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USE OF RESONANCE IN WATERJET TECHNOLOGY

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Abstract: *Abstract: The paper deals with increasing the efficiency of material disintegration process by the action of – non abrasive waterjet. The greater efficiency of this process can be achieved through the resonance of water flow in a hydrodynamic system. It concerns the generation of flow pulses and flow modulation through an acoustic circuit. Currently known patented and unpatented modulation methods are mentioned in this paper.*

Keywords: ***Hydrodynamic system, resonance, disintegration of surface.***

1. Introduction

A conventional use of the waterjet technology includes many areas such as surface disintegration, cutting of wide range of materials and removal of surface layers during surface cleaning. The effectiveness of the continuous flow action can be significantly raised by its modulation, mainly by pulses. Currently there are known laboratory and technical positive expertises in generating a flow modulation in various ways: an unpatented way by a throttle rotation segment, or a patented way by an oscillating tip and acoustic actuator. In current practice it is used a self-resonating nozzle (unpatented) with an integral mechanical modulator of the flow in the form of a spline rotor that is placed before the nozzle exit area. The flow resistance is cyclically changing by rotation and thus modulates the velocity of the water flow exiting the nozzle. A disadvantage is a high wear rate of the moving parts in the nozzle and a need to maintain the rotor drive. A built-in acoustic transformer connected to a magnetostrictive or piezoelectric converter is placed near the outlet end of a patented ultrasound nozzle. In principle the oscillating tip generates in front of the outlet nozzle end a high - intensive ultrasound field, i.e. the field that modulates the high speed water flow at the nozzle exit. (Vijay, 1992).

Pressure pulsations are primarily generated in the acoustic chamber filled with a pressure liquid by the acoustic actuator and secondarily amplified by the acoustic concentrator (Foldyna, 2005). The author together with a team has filed a patent application (Kušnerová, 2008), which concerns the possibility of using the flow resonance in the hydrodynamic system (Fig. 1). The pulsation is primarily implemented by friction and secondarily amplified by the resonant chamber.

2. Theoretical solution

The hydrodynamic system generates modulated oscillations of a resonant frequency which depend on the input parameters, i.e. on the geometric dimensions of system elements and also on the fluid

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pressure settings. The fundamental frequencies of fluid oscillation represent the output parameters.

1. Method of solution is based on the equation of motion, which generally describes the phenomenon of proper oscillations of the system. We compile and solve linear ordinary differential equation with constant coefficients without the right hand side of the equation (1), where *y* is the variable of the oscillation deflection, ω_0 is the fundamental angular frequency and f_0 is the fundamental simple frequency.

$$m_a \frac{d^2 y}{dt^2} + r_a \frac{dy}{dt} + \frac{1}{c_a} y = 0 \Rightarrow \omega_0^2 = \frac{1}{m_a c_a} \Rightarrow f_0 = \frac{1}{2\pi} \sqrt{\frac{1}{m_a c_a}} \quad . \tag{1}$$

   The equation (1) is not solved with the right hand side, because the surround resistance effects r_a are solved by using a material - quality conversion coefficient for acoustic mass that is experimentally determined.

2. Method of solution is based on the evaluation of the acoustic impedance Z_a of the oscillating system at resonance. The acoustic impedance as a complex acoustic resistance shall receive minimum values by analogy to the Thomson relation if the reactance of acoustic mass X_{ma} equals to the acoustic compliance X_{ca}. The solution (2) displays the same expression of the fundamental fluid oscillation frequency as the equation (1).

$$\overrightarrow{Z_a} = r_a + i\, X_a = r_a + i\left(\omega_0 m_a - \frac{1}{\omega_0 c_a}\right);\; X_{ma} = X_{ca} \Rightarrow f_0 = \frac{1}{2\pi}\sqrt{\frac{1}{m_a c_a}} \, . \tag{2}$$

The total impedance equals to the sum of the individual impedances in the electromagnetic oscillation circuit. By analogy, even in the hydrodynamic oscillation system as well as in the acoustic circuit, the total acoustic mass m_a corresponds to the sum of partial acoustic mass and a reciprocal value of the total acoustic compliance c_a equals to the sum of reciprocal values of the individual acoustic compliance. In our particular case it concerns these elements: three tubes (supply tube, connecting tube and output nozzle, $i = 3$) and two chambers (inlet chamber and resonance chamber, $j = 2$)

$$m_a = \sum_{i=1}^{3} m_{ai} \;\; ; \;\; \frac{1}{c_a} = \sum_{j=1}^{2} \frac{1}{c_{aj}} \, . \tag{3}$$

The analytical derivation of the acoustic mass and acoustic compliance corresponding to the relevant elements must respect diversity in a carrier environment, i.e. liquid and gas (Kušnerová, 2008). The fundamental frequency of fluid oscillations was predicted by both methods and was verified by measuring.

