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Performance effects of heat transfer and geometry on heat pipe thermal modules under forced convection☆

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ABSTRACT

The geometry and heat transfer effects on heat pipes embedded heat sinks-cooling system are investigated in the present paper. In the forced convection system, two different heat pipe geometrical shapes of L and U configurations are taken into account. This study adopts a versatile superposition method and least-square estimators with thermal resistance network analysis to design and experiment their geometry and heat transfer effects under different fan speeds and heat source areas. The results suggest that the characteristics of system performance under varying speeds and areas are significantly different from those under altering speeds and areas. When the thermal performances of these two configurations are 0.04 °C/W of U-shaped heat pipes at 78.85 W, and L-shaped heat pipes are lowest 1.04 °C/W at 34 W, respectively, the lowest thermal resistances of the representative L- and U-shaped heat pipe–heat sink thermal modules are respectively 0.25 °C/W and 0.17 °C/W under twin fans of 3000 RPM and 30 × 30 mm^2 heat sources. The result of this work is a useful thermal management method to facilitate rapid analysis and has provided a useful insight into the design of heat pipe cooling systems.

1. Introduction

The extended surface fin is usually added to enhance the rate of heat removal for traditional air cooling techniques. The conventional way to dissipate heat from microprocessors especially in Central Processing Units (CPUs) and Graphic Processing Units (GPUs) cooling was forced convection using a fan with a heat sink directly. However, with the advances in computer and semiconductor manufacturing industry, integral circuit design is getting more and more complex so that the electronic components of CPUs, GPUs, and LED lighting lamps (LEDs) are made toward the small size, increased power and high efficiency development. They generate more and more heat and heat flux is significantly increased. Thus, the cooling problems of electronic device are daily major [1–3]. The manufacture technology of embedded heat pipes into heat sinks is rapid developments to ensure faster dissipation of the heat which is a quite obvious application in high-performance cooling devices. Therefore, heat pipe thermal modules that transfer energy away from the heat source through convection mechanism possessing simple metal heat sinks and fans are used to solve the hot-spot problems [4–7]. Technical development related with the application of two-phase flow heat transfer assembly to thermal modules has become mature. Heat pipe absorbs large amounts of latent heat from a heat source through the phase change of working fluid inside and transfers rapidly heat flow to the other side by vapor form without any fluid machinery. The computer-aided thermal design of heat sink with heat pipe/vapor chamber progresses a high-quality thermal condition development [8]. The heat pipe thermal module has better thermal performance and is that most of the heat first transfers to the evaporator of a heat pipe, so the evaporated liquid working fluid of the heat pipe produces steam. Steam releases heat through condensation and recondenses into liquid returning to the evaporator, driven by capillary force, while the rest of the heat capacity is removed from the heat sink through forced fan convection [9,10]. The thermal dissipation performance of some heat pipes bent into the required geometric shape and embedded into the metal base plate or fin stack compares well with that of a vapor chamber. Wang et al. [11,12] had experimentally studied the thermal resistances of an aluminum heat sink with horizontally-embedded two and four U-shaped heat pipes of 6 mm diameter under fixed heat source area and single fan. They showed that two heat pipes embedded in the base plate carry 36% of the total dissipated heat capacity from the heat source, while 64% of heat capacity was delivered from the base plate to the fins. Moreover, if the temperature of the heat source is not allowed to exceed 70 °C, the total heat adsorption power of heat sink with two and four embedded heat pipes will not respectively exceed 131 W and 164 W. Finally, a program was developed using Visual Basic to rapidly calculate the thermal performance

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Nomenclature

k	thermal conductivity, W/m°C
L	distance between evaporation and condensation sections of heat pipe, meter
Q	total heat transfer rate, Watt
Q_b	heat transfer rate from base plate to fins, Watt
R	thermal resistance, °C/W
R_t	total thermal resistance, °C/W
R_h	heat pipe thermal resistance, °C/W
T	temperature, °C

Subscripts

a	air/ambient
b	base plate
f	fin
s	heat source/dummy heater
n	position of embedded L-/U-shaped heat pipes

of a heat sink with embedded heat pipes [13]. Mohamed et al. [14,15] investigated also the thermal performance of a heat sink with finned U-shaped heat pipes for optimum L-ratio (ratio of the evaporator section length to the condenser section length) of the U-shaped heat pipe, which was found to be dependent on heat pipe diameter and the fin spacing and was of practical engineering importance in the optimum design of the heat sink. The performance analysis of a finned U-shaped heat pipe used for desktop PC-CPU cooling was estimated for both natural and forced convection modes under steady state condition.

