Identification of the vibration frequency and form of the AWJ machinein aspect of cutter head vibration

Identyfikacja częstotliwości i postaci drgań maszyny AWJ w aspekcie drgań głowicy

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As part of a comprehensive study of influence of vibrations on the abrasive waterjet process, this article discusses about the identification of modal properties of the waterjet machine including the cutter head. The experimental modal analysis of the main gantry components of the machine construction was carried out, i.e. the carrier beam with the tool support and the cutter head. Determination of the modal properties of the machine allowed the identification of these vibrations, which are directly attributable to the construction of the machine and indicate them in the signal registered during the cutting.

KEYWORDS: abrasive waterjet, impulse test, vibration frequencies, vibrations forms

The basic way to increase the cutting performance in a waterjet abrasive machining program is to accelerate the process by increasing its parameters, primarily by the pressure and cutting speed. The increase in these parameters, however, results in higher dynamic loads affecting the machine. As a result, undesirable vibrations can occur that reduce machining accuracy and cutting quality. Therefore, one of the overriding aims of this study is to analyze the dynamic properties (modal parameters) of a specific construction design of a high-pressure abrasive blast machine, leading to the disclosure of causes of vibrations and their effect on the process itself.

The current state of knowledge on the process quality assessment based on vibration analysis is based primarily on vibration measurement and analysis directly in the process [1, 2]. The vibrating cutting process - their frequency and amplitude - depends to a great extent on the cutting and workpiece thicknesses. Also, the diameter of the cutting beam has a great influence on the vibration patterns - with the increase in the diameter of the jet, the spectral density of the power is transferred to the lower frequencies [4]. Geometric parameters of the surface of the resulting intersection depend essentially on the motion and angle of inclination of the cutting head. The recorded vibration signals [5, 6], milled on the cutting head, revealed a strong correlation with the harmonic power spectra of the cut surface roughness profiles.

The authors of the paper [7] have noted that the reduction of vibration clearly improves the surface quality obtained by the high-pressure jet cutting process. This quality is determined by several external conditions - such as the flow of the tooling and the machine bath - and the internal conditions – e.g. the nature of the high pressure pump and the motion system [1]. The unevenness at the intersection is also affected by the different velocity of the abrasive particles observed at the cutting height and in the cross section of the cutting beam. Researchers [8, 9] have also confirmed that a method of recording sound in a wide frequency band allows observing mass changes in a stream in which different kinetic energy values contribute to changes in the structure of the fractured surface.

The frequency ranges revealed in the studies [3] depend on the process parameters, but there are frequencies in which the amplitude of the vibration amplitude is significantly increased for certain inducing frequencies, even when the periodic inducing forces are small.

Knowledge of parameters such as vibration patterns, their frequencies and attenuation coefficients, predicts the behavior of the subject under external influences.

In experimental modal analysis two main methods are distinguished: frequency method and impulse method. They differ primarily by the way the vibrations of the system under test are forced. In vibration induced vibration frequency, vibration induced by the vibration induced vibration system is impulsively induced by the pulse-induced vibration signal. with modal hammer.

In the study, a pulse test method was used to induce a short-duration high-amplitude signal. The shape of the signal waveform, its durability and amplitude determine the range of the force spectrum that can be affected by the hardness of the hammer tip - in the present study, a limiting band of up to several hundred Hz was used. The pulse method is easier to use because it does not require a special vibration generator.

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Research position

In order to carry out experimental modal analysis with the impulse test method for a specific machine layout, a measuring circuit was constructed using:

- 3 piezoelectric accelerators (for each axis of the head travel in mutually perpendicular directions) type 4326-A from Brüel & Kjær,
- Brüel & Kjær modular hammer type 8202,
- National Instruments computer with PXI 4472B card and LabView software.

An overview of the supporting structure of Ridder's Waterjet Waricut HWM-P1520/1-3D is shown in fig. 1.

