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MODULATION OF WATERJET BY ULTRASONIC: MEASUREMENT OF DYNAMIC PRESSURE AND FORCE EFFECTS

MODULOVÁNÍ VODNÍHO PAPRSKU ULTRAZVUKEM: MĚŘENÍ DYNAMICKÉHO TLAKU A SILOVÝCH ÚČINKŮ

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Series of measurement of a dynamic pressure inside the ultrasonic nozzle under its various configurations were performed within the framework of research focused on modulation of waterjet by ultrasonic. Force effects of modulated jet at various distances from the nozzle exit were measured as well. Both acquisition and processing of measured data were realized using NI LabVIEW. Results of measurement are compared and discussed in the paper.

Key words: waterjet, modulated jet, ultrasonic modulation, dynamic pressure, stagnation force of the jet.

Introduction

Extending the use of waterjets to areas such as hard rock mining and other underground engineering applications requires significant improvement in their performance. One of possible approaches to increase the performance of waterjets is pulsing the jet. This follows from the fact that the impact pressure on a target generated by a slug of water is considerably higher than the stagnation pressure of a corresponding continuous jet.

When a continuous waterjet impinges normally on a flat rigid surface at the velocity of v_0, the maximum pressure at the point of impact is the stagnation pressure p_s, given by:

$$p_s = 500\, v_0^2 \tag{1}$$

However, if a drop or a slug of water strikes the same target at the same velocity of v_0, the initial impact pressure will be much higher. So-called waterhammer pressure developed by the initial impact of a waterjet can be determined as:

$$p_i = 1477000\, v_0 \tag{2}$$

Thus pulsing the jet leads to an amplification of the impact pressure $z = p_i/p_s = 2954/v_o$. Since velocities of continuous jets currently used in outdoor applications do not exceed 700 ms^{-1}, the impact pressure of pulsed jet will be at least 4 times higher at the same velocity and therefore significant improvement in cutting performance can be expected.

A particular method of generating pulsed jets represents modulating a continuous stream of water. Unlike single pulses and interrupted jets, a modulated jet escapes from the nozzle as a continuous stream of liquid having unsteady velocity (cyclically modulated over time). Slow and fast portions of each cycle tend to flow together, forming a train of "bunches" in the free stream, which eventually separate (Nebeker & Rodrigues, 1976 and Nebeker, 1981).

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At present, an extensive research program is performed in the Institute of Geonics in Ostrava oriented at the evaluation of potential of modulated jets in cutting of various materials as well as at the understanding of fundamental processes occurring both within and outside the nozzle during ultrasonic modulation of the jet. This paper will discuss experimental results of measurement of dynamic pressure inside the ultrasonic nozzle and stagnation force of the modulated jet at various configurations of the ultrasonic nozzle.

Ultrasonic modulation of the jet

Ultrasonic modulation of a jet is produced by the vibrating tip of an ultrasonic velocity transformer located inside a nozzle. The vibration is generated by an ultrasonic transducer connected to the velocity transformer. A detailed description of the concept and configuration of the ultrasonic nozzle can be found e.g. in Puchala & Vijay (1984), Vijay (1992), Vijay & Foldyna (1994) and Foldyna et al. (2001). The ultrasonic nozzle can be "tuned" by setting the position of vibrating tip to obtain maximum modulation of the high-speed waterjet.

Experimental facility

The experimental facility consisted essentially of a high-pressure water supply system, an ultrasonic nozzle device and a PC-based measuring system.

High-pressure water was supplied to the nozzle by a plunger pump capable to deliver up to 43 l/min of water at pressure up to 120 MPa.