Russel et al. [16] identified the effect of orientation on the performance of the U-shaped heat pipe with grooved and sintered wick structures. Thermal modules with U-shaped heat pipes are currently used for CPU/GPU cooling. Natural and forced convection can both be used to obtain optimum results for minimum thermal resistance and lead to the generation of high capillary forces for anti-gravity applications [17]. The thermal performance of a heat sink with finned U-shaped heat pipes is carried out to compatible research for a wide range of high-frequency microprocessors. Besides, another heat pipe bent into metal base plate is the L shape. One set of risers of the L-shaped heat pipes functions as the evaporating section while the other set attached to fins acts as the condensing section. This shape of heat pipe–heat sink is particularly well-suited for cooling electronic components such as microprocessors using forced convection. Wang [18] vertically arranged six L-type heat pipes in such a way that the bottom acts as the evaporating section and the risers act as the condensing section, and derived a mathematical model including all major components from the thermal interface through the heat pipes and fins. A Windows-based computer program also uses an iterative superposition method to predict the thermal performance. Thermal performance testing shows that a representative heat sink with six L-type heat pipes will carry 160 W and has reached a minimum thermal resistance of 0.22 °C/W. The total thermal resistance varies according to the functionality of the L-type heat pipes. In recent years, heat pipe-based two-phase flow heat transfer modules have emerged to effectively reduce the temperature of small-area LED lighting lamps with higher degrees of heat flux [19,20]. Wang [21,22] analyzed and designed the optimum thermal performance of a flat heat pipe-thermal module application in a high-end VGA card cooling system, which is able to cope with a heat flux GPU of over 62.5 W/cm^2. The optimum total thermal resistance of a flat heat pipe-thermal module is 0.232 °C/W at a high power GPU of 180 W and inclination angle of 180°. The technical development of two-phase flow heat transfer assembly to thermal modules has matured and is one of the best options, especially in LED thermal problems. Lu et al. [23] used the flat heat pipe (FHP or vapor chamber) to improve the thermal characteristics of a high power LED (light-emitting diode) package. The obtained results indicated that the junction temperature of the LED is about 52 °C for an input power of 3 W and, thus, the total thermal resistance of LED system is 8.8 K/W. Wang et al. [24–26] presented a successful experimental analysis with VCTM V1.0 to develop a 30 W high-power LEDs vapor chamber-based plate, finding that the thermal performance of the LED vapor chamber-based plate was an improvement over that of the LED copper-based plate with an input power above 5 W. Results show that the maximum effective thermal conductivity is 870 W/m°C and, compared with the experimental value, the calculating error is no more than ±5%. The LED vapor chamber-based plate successfully resolved the hot-spot problem of 30 W high-power LEDs.

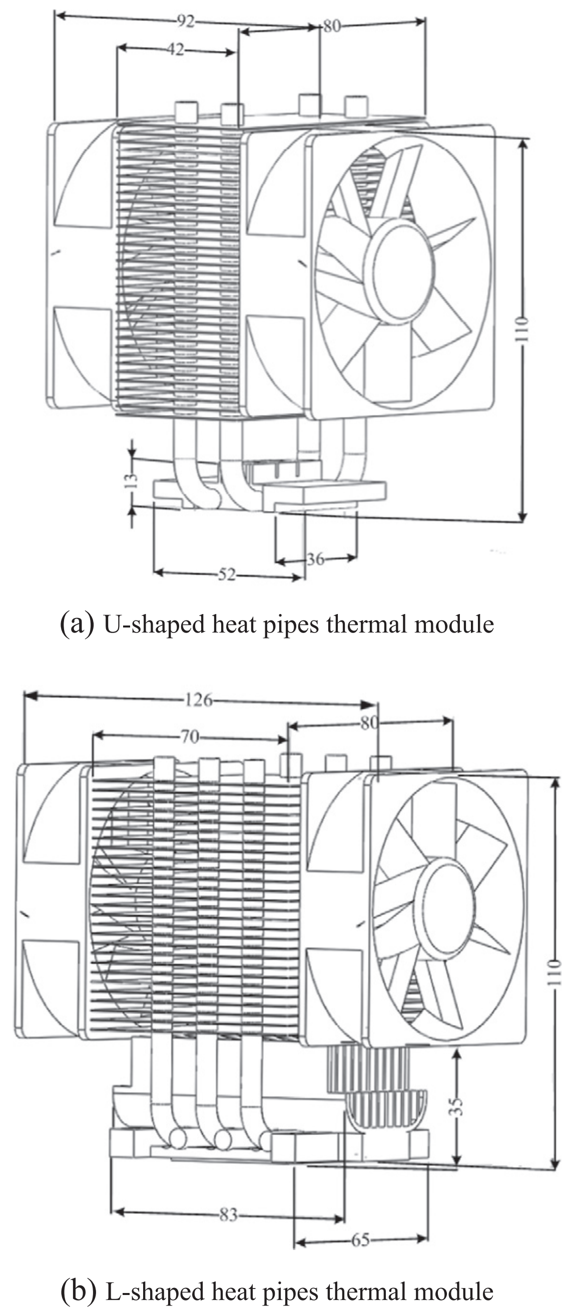

Fig. 1. Heat pipe thermal modules (a) U-shaped heat pipe thermal module (b) L-shaped heat pipe thermal module.