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Vibrations of the technological head of the abrasive water jet during cutting of structural steel

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Abstract:

Vibration measurement is a fundamental aspect of ensuring the optimal and reliable operation of machinery, with implications for production quality, economic efficiency, and safety. The monitoring of machine condition provides essential data for the early detection of damage to machine parts, thereby preventing unanticipated failure modes and disruptions in production. Accordingly, this paper focuses on the measurement and assessment of fundamental vibration parameters, with a particular emphasis on frequency and vibration acceleration amplitude that allows to optimize the production quality assessment. Experimental measurements were conducted on a technological head of production system using abrasive water jet technology (AWJ) with a varied feed rate while cutting two types of structural steel. Based on the results of these measurements, recommendations were formulated regarding suitable and inappropriate combinations of operating parameters, thereby enhancing current knowledge regarding the influence of technological parameters on the amplitudes of vibration acceleration in the operation of production systems with AWJ technology.

Keywords: abrasive water jet, feed rate, abrasive mass flow, vibration amplitude, frequency spectrum

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1. Introduction

The fundamental principle of water jet machining technology is the removal of material by means of a liquid, typically containing solid particles, impinging upon a workpiece in a manner that enhances the process efficiency [1]. The liquid is concentrated into a narrow jet that flows from the nozzle under sufficient pressure and impacts the material, using appropriate technological tools. As the jet interacts with the machined material, it gradually deflects in the cutting direction and loses kinetic energy. In clean water jet cutting, pure water is employed, which has undergone chemical and mechanical treatment without the addition of particles. The utilization of high-pressure liquid properties, typically about 400 MPa, serves to create an effective cutting tool [2]. The abrasive water jet, which may be considered a type of grinding tool, employs abrasive grains dispersed in the jet to enhance cutting efficiency. Its material removal mechanism is similar to that of traditional machining methods. The majority of water jet cutting machines achieve elevated pressures through the use of a multiplier, which generates high pressures based on the surface area differential between two interconnected pistons. The flexibility and cold cutting capabilities of abrasive water jets render them advantageous for cutting an array of materials, including those that are exceedingly hard or soft, composites, and sandwich materials that are challenging to machine with conventional technologies.

The cutting of materials by abrasive water jets (AWJ) has been the subject of study for several decades. The scientists who pioneered this field of research were Hashish [3] and Zeng and Kim [4]. Subsequently, further investigations were conducted with the aim of improving the machining process, for example by Kovacevic and Yong [5, 6]. The current state of research on abrasive water jet technology indicates that one of the significant challenges is the quantification and modeling of the impact of technological parameters on surface quality parameters, particularly on wear-resistant steels. The assessment of cutting quantity and quality has been a persistent area of investigation by several research groups [7–9].

Despite the emergence of an expanding array of solutions to this problem, including methodologies and evaluations of experiments that are valid for specific measurement conditions, the current solutions still lack comprehensive coverage of several variations. Microscopic models that describe the mechanism of material cutting have been developed, as have macroscopic models of cutting front behavior. The Ostrava group has also presented an interesting multi-parametric phenomenological description of the cutting process [10, 11]. The research group at TU Košice commenced their investigation into this field as part of a broader program of research into the operational states of manufacturing processes utilizing progressive technologies [12, 13]. This was followed by an examination of the impact of process parameters on surface quality.

In addition to numerous experimental studies aimed at elucidating the factors influencing the performance of the cutting process, a substantial body of research has been conducted to model the processes between the jet and cutting of the material, with the objective of gaining insight into the underlying physical mechanisms [14]. Partial analyses of input technological factors pertaining to the generation of vibration have also been conducted [15].

