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Application of response surface methodology in the parametric optimization of a pin-fin type heat sink ☆

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Abstract

In this paper, an effective procedure of response surface methodology (RSM) has been successfully developed finding the optimal values of designing parameters of a pin-fin type heat sink (PFHS) under constrains of mass and space limitation to achieve the high thermal performance (or cooling efficiency). Various design parameters, such as height and diameter of pin-fin and width of pitch between fins are explored by experiment. The thermal resistance and pressure drop are considered as the multiple thermal performance characteristics. Experiments are performed by a standard RSM design called a central composite design (CCD). The results identify the significant influence factors to minimize thermal resistance and pressure drop. The obtained optimal designing parameters have been predicted and verified by conducting confirmation experiments.

Keywords: Response surface methodology; Optimization; Pin-fin heat sink; Central composite design

1. Introduction

In recent years, the heat sink has been extensively used to provide cooling function for electronics components because the circuit density and power dissipation of integrated circuit chips are rapidly increasing in order to increase the heat flux levels within these chips. The accumulation of large amount of heat flux can create considerable quantities of heat stress on chips, substrate, and its package. Therefore, it is necessary for employing effective heat sink module to maintain the operating temperature of electronic components at a satisfactory level. If there is appropriate and effective heat sink design, it will critically affect the reliability and life span of chip function. There have been many investigations of the optimum design parameters and selection of heat sink with a high-performance heat removal characteristic [1–7]. Ellison [1] and Kraus and Bar-Cohen [2] have presented the fundamentals of heat transfer and hydrodynamics characteristics of heat sinks including the fin efficiency, forced convective correlations, applications in heat sinks, etc. Iyengar and Bar-Cohen [3] determined the least-energy optimization of plate fin heat sinks in the status of forced convection. Park et al. [4,5] performed an investigation of numerical shape optimization for high performance of a heat sink with pin-fins. Park and Moon [6] proposed the progressive quadratic response surface model to obtain the optimal

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Nomenclature

a_i	Linear effect of x_i
a_{ii}	Quadratic effect of x_i
a_{ij}	Linear-by-linear interaction between x_i and x_j
D	Pin diameter
f	Response function (or response surface)
H	Pin height
P_{in}, P_{out}	Average pressure in the inlet and outlet of test section
ΔP	Pressure drop
Q	Heat dissipation produced by the heating unit
R_{th}	Thermal resistance
S1	Longitudinal pitch
S2	Transverse pitch
T_{in}	Temperature in the inlet of test section
T_{max}	Highest temperature of tested heat sink base
x_1, x_2, x_3,..x_n	Independent input variables
y	Desired response
ε	Fitting error

values of design variables for a plate-fin type heat sink. Sahin et al. [7] investigated the effect of design parameters on the heat transfer and pressure drop characteristics of a heat exchanger using the Taguchi experimental design method.

From the above descriptive analysis, the optimal design and selection of effective heat sink module is becoming one of the primary challenges of the computer science and technology industry. In this study, the optimal values of designing parameters of a pin-fin type heat sink (PFHS) are numerically acquired using the quadratic model of response surface methodology (RSM), associated with a sequential approximation optimization (SAO) method to reach the high thermal performance (or cooling efficiency). The RSM relates to the regression analysis and the statistical design of experiments for constructing the global optimization [8] and is one of the most widely used methods to solve the optimization problem in the manufacturing environments [9–12]. To achieve the high thermal performance (or cooling efficiency) under the given design constrain, the predictive model for thermal performance characteristics will be created using the RSM.

2. Experimental detail

2.1. Experimental apparatus

The experimental setup under consideration for optimization is a fan-drive heat sink with pin-fins consisting of air blower, pre-heater, adjustable contraction zone, honeycomb, air-flow channel, test section, and measurement facilities and is illustrated schematically in Fig. 1(A). Air is supplied by a centrifugal blow with the variable-speed drive and then passed through an insulated chamber. The air-flow channel is designed to simulate the electric micro-fan (an external wing diameter of 65 mm and a motor diameter of 25 mm) installed over the heat sink. The static pressure in air-flow channel is measured using a static-pressure tapping located within the middle of this channel. The test section in Fig. 1(B) is constructed by a hollow rectangular block (720 × 720 × 150 mm) made up of upper and bottom plate. Air can exhaust through the horizontal around of test section. The outlet temperature of the air stream located in the horizontal around of test section is measured with thermocouple and data acquisition system. The static-pressure tapping measures the static pressure of air-stream exhausting from the horizontal around of test section. The heating unit located in the middle of bottom plate consists of the electric heater, voltage transformer, a firebrick of 25 mm thickness and the thermal insulator. The electric heater and voltage transformer are used to control the heat flux along the bottom of base plate. The heat generated by heating unit is conducted through the heat sink at first and then it is diffused to the environment by means of forced convection.