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EXPERIMENTAL INVESTIGATION OF SYNTHETIC JET ARRAY

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Abstract: *Paper deals on an experimental investigation of a synthetic jet array. This investigation focuses on a partial problem of the general task "a synthetic jet array interacting with a channel flow". The experiments have been performed with water as a working fluid using hot-wire anemometry, laser Doppler vibrometry and particle image velocimetry methods.*

Keywords: ***Synthetic jet array, actuator, piezoelectric membrane, heat transfer, particle image velocimetry.***

1. Introduction

Experimental setup is made from a channel and a synthetic jet (SJ) array. SJ is generated by the periodic motion of an actuator oscillating membrane. It is synthesized by the interactions within a train of vortices. The time-mean mass flux in SJ orifice is zero; hence the other common expression is zero-net-mass-flux (ZNMF) jet (Smith and Glezer, 1998, Glezer and Amitay, 2002, and Cater and Soria 2002). The arrangement for general task "a synthetic jet array interacting with a channel flow" can be useful in many micro-scale applications, such as cooling of micro-electronics or the detection of various (biological, biomedical or chemical) species. The flow regime in micro-scale is usually laminar with very small Reynolds numbers. Therefore, the transfer processes such as mixing and cooling are typically based on gradient diffusion (Timchenko *et al.*, 2007, Dančová *et al.*, 2009).

2. Experimental investigation

2.1. Problem parameterization

SJ is characterized by several independent parameters. Considering the plug flow model (one-dimensional piston like flow in the actuator orifice), the main parameters are: the actuator orifice diameter D, the time-mean orifice velocity U_0, the "stroke length" L_0, the Reynolds number of SJ and the Strouhal number. All parameters are defined e.g. in (Smith and Glezer, 1998, Glezer and Amitay, 2002, or Dančová *et al.*, 2009).

2.2. Experimental setup

The experimental setup is made out from plexiglass (Fig. 1a), internal dimensions are (200 x 200 x 40) mm, length x width x high. The upper wall is bolted with four screws – this connection enables to take off this wall. SJ array is made from four SJ actuators, for dimensions see Fig. 1b. SJ actuator consists of a sealed cavity (diameter $D_D = 36$ mm), which is equipped with an emitting orifice (diameter $D = 3.0$ mm) and with an actuating piezoelectric membrane (KINGSTATE KPS-100). The piezoelectric membrane (PM) was used because it has many significant advantages, e.g. applicability in different fluids, in broad temperature ranges, and in heavy-duty facilities. Other advantages of PM are long an operational lifetime and low power consumption.

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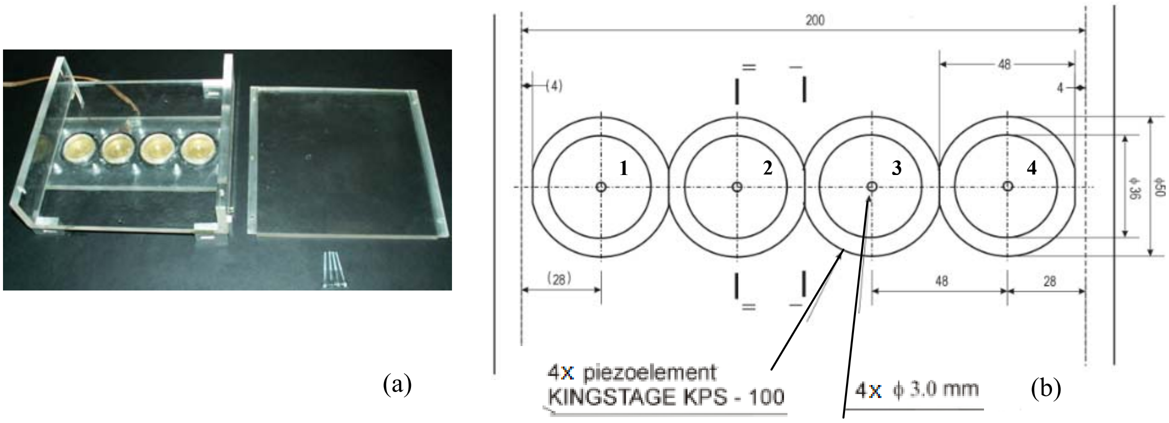

(a) (b)

Fig. 1: SJ array equipment
(a) disassembled device, (b) detailed view of the SJ array of actuators (bottom view).

