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Experimental Study on the Cooling Performance of the Pneumatic Synthetic Jet

Roger Ho Zhen Yu [a1], Qummare Azam [a2], Mohd Azmi bin Ismail [a1,*], Muhammad Iftishah Ramdan [a1,*], and Nurulaida binti Mohd Nri, [a3]

[a)] *School of Mechanical Engineering, University Sains Malaysia, Penang, Malaysia*

*Corresponding author: azmi_meche@usm.my

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ABSTRACT

Synthetic jet is an unsteady jet which generates turbulence fluid flow, which is effective in cooling the microelectronic devices. The oscillating diaphragm of the synthetic jet produces the air flow and delivers to the microelectronic heat sink for the cooling process. In this paper, an experiment was carried out to investigate to cooling performance of the synthetic jet on the microelectronic heat sink by varying driven frequency and heat dissipation rate of the heat sink. The driven frequencies range from 0 Hz to 8 Hz and the heat dissipation rates range between 2.5W to 9W. The Cooling Performance of the synthetic jet is evaluated by the thermal resistance and Nusselt number. The results reveal that the thermal resistance decreses, and the Nusselt number increses, with both driven actuator frequency and Reynold number.

KEY WORDS: *Synthetic Jet, Driven Frequency, Reynolds number, Thermal Resistance, Nusselt number*

NOMENCLATURE

Re	Reynold Number
U	Flow Velocity
D_h	Hydraulic Diameter
v	Kinematic Viscosity
R_T	Thermal Resistance
T_h	Heater Temperature
T_∞	Ambient Temperature
Q	Heat Dissipation
h	Heat Transfer Coefficient
T_s	Heat Sink Temperature
A_T	Surface Area of Heat Sink
Nu	Nusselt Number
k	Thermal Conductivity

1.0 INTRODUCTION

As the space of the high power microelectronic system is limited, a greater amount of heat is generated during operation period. Thus, a high efficiency cooling system is required to remove the residual heat from the heated devices to the surrounding. Active cooling method has recently drawn the attention in the microelectronic devices. Synthetic jet which is also known as the active cooling method offers zero net mass flux and no external fluid source is required to operate the system. Synthetic jet consists of an air cavity, oscillating diaphragm and orifice as shown in Figure 1. The oscillating diaphragm inside the synthetic jet generates a periodic volume change in the cavity as well as the pressure variation. Air fluid is entrained into and expelled out from the orifice which is connected with the cavity.

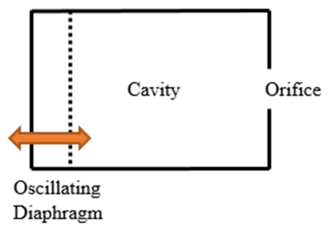

Figure 1: Synthetic Jet Operation

The researchers, Mahalingam and Glezer [1] had showed that synthetic jets can eventually lower the temperature of the high powered heat sink from 71.5 °C to 36 °C. Besides, Mahalingam and Glezer also proved that the synthetic jets dissipated around 20%–40% more heat than fan cooling with a flow rate of 3–5 Cubic Feet per Minute (CFM). Bhapkar, Srivastava, and Agrawal [2] show the cavity shape plays an important role in enhancing the heat transfer coefficient with synthetic jets. The proper orifice shape can improve performance of synthetic jet at lower jet-to-surface spacing. Orifice shape also further explained by Chaudhari et al [3] by examining that a higher heat transfer enhancement in square orifice as compare with a rectangular or circular shape orifice at larger z/d while rectangular orifice provide better performance with aspect ratio between 3 to 5.

