An experimental study on heat transfer performance of a pulsating heat pipe radiator for CPU heat dissipation

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Abstract: To meet the requirement of electronic heat dissipation with high heat flux, a kind of heat dissipation device using pulsating heat pipe (PHP) for CPU heat dissipation was put forward. The heat transfer performance and surface temperature distribution of the radiator are analyzed by analyzing the wall temperature distribution and the distribution of the evaporator and condenser of the PHP. The experimental results show that the change of wind speed has obvious influence on the operation of the PHP radiator. The surface temperature distribution of the PHP radiator is very uniform, which is especially beneficial for CPU cooling. The heat transfer performance of the PHP is better, and the minimum average thermal resistance is 0.19 k/W. In addition, there is no drying phenomenon when the temperature reaches about 120 °C, which indicates that the pulsating heat pipe has a very high heat transfer limit.

1 Introduction

With the development of LSI and VLSI, the miniaturization and integration of electronic components make the heat loss per unit area increase significantly. The heat dissipation problem of electronic components is gradually emerging [1-3]. Generally, the CPU operating temperature limit is 80 °C, and the system reliability will be reduced by 10% when each temperature exceeds this value for 2 °C. And more than 55% of the electronic equipment failure is caused by overheating. Therefore, CPU heat dissipation has become a constraint issue, and a global research hotspot [4-7].

As an efficient heat transfer element, heat pipe is often selected and used in heat dissipation design. With the emergence of some new heat dissipation problem, traditional heat pipe cannot meet the use requirement. Thus, there have been some new type of heat pipe technology. PHP [8] is currently applied many new type heat pipes, and there are few in for electronic device cooling research. Therefore, its application in the field of electronic cooling is highly valued [9].

Considering various factors of CPU heat dissipation, PHP heat dissipation is an efficient passive heat dissipation technology. It has simple structure, low cost, good heat transfer performance, and without additional power [10], it can also better meet the needs of today's CPU cooling market [11]. The PHP radiator with high thermal conductivity, excellent isothermal property and high heat dissipation efficiency is also very suitable for heat dissipation under the condition of small temperature difference and high heat flux [12].

Therefore, this paper proposes a new heat dissipation technology that applies PHP to CPU heat dissipation to satisfy the current high heat flux electron heat dissipation, and has carried out the experimental study about it. The heat transfer performance and surface temperature distribution of the radiator are analyzed by analyzing the wall temperature distribution and the distribution of the cold and hot sections of the PHP.

2 Experimental system and methods

2.1 Experimental systems and devices

This experiment modeled on the heat transfer characteristics in the process of computer CPU work. The experimental system consists of heating system, heat dissipation system and data acquisition system (as shown in Fig. 1). The heating system consists of ammeter, voltmeter, power meter, heating block, copper plate, etc. A copper plate (which can play the role of equalizing temperature) is used to simulate the heating process of CPU. The copper plate is assembled with heat sink and electric heating plate on the upper and lower sides to form the main body of the heating system. In order to reduce the heat resistance, thermal conductive silica gel is filled in between the copper plate, heat sink and heating plate respectively, and the heating power is controlled by adjusting the power meter. To enhance the heat dissipation capability of the condenser, the cooling system adopts variable frequency cooling fan. The wind speed is changed by adjusting the frequency converter, and the anemometer is used to monitor the wind speed. The data acquisition system adopts Agilent 34972A data collector and K-type thermocouple to conduct real-time acquisition of the wall temperature of the radiator of the PHP, and the acquisition

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of the temperature signal to the computer real time monitoring and storage. Eight thermocouples were arranged to monitor the wall temperature change of the PHP. Among them, five thermocouples (T1, T2, T3, T4,) were embedded in the copper plate, two thermocouples were arranged on the adiabatic section (T5, T6) and the condensation section (T7, T8) (As shown in Fig. 2). The sizes of heating plate and copper plate are respectively 60 mm×60 mm×2 mm.

The PHP radiator is mainly composed of PHP, fin and heat sink, as shown in Fig. 3. Pulsating heat pipe by the inner diameter of 2 mm, outside diameter is 4 mm copper tube regularly bent into two closed circulation channels. The heat pipe is equipped with aluminum alloy fins, which can increase the heat dissipation area and improve the cooling effect. In this experiment, using the liquid working medium for deionized water, liquid rate is 50%. When the working fluid is filled, the welded liquid-filled fine copper pipe in the main pipeline is connected to the vacuum unit. And the working fluid is filled according to the needs under high vacuum, the fine copper pipe is welded and sealed.