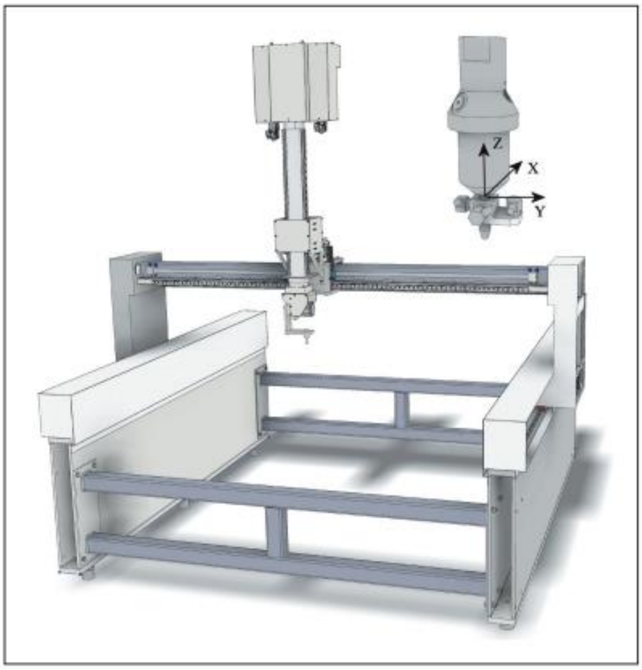


Fig. 1. HWM-P1520/1-3D bearing frame model and the method of fixing piezoelectric accelerometers together with the adopted coordinate system (compatible with the machine axes)

At the tip of the cutting head, a simple device for fixing three accelerators in the *X*, *Y* and *Z* directions (fig. 1) was designed. The analyzes were carried out using the software "System for testing machine tools in industrial conditions", developed at the Department of Machine Building of Silesian University of Technology [10].

The placement of the sensors allowed for a modal analysis with a roving source of excitation. Two directions of extinction were combined with the planar plane of the machine table - *X* and *Y*. The *Z* axis does not directly affect the accuracy of typical 2D machining.

Tests were performed for several machine positions. These included 2 different slider extensions - the *Z* axis - and different head positions relative to the table - the *X* and *Y* axes (fig. 2).

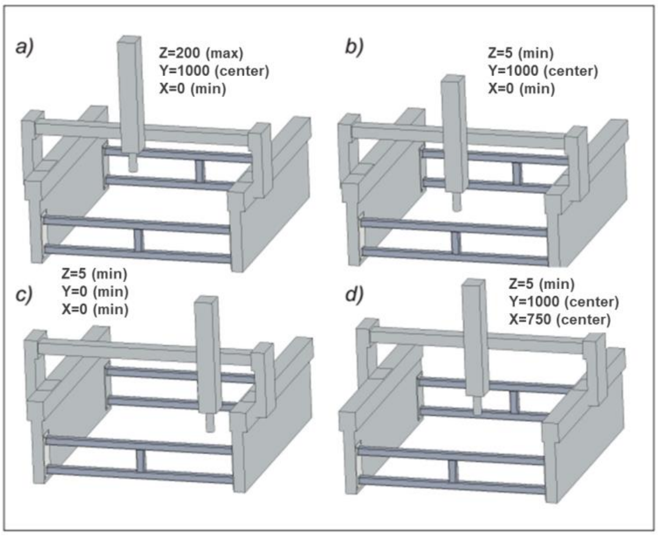
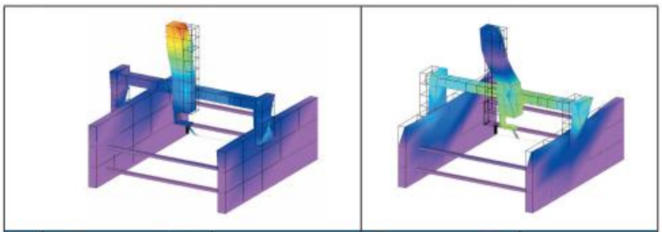


