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INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

Performance of air ejector with pulsating primary flow

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Abstract: The article deals with pneumatic measurement on subsonic axi-symmetric air ejector. Performances and of the ejector with and without pulsations of primary flow are compared, measuring of characteristic pressures and mass flow rates are performed and ejector efficiency is evaluated. The pulsations of primary flow are produced by a synthetic jet generator, which is placed in the supply line of the primary flow just in front of the primary nozzle. It is found out that using of primary flow pulsations yields higher back pressure behind the ejector and higher efficiency. Experiments for further investigation are suggested.

1. Introduction

The article deals with experimental investigation of mixing in axi-symmetric subsonic ejector with included device generating synthetic jet. The aim of synthetic jet is to intensify the mixing process. The mixing can by intensified by many ways that can be divided into two groups, passive and active, as they were in publication by authors Ginevsky, Vlasov and Karavosov [1]. Shaping of the primary nozzle trailing edge belongs to the passive methods, generating of flow pulsation is an active method. The work [1] deals with free flows from jets, number of works dealing with active or passive control of mixing in ejectors are quite limited. E.g. Havelka et al. in experimental work [2] used a device inserted into the primary nozzle to add a tangential velocity component into the primary flow. Measuring showed that the secondary mass flow rate is increased for certain range of tangential velocity and the shorter mixing chamber is satisfactory. Waitz et al. investigated intensification of mixing with the help of a lobe nozzle in work [3]. Dvorak [4] optimized the lobe nozzle for mixing and found out that a nozzle with low number of big lobes is advantageous for high efficiency of the ejector. Chang and Chen [5] used a petal nozzle in a supersonic ejector and compared it with common diverging nozzle. They showed that the ejector with petal nozzle is better for higher area ratio $A_3/A_{cr} \geq 150$ than the ejector with common nozzle.

The aim of the study made by Dvořák and Dančová [6] was to determine the influences of a synthetic jet (SJ), which was placed in the beginning of the mixing chamber. It was found out that the SJ accelerated the mixing process only negligibly, but it stabilized the flow fluctuations in the diffuser and thus the higher back pressure and higher efficiency were achieved. Velocities of the primary flow were affected during the suction and the outflow period of the SJ and so the velocity fluctuations were increased in this area too.

The aim of current study is to use the SJ actuator to generate pulsation in the primary flow in front of the mixing chamber.

2. Method

Dimensions of the synthetic jet actuator used for generating of primary flow oscillations and its position on the primary nozzle are obvious form Figure 1. The SJ actuator consists from sealed cavity and two loudspeakers (MONACOR SP-8/4SQ) with nominal parameters: 4Ω, 20Wmax. These loudspeakers have the same power and diameters (Dc = 70mm, membrane diameter Dm = 68mm) and are series-connected. Loudspeakers membranes have stiff cone shape and they can be considered pistons, which control the jet. Actuator was fed with

sinusoidal signal with electrical power P = 9.2W. Signal was generated from Tektronix AFG 3102 signal generator and was amplified with Omnitronic MPZ-180 amplifier.
A circular converging nozzle with diameter d = 19.2mm was used. The mixing chamber had diameter D = 40mm. The area ratio of nozzles was $\mu = A_1/A_2 = 0.3$ and the relative length of the mixing chamber was L/D = 8. A diffuser with 6° enlargement and with outlet diameter 71.2mm was placed behind the mixing chamber. First step of the measurement was the determination of the system nominal frequency – i.e. frequency on which ejector works with the highest power. Nominal frequency was found as f = 69.1Hz.
For pressure measuring, we used pressure sensors Druck LP 1000 with range 100, 500, 1000 and 2000Pa. These low pressure sensors with high accuracy are slow, so only mean value of pressures are measured. Arrangement of the experiments is obvious from figure 2.