During the experiment, the specific wind speed value is set as 0 m/s and the input heating power is 45 W. In order to enable the PHP to operate fully under each working condition, the wind speed of the PHP increased by 0.3 m/s every 30 minutes after the php was stable, and the heating power remained unchanged during the experiment. After the end of one set of experiments, the PHP was placed in a room temperature of 25 °C for full cooling. And before the next set of experiments, the PHP is shaken to randomly distribute the working fluid. The experimental wind speed was 0 m/s, 0.1 m/s, 0.3 m/s, 0.5 m/s and 0.7 m/s, respectively.

3 Results and discussion

Thermal resistance is an important index to measure the heat transfer capability of PHP. The smaller the thermal resistance, the better the heat transfer capability. The specific expression is as follows:

\[
R = \frac{T_e - T_c}{Q_{in}}
\]

\[
T_e = \frac{1}{4} \sum T_{ei}
\]

\[
T_c = \frac{1}{2} \sum T_{ci}
\]

Where R stands for thermal resistance and the unit is °C/W; Qin represents the heating power as input, and the unit is W. Te represents the average temperature of the evaporation section, and the unit is °C. Tc is expressed as the average temperature of the condensation section, and the unit is °C. Among them, Qin is the input power of the heating plate, and its value is read directly by the power meter.

3.1 Heat transfer performance analysis of PHP

Combined with the experimental method and the operation characteristics of the PHP, the first large temperature oscillation of the heat pipe is defined as the start of the PHP. In the start-up process, the working fluid at the condensing section of the PHP begins to oscillate, while the temperature oscillation in the evaporation section is not obvious. Therefore, the start-up performance of the PHP is studied by the temperature oscillation curve of the condensing section. The heat transfer of PHP can be
directly reflected by the temperature difference between evaporator and condenser.

**Fig. 4.** The average temperature of the hot and cold sections changing with the heating time.

The temperature on the radiator surface decreases with the increase of the wind speed, which indicates that the heat of the radiator can be effectively taken away by forced convection. With the increase of the wind speed, the heat accumulation of the radiator is relatively low, and the temperature rises relatively slowly. When the heating time is 493 s, the PHP starts, and the corresponding fan wind speed is 0 m/s. In combination with the average temperature distribution curve of evaporation section and condensation section running at each wind speed in Fig. 4, it can be found that when the PHP is started-up, the temperature difference between the hot and cold sections increases first and then decreases with the increase of wind speed, and the temperature oscillation gradually tends to be of small amplitude and high frequency. This mode of oscillation makes the PHP have good stability. After the PHP is started, it runs steadily for a period, which is extremely beneficial to the cooling environment of CPU.

### 3.2. Temperature distribution of the evaporator

Because of the working principle of PHP is unique, its evaporation temperature distribution is uneven, the PHP radiator of evaporator of direct contact with the CPU, the evaporator temperature will be a direct impact on the CPU, the local overheating, may cause the CPU performance degradation or even damage. Therefore, the uniform distribution of T1, T2, T3 and T4 has a great impact on the heat transfer performance of the PHP radiator.

**Fig. 5.** The temperature difference of hot and cold sections changing with the change of time.

Fig. 5. shows the temperature curve of the evaporator and the condenser changing with the heating time. It can be found that the surface temperature distribution of the PHP radiator is very uniform.

### 3.3 Thermal resistance at different wind speeds

**Fig. 6.** The change of evaporator temperature with time

Fig. 6. shows the temperature curve of the evaporator with the change of time. It can be found that the temperature curves of the four evaporators basically coincide, indicating that the surface temperature distribution of the PHP radiator is very uniform.

Fig. 7. shows the variation of the average thermal resistance of the PHP radiator under different wind speeds. It can be seen from the figure that the thermal resistance first increases and then decreases with the increase of the wind speed. When the wind speed is 0 m/s, there is a minimum average thermal resistance, with a minimum average thermal resistance of 0.19 k/W. When the wind speed is 0.3 m/s, the maximum average thermal resistance is 0.44 k/W, indicating that the heat transfer performance of the PHP is very good. When the heat sink of the PHP is heated to about 120 °C, it can still dissipate heat normally, and there is no drying phenomenon, which also indicates that the PHP has a very high heat transfer limit.
4 Conclusions

(1) the surface temperature of the radiator of PHP decreases with the increase of wind speed, and the change of wind speed has certain influence on the heat transfer performance of the radiator. After a period of operation, PHP has achieved stable operation after startup.

(2) With the change of wind speed, the temperature curve of the evaporation section is basically consistent, which indicates that the surface temperature distribution of the PHP radiator is very uniform, which is extremely beneficial to CPU heat dissipation.

(3) The heat transfer performance of the PHP is excellent, and the minimum average thermal resistance is 0.19 k/W. In addition, there is no drying phenomenon when the temperature reaches about 120 ℃, which indicates that the PHP has a very high heat transfer limit.

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