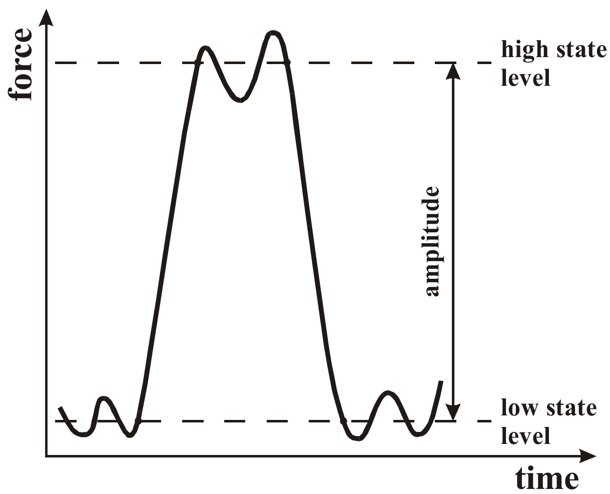

Figure 1. Pulse characteristics

The ultrasonic nozzle was equipped with piezo-electric transducer vibrating at 20 kHz (at maximum power of 600 W). Two configurations of the ultrasonic nozzle were used during experiments: (i) nozzle equipped with vibrating tip 2,0 mm in diameter (referred as nozzle I in the paper) and (ii) nozzle equipped with vibrating tip 10,0 mm in diameter (referred as nozzle II in the paper).

Dynamic pressure in the nozzle was measured by a calibrated piezoelectric pressure sensor Kistler 6211; operating pressure was measured at the ultrasonic nozzle inlet by a piezoresistive pressure sensor Kristal RAG25A1000BC1H. Force effects of the jet were measured by the apparatus for the measurement of stagnation force of the jet, consisting of piezoelectric force sensor Kistler 9301A and charge amplifier Kistler 5007. The apparatus was developed at the Institute of Geonics in Ostrava (for more details on apparatus and measurement method, see Vala, 1994, and Foldyna & Sitek, 2000).

Data acquisition and processing was performed using PC-based measuring system equipped with DAQ board NI PCI-MIO-16E-1 and controlled by NI LabVIEW 6.1. The measured time domain signal was processed to obtain pulse characteristics such as amplitude and low state level of the pulse (see Figure 1). The time domain signal was also transformed by FFT to obtain frequency domain of the signal.

Results and discussion

Measurement of dynamic pressure in the nozzle

Series of measurement of dynamic pressure in the nozzle during ultrasonic modulation was performed under following testing conditions: operating pressure of 20 MPa, nozzle diameter of 1.98 mm, and ultrasonic power of 600 W. Tests were performed using both nozzle I and nozzle II.

The results do not indicate any significant differences in dynamic pressure developed during ultrasonic modulation in both nozzle configurations. However, results seem to indicate that the tip position in the nozzle has only a marginal influence on dynamic pressure in the nozzle. Examples of time and frequency domains of the dynamic pressure in the nozzle can be seen in Figure 2 for nozzle I and Figure 3 for nozzle II.

Measurement of force effects of modulated jet

Series of measurement of force effects of the modulated jet was performed under following testing conditions: operating pressure of 20 MPa, nozzle diameters of 1.19 mm and 1.98 mm, and ultrasonic power of 600 W. Standoff distance was changed during the tests. Again, tests were performed using both nozzle I and nozzle II.

The results of the measurement of force effects indicate significant difference between effects of modulated jets produced by tested nozzle configurations. Whereas force effects of the modulated jet generated by the nozzle I are strongly influenced by the tip position inside the nozzle, tip position in the nozzle II influences force effects of the jet to a much lower degree. Moreover, force effects of the jet produced by the nozzle II seems to be higher in comparison with that produced by the nozzle I. The

