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MEASUREMENT OF FORCE EFFECTS OF MODULATED JET

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Forced modulation of a continuous stream of water represents the most promising method of pulsed jet generation because of its simplicity and practicality. Experimental results obtained with the ultrasonic vibration of a tip situated inside the nozzle indicate that using this technique one can achieve performance of the jet even order of magnitude higher in comparison to continuous jet at the same hydraulic parameters (Vijay & Foldyna, 1994). In this paper, results obtained in measurement of force effects of water jets modulated by ultrasonic vibration of a tip situated inside the nozzle are presented. Both method of modulation of the jet and method of measurement of force effects of the jet are briefly described. Results are obtained in form of amplitude spectra and compared with those obtained with continuous jets at the same operating parameters. Potential of the measurement of force effect of modulated jets in determination of optimum configuration of the ultrasonic nozzle is discussed.

Key words: water jet, modulated jet, ultrasonic modulation, force sensor, stagnation force of the jet.

Introduction

Despite the impressive advances made in the field of water jet technology during the last decades, the use of water jets for hard rock mining and other underground engineering applications remains unattractive. The main reason for this apparent lack of interest is that the performance of water jet techniques is not competitive with the existing conventional mechanical systems. Therefore, extending the use of water jets to these areas requires significant improvement in their performance.

From an analysis of the impact of a water jet on a target, it can be shown that the impact pressure generated by a slug of liquid is considerably higher than the corresponding stagnation pressure generated by a continuous jet. Therefore, if a continuous jet could be divided into a train of slugs, the resulting pulsed jet could significantly improve the performance in the cutting of hard rocks. Furthermore, one can assume that additional effects (for example, enhanced penetration and the subsequent crack propagation in the material) due

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to impact of pulsed jets may provide new methods for the cutting and fracturing of hard and brittle materials.

Since the early seventies, incessant attempts have been made for generating various types of pulsed water jets (for details, refer to the paper by Vijay, 1993). In this paper, attention is focused on a particular method of generating pulsed jets that involves modulating a continuous stream of water with an ultrasonic vibrator upstream of the nozzle exit.

Unlike single pulse 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. In this paper a brief discussion on theoretical aspects of measurement of force effects of modulated high-speed water jets is given with sample experimental data obtained in measurement of stagnation force of the jet to illustrate the difference of force effects of modulated jets compared to continuous water jets.

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 in Puchala & Vijay (1984) and Vijay (1992).

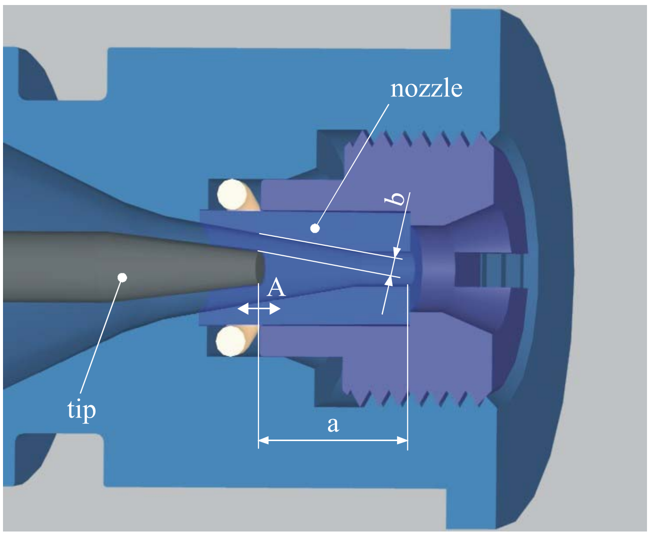

Fig. 1. Geometric configuration of the ultrasonic nozzle

The geometric configuration of the nozzle with the vibrating tip inserted upstream the nozzle exit is shown in Figure 1. The tip vibrates axially with amplitude A so that both the distance a and the gap b periodically changes from maximum to minimum values.

The ultrasonic nozzle can be "tuned" by setting the distance a to obtain maximum modulation of the high-speed water jet. However, the distance a has to be large enough to avoid contact between the nozzle surface and the tip.

