23rd International Conference
ENGINEERING MECHANICS 2017
Svratka, Czech Republic, 15 – 18 May 2017

AXISYMMETRIC VALVE WITH SYNTHETIC JET ACTUATOR

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Abstract: *The paper presents the principle of axisymmetric valve operation. The investigated valve used synthetic jets as control jet and it is the fluidic valve without mowing ore deforming elements. The investigation has focused on the influence of actuator supply power on the main stream velocity profile, including stream switching. Additionally resonant frequency of actuator and operation characteristic of actuator was designated.*

Keywords: Fluidic valve, Synthetic jet, Coanda effect.

1. Introduction

One of the most commonly used devices, in fluidic systems, are different types of valves. One of the special type of valve is axisymmetric valve patented by Tesař and Trávníček, 2010. Example application of axisymmetric valve is showed in Fig. 1, and its operation is described in (Tesař et al., 2014; Tesař et al., 2012).

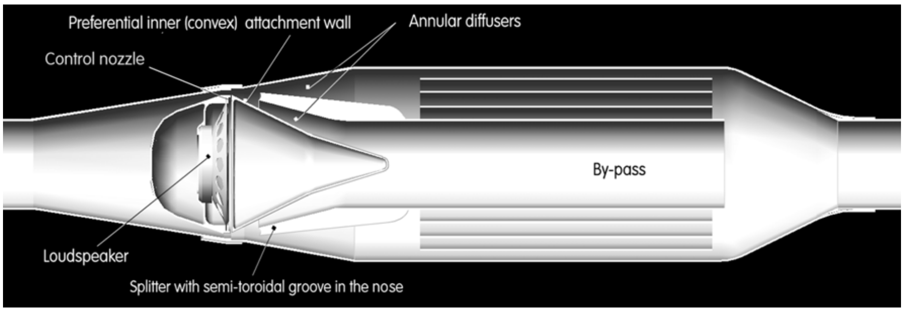

Fig. 1: Example of axisymmetric valve application from Patent document (Tesař and Trávníček, 2010).

Axisymmetric valve use two phenomena: synthetic jets and Coanda effect. Normally the main stream flows around the core of the valve and adheres to the inner cone. As a result, most volume of main stream flows through inner pipe (in Fig. 1 named by-pass). If the synthetic jet actuator (mounted in the core) will start operating then the main stream is repelled from inner cone by synthetic jet flowing from the control nozzle and stream adheres to the outer cone. As a result, most of the main stream volume flows through annular pipe (outer pipe). After deactivation of synthetic jet actuator main stream go back to the first state.

Described valve belongs to fluidic valve. Fluidic valves are distinguished by the lack of moving or deforming elements. Therefore they are reliable, robust and fast acting. The way of fluidic valve operation makes that they can be used with small and weak input. Due to restrictions as to the size of the input and a relatively complex operating rules the fluidic valves aren't widely used. Example application and type of fluidic valve are described in Tesař, 2004, Tesař 2005, Trávnícek et al., 2014.

As mentioned described fluidic valve use two phenomena: synthetic jets and Coanda effect. Coanda effect is a phenomenon of jets adhesion and flow nearby solid boundaries. This effect is used in every fluidic valve and in other applications (Singh and Ramamurthi, 2009; Lalli et al,. 2010). Synthetic jets are responsible for the main stream switching and serve as a control jets. They are generated

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by periodically ingestion and expulsion of fluid at the exit of a nozzle or across orifice (Tanh and Zhong, 2006). The expulsion volume of fluid moves away from orifice and on its edges are formed edge vortices. Although the time-averaged mass flow rate through the nozzle during one full cycle of operation is zero, the edge vortices generates nonzero mass flow rate at some distance from the orifice. Periodically suction and blowing of fluid to some chamber is possible by replacement one of actuator's wall by movable element. Depending on the method of accomplishing the movement of wall, can distinguish piezoelectric, electromagnetic, acoustic and mechanical synthetic jet actuators. Most commonly used for this purpose are speakers (Trávnícek et al., 2014; Tesař and Trávníček, 2010; Gil and Strzelczyk, 2016). They are available, cheep and produced on a mass-scale. However they are now better actuator solution (Saha et al., 2012).

The aim of this work is to investigate the influence of synthetic jet actuator supply power to change the main stream velocity profile, including the stream switching. In the investigation will be carried out with different value of main stream volume flow rate.

2. Experimental setup

The laboratory model of valve is showed in the Fig. 2. The model is composed of the main nozzle with core and outer cone mounted on the nozzle outlet. In core is build-in the synthetic jet actuator and at the circuit of the core is made a control nozzle through which synthetic jet flows. The control nozzle width is b_x = 0.5 mm. The valve operates as described previously.

