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Heat transfer characteristics of pin-fin heat sinks cooled by dual piezoelectric fans

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ABSTRACT

The heat transfer of pin-fin heat sinks cooled by dual piezoelectric fans is investigated experimentally by infrared thermography. The effects of the phase difference, the configuration, the elevation of the piezoelectric fans, and the dimensions of the heat sinks on the thermal performance of the heat sinks are discussed. The experimental results show that the thermal resistance reaches the minimum (3.37 °C/W) when the fin width is 8 mm, the two piezoelectric fans are in edge-to-edge configuration, and the fans vibrate counter phase in a series of nine-fin heat sinks with a fin height of 15 mm. The minimum thermal resistance (2.4 °C/W) is obtained when the fin width is 5.1 mm and the two piezoelectric fans are in edge-to-edge configuration and vibrate counter phase in a series of sixteen-fin heat sinks with a fin height of 30 mm. The thermal resistance increases significantly when the elevation of the two piezoelectric fans is increased. The effects of the phase difference and the configuration of the two piezoelectric fans on thermal resistance depend on the dimensions of the heat sinks. However, for most tested heat sinks, the minimum thermal resistance is obtained when the two piezoelectric fans are in edge-to-edge configuration and vibrate counter phase.

1. Introduction

Rapid advancements in technology have decreased the size of electronic equipment and have increased their efficiency. However, the miniaturization and densification of electronic equipment reduces the space available for heat dissipation and increases heat flux. Thus, an important product design issue is effectively preventing instability and damage caused by overheating in electronic products.

Piezoelectric fans are a novel heat dissipation method that have a small size, a low weight, low energy consumption, low noise, and a long lifespan. As such, they are highly suitable for cooling electronic components. These devices are operated by applying a drive voltage to the piezoelectric material with a thin blade on one end. The resulting piezoelectric effect causes the material to deform. The resulting vibration of the thin blade and movement of the surrounding fluid, thus dissipates heat.

The thermal performance of a single piezoelectric fan has been extensively studied in the literature [1–9]. However, the thermal performance of multiple piezoelectric fans has not been sufficiently investigated. In Kimber et al. [10], a study of the aerodynamic coupling of two vibrating cantilevers found that, in face-to-face configuration, a reduction in fluid damping is observed for in phase vibration while it is increased for counter phase vibration. In edge-to-edge configuration, in phase vibration increases fluid damping and counter phase vibration decreases fluid damping. Abdullah et al. [11,12] presented the effects of tip gap, amplitude, and orientation of three piezoelectric fans on the heat transfer of plate-fin heat sinks. Heat transfer efficiency was highest in piezoelectric fans that had the minimum tip gap, the maximum amplitude, and a vertical orientation. In simulations of the two-dimensional unsteady flow field generated by a vibrating cantilever pair, Choi et al. [13,14] analyzed the effects of the phase difference and the distance between the two vibrating cantilevers. The numerical results showed that the cantilever pair vibrating counter phase is more effective in generating the air flow than the other tested cases. The optimal distance between the two cantilevers vibrating counter phase is equal to twice the size of the fully grown vortex generated by the single cantilever. Sufian et al. [15,16] investigated the heat dissipation efficiency of heated surfaces cooled by dual piezoelectric fans. Thermal performance was compared under varying phase differences and configurations of

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Nomenclature

a	amplitude of piezoelectric fan (m)
A	cross-sectional area of heating element (m^2)
A_t	heat transfer area of heat sink (m^2)
b	thickness of heat sink base plate (m)
d	distance between measuring points in heating element (m)
d_{fan}	distance between two piezoelectric fans (m)
G	inter-fin spacing (m)
h_{fan}	distance between heat sink and piezoelectric fan (m)
H	fin height (m)
k_{al}	thermal conductivity of aluminum alloy (W/mK)
L	length of heat sink base plate (m)
n	fin number
Q	heating power (W)
R_{th}	thermal resistance (°C/W)
T_{ave}	average temperature of top surface of heat sink base plate (°C)
T_l	temperature of lower measuring point in heating element (°C)
T_u	temperature of upper measuring point in heating element (°C)
T_∞	temperature of cooling air (°C)
U	overall heat transfer coefficient (W/°C m^2)
W	fin width (m)
X, Y, Z	coordinates (m)

Greek Symbols

ϕ	phase angle of piezoelectric fan (degree)
$\Delta\phi$	phase difference of piezoelectric fans (degree)

the two piezoelectric fans vertically oriented to the heated surfaces. The experimental and simulation results showed that thermal performance is better when the piezoelectric fans vibrate in phase rather than counter phase. Additionally, the performance of the two piezoelectric fans is better in face-to-face configuration in comparison with edge-to-edge configuration. Ma et al. [17] investigated the cooling performance of a multiple piezoelectric-magnetic fan (MPMF) system embedded in a plate-fin heat sink. The experimental results indicated that the MPMF system at the optimum fan tip location can improve the thermal resistance by 53.2% over natural convection condition.