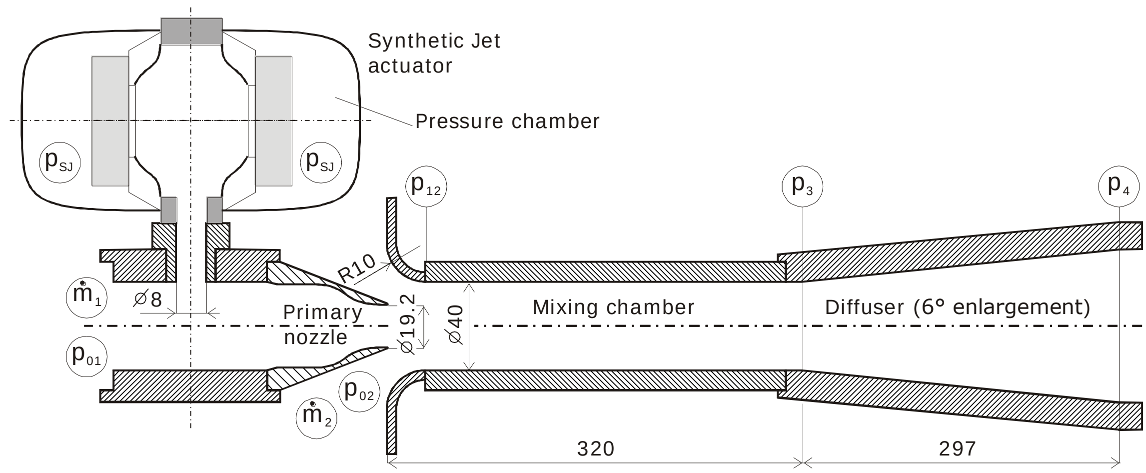

Figure 1: System of the synthetic jet and the ejector.

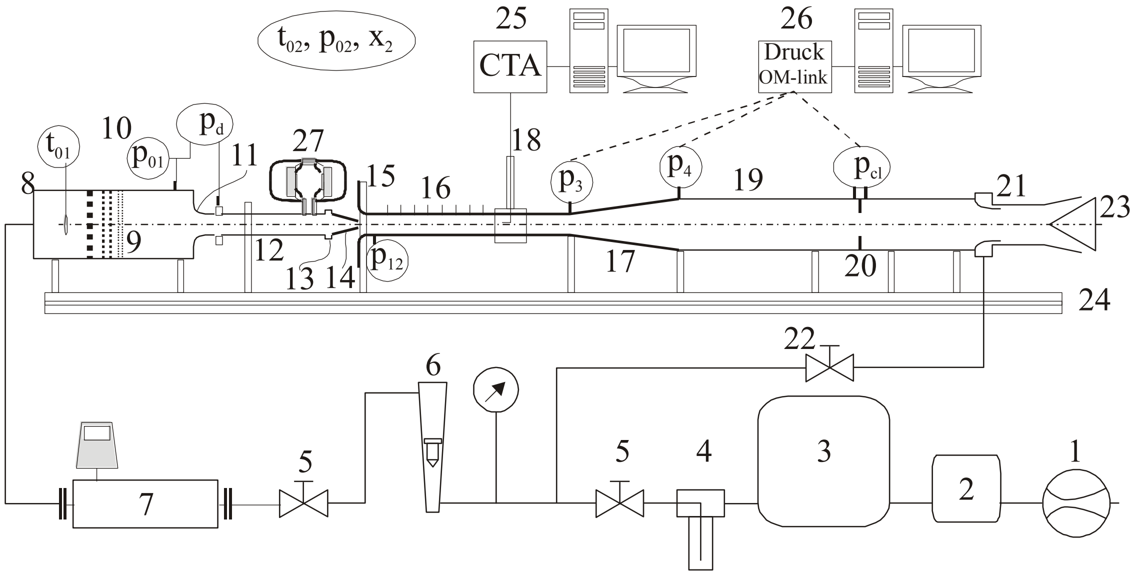

Figure 2: Experimental arrangement: 1 - compressor, 2 - air dryer, 3 - tank, 4 - reduction valve, 5 - filter, 6 - rotameter, 7 - Coriolis mass flow meter, 8 - stilling chamber, 9 - stilling riddles, 10 - measuring of primary stagnation pressure p_{01}, 11 - measuring of primary mass flow rate, 12 – primary flow supply, 13 – holder of primary nozzle, 14 – primary nozzle, 15 - secondary nozzle, 16 - mixing chamber with static pressure taps, 17 – diffuser, 18 - CTA probes, 19 – outflow pipe, 20 - measuring of total mass flow rate, 21 - suction ejector, 22 - control valve, 23 – chocking, 24 - bed, 25 - CTA measuring, 26 – pneumatic measuring, 27 – generator.