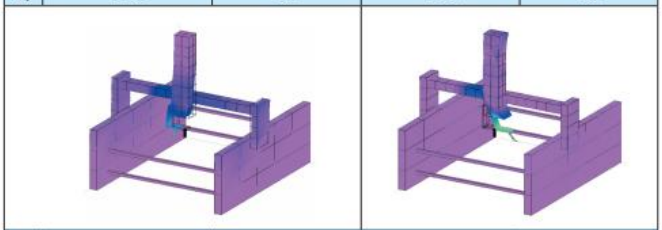
Fig. 2. Axis locations for modal studies

Test results

Sample modal analysis results for 4 axial position variants are shown in fig. 3 and fig. 4.

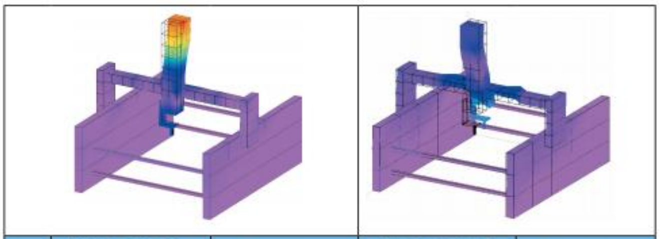


	Frequency of own vibration, Hz	Damping, %	Frequency of own vibration, Hz	Damping, %
a)	9,9	2,8	17	1,9
b)	11	2,9	16,8	2
c)	11,5	2,5	17	2
d)	11,4	2,1	16,8	2,2

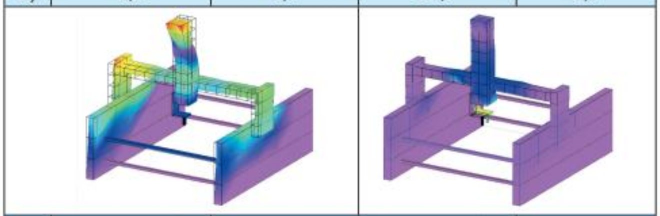


	Frequency of own vibration, Hz	Damping, %	Frequency of own vibration, Hz	Damping, %
a)	43	2	67	2,4
b)	43	2,3	67	2,5
c)	45	2,3	67	2,6
d)	42	1,8	67	3

Fig. 3. Summary of vibration parameters of the machine carrier structure in the *X* direction for individual axis positions (according to fig. 2)



	Frequency of own vibration, Hz	Damping, %	Frequency of own vibration, Hz	Damping, %
a)	8,3	3	25,3	1,7
b)	9,2	2,7	24,5	1,8
c)	10	3,4	25,6	3,9
d)	9,2	3,1	25,7	2,1



	Frequency of own vibration, Hz	Damping, %	Frequency of own vibration, Hz	Damping, %
a)	28	1,7	43	3,7
b)	27,8	2,4	42,4	2
c)	30,8	2,5	44	2
d)	28,2	2,8	42,3	2

Fig. 4. Summary of vibration parameters of the machine carrier structure in the *Y* direction for individual axis positions (according to fig. 2)

The first machine vibration frequencies are relatively small - about 10 Hz. These values in a small degree depend on the position of axis, and the relationship being logical. Column depreciation (*Z* axis) - configuration b) - reduces the first vibration frequency of the column and head relative to configuration a). Retraction of the gate to the middle position - configuration d) - virtually reduces all vibration frequencies relative to configuration a).

Wavy surface, usually emphasized when cutting homogeneous materials with large feeds, could have originated in the vibrations of the machine itself. Fig. 5 shows results of the surface corrugation profile after cutting at a feed rate of 90 mm/min (1.5 mm/s) of carbon steel sample S235RJ 20 mm thick.