Despite the continuous studying of the variations of developed solutions to this problem, including methodologies and evaluations of experiments tailored to specific measurement conditions, current solutions still fail to cover several conditions. Abrasive water-jet cutting is a multiparametric process where the quality of the output characteristics is dependent on the inputs. This dependency has been substantiated through various experiments and theoretical analyses and is getting better understood. Nevertheless, there are numerous ongoing efforts to develop models that characterize the quality of the cut area under specific conditions. These models take into account a number of factors, including the material type and thickness, the feed rate and distance of the technology head, the abrasive mass flow rate and grain size, operating pressure, and other parameters [16, 17].

The present article examines the effect of the technological head feed rate and type of machined material on the technological head vibration characteristics. The evaluation is based on a graphical comparison and an analysis of the effect of changing factors on the vibration acceleration amplitude and frequency of the technological head vibrations. Furthermore, the presented experimental work aims to supplement data applicable for modelling and diagnostic processes in the multi-factorial water-jet technology.

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2. Experimental Materials and Methods

The AWJ system used at experiments comprises the following main components:

A table XY CNC WJ1020-1Z-EKO for cutting applications utilizing the abrasive water jet technology, A PTV 19/60 HSQ 5x type multiplier to generate high-pressure water at a flow rate of up to 1.9 dm^3/min (minute is used in this segment to express volume flow as well as feed rate over time), and a technological head PASER IIITM with focusing tube (Fig. 1).

In this research, the total of six experiments were conducted. All measurements started from the same initial position, designated as point X (320 mm, 370 mm), to ensure consistency and accuracy. The distance between the water jet focusing tube and the material being cut was maintained at a distance of 2 mm. The experiments were also conducted under the following additional conditions:

The machined material parameters:

- Thickness: 10 mm
- Machined steel type: 12 050; 11 523

The technological parameters:

- Water working medium pressure: 380 MPa
- Abrasive type: Australian garnet (AG)
- Abrasive average grain size: MESH 80 (0.275 mm)
- Abrasive mass flow rate: 230 g/min
- Water orifice diameter: 0.25 mm
- Focusing tube diameter: 1.02 mm
- Focusing tube length: 76 mm
- Cutting head feed rate: 40 mm/min; 100 mm/min; 400 mm/min.

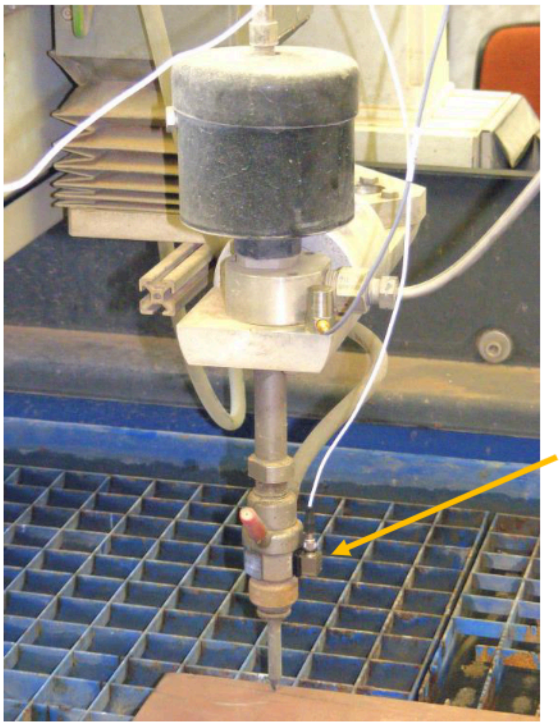

Fig. 1. Technological head with installed accelerometer marked with an arrow

The single-axis piezoelectric accelerometer Omega ACC103 was used to measure the vertical vibrations during the experiments. The basic technical parameters of the sensor are listed in Table 1.

Table 1. Selected technical parameters of the Omega ACC103 accelerometer

Acc. range (±pk) [m.s^{-2}]	4900
Nominal voltage sensitivity (at 160 Hz) [mV/g]	10
Frequency range [Hz]	2 – 10,000
Amplitude linearity [%]	±2
Rated output shift [%]	up to ±5

Data acquisition was performed using NI-9233 hardware with the main technical parameters listed in Table 2. The LabVIEW SignalExpress software by National Instruments was used for data recording and processing.