2.3. Experimental methods

Three different experimental methods were used. For SJ actuator frequency characteristic a hot wire anemometry (HWA) was used in regime of constant temperature. The sampling frequency and number of samples were 7 kHz and 32768, respectively. For data analysis the commercial software StreamWare version 3.03 and Excel was used.

The actuator piezoelectric membrane centre displacement and velocity was measured using laser Doppler vibrometry (LDV). Measurement is based on the Doppler effect, and the portable digital vibrometer Ometron VH-1000-D B&K 8338 was used. The main parameters: frequency range 0.5 Hz ÷ 22 kHz; measurement ranges (full scale (peak- peak)) 20 mm/s, 100 mm/s, 500 mm/s; spurious free dynamic range (SFDR): > 90dB; and best resolution: 0.02 μm/s/Hz$^{0.5}$. The response of a PM to a harmonic driving signal for frequency f = 15 Hz was measured. The LabView software was used to acquire and analyze the signal obtained from the Ometron vibrometer. Software Excel was used for additional calculations and analysis.

Behavior and flow field of SJ array was measured using particle image velocimetry (PIV). Seeding particles for the PIV experiments were polyamide balls with diameter 20 μm, which density is comparable to water. The particles were illuminated by a double pulse laser with maximum 125 mJ per 10 ns pulse and repetition rate 2 x 15 Hz. The typical delay time between two pulses was 5 ms. The laser beam was expanded into a light sheet of about 1 mm thick. The image pairs were acquired using the camera (HiSense model MKI, DANTEC) with a spatial resolution of 1280 x 1024 pixels. The resulting vector maps were averaged over 100 PIV records. Velocity vectors were determined by adaptive correlation over interrogation windows 32 x 32 pixels at a 25 % overlap. Data processing used the commercial software DynamicStudio version 2.21 (DANTEC).

3. Results

The SJ array actuators were fed with sinusoidal current. The input electrical voltage and current were about 19 $V_{effective}$ and about 3 mA (rms).

3.1. Hot wire anemometry

It is known that SJ actuators work very well near their resonance/natural frequencies. Following this fact, the frequency characteristic of the SJ actuator is the first step of the experiments. If the actuator works with the natural frequency, it has the highest power and velocity. Fig. 2 shows the frequency characteristic. Frequency was measured in range of (10-60) Hz. Fig. 2 shows that SJ actuator works with the highest voltage, velocity respectively, on 15 Hz, which is the working frequency of SJ array. The far from natural frequency, the more velocity U_0 values decrease (Fig. 2a). SJ actuator has also the second resonance, which follows the Helmholtz resonator frequency (see Kinsler *et al.*, 2000).

