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Natural convection heat transfer of a straight-fin heat sink

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ABSTRACT

The influence of mounting angle on heat dissipation performance of a heat sink under natural convection condition is investigated in this paper by numerical simulation and experimental test. It is found that the heat sink achieves the highest cooling power when its mounting angle is 90°, while it reaches the lowest when the mounting angle is 15°, which is 6.88% lower than that of 90°. A heat transfer stagnation zone is the main factor that affects the cooling power of the heat sink, and its location and area vary with the mounting angle. It is identified that cutting the heat transfer stagnation zone is an effective way to improve the heat sink performance.

1. Introduction

Heat sink is a passive heat exchanger that transfers heat generated by an electronic or a mechanical device to a fluid medium, such as air and liquid coolant. Heat dissipation is very important in the modern electronic industry, according to the statistical data, high temperature causes more than 55% failures of electronics [1]. The heat sink is also used in other areas, for example, heat dissipation of DSC (Dye-Sensitized Solar Cell) [2]. The heat sink has different structures, and can be classified into active and passive types. Compared to the active heat sink, the passive heat sink dissipates thermal energy through the nature convection, and usually it is made of aluminium finned radiator, so it has high reliability and low cost characters. The driving force in the passive heat sink is buoyancy force generated by temperature difference. The natural convection of heat sink can be divided into limited and infinite space convections according to the external space.

Most of the passive heat sinks have simple structure and low cost characters because of their straight fins. Elenbaas [3] carried out the earliest investigation on natural convective heat dissipation for a parallel fin heat sink, Bodoia and Osterle [4] deduced a theoretical solution of the natural convection heat dissipation for the parallel vertical fin heat sink on the basis of theoretical analysis. Other researchers studied and optimised the geometrical dimensions of parallel fin heat sink, and gave out some formulas for calculating geometrical dimensions [5–11]. Heat dissipation performance of the parallel straight fin heat sink can be improved by increasing air turbulence between the fins, such as arranging staggered cylinders [12], drilling holes on base plate [13], opening slots [14] or drilling holes on the fins [15].

The above studies are all conducted with the horizontal or vertical heat sink [16–18], nevertheless, the influence of the heat sink mounting angle on heat dissipation is rarely mentioned. Mehrtash et al. [19] studied the effect of inclination of fin-plate heat sink on heat dissipation by numerical simulation with three-dimensional steady-state natural convection. Based on Mehrtash's research results, Tari et al. [20] developed a Nusselt number formula, and found that the fin spacing is an important parameter affecting heat sink thermal performance [21]. Shen et al. [22] investigated heat dissipation properties of the heat sinks placed in eight different directions, and discovered that the denser the fin arrangement, the more sensitive the directionality. There are two main factors limiting the sink natural convection heat dissipation, one is that the heat transfer direction does not match with natural convection flow, and the other one is that the convection between the fins is blocked.

In this paper, the influence of heat sink mounting angle on its heat dissipation is investigated. A test rig is designed and built to measure heat dissipation performances of a heat sink at different mounting angles. The numerical simulation of the heat sink performance is carried out, and the simulation results are compared with the experimental data. The optimum mounting angle of the heat sink is obtained, which is useful for heat sink design and installation.

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Nomenclature

A	heat sink surface area, m^2
c_p	specific heat capacity of fluid, J kg^{-1} K^{-1}
h	heat transfer coefficient, W m^{-2} K^{-1}
k	thermal conductivity, W m^{-1} K^{-1}
Q_{hs}	heatsink input power, W
R_{th}	thermal resistance, K W^{-1}
R_{hts}	the ratio of stagnation zone accounts for the fin whole area, dimensionless
T_{ave}	average temperature of heat sink plate, K
T_{am}	ambient temperature, K
ΔT	temperature difference between heat sink surface and the ambient temperature, K
u, v, w	components of velocity, m s^{-1}
x, y, z	components of coordinate
$x_1, x_2, x_3, \ldots x_n$	independent variables
$\delta x_1, \delta x_2, \delta x_3 \ldots \delta x_n$	errors of independent variables

Greek symbols

β	thermal expansion coefficient, K^{-1}
ρ	air density, kg m^{-3}
ρ_0	air density at T_0, kg m^{-3}
μ	viscosity, N s m^{-2}

2. Experimental apparatus

2.1. General description

The main components of the test rig include a JP1505D DC power supply, a DC heating plate, an Agilent 34970A Data Acquisition, a number of K-type thermocouples and PT100 RTDs. The schematic of the test rig is shown in Fig. 1. The experimental system is located in a large closed space without the external interference to achieve the heat sink natural convection environment. A special support is designed to ensure the heat sink could rotate 360° freely, as shown in Fig. 2. The heat sink and heating plate are fastened by bolts to reduce the contact thermal resistance and prevent the relative displacement between them. The heating plate is controlled by the JP1505D DC power supply for different heating powers. The maximum output power of the power supply is 750 W, its output voltage range is from 0 V to 150 V with accuracy ±0.3 V and its current range is from 0 A to 5 A with accuracy ±0.01 A. The electric heating power is constant during the testing, the surface temperature of heat sink is measured and used to judge heat dissipation performance of the heat sink. The lower surface temperature of the heat sink, the better heat dissipation performance. Assuming heat is only dissipated by the heat sink when the temperature of the heat sink substrate became constant, the heat sink performance can be assessed by its surface temperatures.