Table 2. Selected technical parameters of the NI-9233 DAQ module

ADC resolution [bit]	24
Dynamic range [dB]	102
Max. sampling rate [Sa/s]	50 k
Time base clock frequency [Hz]	12.8 M

3. Results

The selected machined materials (steels 12 050 and 11 523) were subjected to two different feed rate speeds of the technological head (50 and 100 mm/min), and the resulting vibration acceleration amplitude was recorded in the form of time courses. An example of the time record of the vibration acceleration amplitude for both materials cut at a feed rate of 40 mm/min is depicted in Figures 2 and 3. The Fast Fourier Transformation was used to evaluate the vibration acceleration amplitude values, as recorded in the time series, over the frequency range of 100 Hz to 10 kHz, with a frequency step of 100 Hz.

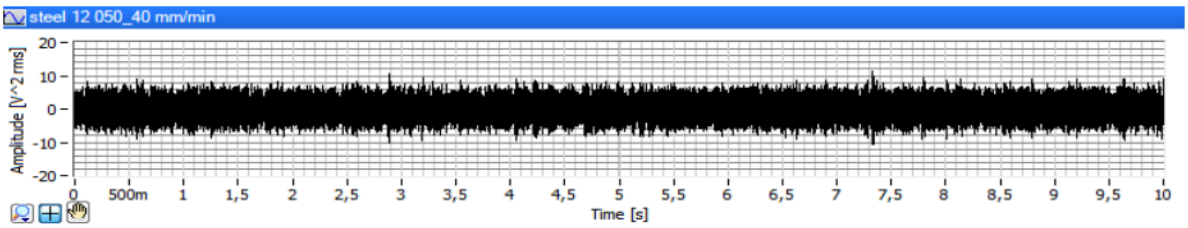

Fig. 2. A time record of the vibration acceleration amplitude of 12 050 steel cutting at a feed rate of 40 mm/min

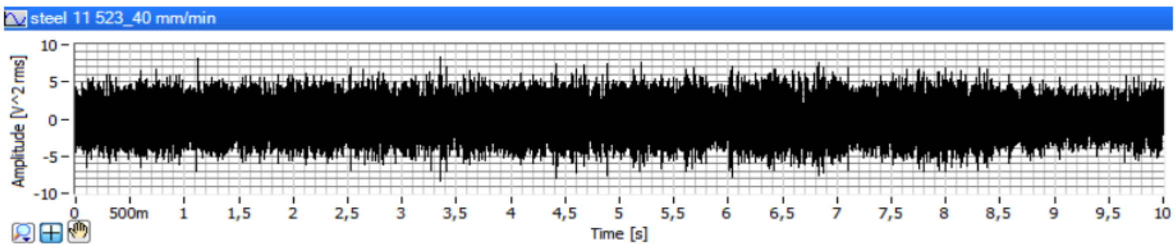

Fig. 3. A time record of the vibration acceleration amplitude of 11 523 steel cutting at a feed rate of 40 mm/min

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The evaluation of measured values involves constructing graphical representations of the dependencies between variables and the frequency range of vibration acceleration amplitude of the technological head within the frequency range of 0 to 10 kHz. For the material steel 12 050, the cutting process at a feed rate of 40 mm/min demonstrates alterations in vibration acceleration amplitude in relation to frequency, as shown in Fig. 4.