Measurement of stagnation force of the jet

Common methods of measurement of force effects of high-speed water jet fail because of extreme concentration of energy at the impact area (up to 1 $GJ.m^{-2}$). Such a concentration of energy causes destruction of each type of sensor inserted into the stream. Therefore, an original method of measurement of stagnation force of the jet was developed at the Institute of Geonics in Ostrava.

The method can provide information not only about jet and/or nozzle quality but also about jet behavior and structure. In the measurement, high-speed water jet impacts onto flat circular surface made from material with high resistance against the jet effects (such as PCD coated surface). Impact of the jet on the surface generates stagnation force that is measured by force sensor (see Fig. 2). More detailed description of the measuring equipment can be found

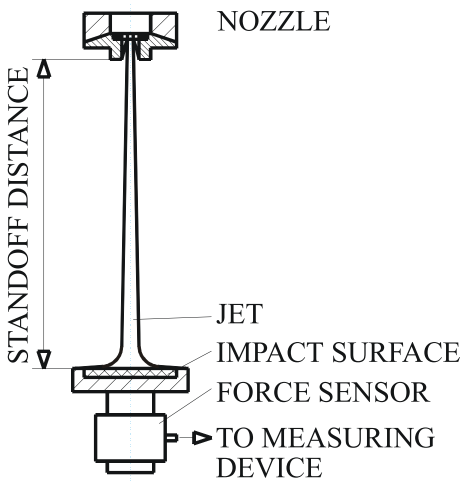

Fig. 2 Sketch of measurement of force effects of the jet

in previously published papers (see e.g. Vala, 1994). Recorded signals are processed to determine average value of static force generated by the jet impact. Behavior of the jet is determined by frequency analyses of the signal.

Presence of peaks in measured signal at certain frequencies indicates breaking-up of the jet. On the other hand, signal with low-level flat spectrum indicates coherent jet.

Testing equipment

The measurement was performed using plunger pump delivering up to 43 l/min of water at pressures up to 120 MPa. Ultrasonic nozzle was equipped with piezoelectric transducer vibrating at 20 kHz (at maximum power of 1 kW).

Force effects were measured by the above-mentioned apparatus consisting of force sensor Kistler 9301A and charge amplifier Kistler 5007. Data acquisition and processing was performed using PC-based measuring system with DAQ board NI PCI-MIO-16E-1 and controlled by NI LabVIEW 6i. The measured time domain signal was transformed by FFT to obtain frequency domain of the signal.

Results and discussion

Series of measurement of force effects of the jet was run under following testing conditions: operating pressure of 20 MPa, nozzle diameter of 1,98 mm, vibrating tip diameter of 2,0 mm and ultrasonic power of 1 kW. Standoff distance and distance of the tip from the nozzle exit (***a***) were changed during the tests.

Figure 3 shows an example of time and frequency domains of the measured signal. The time domain indicates that the amplitude of stagnation force of the modulated jet varies in time within the range from 0 up to 400 N. The frequency domain exhibits relatively flat spectrum with strong peak of 125 N at frequency of about 20 kHz that corresponds to the modulation frequency of the jet.

Figure 4 presents time and frequency domains of the measured signal generated by continuous jet under the same testing conditions. It can be seen that both time and frequency domains of the signal differ significantly from those obtained with modulated jet.

Figure 5 illustrates the influence of the standoff distance and tip position (a) on the peak amplitude of stagnation force (at 20 kHz under given testing conditions). It indicates that the peak amplitude is strongly influenced by both standoff distance and tip position.

Conclusions

Measurement of stagnation force of the modulated high-speed water jet has shown that the ultrasonic nozzle can be “tuned” by changing the vibrating tip position with respect to the nozzle exit to maximize impact effects of the jet. Thus, the method can be used to optimize configuration of the ultrasonic nozzle with respect to maximum performance of the modulated jet.

