Microelectronics Reliability 84 (2018) 75–87

Contents lists available at ScienceDirect

Microelectronics Reliability

journal homepage: www.elsevier.com/locate/microrel

Cooling performance and characteristics of metal piezoelectric fans in a heat sink-equipped handheld projector

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ARTICLE INFO

Keywords:
Pin fin heat sinks
Piezoelectric fan
Power consumption
Nusselt number
Correlation

ABSTRACT

In this study, the thermal performance of several pin-fin arrays in a horizontally-oriented pico projector cooled with and without a metal piezoelectric fan was evaluated at several heating powers. The vibrating frequency of the 20-V_{rms} Al piezoelectric fan and the 30-V_{rms} stainless steel piezoelectric fan ranged from 242 Hz to 257 Hz, and from 171 Hz to 186 Hz, respectively. The results showed that the thermal resistance of the fin array cooled with a piezoelectric fan vibrating at a specific frequency in the pico projector would not monotonically reduce with the increase of the heating power. At a heating power of 7 W, the thermal resistance of S1.5 fin array cooled with a 251-Hz Al and 180-Hz stainless steel piezoelectric fan was approximately 14.8 K/W and 12.2 K/W, respectively, while the average heat transfer coefficient of S1.5 fin array cooled with a 251-Hz Al and a 180-Hz stainless steel piezoelectric fans achieved approximately 21 W/m^2 K and 31.5 W/m^2 K, respectively. The results also reported that the increase of the fan tip velocity resulted in the increase of both the average heat transfer coefficient of the fin arrays and the power consumption of the piezoelectric fan. An empirical correlation for estimating Nusselt number of those pin fin heat sinks was developed in a form of $\overline{Nu} = 0.1715Re_{\max}^{0.3314}Pr^{0.34}$ with mean deviation of 8.59% between the predicted value and the measured one for all conditions. Using a piezoelectric fan having high Reynolds number that can be achieved by increasing both the first natural frequency and the vibrating amplitude of the piezoelectric fan to cool a dense pin fin array is suggested.

1. Introduction

Pico projectors are portable electronic devices used to project the information on the screen of mobile electronic devices such as smartphones or notebook computers onto a nearby larger surface. Since they are so useful, pico projectors have become a built-in component in certain smartphones for the past few years, and are expected to be in widespread use. The light engine responsible for projecting the digital information in the pico projector produces a substantial amount of heat in the pico projector that is normally a compact enclosure with some openings. For a stable image quality while projecting, the heat produced by the light engine has to be efficiently dissipated. Although attaching fin arrays to the light engine in a pico projector without using a fan is a low-cost and reliable way to cool the light engine, fairly low heat transfer coefficient of the fin array enclosed in a pico projector has been pointed out in [1].

Therefore, using a blower to cool a fin array attached to a high-power light source is suggested to effectively reduce the temperature of the light engine in a pico projector. Besides the traditional blowers which drive airflow using rotational blades, piezoelectric fans that oscillate flexible cantilevers to drive periodic airflow have been considered as an alternative to enhance heat transfer by forcing air to flow over hot chip surface in a noiseless and space-saving way. Numerous studies [2–13] on the piezoelectric fans have been conducted over the past few years. Among those studies, the product of the vibrating amplitude and the frequency of the piezoelectric fan have been used to substitute the unknown airflow velocity induced by a given piezoelectric fan [4,5,12]. Moreover, Mylar piezoelectric fan was installed in a pico projector to cool the assembly of the light engine and an aluminum fin array with various heating powers [14]. Compared with the case without using a piezoelectric fan, the thermal resistance of the horizontal pico projector reduced by 3.4 K/W, as a 133.5-Hz Mylar piezoelectric fan was used to cool pin-fin array at a heating power of 7 W. Sufian and Abdullah [15] used 110-Hz piezoelectric fans to cool a heat sink-LEDs assembly.

According to the theory of the vibration of a cantilever [16], the first resonant frequency of a metal beam could be higher than that of a polymer beam because of the high Young's modulus that metal blade possesses. In this regard, piezoelectric fans that have a metal blade and are actuated with an appropriate voltage to modulate the vibration

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https://doi.org/10.1016/j.microrel.2018.03.012
Received 30 October 2017; Received in revised form 2 February 2018; Accepted 14 March 2018
Available online 20 March 2018