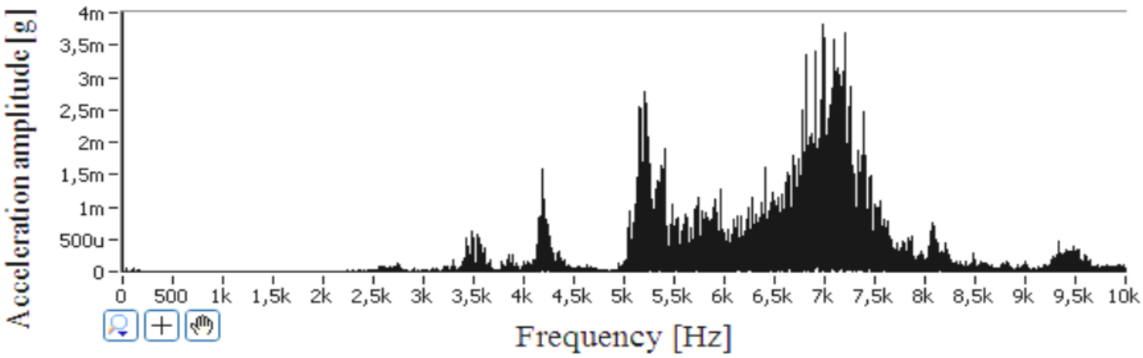

Fig. 4. An acceleration amplitude dependency on the vibration frequency of 12 050 steel during the cutting process at a feed rate of 40 mm/min

The graphical dependencies and envelopes were evaluated for feed rate speeds of 100 and 400 m/min. The graphical dependencies of acceleration amplitude and vibration frequency and frequency range envelope were analyzed for machined steel 11 523 at technological head feed rates of 40, 100, and 400 mm/min.

Figures 5 and 6 present graphs of vibration acceleration amplitude envelopes and frequency range for the two selected steel material types and the three studied feed rate speeds of 40, 100, and 400 mm/min.

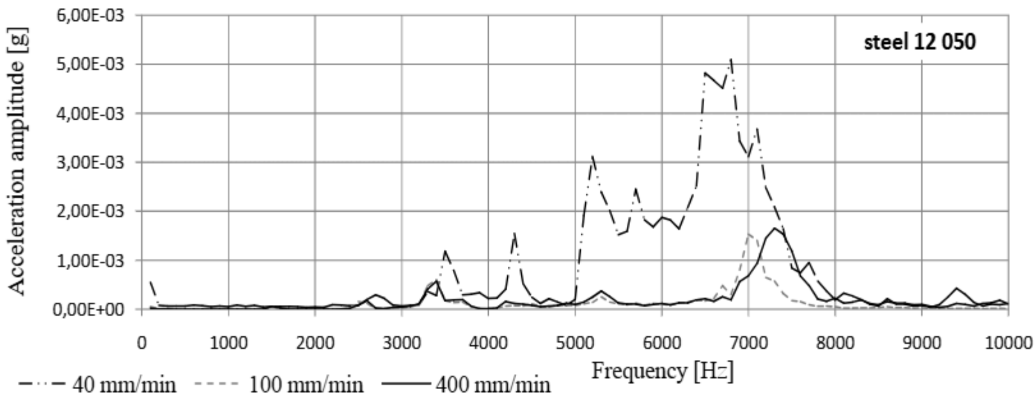

Fig. 5. The technological head vibration frequency spectrum envelopes when cutting the 12 050 steel