The highest heat transfer enchancement is occurred at the smallest jet-to-surface spacing (z/d = 2). Diffusion shaped orifices with opening angle of 60° improves the heat transfer by 30% than the round orifices. The opening angle between 0° and 90° produced the highest heat transfer [4]. Experiment study of the effect of orifice shape on heat transfer characteristics of a synthetic jet on a heated flat plate had been conducted by Bhapkar et al [5]. The increasing in aspect ratio of orifice will reduce the heat transfer. The elliptic orifice is examined to gained better heat transfer as compare with other orifice shape. In square shaped heated element, the largest hydraulic diameter and smallest aspect ratio produce the highest cooling performance. Nusselt number decrease up to 85% of the peak value by doubling the aspect ratio and maintain the hydraulic diameter [6]. A higher suction duty cycle of the synthetic jet at low Reynold number will generate greater penetration depth into the surrounding fluid [7].

In this paper, cooling performance of synthetic jet with multi rectangular slot orifices at difference driven frequencies and heat dissipation rate are investigated.

2.0 EXPERIMENT SETUP

2.1 Pneumatic Cylinder

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The pneumatic synthetic jet consists of a double acting pneumatic cylinder, diaphragm and a steel cylinder as shown in Figure 2. Steel cylinder acts as the holder to hold the pneumatic cylinder in a fixed position. The synthetic jet is placed at the fitting of the air chamber by epoxy.

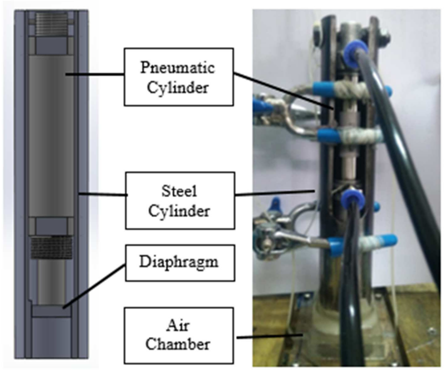


Figure 2: Pneumatic Synthetic Jet

2.2 Air Chamber

The air chamber is made of Perspex with 8 rectangular slot orifices. An air chamber with dimension of 90mm X 62mm X 65mm is designed. The air chamber consists of 8 rectangular slot orifices with 40mm X 9mm respectively as shown in Figure 3. Figure 4 shows the design of the air chamber with cylinder fitting and orifice. The flow velocity of each driven frequency is measured by using the anemometer.

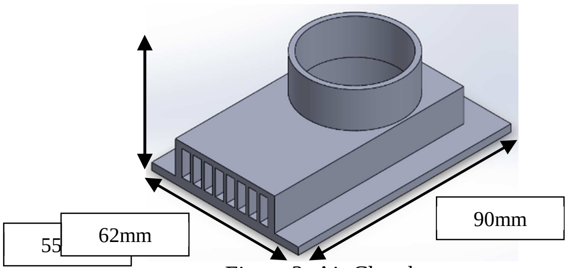


Figure 3: Air Chamber

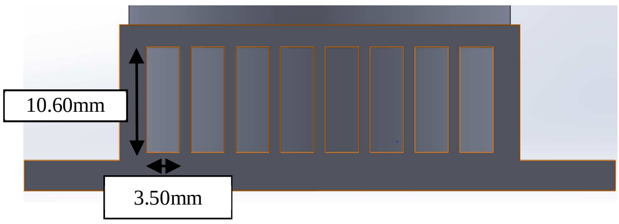
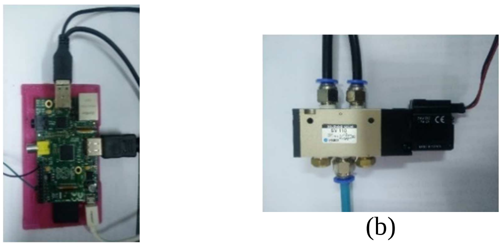


Figure 4: Rectangular Orifices

2.3 Control System

The raspberry pie control system is used to control the driven frequencies of the pneumatic cylinder. Python Code is created in raspberry pie control system. A 5/3 way pneumatic valve with solenoid is also used to deliver the high pressure compressed air to the pneumatic cylinder and to control the flow speed produced by the synthetic jet. The respond time for the solenoid is 3 second which is sufficient to perform at the experimental frequencies.