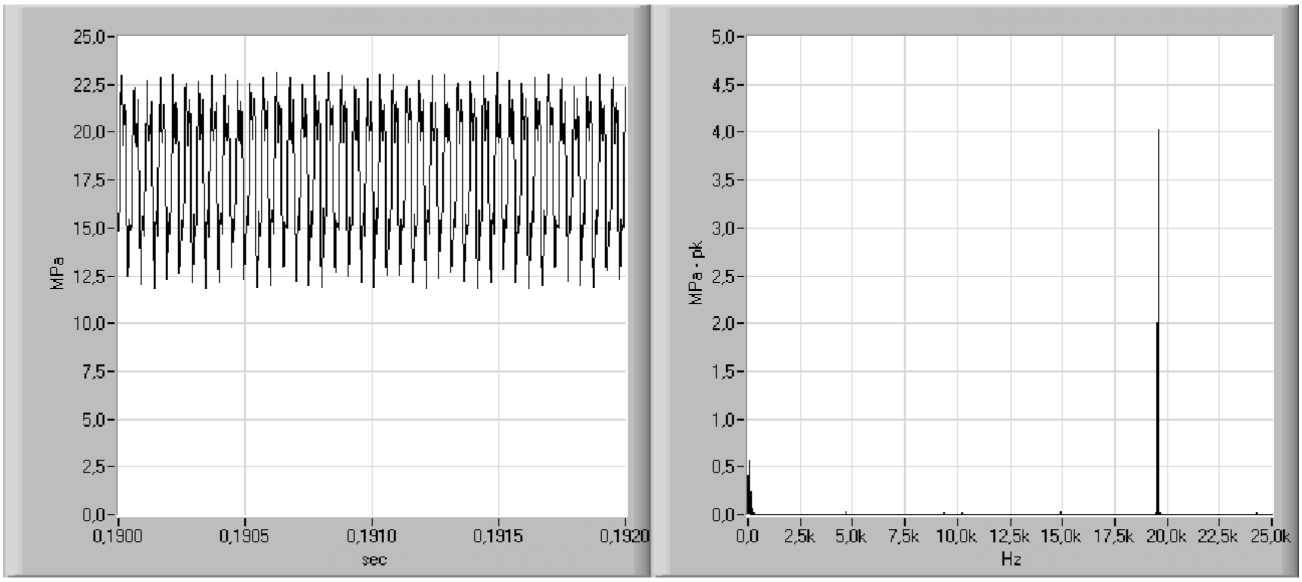

Figure 2. Time and frequency domains of pressure in nozzle I. Testing conditions: p = 20 MPa, d = 1.98 mm, P_U = 600 W

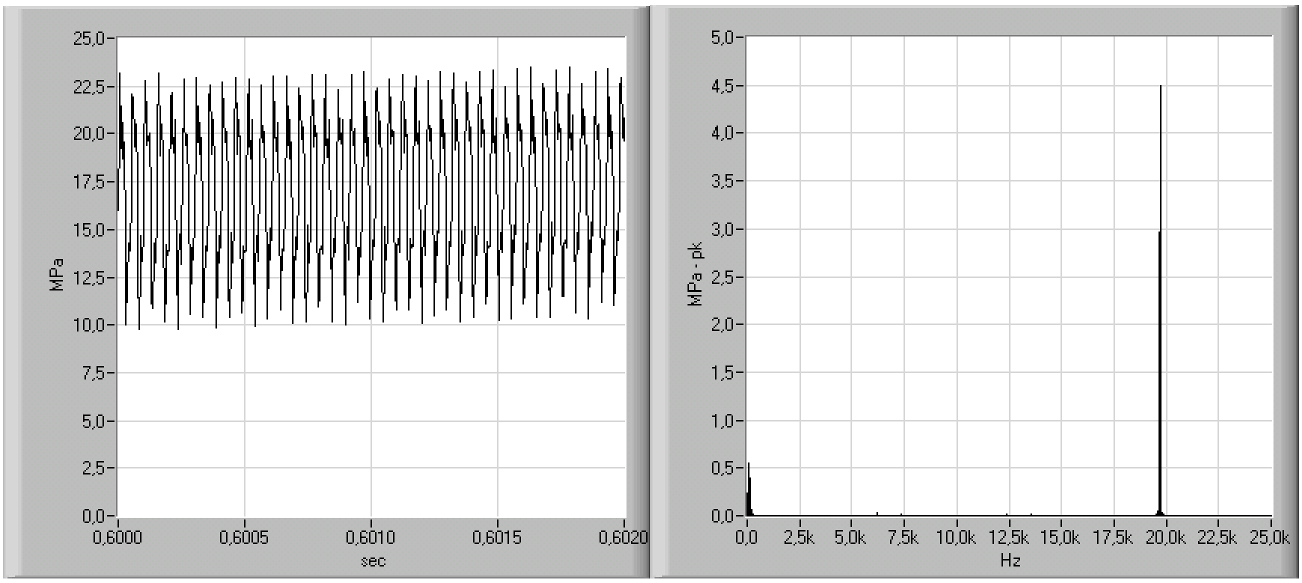

Figure 3. Time and frequency domains of pressure in nozzle II. Testing conditions: p = 20 MPa, d = 1.98 mm, P_U = 600 W