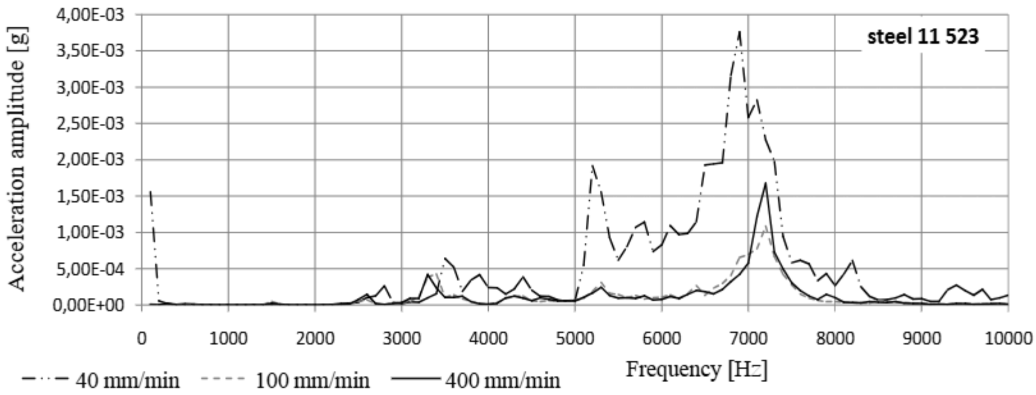

Fig. 6. The technological head vibration frequency spectrum envelopes when cutting the 11 523 steel

Figures 7-9 present graphs of vibration acceleration amplitude envelopes and frequencies for the various feed rate speeds under investigation.

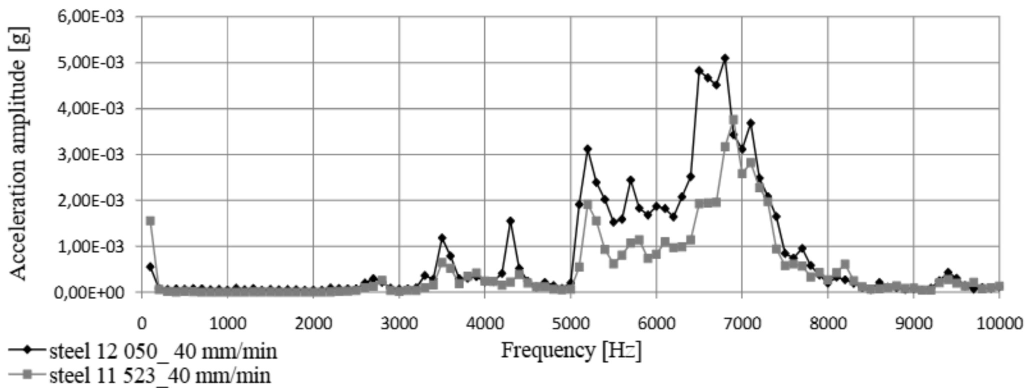

Fig. 7. The technological head vibration frequency spectrum envelopes comparison at the cutting feed rate of 40 mm/min

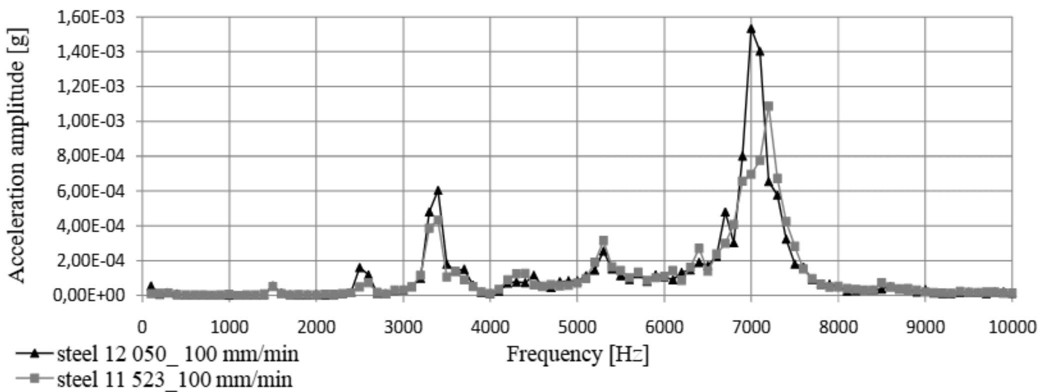

Fig. 8. The technological head vibration frequency spectrum envelopes comparison at the cutting feed rate of 100 mm/min