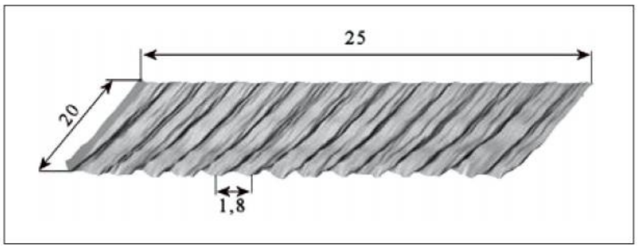


Fig. 5. Measurement results of steel surface profile with thickness of 20 mm after cutting at a speed of 90 mm/min

Results show that the average surface waviness is 1.8 mm, and its amplitude is greatest at the outlet of the cutting material. Tests conducted to force the surface waveform indicate that if the waveform was caused by vibration, their frequency would not exceed 1.2 Hz.

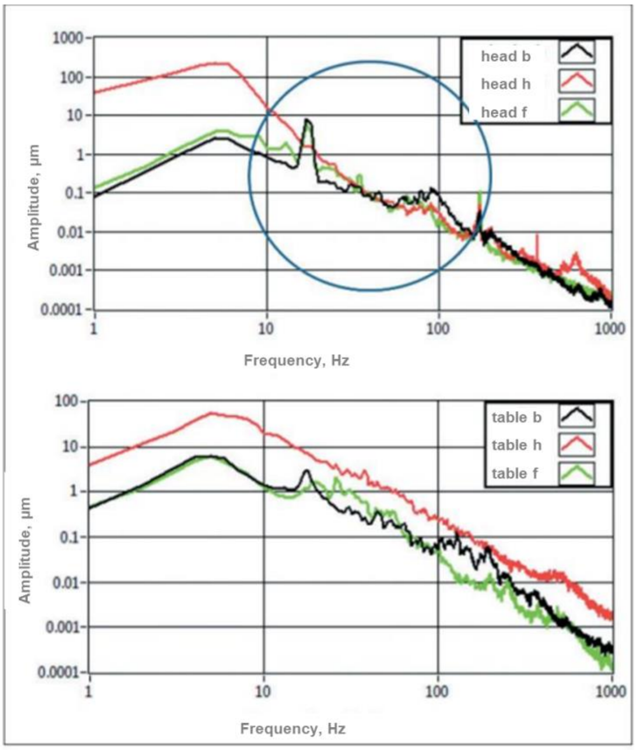


Fig. 6. Frequency displacement values for the 3 components of the head and table (feedrate: 137 mm / min, material S235RJ, thickness: 20 mm) [11]. The colors determine the direction of vibration measurement, where: *b* is measurement of vibration in the direction perpendicular to the intersection (direction of cutting head movement), *h* - measurement of vibration towards the axis of the cutting jet perpendicular to the surface of the object, *f* - measurement of vibration in the direction of cutting head feed

Referring these results to the results in article [11], they can be interpreted in the context of the effect of modal vibrations of the entire machine on the head oscillation recorded during the cutting process.

Fig. 6 shows an example of the spectrum for the cutting head and the vibration of the table. Amplitude spectra are shown in displacement units.

From the graphs it is evident that the vibration patterns identified in the vibration test of the machine's own frame have an influence on the signal recorded during the machine operation, which is especially evident in the area shown in Figure 6. One of the frequencies (17 Hz) is dominant and tied with its displacement, occurring during cutting, is a maximum of 10 µm. Other forms of vibration have significantly lower impact on the head oscillations. The vibration of the table (fig. 6 - the sensors were placed on the object) were not reflected in the vibrations of the machine frame, which seems logical considering the mechanical separation of the table and the bathtub from the load-bearing structure.

Conclusions

The experimental modal analysis of the load bearing construction of the exemplary 5-axle AWJ machine, which has utility parameters comparable to competing products, has enabled the machine to learn features of this type of machine. The relatively low frequencies of the machine's own vibrations result from its characteristic construction. On the one hand, the machine is not loaded with high forces (as already shown in earlier studies [12]) and, on the other hand, high feed rates (up to 20 m/min) and acceleration cause heavy loads inertia. It has also been shown that the dynamic susceptibility for 10 Hz is approximately 0.7 mm/N.

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