As mentioned above the synthetic jet actuator is built in the core. It consist, of two opposite loudspeakers Monacor SP-6/8SQ (the input impedance is R = 8 Ω and nominal electric input power is P = 20 W) mounted on a metal ring. On the circuit therefore (ring) was done 24 holes in diameter ϕ3 mm, through which flow synthetic jet. The ring is mounted in a core and synthetic jet outflow is confined by control nozzle (Fig. 2).

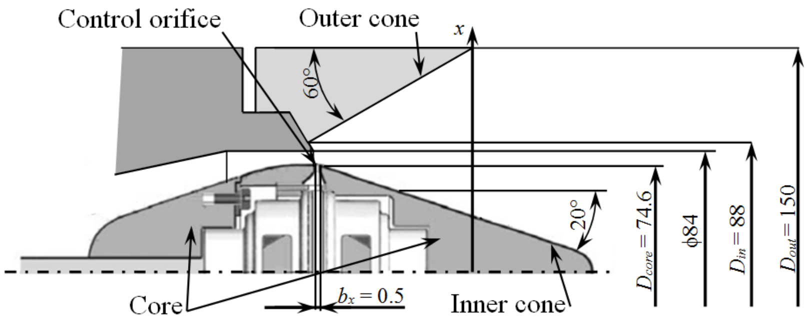

Fig. 2: Detail drawing of the laboratory model of the fluidic valve used in the experiments.

During the experiment it was necessary to measure the volume flow rate through the valve. For this purpose was used an orifice-type flowmeter. Whereas to measuring of the local velocity was used hot-wire anemometer. In tests was used probe model 55P16 (wire length 1.25 mm and diameter 5 μm) connected to MiniCTA 54T42. The temperature correction has been included.

3. Results

3.1. Measurements of synthetic jet

First step of investigation was to find characteristic frequency of synthetic jet actuator and designation of dependence between the supply power of the actuator and synthetic jet velocity. During the measurements the hot-wire probe was placed 1mm from the control nozzle and volume flow rate in a valve was $Q = 0\ m^3s^{-1}$.

To find the characteristic frequency was used two methods (Fig. 3a and 3b) with constant value of actuator supply power P = 3 W. It was designated dependence between frequency of power supply and impedance of loudspeakers (Fig. 3a) or synthetic jet velocity (v_{SJ} Fig. 3b). The maximum value of measured parameters (impedance or velocity) reveals the characteristic resonant frequency for actuator. In bout case the resonant frequency was f = 147 Hz. Next step of the measurements was designated the main operation characteristic of synthetic jet actuator (dependence between supply power and synthetic jet velocity) (Fig. 3c). The measurements were carried out for frequency $f = 147$ Hz. As shown in Fig. 3c, this dependace is logarithmic.

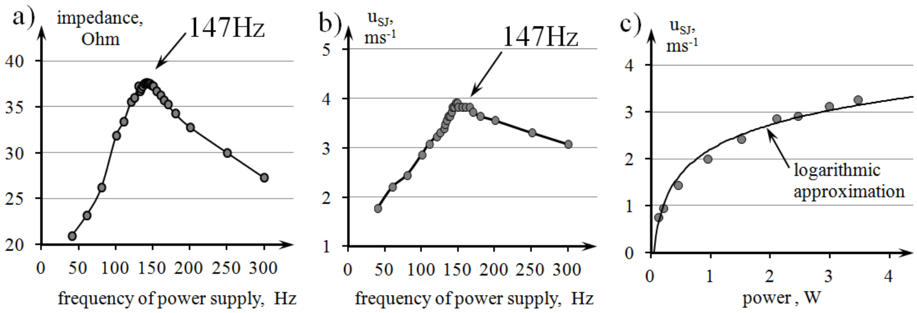

Fig. 3: Operation characteristic of annular synthetic jet actuator: dependence between frequency of supply power and a) speakers impedance or b) synthetic jet velocity for P = 3 W, c) dependence between actuator supply power and synthetic jet velocity for f = 147 Hz.

3.2. Main tests

As described above, the main stream flows along inner or outer cone depending on whether the synthetic jet actuator is active or not. In this part of an experiment it was measured how the main stream velocity profile changes depending on the synthetic jet velocity. For this purpose it was measure velocity profile on the *x* axis shown in the Fig. 2. The *x* axis overlaps with end of outer cone. It must be noted that value 0 on the *x* axis means intersection of the *x* axis and symmetry axis of the valve.

The measurements have been carried out with three different volume flow rate – $Q_1 = 0.004$ m^3s^{-1}, $Q_2 = 0.0025$ m^3s^{-1}, $Q_3 = 0.0018$ m^3s^{-1} – and with five different synthetic jet actuator supply power – $P_1 = 0$ W ($v_{SJ1} = 0$ $m.s^{-1}$) , $P_2 = 0.5$ W ($v_{SJ2} = 1.43$ $m.s^{-1}$), $P_3 = 1$ W ($v_{SJ3} = 2$ $m.s^{-1}$), $P_4 = 2$ W ($v_{SJ4} = 2.86$ $m.s^{-1}$), $P_5 = 3$ W ($v_{SJ5} = 3.12$ $m.s^{-1}$), where $P_1 = 0$.W means that actuator was turned off.