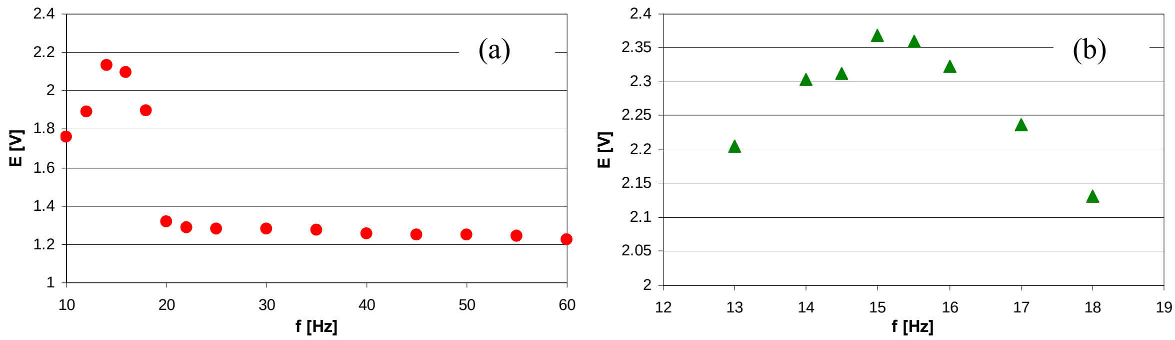

Fig. 2: (a) Frequency characteristic of SJ actuator, (b) detailed view.

3.2. Laser Doppler vibrometry

Figs. 3a and 3b show the results from LDV measurement. The sampling rate for this measurement was 3000 Hz. The period starts with the leading edge of the TTL signal. TTL signal has the same frequency (15 Hz) as the frequency of SJ actuators driving signal from the signal generator. Fig. 3a shows measurement of the membrane centers velocities in time (colored curves), blue curve is TTL signal. There is a visible phase shift between TTL signal and the response of the membrane. Here is also shown, that the SJ actuators work without phase shift, which is important for the general task of SJ array with affection of channel flow. Fig. 3b shows the membrane centre displacement in time compared with TTL. Velocities are measured with laser Doppler vibrometer and displacements are calculated from measured values. This is the reason why curves in Fig. 3a have not smooth character.

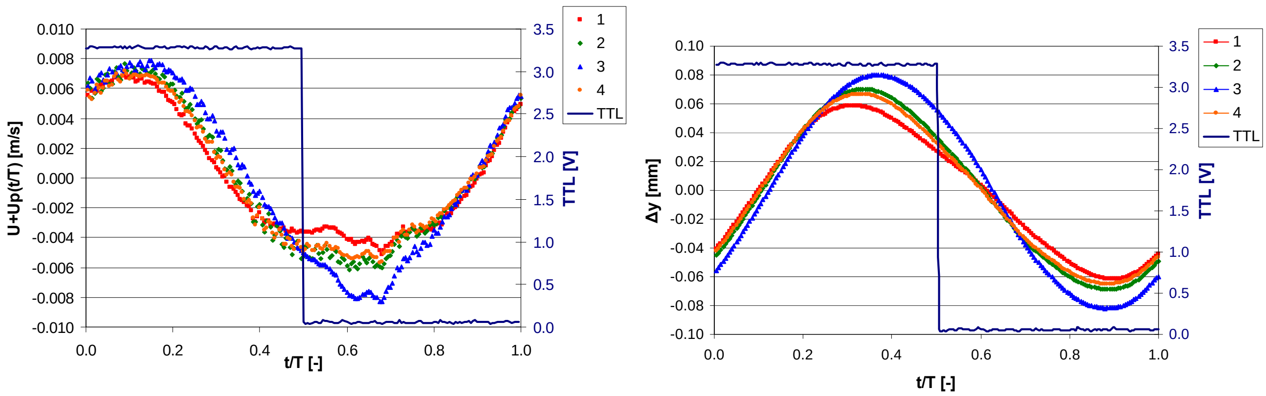

Fig. 3: SJ array: (a) membrane centers velocity, (b) membrane centers displacement.

3.3. Particle image velocimetry

First step of PIV experiments is the synchronization of SJ actuators with laser and camera system. Synchronization procedure is described e.g. in (Kotek and Kopecký, 2009). Experiments were performed with and without the upper wall of the equipment (Fig. 1a). Experimental results on Fig. 4a show whole SJ array in time of full extrusion from the actuators cavities with the upper wall of the equipment in form of velocity magnitude vectors. Monitored plane was aligned to the collective center line of all orifices. It demonstrates the influence of particular SJs. On Fig. 4b is seen SJ array in the same time as Fig. 4a, but the view is displaced 10 mm from the orifice axes. Fig. 5 represents the SJ array in time of full extrusion without the equipment upper wall. There is visible a small influence between SJs in form of outer SJ bending.