The data collection system consists of TC, RTD and Agilent 34970A Data Acquisition, the locations of the measuring points are shown in Fig. 3. TCs are set at Points 1 to 6 to get the heat sink bottom temperatures, RTDs are set at Points 7 to 9 to measure the fin surface temperatures. Agilent 34970A Data Acquisition with module 34902A, which features a built-in thermocouple reference and 16 two-wire channels, has 6 1/2-digit (22-bit) internal DMM and can scan up to 250 channels per second. The K-type armoured thermocouple WRNK-191 is used in the experiment. The material of WRNK-191 is nickel-chromium & nickel-silicon and its measurement temperature range is from 0 °C to 600 °C with accuracy ±0.5 °C. Because of high thermoelectric power, the WRNK-191 TC has high sensitivity and its thermal response time is 3S. The measurement temperature range of SMD Pt100 RTD Temperature Sensor used for the fin surface is from −50 °C to 200 °C with accuracy ±0.15 °C. It can be directly pasted to the fin surface with

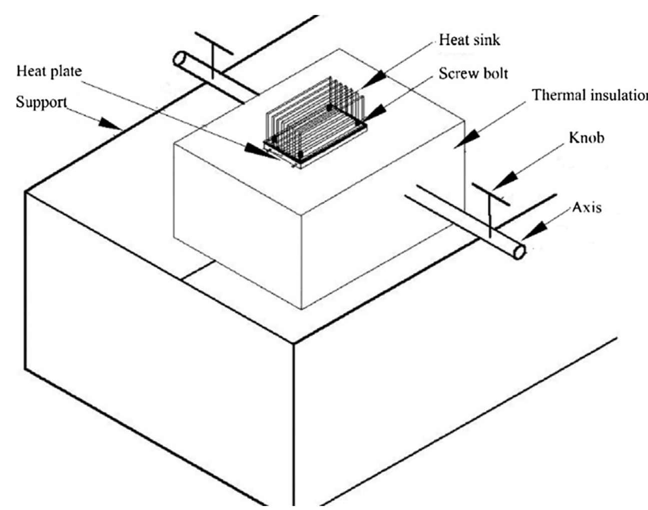

Fig. 2. Schematic of support.

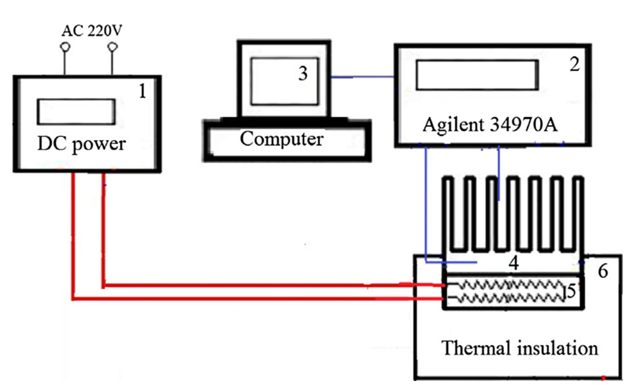

Fig. 1. Schematic of the test rig: (1) DC power; (2) Agilent 34970A; (3) computer; (4) heat sink; (5) heating plate; (6) thermal insulation.

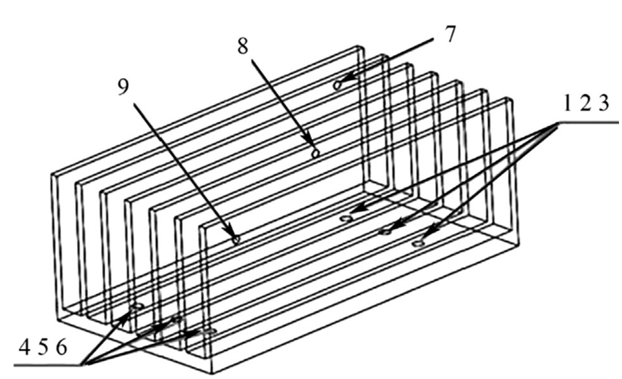

Fig. 3. Arrangement of measuring points. Points 1–6K-type thermocouples; Points 7–9, PT100 RTDs.