleration amplitudes are very dense, overlaying the individual spectra for comparison purposes does not provide the desired meaningful value. The envelope method is not suitable since periodic events are not involved. The Peak-to-Peak parameter describes the maximum deflections of the amplitudes and neglects the lower values. The average of the absolute values of the amplitudes, in turn, smooths out the outliers. For these reasons, for a better comparison of the FFT spectra, attention was focused on the RMS value over the whole frequency range.

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

- measured vibration values when machining the material at a feed rate of 200 mm/min.
- measured vibration values when machining material at a feed rate of 700 mm/min
- measured vibration values when machining material at a feed rate of 1200 mm/min
- measured vibration values when machining material at a feed rate of 1700 mm/min

The graphs (Figs. 4 - 7) present the RMS values versus frequency measured when the variable feed rate factors are set to 200, 700, 1200, and 1700 mm/min separately for the examined 220 and 280 A currents.

From the graphical dependence shown in Figure 4, it can be seen that the maximum value of the vibration acceleration amplitude is 0.03369 g and it was obtained when a current of 280 A at a frequency of 0.2 Hz was used. When the vibration was measured with a current of 220 A, the maximum value of the vibration acceleration amplitude was 0.00756 g at a frequency of 8 700 Hz. From the graphical dependence of Fig. 5 of the vibration acceleration amplitude on the frequency at a given speed of 700 mm/min during the cutting of S355J2C material, it is clear that the maximum value of vibration acceleration amplitude was obtained when machining with a current of 220 A, namely 0.086273 g at a frequency of 0.2 Hz. When the current was increased to 280 A the maximum value of vibration acceleration amplitude was 0.014585 g at a frequency of 7 400 Hz. At the selected feed rate of 1200 mm/min during plasma cutting of the material Fig. 6, it can be seen that the maximum value of the vibration acceleration amplitude was again obtained when a current of 220 A was used - 1.158542 g at a frequency of 0.3 Hz. When machining with a current of 280 A, the highest value of vibration acceleration amplitude was measured at a frequency of 0.2 Hz - 0.511182 g. From the dependence Fig. 7 it is clear that the highest value of vibration acceleration amplitude was obtained when machining with a current of 280 A - 0.39364 g at a frequency of 8900 Hz. When using a current of 220 A, the highest vibration value was measured at a frequency of 0.2 Hz - 0.102763 g.

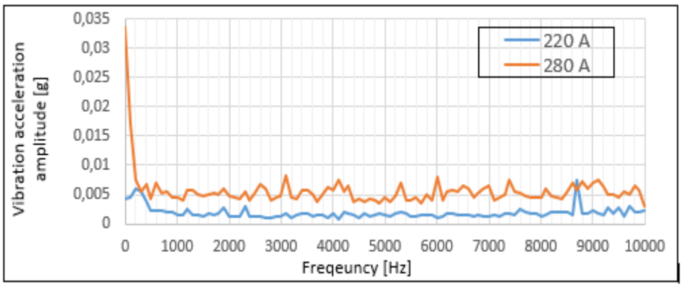

Figure 4. Dependence of vibration acceleration amplitude on frequency when machining at a feed rate of 200 mm/min for currents of 220 and 280 A

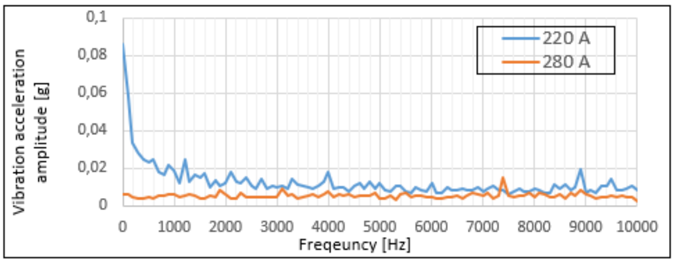

Figure 5. Dependence of vibration acceleration amplitude on frequency when machining at a feed rate of 700 mm/min for currents of 220 and 280 A

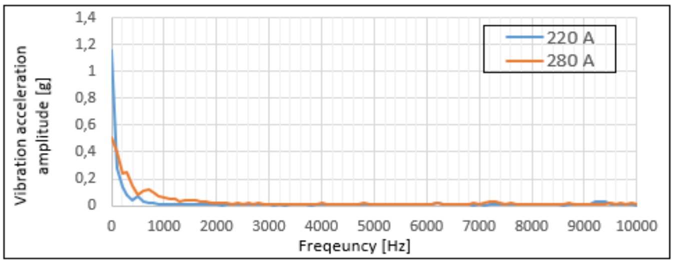

Figure 6. Dependence of vibration acceleration amplitude on frequency when machining at a feed rate of 1200 mm/min for currents of 220 and 280 A

