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Cavity Effect of Synthetic Jet Actuators based on Piezoelectric Diaphragm

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Abstract. An active flow control technology known as synthetic jet actuator (SJA) is a zero-net mass-flux device to create pulsed jet that produces momentum to its surroundings and uses a vibrating diaphragm inside the cavity to generate an oscillatory flow through a small orifice. The performance of SJA depends on the design of an orifice and cavity, and oscillating membrane. SJA design based on piezoelectric diaphragm used in this project because of their size, lightweight, no need for external air supply, without the pipe complex, fast response time and low power consumption. This paper describes the cavity effect to SJA designs and experiments were performed to determine the air jet velocity produced through the orifice using a hot-wire anemometer at a different cavity thickness. The results demonstrate that the jet velocity increase would be better if the cavity thickness is reduced. However, more studies are needed to optimize the size of cavity and orifice for appropriate applications.

Introduction

In the realm of flow control technology, many devices that can be used whether it consists of the type of active or passive. Certainly these devices at least will have a positive impact on the needs and demands of researchers to solve flow problems identified. However, the extent to which it can reduce or solve the problem is depending on device selection. Based on the literature review, the device that is appropriate to the application could be obtained by observing the advantages and disadvantages.

Synthetic jet actuator (SJA) is one of active flow control devices used to delay or eliminate the flow separation on airfoils have been studied by numerous researchers for many years [1,2,3,4]. SJA also can be used for other applications such as jets thrust vectoring [5], heat transfer augmentation [6,7],control the flow at low Mach numbers [8,9], and wishing to change the effect of airfoil camber and manipulating vortex flow [10].

Basically the design of SJA includes slot or circular orifice, a cavity and oscillating membrane[11]. Fig. 1 shows the design of certain physical parameters such as the size of the cavity (cavity thickness, h_c, cavity length, d_c, and cavity width, w_c), orifice (orifice diameter, d_o, and orifice thickness, h_o) and piezoelectric diaphragm as an oscillating membrane. Piezoelectric diaphragm was chosen because of their size, light weight, no need for external air supply, without complex plumbing, rapid time response, low power consumption and low cost [12].

The dimensions of the cavity and orifice, frequency and amplitude of oscillation and the properties of working fluid are all controllable parameters that directly affect the performance of the SJA [13]. The simulation studies for different cavity parameters have been done by previous researchers [14,15] which shows the changes in the performance of SJA. Therefore, the objective of this project is to study the effect of cavity to the SJA performance based on the experimental method. Experiments were conducted to measure the air jet velocity using a hot-wire anemometer and to determine the best operational frequencies and voltages of the actuators for different cavity thickness.

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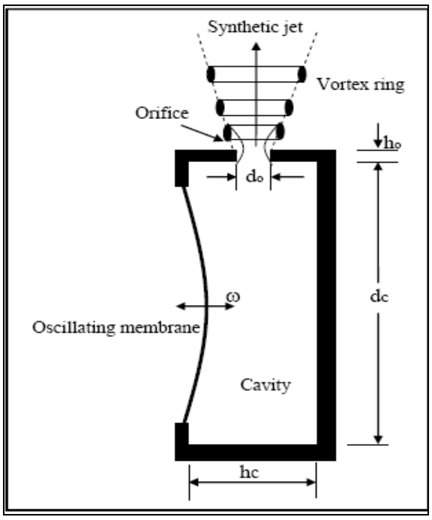
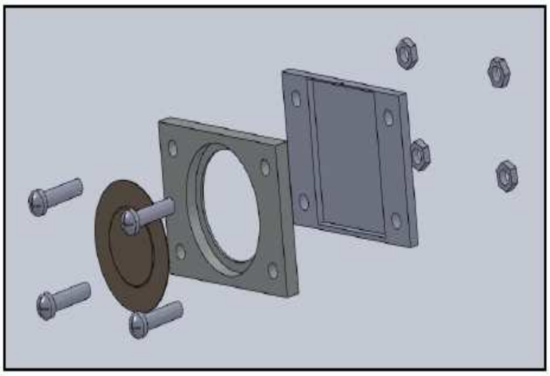


Fig. 1 Side view of a synthetic jet actuator

Experimental Setup

Three models of SJA were built with different cavity thickness but the same orifice size. The model designs are illustrated in Fig. 2 and the configurations can be seen in Table 1.