3. Results

The results for ejector with pulsation generator OFF and ON are in figures 3, 4, 5 and 6. The efficiency of the ejector is defined by relation

$$\eta = \frac{m_2}{m_1} \frac{\left(\frac{p_4}{p_{02}}\right)^{\frac{\kappa-1}{\kappa}} - 1}{1 - \left(\frac{p_4}{p_{01}}\right)^{\frac{\kappa-1}{\kappa}}} \frac{T_{02}}{T_{01}}, \qquad (1)$$

where m is mass flow rate, p static pressure, p_0 stagnation pressure, T_0 stagnation temperature and κ ratio of specific heats. Subscript 1 denotes primary flow, 2 secondary flow, 3 mixed flow and 4 state behind the ejector, i.e. behind the diffuser. For incompressible fluid, or for compressible fluid when $T_{01} = T_{02}$ and $(p_{01} - p_{02})/p_{02} <\approx 0.05$ the relation (1) can be simplified to

$$\eta = \Gamma \frac{p_4 - p_{02}}{p_{01} - p_{04}}, \qquad (2)$$

where ejection ratio Γ is used. The ejection ratio is given by relation

$$\Gamma = \frac{m_2}{m_1} = \frac{c_2}{c_1} \frac{A_2}{A_1} \frac{\rho_2}{\rho_1}, \qquad (3)$$

where c is velocity, A area of inlet nozzle and ρ density.

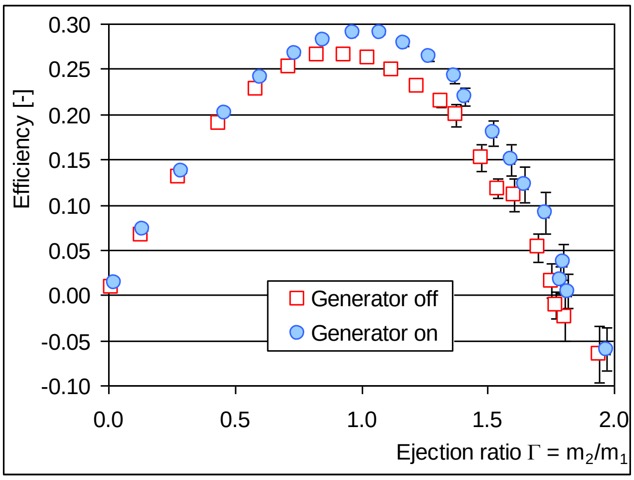

Figure 3: Ejector efficiency.

The evaluation of ejector efficiency from measured data is in figure 3. We can see that with pulsation generator turned ON the efficiency are higher. It means that higher back pressure and ejection ratio are obtained.

This is visible also in figure 4, where the relative back pressure is curried out. We can also see that the fluctuations of back pressure are not decreased while pulsation generator is operating. These results contrast with work [6], where fluctuations of back pressure were strongly suppressed with operating synthetic jet actuator.

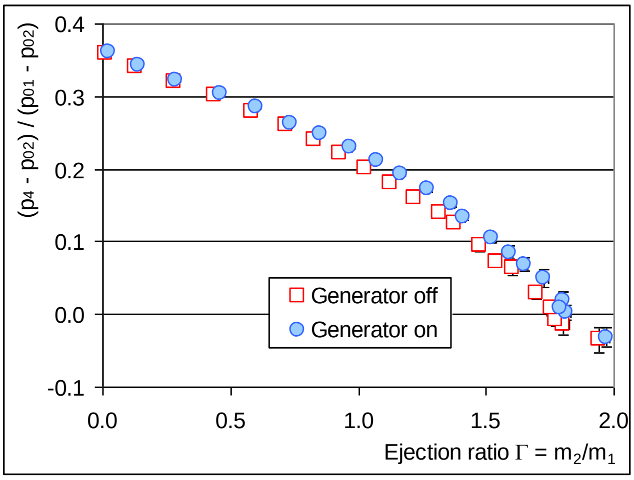

Figure 4: Relative back pressure behind the diffuser $(p_4 - p_{02}) / (p_{01} - p_{02})$.

The relative suction pressure in the beginning of the mixing chamber is in figure 5. We can see that during operation of the generator the curve changes – it moves towards higher ejection ratios, while the suction pressure p_{12} decreases only negligibly. These results are rather surprising because suction pressure, which is measured in the beginning of the mixing chamber, is given by ejection ratio, see [6]. It is because the suction pressure determines the inlet velocity of both flows and thus, for used inlet area ratio $\mu = A_1/A_2$, the ejection ratio is given. It means that all measured data should fall into the single curve in figure 5.

It can indicate that during deceleration and acceleration of the primary flow, the effective inlet area ratio or velocity ratio $\omega = c_2/c_1$ change. For given expansion pressure p_{12}, which is measured on the mixing chamber wall, the velocity of secondary flow c_2 should be almost constant. Velocity c_1 will oscillate because of pressure changes, but the mean velocity should be lower. These will require further investigation.

