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Investigation of a multiple piezoelectric–magnetic fan system embedded in a heat sink

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ABSTRACT

Previous studies have investigated the thermal performance of embedding a single piezoelectric fan in a heat sink. Based on this work, a multiple piezoelectric–magnetic fan system ("MPMF") has been successfully developed that exhibits lower fan power consumption, optimum fan pitch and an optimum fan gap between the fan tips and the heat sink. In this study, the cooling performance and heat convection improvement for the MPMF system embedded in a heat sink are evaluated at different fan tip locations. The results indicate that the fan tip location of the MPMF system at $x/S_l = 0.5$ and $y/S_h = 0$ is an optimum configuration, improving the thermal resistance by 53.2% over natural convection condition for the fan input power of 0.1 W. The MPMF system breaks the thermal boundary layer and causes fluctuations inside the fins of the heat sink to enhance the overall heat transfer coefficient. Moreover, the relationship between the convection improvement and the Reynolds number for the MPMF system has been investigated and transformed into a correlation line for nine different fan tip locations to provide a means of predicting the cooling performance for the MPMF system embedded in a heat sink.

1. Introduction

Piezoelectric fans composed of piezoelectric material and plates have recently been studied as components in thermal management devices.

Toda [1] proposed the concept of piezoelectric fans and developed a simplified theory for vibration prediction and flow field behavior. The results indicated that the theoretical analysis matched previous experimental findings. Several types of piezoelectric fans for cooling electronic devices had been constructed and tested by Yoo et al. [2,3]. Analyses of series and parallel piezoelectric bimorphs with different widths of metal shims at different resonant frequencies were performed. The results indicated that the resonance frequencies of the fans were mainly determined by the length of the vibrating plate. In addition, the wind velocity exhibited a nearly linear relationship to the applied voltage and displacement of plate tip. The displacement of the plate tip was related to the material of the vibrating plate and the fan geometry. A piezoelectric fan with two symmetrically placed piezoceramic patches was investigated through analytical modeling by Bürmann et al. [4]. The results revealed the optimum patch-beam thickness ratio and the patch-beam length ratio to maximize the dynamic electromechanical coupling factor. Specifically, a thickness ratio of approximately 0.8 and a length ratio of approximately 0.6 were found to maximize the dynamic electromechanical coupling factor for this material combination and for a fixed clamp-patch distance.

Kimber et al. [5] conducted experiments to determine the local heat transfer coefficients for a fan vibrating close to the heat source. The entire temperature field was observed by using an infrared camera. Four vibration amplitudes ranging from 6.35 to 10 mm were considered for selected distances between the heat source and the fan tip which varied from 0.01 to 2 times the amplitude. The optimum gap was dependent on the vibration amplitude for the convection coefficient and was small for large amplitudes and increased as the amplitude decreased. Kimber et al. [6] investigated the heat transfer achieved by using arrays of vibrating cantilevers. Two piezoelectric fans were mounted near a surface with a constant heat flux to determine the local convection coefficients. The results revealed that the convection patterns were strongly dependent on the fan pitch and the best thermal performance was obtained when the fan pitch was 1.5 times the vibration amplitude. In 2010, Petroski et al. [7] proposed a cooling system combining two piezoelectric fans with a heat sink. This cooling system exhibited five times the heat transfer rate observed with natural convection.

Ma et al. [8] studied the piezoelectric fan cooling system, made of an aluminum heat sink and a piezoelectric fan. Several parameters, such as the inclined angle, the resonance frequency and the location of the piezoelectric fan, were studied to evaluate the heat dissipation efficiency. Compared with natural convection, the results revealed that piezoelectric fans can effectively break the thermal boundary layer to enhance the heat dissipation efficiency. In addition, the relationship between the convection improvement and the ratio of natural convection to forced convection for a single fan was also investigated. Ma et al. [9] demonstrated an innovative piezoelectric–magnetic fan capable

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Nomenclature

A	vibration amplitude (mm)
A_{conv}	total convection surface of the heat sink (mm^2)
E_w	width of the fan enhancement device (mm)
f	fan resonance frequency (Hz)
Gr	Grashof number of the MPMF system
$\bar{h}$	overall convective heat transfer coefficient ($W/m^2{}^\circ C$)
$\bar{h}_{MPMF}$	overall convective heat transfer coefficient of the heat sink with the MPMF system ($W/m^2{}^\circ C$)
$\bar{h}_0$	overall convective heat transfer coefficient of the heat sink with natural convection ($W/m^2{}^\circ C$)
L	fan length (mm)
L_{PZT}	characteristic length of the fan (mm)
M_{MPMF}	convection improvement by the MPMF system
Q	dummy heat source input power (Watts)
R	thermal resistance (°C/W)
R_0	thermal resistance in natural convection (°C/W)
Re_{MPMF}	Reynolds number for the MPMF system
Ri_{MPMF}	Richardson number for the MPMF system
S_g	heat sink fin gap (mm)
S_h	heat sink fin height (mm)
S_l	heat sink fin length (mm)
S_w	heat sink fin width (mm)
$T_{ambient}$	ambient temperature (°C)
T_{case}	temperature of the copper slug (°C)
T_s	local surface temperature (°C)
$\bar{T}_s$	average temperature of the heat sink (°C)
W	fan width (mm)
x/S_l	fan tip location along the length of the heat sink
y/S_h	fan tip location along the height of the heat sink
η	performance of the MPMF system (%)
ν	kinematic viscosity of the working fluid (m^2/s)