3. Experimental solution

The laboratory measurements of force effects of the modulated jet were carried out at the Institute of Geonics AS CR, v. v. i. in Ostrava (with the oscillating chamber without any friction element). An amplitude dependence of the applied forces on the resonant frequencies was expressed after the fast Fourier transformation (Fig. 2). The fluid pressure was adjusted into a set of discrete values of 5 MPa, 10 MPa, 15 MPa, 20 MPa and 25 MPa. The high-speed liquid jet was generated by a high-pressure plunger pump with a water flow rate of 43 $\mathrm{l{\cdot}min^{-1}}$ and a working pressure of 120 MPa. A piezoresistive pressure sensor was placed at the outlet section of the pump, which was used to adjust the working pressure. The force effects of the jet were measured by the apparatus for the measurement of stagnation force of the jet (Sitek, 1994), (Vala, 1994), consisting of piezoelectric force sensor Kistler 9301A. The signal obtained from that sensor was amplified in a charge amplifier KISTLER 5007. We conducted a total of 186 direct measurements of the frequency when setting of the input parameters with different values, i.e. liquid pressure and geometric dimensions of the system. The presented demonstration of the experiment corresponds to the fluid pressure of 15 MPa and the fundamental resonant frequency of 8.3 kHz. The amplitude of force reaches about 5.6 % of the static force component.

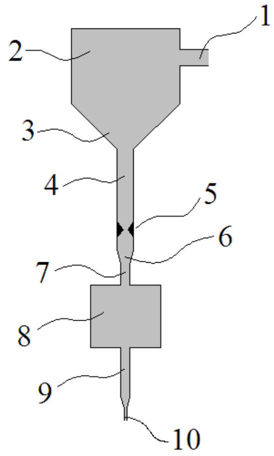

Fig. 1: Scheme of the hydrodynamic oscillating system. 1 supply tube; 2 upper part of the inlet chamber; 3 bottom part of the inlet chamber with a conical taper working as the mechanical amplifier; 4 connecting tube; 5 pulse generator; 6 connecting tube with a conical taper working as the mechanical amplifier; 7 inlet tube of the resonance chamber; 8 resonance chamber; 9 connecting tube; 10 nozzle at the exit from the system.

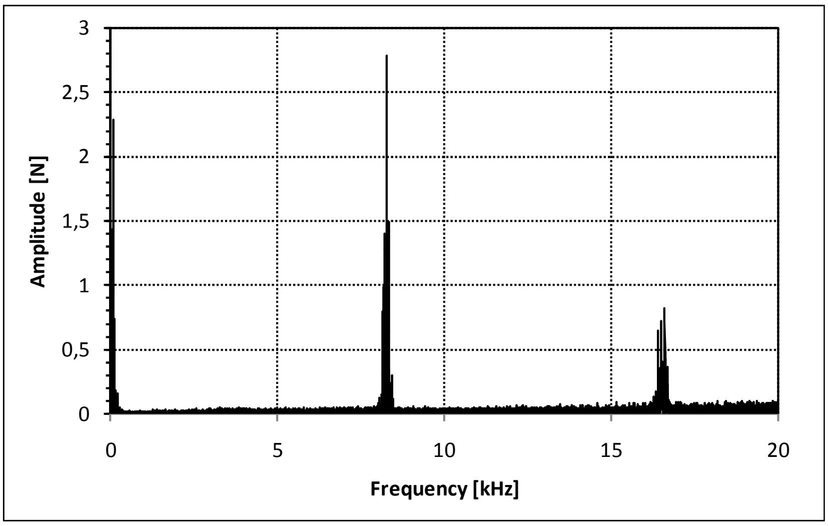

Fig. 2: Frequency record of the force amplitude measurement.

4. Comparison of theoretical and experimental results

A source of data used for the development and verification of the fundamental oscillation frequency of the hydrodynamic system was as follows: the direct measurement of the tunable geometric dimensions of elements, the adjustment of the fluid pressure, the indirect flow rate and velocity of acoustic oscillation measurement, the direct measurement of the fundamental oscillation frequency and other different indirect measurements using the tabulated values and regression calculations in Excel.

A comparison of the results of calculations and measurements (Tab. 1) is done by evaluating of the relative differences between the fundamental frequencies f_{ZM} and predicted fundamental frequencies of oscillations f_0 .

$$\rho_{\Delta f} = \frac{|f_0 - f_{ZM}|}{f_{ZM}} 100\,\% . \tag{4}$$

The arithmetical mean of the partial relative differences $\overline{\rho_{\Delta f}}$ for given discrete values of pressure p reaches the required compliance of less than 5 %.

Tab. 1: Comparison of the theoretical f_0 and measured f_{ZM} fundamental frequencies.

p [MPa]	f_0 [kHz]	f_{ZM} [kHz]	$\rho_{\Delta f}$ [%]
5	4.697	4.986	5.8
10	6.617	6.363	4.0
15	8.071	8.259	2.3
20	9.281	8.914	4.1
25	10.987	10.269	0.7
		$\overline{\rho_{\Delta f}}$	3.4

5. Conclusions

The paper gives brief information on current possibilities of using the waterjet technology with emphasis on the importance of using resonance in this technology. The measurements show that the water jet has the variable axial velocity component due to pulse generation. At a certain distance from the nozzle, the initial continuous flow breaks up into a series of water clusters and the jet begins to behave as the pulsating jet. Its cutting ability can be greatly increased. The impact pressure generated by the impact of water clusters on the disintegrated material is considerably higher than the stagnation pressure generated by the impact of the continuous jet of comparable parameters (Foldyna, 2004), (Vijay, 1992, 1994). The pilot testing of disintegration by the action of pulsating waterjet showed at least twice high performance of the material disintegration compared with the performance when using the continuous waterjet of the same parameters (Foldyna, 2004). This analysis and experiments also show that the level of pressure pulsations generated only by modulation of the acoustic circuit, i.e. by the hydrodynamic oscillating system is not high enough. The resonance chamber may be similarly used as the secondary acoustic source (amplifier) in acoustic.

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