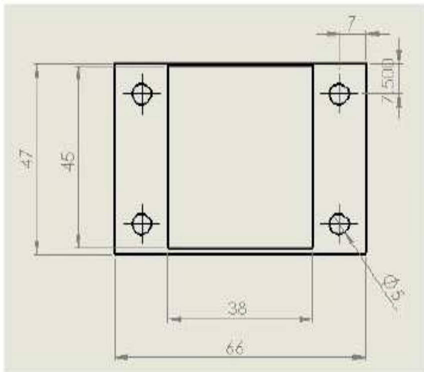


Fig. 2 Model design of SJA

Table 1: The configurations of synthetic jet actuator

	Cavity volume (mm^3)	Cavity			Orifice		Diaphragm	
		h_c (mm)	d_c (mm)	w_c (mm)	d_o (mm)	h_o (mm)	thickness (mm)	diameter (mm)
Model 1	8550	5	45	38	1	0.5	0.63	41
Model 2	5130	3	45	38	1	0.5	0.63	41
Model 3	3762	2.2	45	38	1	0.5	0.63	41

Piezoelectric diaphragm was used as an oscillating membrane to generate the air jet through orifice of the SJA. Diaphragm material is a combination of metal (brass), ceramic and silver electrode. Function generator was used to apply electrical signals including the operating voltage and frequency on the piezoelectric diaphragm. This test involves the manipulation of applied frequency and input voltage to SJA under a square waveform. AFG 3021B function generator is used for supplying voltage to the range of 10 mVp-p up to 10 Vp-p and frequency up to 12.5 MHz. The operation requires high voltage to produce air jet and give a good performance to the SJA.

High-voltage amplifier instrument is necessary to gain the input voltage provided by the function generator. Trek Model 601C two-channel amplifier was used for the experiments. This amplifier is able to increase the input voltage to 100 times and has been used to drive the piezoelectric diaphragm, which began to bend and vibrate. During the test run, applied frequency varied from 100 Hz to 450 Hz with increment of 50 Hz and fixed input voltage of 2V supplied by function generator. The experiment schematic is shown in Fig. 3.

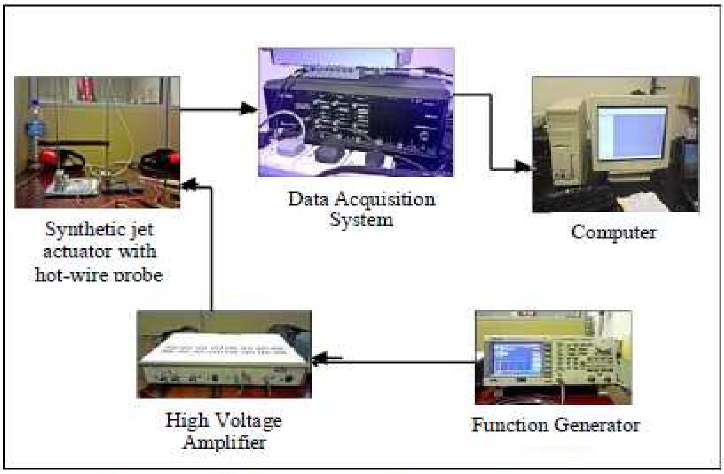


Fig. 3 Experimental schematic of synthetic jet actuator

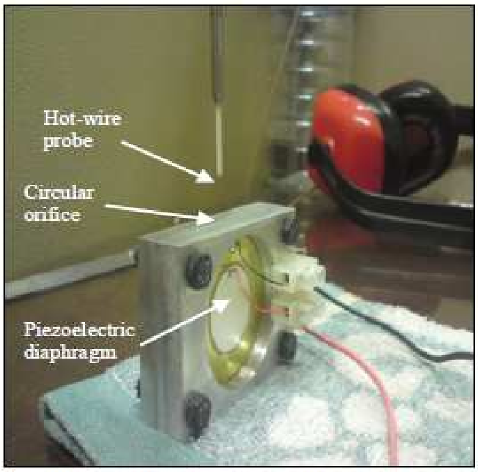


Fig. 4 Single hot-wire anemometer probe on top of orifice

Air jet velocity generated from the operation of piezoelectric in the cavity and out through the orifice can be determined using a hot wire anemometer. SJA performance based on the strength of the produced jet. Faster jet shows a better performance of SJA and the amount required is dependent on application requirements.