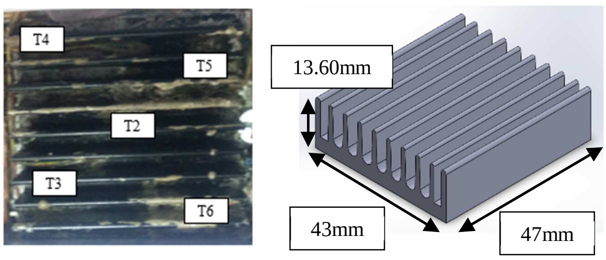


(a) (b)

Figure 5: (a) Raspberry Pie Control System (b) Pressure Valve with Solenoid

2.4 Heat Sink with Heater

Aluminium heat sink with dimension of 47mm X 43mm X 13.6mm is used in the investigation. A heater of 50mm X 50mm was attached at the bottom of the heat sink. Nickel Alloy (Type K) thermocouples was used and placed at the different locations along the experiment in order to collect and measure the temperature of the heat sink. One of the thermocouple were placed at the center heater while another 5 thermocouple were placed at different locations at the heat sink as shown in Figure 6. Another thermocouple was used to measure the ambient temperature. All the temperatures were recorded and stored in the Digi-Sense Scanning Thermometer.



(a) (b)

Figure 6: (a) Location of the Thermocouple (b) Aluminum Heat Sink

3.0 DATA DEDUCTION

Reynolds number {Re} is defined as the ratio of inertial forces to viscous forces. Re is also represent the dimensionless flow characteristic that is generated by the pneumatic synthetic jet. Re of the fluid is calculated as below:

$$Re = \frac{U \cdot D_h}{v} \quad (1)$$

Thermal resistance{R_T} is undoubtedly affect the cooling performance of the synthetic jet and it can be determined by equation below:

$$R_T = \frac{T_h - T_\infty}{Q} \quad (2)$$

Heat transfer coefficient {h} of the heat sink is determined based on the equation below. h is assumed to be equivalent along the orifices

$$Q = hA_T(T_s - T_\infty) \quad (3)$$

The Nusselt number {Nu} is used to characterize the heat transfer from a solid surface to the surroundings.

$$Nu = \frac{hD_h}{k} \quad (4)$$

4.0 RESULT AND DISCUSSION

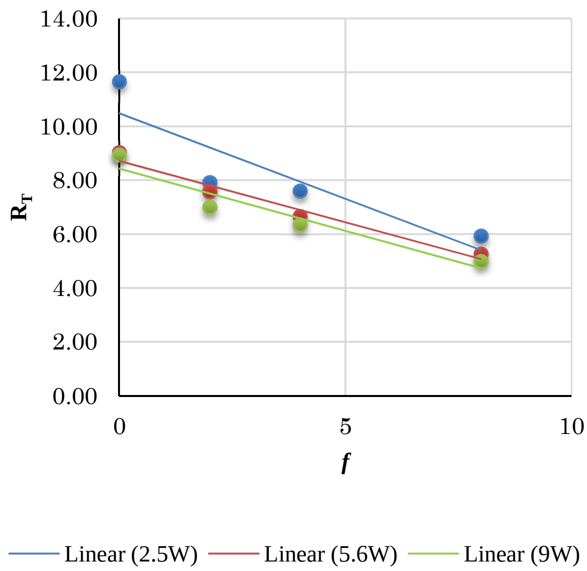


Figure 7: Graph of R_T against *f*

R_T is one of the factor that influences the cooling performance of the investigation. In the experiment, the pneumatic cylinder is supplied by 4 bar compressed air pressure. Three different heat dissipation are investigated with different driven frequencies. Figure 7 show the findings of thermal resistance with difference driven frequencies and heat dissipations. The lowest thermal resistance indicates more heat transfer to the surrounding. From the figure, it shows that the thermal resistance decreases as the driven frequency increases in all three heat dissipation. 9W power dissipation shows the lowest thermal resistance as compare with others heat dissipation. This shows that 9W heat dissipation induces the most heat transfer to the surrounding. Besides, driven frequencies also influences the thermal resistance. As the driven frequency increases, the flow velocity will increase which lead to higher convection effect in all three heat dissipation. Driven frequency of 8Hz shows the lowest thermal resistance as compare to other driven frequencies. The lowest thermal resistance ($4.99°C/W$) at *f* of 8Hz and power dissipation of 9W.