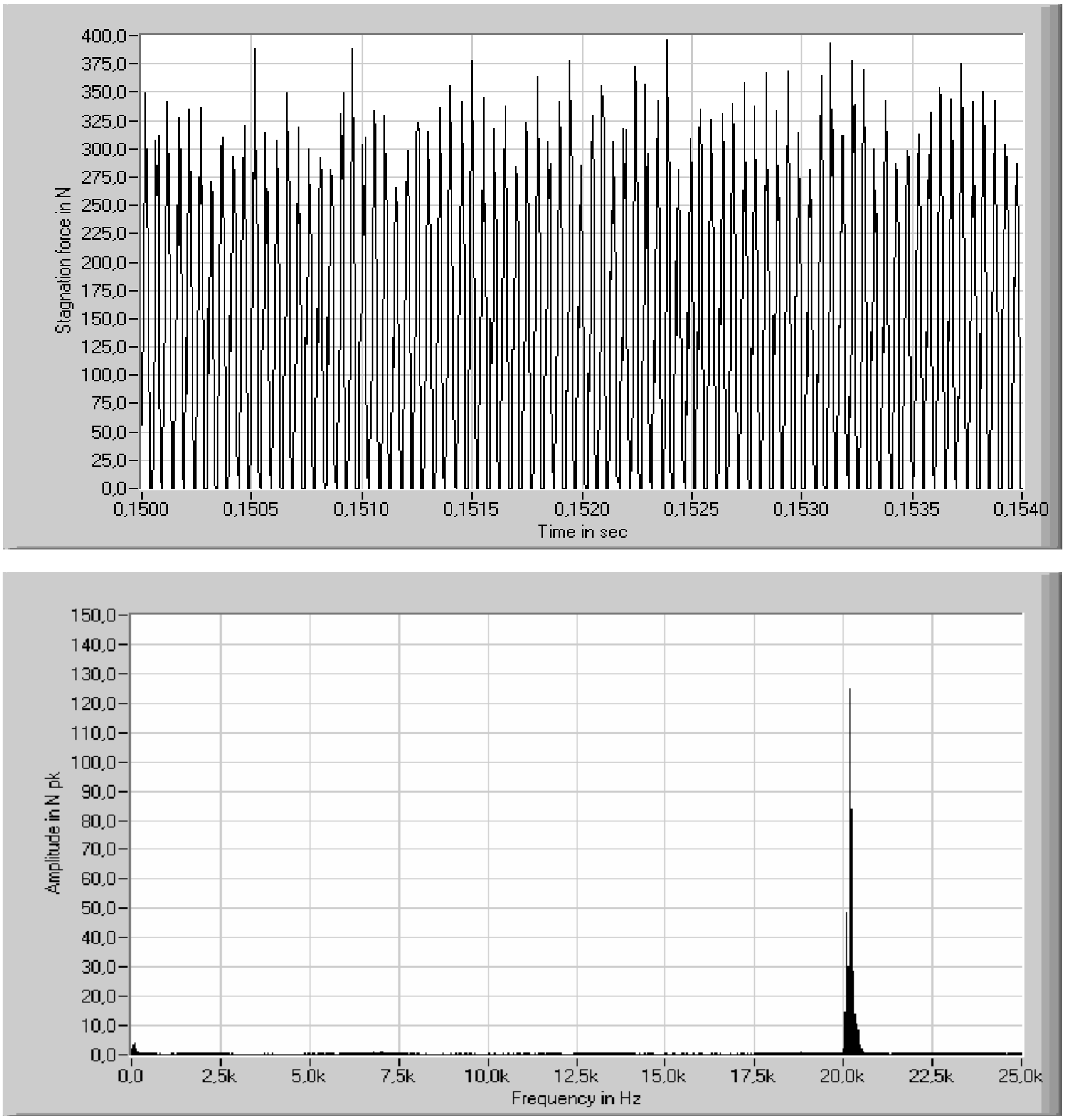

Fig. 3 Time and frequency domain of measured signal for modulated jet. (Testing conditions: operating pressure 20 MPa, nozzle diameter 1,98 mm, vibrating tip diameter 2,0 mm, tip position ***a*** 12,2 mm, ultrasonic power 1 kW, standoff distance 40 mm.)