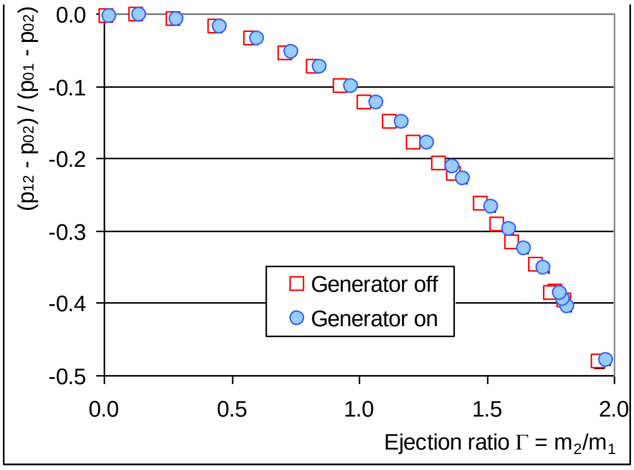

Figure 5: Relative suction pressure in the beginning of the mixing chamber $(p_{12} - p_{02}) / (p_{01} - p_{02})$.

The differences are also obvious on figure 6, where mixing pressure, measured behind the mixing chamber, is curried out. Again, higher ejection ratio is obtained with almost the same mixing pressure while oscillation generator is operating. With the same static pressure, the dynamic pressure and mass flow rate behind the mixing chamber are higher and higher back pressure behind the mixing chamber is obtained.

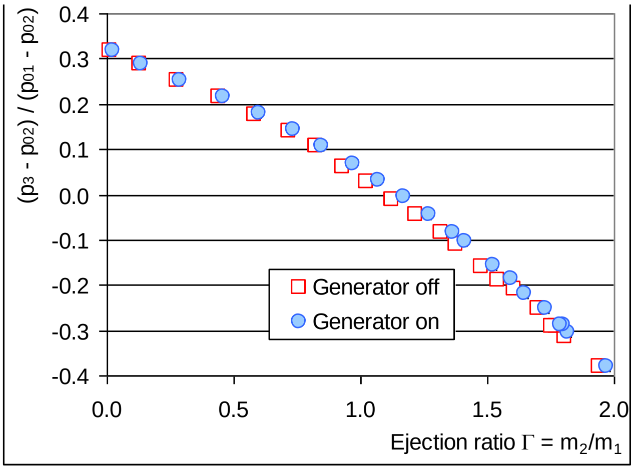

Figure 6: Relative mixing pressure behind the mixing chamber $(p_3 - p_{02}) / (p_{01} - p_{02})$.

4. Conclusions

Ejector with primary flow oscillation generator was investigated with the help of low pneumatic measurements. It was found out that for generator turned ON, the back pressure and the efficiency are higher. During that, the ejection ratio is higher while expansion and mixing pressures do not change. It indicates that inlet area ratio and velocity ratio could be affected due to the operating generator.

For further work, we plan to measure all pressures with very fast pressure sensors and also to measure velocity and turbulence profiles inside the mixing chamber with hot wire anemometry and particle image velocimetry.

5. ACKNOWLEDGEMENTS

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6. References

[1] Ginevsky A. S., Vlasov Y. V., Karavosov R. K.: Acoustic Control of Turbulent Jets. Springer-Verlag Berlin Heidelberg 2004, Germany.

[2] Havelka P., Linek V., Sinkule J., Zahradnik J., Fialova M.: Effect of the ejector configuration on the gas suction rate and gas hold-up in ejector loop reactors. Chemical Engineering Science, Vol. 52, No. 11, pp. 1701 - 1713, 1997.

[3] Waitz I. A., Qiu Y. J., Manning T. A., Fung A. K. S., Elliot J. K., Kerwin J. M., Krasnodebski J. K., O'Sullivan M. N., Tew D. E., Greitzer E. M., Marble F. E., Tan C. S. and Tillman II T. G.: Enhanced Mixing with Flowwise Vorticity. Proy. Aerospace Sci. Vol. 33, pp. 323-351, 1997.

[4] Dvořák V.: Study of optimization of lobed nozzle for mixing. Colloquium Fluid Dynamics, Institute of Thermomechanics AC CR, Prague, Czech Republic, pp 17-18, 2007.

[5] Yuan-Jen Chang, Yau-Ming Chen: Enhancement of a steam-jet refrigerator using a novel application of the petal nozzle. Experimental Thermal and Fluid Science 22 (2000) 203-211.

[6] Dvořák V., Dančová P.: Experimental Investigation into Flow in an Ejector with Perpendicular Synthetic Jet. In: Experimental Fluid Mechanics 2009, Liberec 25. – 27. November 2009. pp 44 – 51.