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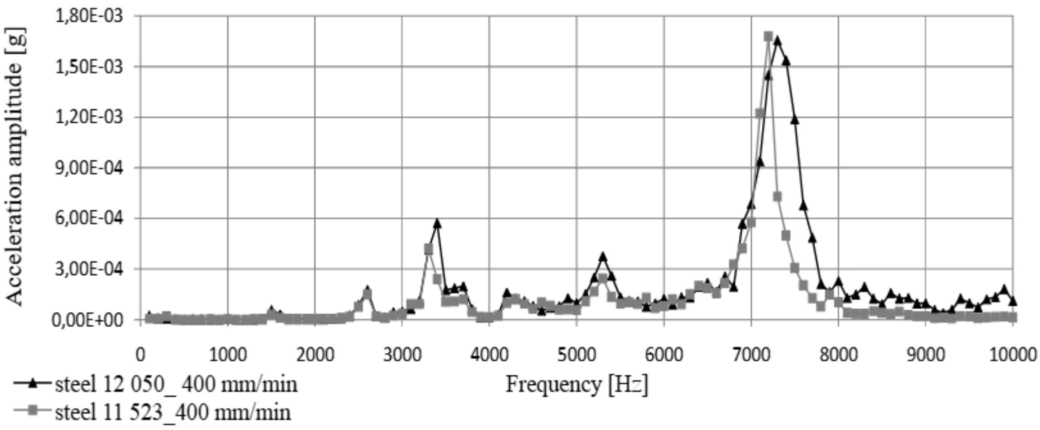

Fig. 9. The technological head vibration frequency spectrum envelopes comparison at the cutting feed rate of 400 mm/min

The maximum vibration acceleration amplitude values of the technological head are situated within the frequency range of approximately 6.8 kHz to 7.3 kHz. The following points summarize the measured values of the experimental cutting of steel materials 10 050 and 11 523 using the abrasive water jet technology, in accordance with the specified conditions.

It was observed that the highest vibration acceleration amplitude values occurred at the three measured technological head feed rates during cutting of both sample materials within the frequency range from 6.8 to 7.3 kHz, which is within the examined range of 100 Hz to 10 kHz. Furthermore, it was found that the vibration acceleration amplitude initially decreased and then increased moderately with an increase in the technological head feed rate when cutting the steel 12 050 material within the aforementioned examined range. A comparison of the feed rates 40 mm/min and 100 mm/min reveals a drop of 69.9%.

In the case of cutting steel 11 523 material in the examined range, an increase in the numerical value of the feed rate initially results in a decline in vibration acceleration amplitude, followed by a gradual and consistent growth. A comparison of the feed rates 40 mm/min and 100 mm/min reveals a drop of 71.13%.

The vibration acceleration amplitude for both materials in the aforementioned range reaches its highest value at the feed rate of 40 mm/min. The highest values of the vibration acceleration amplitude for the three measured technological head feed rates during the cutting of both sample materials are located in the frequency range from 6.8 to 7.3 kHz of the examined range from 100 Hz to 10 kHz.

The vibration acceleration amplitude firstly drops and then grows moderately with the increasing value of the technological head feed rate when cutting the steel 12 050 material in the examined range. When comparing the feed rate 40 mm/min with 100 mm/min, the drop is 69.9%.

4. Conclusion

This article presents the findings of a research study that examined the impact of different technological parameters (material type and feed rate) on the acceleration amplitude and vibration frequency of the technological head during abrasive water jet machining. With regard to the materials and feed rates under examination, the study identifies specific maximum values of vibration acceleration amplitude within the frequency range of 6.8-7.3 kHz.

Based on the graphical dependencies that were created and evaluated, the following recommendations can be formulated for steels 12 050 and 11 523. The experimental conditions indicate that it is preferable to avoid using a feed rate of 40 mm/min. Furthermore, the use of feed rates of 100 or 400 mm/min is recommended, as these speeds have been shown to generate significantly lower vibration acceleration amplitudes.

The presented work contributes to long-term research and is in good agreement with results reported previously.

Acknowledgements

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