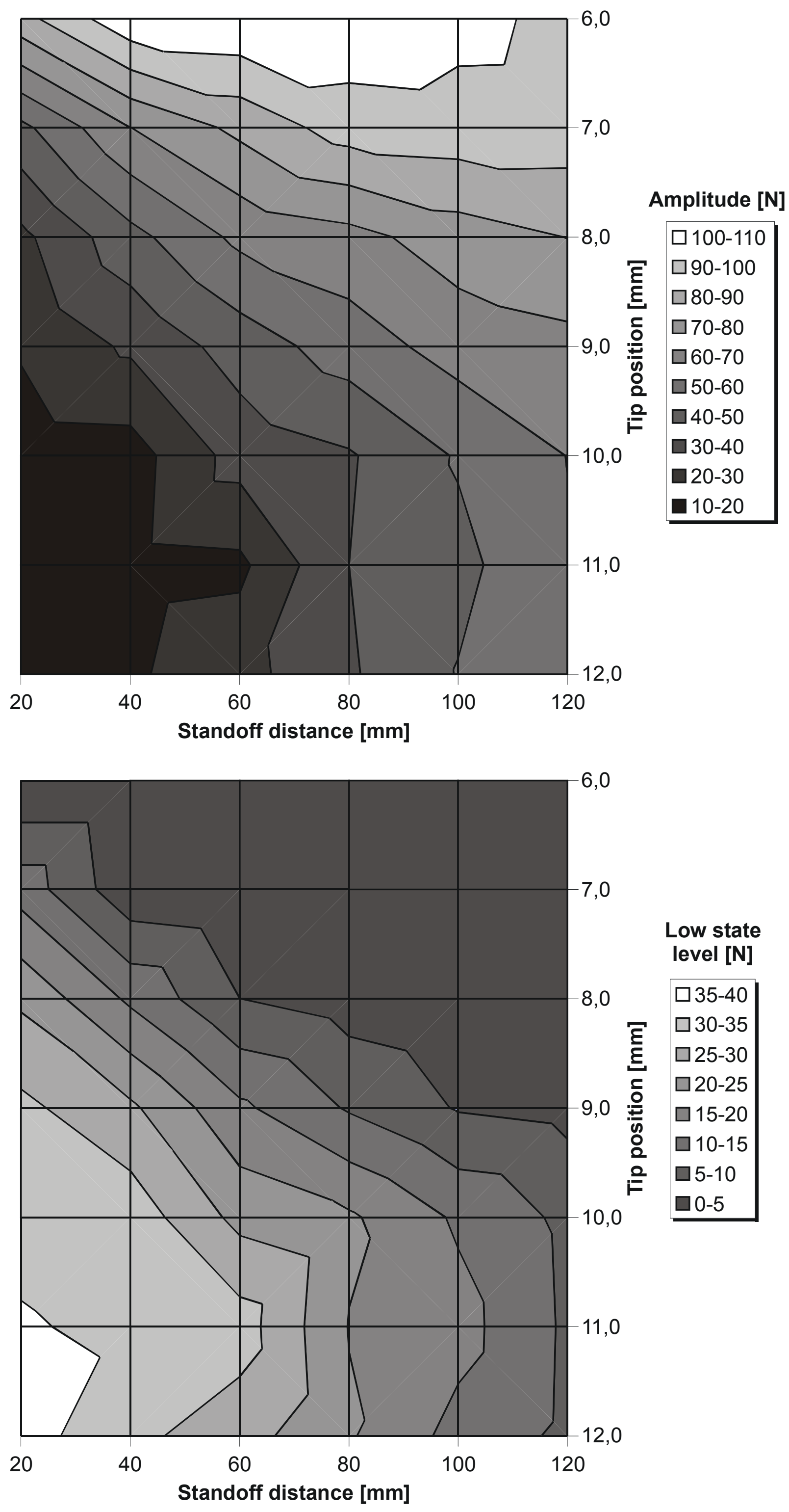

Figure 4. Influence of tip position and standoff distance on the amplitude and low state level of the pulse (nozzle I). Testing conditions: p = 20 MPa, d = 1.19 mm, P_U = 600 W