The above literature indicate that piezoelectric fans are effective for dissipating heat in electronic products and are easy to install in many environments that require heat dissipation. When common axial fans cannot be used for cooling or when a region requires local heat dissipation, piezoelectric fans can provide effective and reliable heat dissipation. A single piezoelectric fan effectively dissipates heat in low power electronic components; however, high power electronic components require multiple piezoelectric fans to achieve reliable heat dissipation. Many recent studies have studied the effectiveness of a single piezoelectric fan for heat dissipation in electronic components. However, few have studied the effectiveness of multiple piezoelectric fans for cooling a flat heat source or a plate-fin heat sink. According to the literature, under a low velocity impinging flow, heat transfer efficiency is higher in pin-fin heat sinks than in plate-fin heat sinks [18,19]; therefore, we hypothesized that piezoelectric fans could cool pin-fin heat sinks more effectively than that achieved in previous research. The heat transfer efficiency of pin-fin heat sinks with two piezoelectric fans was investigated by infrared thermography. The heat transfer characteristics of the pin-fin heat sinks were experimentally compared under varying dimensions of the heat sinks and under varying phase differences, configurations, and elevations of the two piezoelectric fans.

2. Experimental setup and procedure

The experimental setup was similar to that as described in Ref. [5]. Fig. 1 shows that the experimental setup includes an infrared thermography system, two piezoelectric fans, an alternating current power supply, a heating system, a temperature measurement device, pin-fin heat sinks, and a transparent acrylic box. The FLIR A325 infrared camera used in the experiments has an un-cooled focal plane array detector with 320 × 240 pixels and has

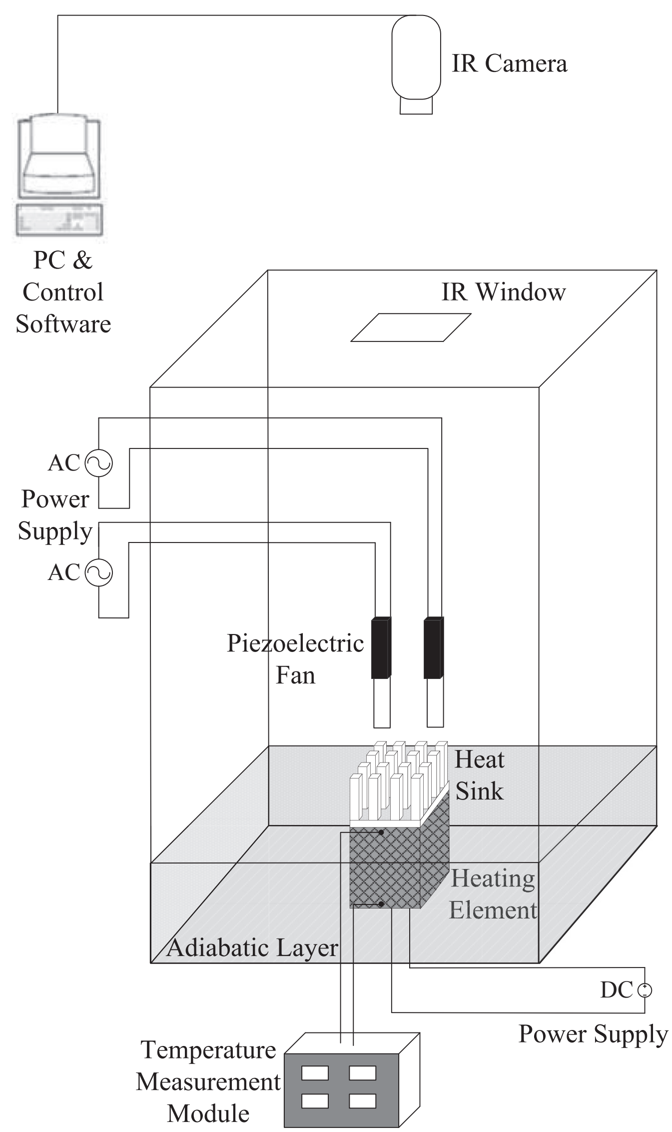

Fig. 1. Schematic diagram of experimental apparatus.