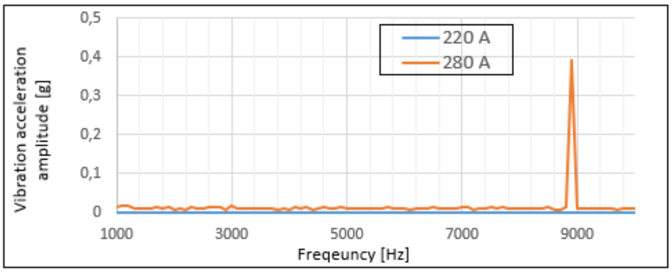

Figure 7. Dependence of vibration acceleration amplitude on frequency when machining at a feed rate of 1700 mm/min for currents of 220 and 280 A

6. COMPARISON OF MAXIMUM RMS PARAMETER VALUES

The RMS parameter was used to analyse the vibration signal comparison for the four feed rates and three changing currents during machining. The maximum RMS values of the vibration amplitude are shown in Table 3. Figure 8 graphically shows the maximum RMS values from the selected steady-state run of 10 seconds. The highest RMS value equal to 1.15 g was recorded at a speed of 1200 mm/min and at a set input factor current of 220 A. A lower RMS value of 0.51 g was also recorded at a feed rate of 1200 mm/min with an input factor of 280 A. The smoothest curve was obtained when machining at a speed of 200 mm/min. In general, it can be observed that with increasing currents used in machining, an increasing trend of vibration amplitude values is recorded.

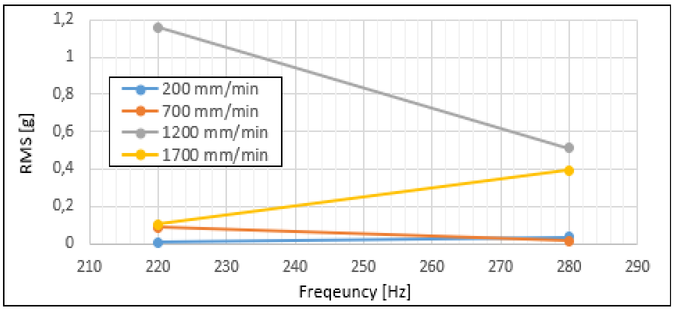

Figure 8. Dependence of the RMS values on the value of the current at the four feed rates

Table 3. Vibration parameter RMS values

		current	
		220 A	280 A
200 mm/min	Frequency [Hz]	8 700	200
	RMS parameter [g]	0,00756 g	0,03369 g
700 mm/min	Frequency [Hz]	200	7400
	RMS parameter [g]	0,086273 g	0,014585 g
1200 mm/min	Frequency [Hz]	300	200
	RMS parameter [g]	1,15854 g	0,511182 g
1700 mm/min	Frequency [Hz]	200	8900
	RMS parameter [g]	0,102763 g	0,39364 g

7. MEASUREMENT EVALUATION

The study analyses the influence of individual input technological factors on the level of vibration parameters. From the measurement results, it is suitable to recommend the elimination of vibration of the machine itself. The first option to eliminate the amplitude values of the machine itself is to adapt the operational use of the machine and its settings by selecting the appropriate current at specific feeds. The second way of eliminating amplitudes is by proper maintenance, especially of moving parts and vibration transmitting parts. It is recommended to check the clearance in the moving axes of the machine, check the transverse path against the longitudinal one, check the condition of the coarse and fine grates, and check the fouling of the shipyard.

It is also recommended to eliminate vibration in the machine surroundings, specifically referring to the transmission of vibration through the machine stowage on the pad. Of these recommendations, there are several aspects to consider that some of these changes could adversely affect economics and production planning.

8. CONCLUSION

Plasma machining technology is currently relatively widely used. Despite its advantages, like any other technology, it has its drawbacks. The development of new equipment and innovations to remove or eliminate these drawbacks is constantly the subject of several researchers not only in Slovakia but also abroad. This study contributes to the clarification of the issues concerning the connection between the input technological factors - current and feed rate and the resulting parameters in our case the magnitude of vibration amplitudes at the nozzle head.

The analysis of the vibration signals showed the influence of the magnitude of the current and the feed rate. In frequency analysis, significant increases in amplitude values were observed for machining speeds of 700 mm/min and 1200 mm/min in the low-frequency parts of the spectrum. On the contrary, when using a speed of 1700 mm/min increases in amplitude values were observed in the high-frequency part of the spectrum. The results published in the paper form the basis for a more detailed solution to the problem, where it is necessary to extend the research on the input technological factors with a suitable range of setting values. Furthermore, it is recommended to evaluate the complete technology by vibration analysis, assign the corresponding frequencies, and then identify the transmission of vibrations to the material being machined.

9. ACKNOWLEDGEMENTS

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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