The velocity profiles on the *x* axis are presented in the Fig. 4. Fig. 4a shows the velocity profile by main stream volume flow rate $Q_1 = 0.004$ m^3s^{-1} with different synthetic jet supply power. As expected the stream is concentrated near the inner cone if the actuator is turn off. After turning actuator the velocity profile of main stream is changing. However, in the Fig. 4a the stream is switched over and adheres to the outer cone only for actuator supply power $P_5 = 3$ W. Evidence of this is high velocity near the outer cone and low near the inner cone (core). It must be noted that in case of stream flows near inner cone the velocity for $x \geq 45$ mm is close to zero and it means that practically all volume of stream flows near the inner cone, but for $P_5 = 3$ W the velocity near inner cone is still relatively high and it means that only some part of main stream adheres to outer cone.

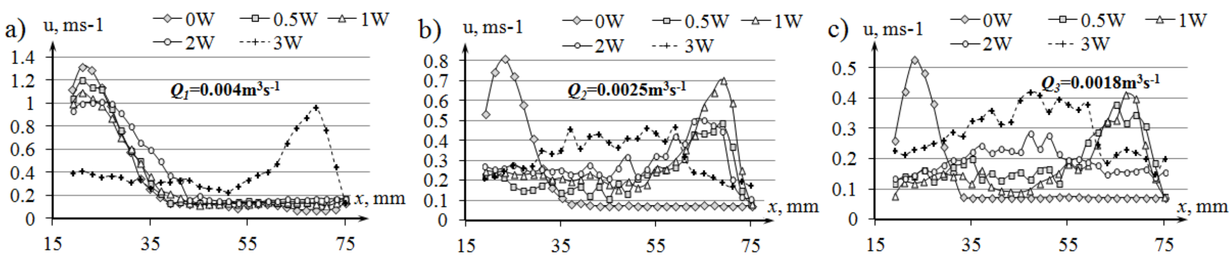

Fig. 4: Velocity profile of main stream for different actuator supply power and volume flow rate of main stream, a) $Q_1 = 0.004$ m^3s^{-1}, b) $Q_2 = 0.0025$ m^3s^{-1}, c) $Q_3 = 0.0018$ m^3s^{-1}.

Fig. 4b shows velocity profile of main stream by volume flow rate $Q_2 = 0.0025$ m^3s^{-1}. As can be seen, the switching over of the main stream occurs when $P_2 = 0.5$ W, $P_3 = 1$ W and $P_4 = 2$ W. The best results are obtained for $P_3 = 1$ W, the stream adhered to the outer cone most preferably. It means that the velocity of control jet shouldn't be too high or too low. If control jet velocity is too low the main stream won't be detached from inner cone or only some little part of stream adheres to outer cone. If control jet velocity is to high in main stream will be created vortices, which disturb the flow. This phenomenon is shown in the Fig. 6b at $P_5 = 3$ W. Very close results were obtained by volume flow rate $Q_3 = 0.0018$ m^3s^{-1} (Fig. 4c).

As shown in the above analysis, selection of appropriate supply power of actuator isn't a simple issue. For more accurate analysis in tab. 1 are noted the conditions of the experiments, at which the main stream adheres to the outer cone most preferably (in opinion of authors). Additionally Tab. 1 contain average velocity of main stream in a interaction region (the cross-section where the synthetic jet affect to main stream), synthetic jet velocity at specific supply power of actuator and the velocity ratio (the ratio of synthetic jet velocity and main stream average velocity). The best results were obtained when the control jet velocity and main stream velocity was similar, the velocity ratio is similar to one.

Tab. 1: Summary of the experiment for the most favorable power of supply value.

Volume flow rate Q [$m^3 \cdot s^{-1}$]	**Average velocity u_{ave} [$m \cdot s^{-1}$]**	**Actuator supply power P [W]**	**Velocity of synthetic jet v_{SJ} [$m \cdot s^{-1}$]**	**Velocity ratio $C_u = v_{SJ}$ [u_{ave}^{-1}]**
0.004	3.42	3	3.12	0.91
0.0025	2.14	1	2.00	0.94
0.0018	1.54	0.5 / 1	1.43 / 2.00	0.93 / 1.30

4. Conclusions

The investigation demonstrates influence of the supply power of actuator on the main stream velocity profile, including stream switching. This relationship has been widely discussed in the paper and it was indicated the most favorable supply power for three different volume flow rate of main stream. As shown above, inadequate (too high or too low) value of synthetic jet velocity influences negatively on the valve operation.

Additionally the velocity ratio was calculated. It was similar to one for the most favorable supply power. It means that average velocity of main stream and synthetic jet velocity should be of similar value so that occurs stream switching.

Acknowledgement

Scientific work financed from the budget for science in the years 2015/2018 as a research project within the program under the name "Diamond Grant ".

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