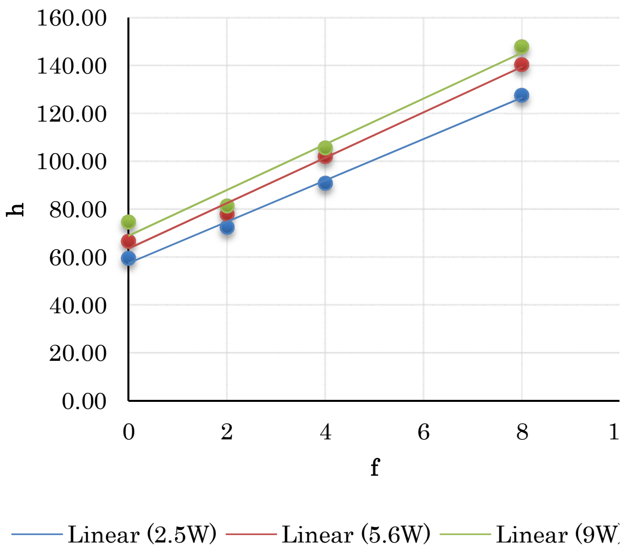


Figure 8: Graph of h against *f*

With the increasing in flow velocity, more convection heat transfer is induced. Figure 8 depicts the influences of driven frequencies on the heat transfer coefficient. Equation 3 show that as the heat dissipation increases, more convection heat transfer to the surrounding with the increasing of the flow velocity. The highest heat transfer coefficient ($147.73W/(m^2K)$) occurs at heat dissipation of 9W and driven frequency of 8Hz.

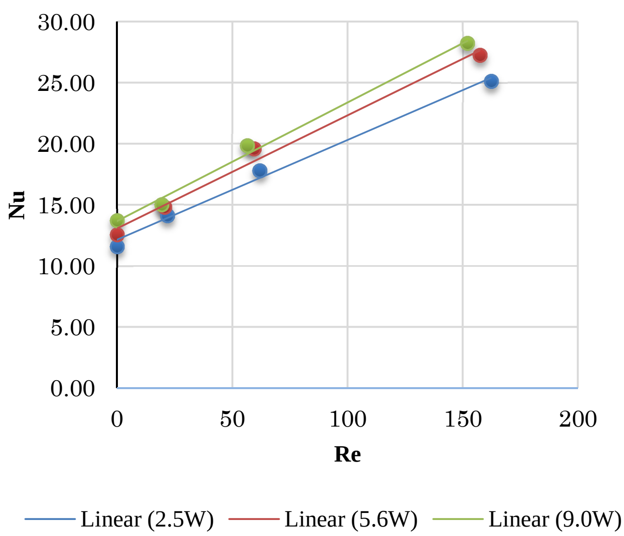


Figure 9: Graph of Nu against Re

Nu is an important dimensionless quantity in heat transfer which relate the convection heat transfer with the conduction heat transfer. Figure 9 shows the relationship of Nu against Re. As Re increases, Nu also increase. With the increasing in driven frequency and flow velocity lead to increasing in Re. This shows more convection heat transfer to surrounding and Nu increases as well. The highest Nu (28.22) is occurred at driven frequency of 8Hz and heat dissipation of 9W.

5.0 CONCLUSION

Cooling performance of the pneumatic synthetic jet with multi rectangular orifices is successfully investigated. The increasing synthetic jet driven frequency lead to increasing in the flow velocity. This eventually induce more convection heat transfer to the surrounding and cool the heated heat sink. The highest heat transfer coefficient, the highest Nu and the lowest thermal resistance are occurred at the driven frequency of 8Hz and heat dissipation of 9W. Pneumatic synthetic jet undoubtedly enhances the cooling performance of the electronic devices.

ACKNOWLEDGEMENTS

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