Hot-wire anemometer is usually operated in constant temperature conditions. The single hot wire probe used was plated prong type that is suitable for determining the speed of air moving out of the hole or orifice. This probe is placed in parallel with the axis of the jet and 1 mm above the orifice of SJA. Fig. 4 shows the position of the hot-wire probe at the SJA.

Before the experiment, the hot-wire probe should be calibrated in advance to ensure that the voltage read by the Data Acquisition System in accordance with the imposed speed. Dantec Dynamics Streamline 90H02 Flow Unit is the calibrator used to calibrate the hot-wire probe and the velocity in meters per second can be read directly through the computer via StreamWare program which is run based on LabView software. Velocity calibration range is 5m/s to 60m/s with an interval of 5m/s.

Results and Discussion

The experimental aim is to determine the air jet velocity created by SJA. The air jet produced is certainly very useful for particular applications according to its performance. Three models of SJA were tested for different cavity size, and same configurations of the orifice and piezoelectric diaphragm.

The air jet velocity produced through an orifice for model 2 at different applied frequency and input voltage of 2 V can be seen in Fig. 5. The graphs show that the air velocity can be classified as pulsed jet which oscillates at a given time interval. It was found that all graphs give different trends of jet velocity when the SJA applied different frequency and this also occurred for model 1 and 3. Refer to model 2, the jet velocity is not consistent for all frequencies applied but has a good speed and trends in the frequency of 250Hz at which the maximum jet velocity is 18.06m/s. Thus it appears that the SJA has performed well in a specific operational frequency.

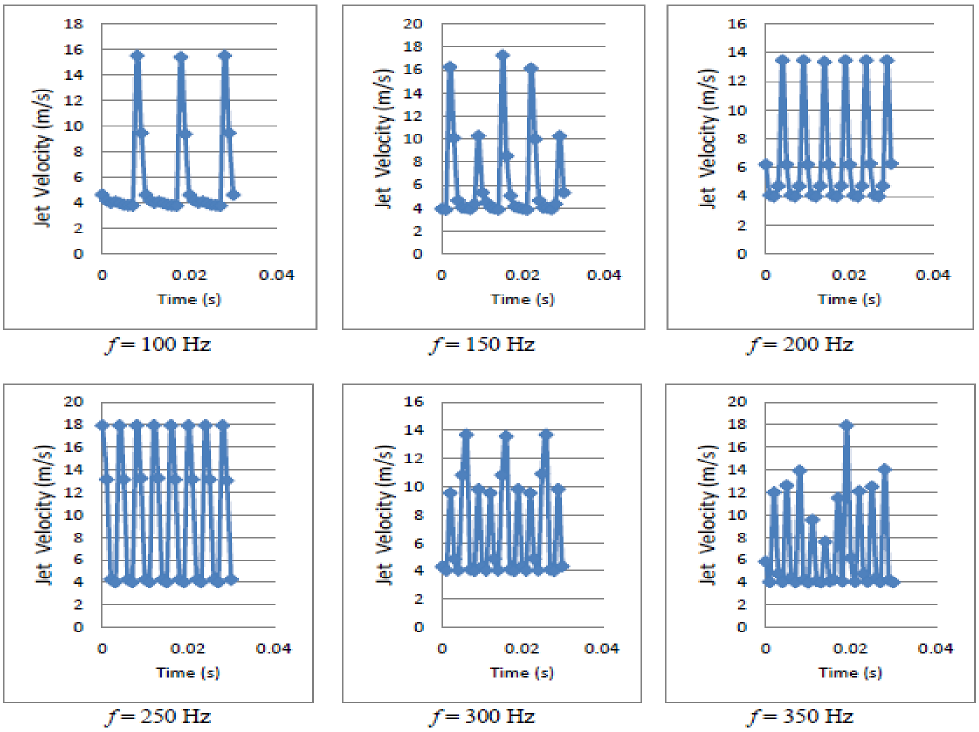


Fig. 5 Jet velocity produced through an orifice for model 2 at different applied frequency and input voltage of 2V

Fig. 6 shows the results of the jet velocity through the orifice at intervals of 0.03 seconds for model 2when the applied frequency of 250Hz and the input voltage is 2V. Three data were recorded from a set of test data that is stored for the period 1 minute. Data were separated into three different parts, at the beginning section (Sample 1), the middle section (Sample 2) and the last section (Sample 3), within the interval of 0.03 seconds and each taken from the original data to show the stability and repeatability of the pulsed jet. The results obtained show that the SJA can maintain the oscillation of air throughout the period of the pulse jet with the same pattern with a minimum errors for the given time interval.