of generating a strong air flow to increase the thermal performance using a single piezoelectric actuator. Ma et al. [10] also developed the T-shaped multiple-vibrating fan cooling system to enhance the system's cooling ability. The experimental results revealed that the surface temperature of a 25 W heat source decreased from 86.9 °C to 55.6 °C. Ma et al. [11] showed that the optimum fan pitch can be found for the fan pitch aspect ratio of 0.233 at different fan input powers for the multiple piezoelectric–magnetic fan system. The optimum fan gap between the fan tip and the heat sink was found to be 0.05, whereas the optimum aspect ratio of the fan pitch was 0.233.

The objective of this study is to present a heat sink cooled by the MPMF system composed of one actuating piezoelectric fan and two passive magnetic fans. The parameters—M_{MPMF} is defined to assess the convection improvement by the MPMF system and η represents the cooling performance of the MPMF system compared to natural convection. The relationship between M_{MPMF} and Re_{MPMF} also has been successfully investigated and transformed to a correlation line for nine different fan tip locations to predict the cooling performance of the MPMF system conveniently.

2. Experimental setup and theoretical analysis

2.1. Experimental setup

The experimental apparatus is shown in Fig. 1, including a dummy heat source that provides a constant heat flux; a DC power supply; a programmable AC power supply, Chroma 61501, which provides AC power and frequency output; a digital power meter, Chroma 66201, which measures AC power signals and related parameters; a data acquisition system, Agilent 34970A; and a MPMF system.

The dummy heat source is constructed by attaching two stainless steel cartridge heaters. A cross-sectional view and the dimensions of the dummy heat source are shown in Fig. 2. Three Omega 36-gauge type T thermocouples are attached inside the copper slug. Two thermocouples are used to calculate the heat source power by following Fourier's law heat conduction equation. The variable H_T is the distance between the two measuring points, taken to be 10 mm. The material of the copper slug is C11000. One thermocouple is placed on top of the heat source to record the upper surface temperature of the copper slug. The upper surface of the copper slug, which simulates a CPU integrated heat spreader, has a length (L_S) of 32 mm × 32 mm with 2 mm filets at the four corners to simulate the heat source. The copper slug is embedded in the insulation system, which is composed of bakelite. The insulation system is designed with gaps between the copper slug and the bakelite to make sure of the low thermal conductivity of air (0.026 W/m°C) to minimize any heat losses from the copper slug to the outside environment.

The MPMF system includes an aluminum base, a piezoelectric actuator, passive magnetic fans and magnetic bases, as shown in Fig. 3.

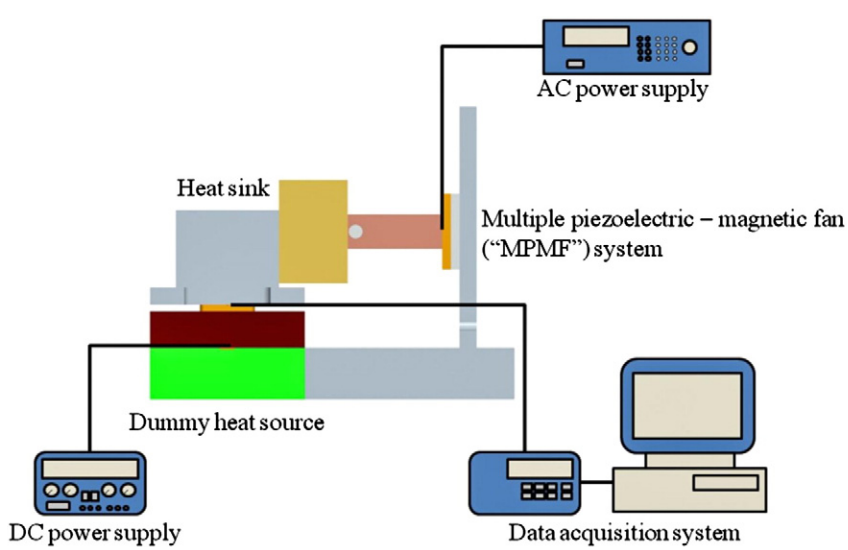

Fig. 1. The schematic view of the experimental setup.