4. Conclusions

This paper brings results of HWA, LVD and PIV experimental research of the synthetic jet array. This part of investigation is important to understand how SJ array behavior is influenced by basic parameters – cavity dimensions, natural frequency of particular actuators, displacement and velocity of the actuator membranes. This knowledge is applied into research of a channel flow which is affected by a synthetic jet array with emphasis on low Reynolds numbers.

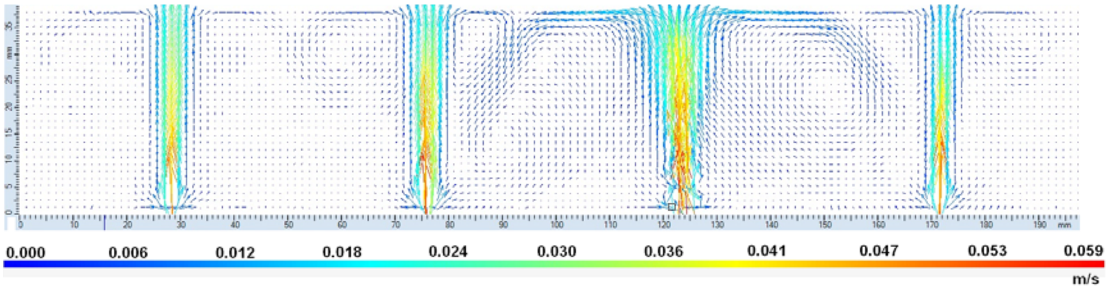

Fig. 4a: SJ array focused on the orifice axes (in form of velocity magnitude vectors).

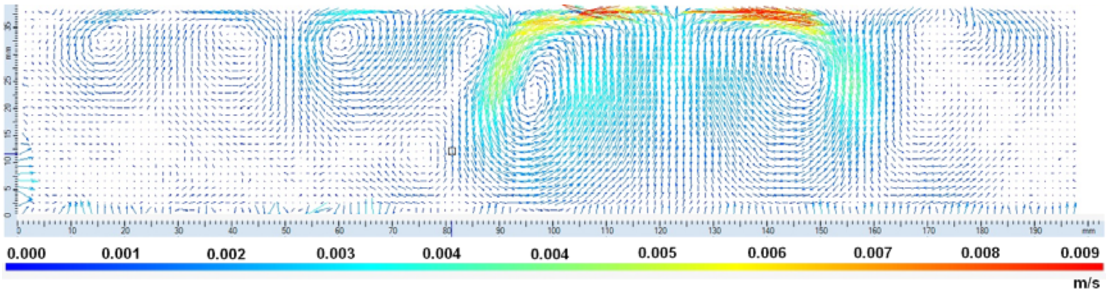

Fig. 4b: SJ array displaced 10 mm from the orifice axes (in form of velocity magnitude vectors).

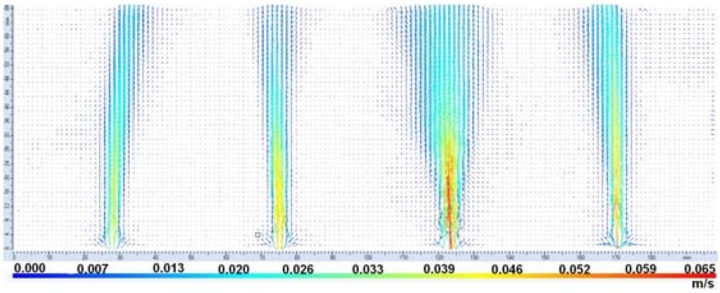

Fig. 5: SJ array without the equipment upper wall (in form of velocity magnitude vectors).

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