influence of the tip position on amplitude and low state level of the pulse is illustrated by Figure 4 for nozzle I and by Figure 5 for nozzle II.

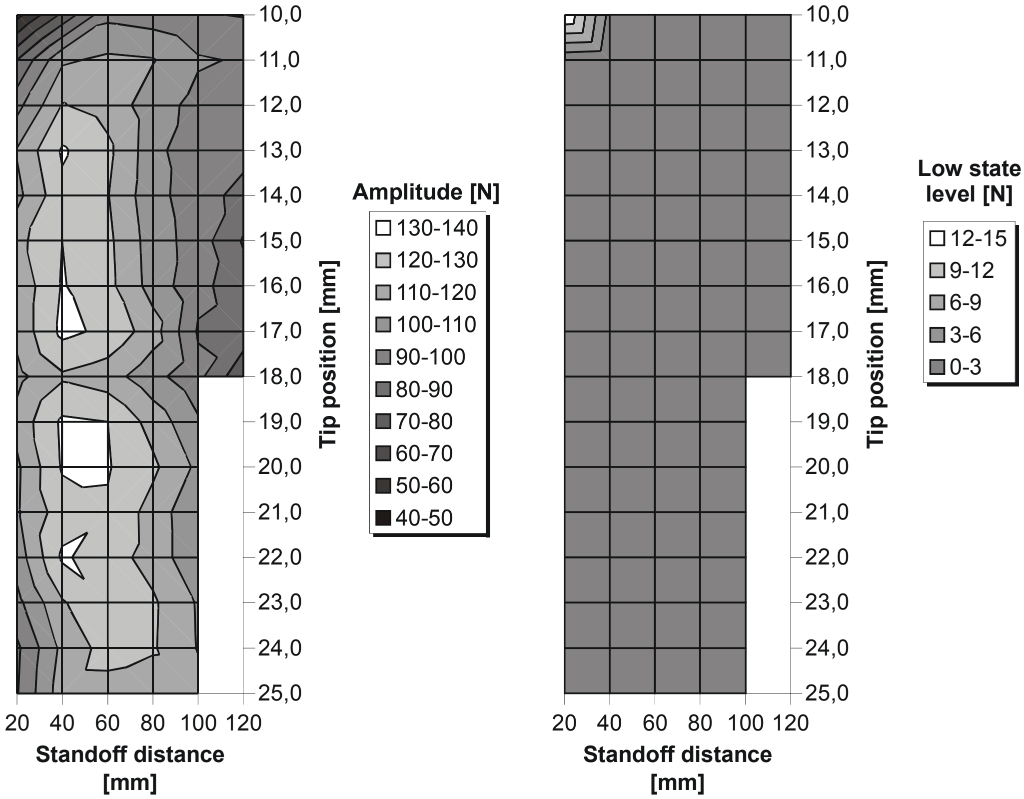

Figure 5. Influence of tip position and standoff distance on the amplitude and low state level of the pulse (nozzle II). Testing conditions: p = 20 MPa, d = 1.19 mm, P_U = 600 W

Conclusions

Measurement of stagnation force of the modulated high-speed waterjet has shown that the ultrasonic nozzle I should be "tuned" by changing the vibrating tip position with respect to the nozzle exit to maximize impact effects of the jet. On the other hand, tip position does not play such an important role in performance of the nozzle II.

The maximum force effects of modulated jets can be determined by the analysis of time domain with respect to pulse characteristics. Thus, the measurement of stagnation force can be used to optimize configuration of the ultrasonic nozzle with respect to maximum performance of the modulated jet.

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