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References

Puchala, R.J. & M. M. Vijay, 1984. Study of an ultrasonically generated cavitating or interrupted jet: Aspects of design. Proc. 7th Int. Symp. on Jet Cutting Technology, Ottawa, Paper B2: pp 69-82.

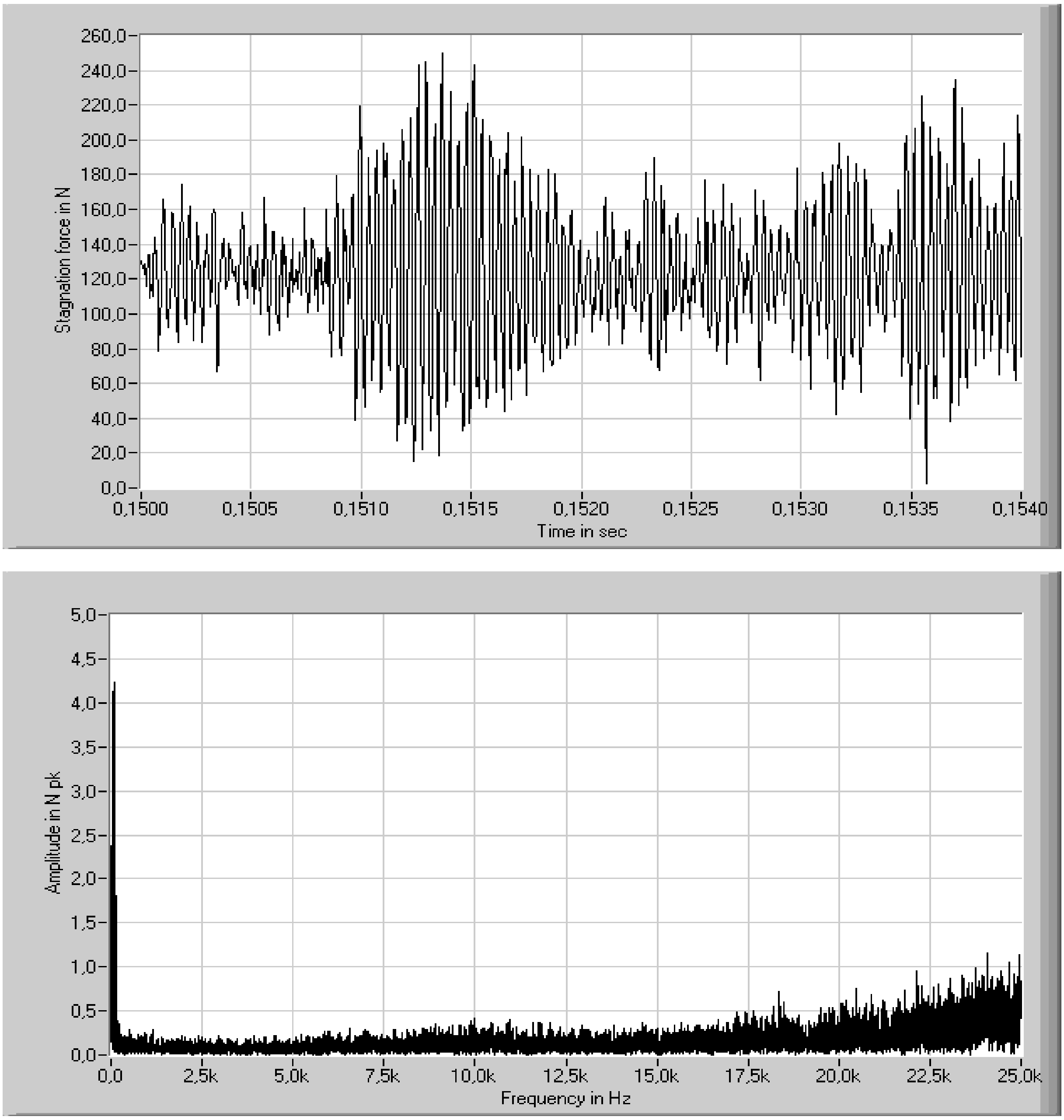

Fig. 4 Time and frequency domain of measured signal for continuous jet. (Testing conditions: operating pressure 20 MPa, nozzle diameter 1,98 mm, standoff distance 40 mm.)