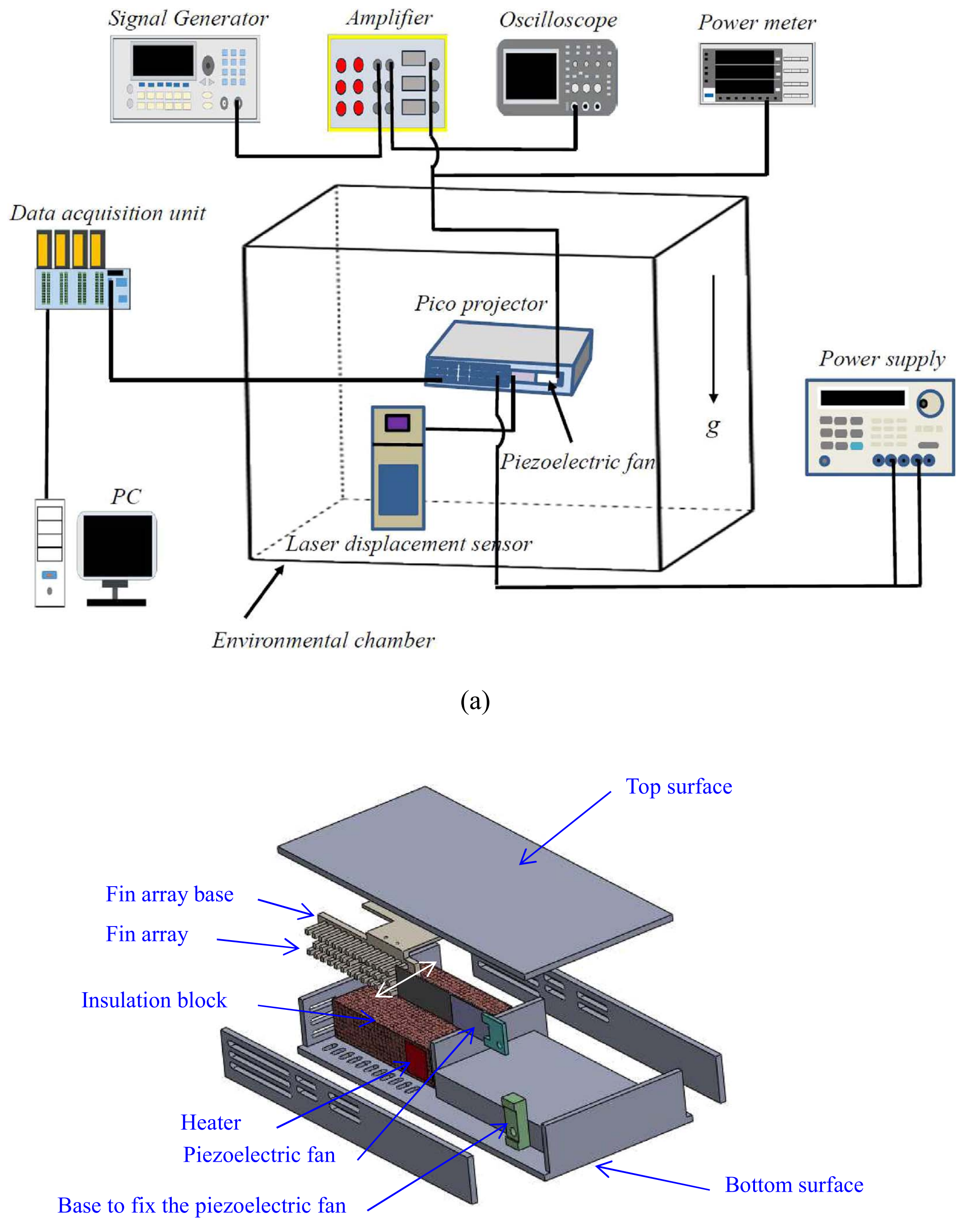

Fig. 1. Schematic diagram of the present (a) experimental setup, and the (b) pico projector that has a white arrow on the blade of the piezoelectric fan to indicate the vibrating motion of the piezoelectric fan relative to the fin array.

amplitude could be a better design for enhancing heat transfer. Therefore, for further decreasing the thermal resistance of the fin array in the pico projector, this study tests the thermal resistance of several pin-fin arrays in a pico projector cooled with a vibrating piezoelectric fan that possesses a metal blade under various operating conditions. In addition, a correlation which relates the Nusselt number of each pin-fin array to both Prandtl number of air and Reynolds number in terms of the vibrating piezoelectric fan will also be proposed in this study.

2. Experimental facility

Fig. 1(a) shows that an environmental chamber, an acrylic pico projector, an actuation unit, a measuring unit, a power supply, and a data acquisition unit comprised the experimental facility of the present study. The actuation unit includes a signal generator, an amplifier, and an oscilloscope, while the measuring unit contains a laser displacement sensor, and a power meter. The environmental chamber of 0.86 m (L) × 0.86 m (W) × 1.16 m (H) in volume was used to conduct all tests in order to acquire the measured data in an enclosure having still air at uniform and constant temperature, 30 °C.

A 120 mm × 53 mm × 19 mm acrylic case having some openings in Fig. 1(b) was fabricated in this study which had similar appearance and dimensions to a commercially available pico projector. A total of 8 thermocouples placed along the centerline on both top and bottom