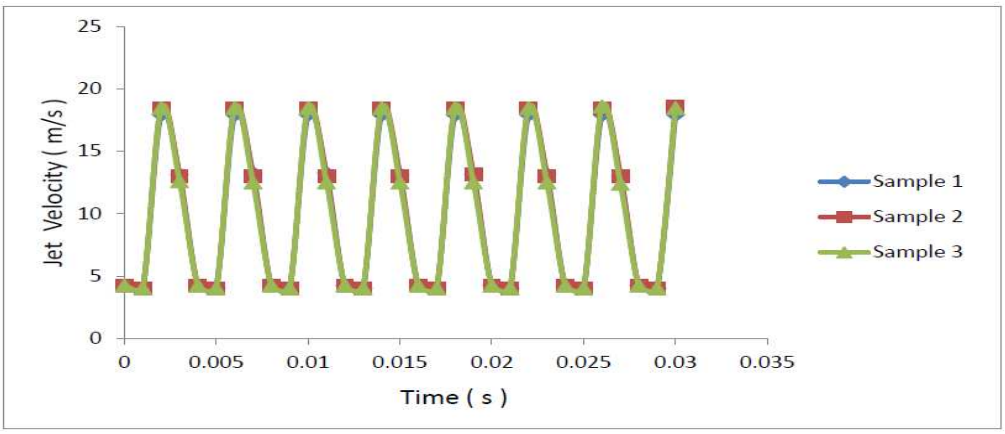
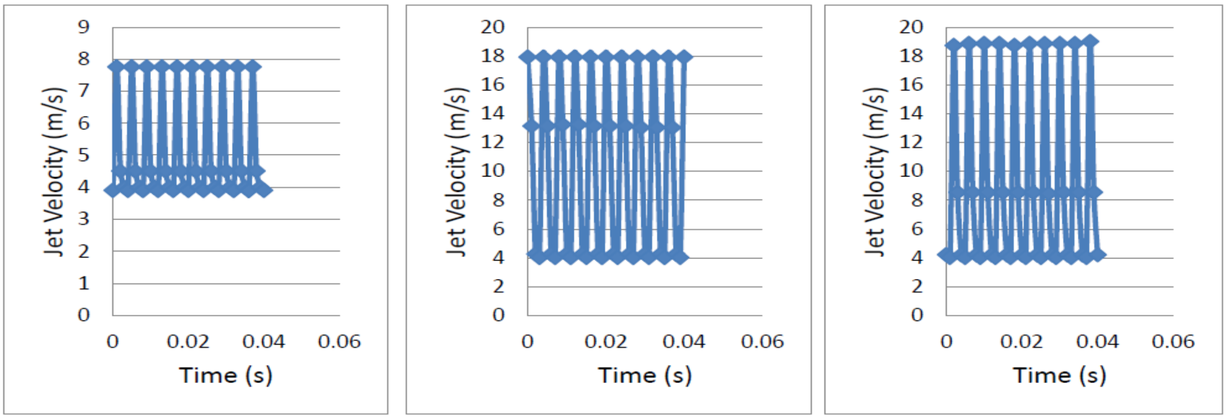


Fig. 6 Jet velocity of model 2 for intervals of 0.03 seconds at frequency 250 Hz and input voltage of 2 V

Basically, the focus of this project is to study the effect of cavity to the SJA performance. There are three designs of SJA has produced, only the thickness of the cavity is changed. This project is to see the real impact on the performance of SJA through experimental methods. The cavity thickness of model 3 is smaller followed by model 2 and model 1. Calculation shows that the percentages of cavity volume reduction of model 2 and 3 compared to the model 1 are 40 % and 56 % respectively.