Vijay, M. M., 1992. Ultrasonically generated cavitating or interrupted jet. U. S. Patent No. 5,154,347.

Vijay, M. M., 1993. Power of pulsed liquid jets. Proceedings International Conference Geomechanics '93, Balkema, Rotterdam: pp 265-274.

Vala, M., 1994. The measurement of the non-setting parameters of the high pressure water jets. Proceedings International Conference Geomechanics '93, Balkema, Rotterdam: pp 333-336

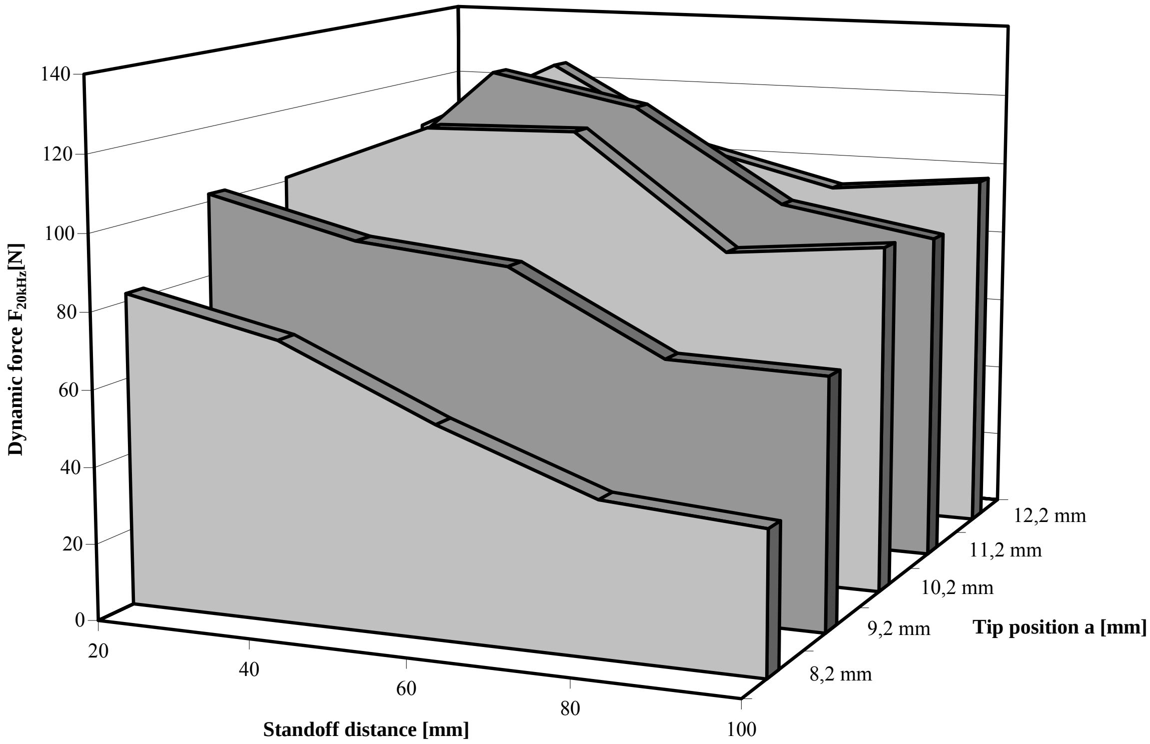

Fig. 5 Influence of the standoff distance and tip position on the peak amplitude of stagnation force (at 20 kHz). Testing conditions: operating pressure 20 MPa, nozzle diameter 1,98 mm, vibrating tip diameter 2,0 mm, ultrasonic power 1 kW.

Vijay M. M., Foldyna J., 1994. Ultrasonically Modulated Pulsed Jets: Basic Study. In: 12th International Conference on Jet Cutting Technology, N. G. Allen, Editor, BHR Group Conference Series, Publication No. 13, Mechanical Engineering Publications Limited, London: pp 15-35