Fig. 7 shows the comparison of the jet velocity produced by three different SJA models for intervals of 0.04 seconds at a constant applied frequency and input voltage. The graphs show the same pattern of air flow in three models when subjected to a specific frequency, but the change in cavity thickness affects the velocity of the jet. The resulting mean velocity of the jet in model 1 is 4.91 m/s compared with model 2 and 3 are 6.54 m/s and 8.32 m/s respectively. This shows that the smaller cavity size is getting a better jet velocity. For further explanation, Fig. 8 is plotted to show the maximum jet velocity against the cavity thickness at different frequencies. Model 3 with *hc* is 2.2 mm shows a better maximum jet velocity followed by model 2 (*hc* is 3 mm) and compared with the model 1 (*hc* is 5 mm).The maximum jet velocity for model 1, 2 and 3 are 7.87 m/s, 18.06 m/s and 19.85 m/s respectively. Therefore, it is clear that by reducing the size of the cavity can improve the performance of the SJA. However, the reduction in the thickness of the cavity has a limit which does not exceed the amplitude of oscillation of the piezoelectric used.



a) h_c =5 mm (Model 1) b) h_c = 3 mm (Model 2) c) h_c = 2.2 mm (Model 3)

Fig. 7 Jet velocity versus time graphs for different model at frequency 250 Hz and input voltage of 2 V: (a) Model 1, (b) Model 2, (c) Model 3

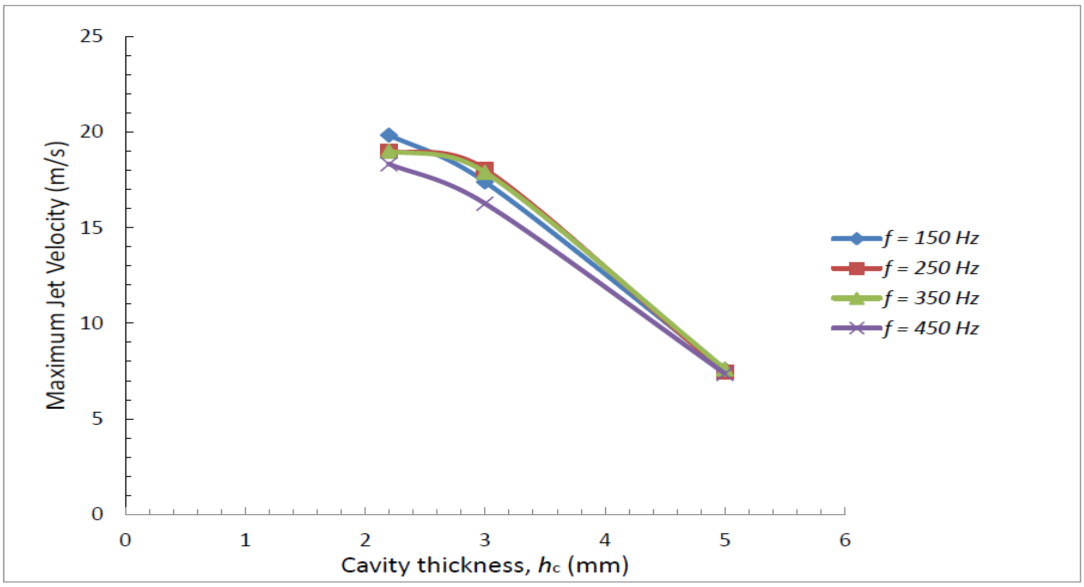


Fig. 8 Effect of cavity thickness on maximum jet velocity at different frequency

Conclusion

The synthetic jet actuator design is based on piezoelectric diaphragm clamped in the cavity to produce oscillatory flow through a circular orifice called the jet pulses which generate the momentum to its surroundings. Experimental methods have been implemented to study the effects of cavity against the air jet produced. Air jet that comes out through the orifice of SJA was measured using a hot wire anemometer. The results obtained have been found that increasing the maximum jet velocity is better with the cavity size is reduced to a certain limit and it seems that the SJA has shown good performance in a specific operational frequency. Finally, the results can be used as a reference in the design of SJA for any applications required. The future work is to optimize the size of an orifice and the selection of piezoelectric diaphragm sizes and materials.

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