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A three-dimensional heat sink module design problem with experimental verification

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ABSTRACT

A three-dimensional heat sink module design problem is examined in this work to estimate the optimum design variables using the Levenberg–Marquardt Method (LMM) and a general purpose commercial code CFD-ACE+. Three different types of heat sinks are designed based on the original fin arrays with a fixed volume. The objective of this study is to minimize the maximum temperature in the fin array and to determine the best shape of heat sink. Results obtained by using the LMM to solve this 3-D heat sink module design problem are firstly justified based on the numerical experiments and it is concluded that for all three cases, the optimum fin height H tends to become higher and optimum fin thickness W tends to become thinner than the original fin array, as a result both the fin pitch D and heat sink base thickness U are increased. The maximum temperature for the designed fin array can be decreased drastically by utilizing the present fin design algorithm. Finally, temperature distributions for the optimal heat sink modules are measured using thermal camera and compared with the numerical solutions to justify the validity of the present design.

1. Introduction

Nowadays, the tendency to design electronic products becomes lighter, thinner, shorter, and smaller. Due to the fact that shrinking in the dimension of these electronic products will result in drastic increase in the heat generation rate when comparing with previous products. For this reason, an efficient cooling system to remove the high heat generation, and consequently maintain the stability and reliability of the products, have received much attention.

The heat sink module is the most common heat exchanger for CPUs and has been extensively used in order to provide cooling function for electronic components. The conventional heat sink module utilized the forced convection cooling technique; dissipate heat from CPUs to the ambient air. The combination of the fan and heat sink design usually involved in this forced convection cooling technique.

The forced convection cooling technique becomes one of the most commonly used devices to cool CPUs since it has the advantageous of simple maintenance process, more reliability and lower manufacturing cost. It has been seen by many researchers that a heat sink with good geometrical design will provide better cooling performance and higher efficiency. It implies that the optimization process must be an effective tool for the heat sink design problem.

If an efficient heat sink design algorithm is provided, it will greatly improve the reliability and prolong the life span of the CPUs. Many investigations of the optimum design parameters and the selection of heat sink module have been proposed in order to offer a high-performance heat removal characteristic. For instance, Kraus and Bar-Cohen [1] presented the fundamental theories for heat transfer and hydrodynamics characteristics of heat sinks. Shih and Liu [2] and Furukawa and Yang [3] presented an approach to design the plate-fin heat sinks by minimizing the entropy generation rate in order to reach the most efficient heat transfer. Leon et al. [4] and Small et al. [5] used computational fluid dynamics (CFD) to study flow and heat transfer behaviors for staggered heat sinks in detail. Iyengar and Bar-Cohen [6] utilized the least-energy optimization algorithm to design the plate fin heat sinks in the forced convection problem. Yang and Peng [7,8] investigated numerically the thermal performances of the heat sink with un-uniform fin width and fin height designs with an impingement cooling. Zhou et al. [9] considered a multi-parameter constrained optimization procedure to design the plate finned heat sinks by minimizing their rates of entropy generation. Park and Moon [10] utilized the progressive quadratic response surface model to estimate the optimum fin design variables for a plate-fin type heat sink. Srisomporn and Bureerat [11] considered a geometrical design problem for the plate-fin heat sinks by using hybridization of the multiobjective evolutionary algorithms (MOEAs) and a response surface method (RSM). Shan et al. [12] established the

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Nomenclature

B_j	design variables
D	fin pitch (calculated variable)
$D1$	the width of row passage (calculated variable)
H	fin height (design variable)
J	functional defined by Eq. (10)
k	thermal conductivity of fin
$L1, L2$	width and depth of the computational domain
N	number of fin plate in each row
q	applied heat flux
S_b	bottom surface
S_h	heating surface
T_f	calculated fin temperature
T_∞	ambient temperature
$\bar{u}_i$	flow velocity
U	fin base thickness (calculated variable)
V	specified fin array volume
W	fin thickness (design variable)
$W1$	fin width (design variable)
Y	desired maximum temperature

Greek symbols

$\boldsymbol{\Psi}$	Jacobian matrix defined by Eq. (16)
Ω	total computational domain
ε	convergence criterion
μ^n	damping parameter

direct link between the pressure drop of heat sinks and system operating curve for the selected fan to optimize a parallel plate impingement heat sink. Park et al. [13] applied the numerical optimization to determine the shape of pin-fins for a heat sink to improve the cooling efficiency. Sahin et al. [14] used the Taguchi experimental design method to examine the effects of design parameters on the heat transfer and pressure drop characteristic of a heat exchanger.

From references mentioned above, the optimum design problems for an efficient heat sink module become a primary challenge in the electronic industry. In order to obtain an optimum design for heat sink modules, the proper types for heat sink modules and a suitable optimization algorithm should be chosen before proceeding to the design problem. Among numerous existing designs of heat sink modules, the design of heat sink with the plate fin array is widely utilized in the cooling enhancement of current electronic equipment. Therefore this type of heat sink module with modifications will be considered in this work. Besides, the present study will also focus on the thermal performance of the fan–sink assembly subjected to forced air cooling.

The Levenberg–Marquardt Method (LMM) [15] has proven to be a powerful algorithm in inverse design calculation for engineering applications. This inverse design method had been applied to predict the form of a ship's hull in accordance with the desired hull pressure distribution by Huang et al. [16]. Subsequently, Chen and Huang [17] applied it to predict an unknown hull form based on the preferable wake distribution in the propeller disk plane. Chen et al. [18] further applied it to the aspect of optimal design for a bulbous bow. Huang and Lin [19] applied LMM in the theoretical and experimental Studies to estimate the optimum shape for gas channel for a serpentine PEMFC. The LMM will be adopted in the present study as an optimization algorithm.

This work addresses the development of an efficient method for parameter estimation in estimating the design variables for heat sink modules that satisfies the constraint of minimizing the maximum surface temperature. However, without experimental verification it is difficult to show that the present design algorithm can be utilized in reality. For this reason in the present study the estimated optimal heat sinks will be fabricated and they will be used in experiment to measure the temperatures by using infrared thermal scanner. Finally these temperatures will be compared with the calculated temperatures to show the accuracy of our computations.

2. The direct problem

The following three-dimensional heat sink module is considered to illustrate the methodology for developing expressions for use in determining the design variables for heat sink module in the present inverse design problem by using LMM and CFD-ACE+ [20].

It is assumed that Ω represents the domain of computation and $\{\Omega\} = \{\Omega_1 \cup \Omega_2\}$, where Ω_1 indicates the domain of fin array and Ω_2 represents the air flow region. The boundary conditions on all the outer boundary surfaces are subjected to the Robin boundary conditions with heat transfer coefficient h and ambient temperature T_∞. A heat flux q is imposed at the heating surface S_h while the rest of bottom surface S_b of fin array remains insulated. Fig. 1(a) shows the geometry of the computational domain of heat sink module and Fig. 1(b) indicates the bottom and heating surfaces of the fin array.

The mathematical formulation of this 3-D heat conduction problem for the fin domain Ω_1 is given by:

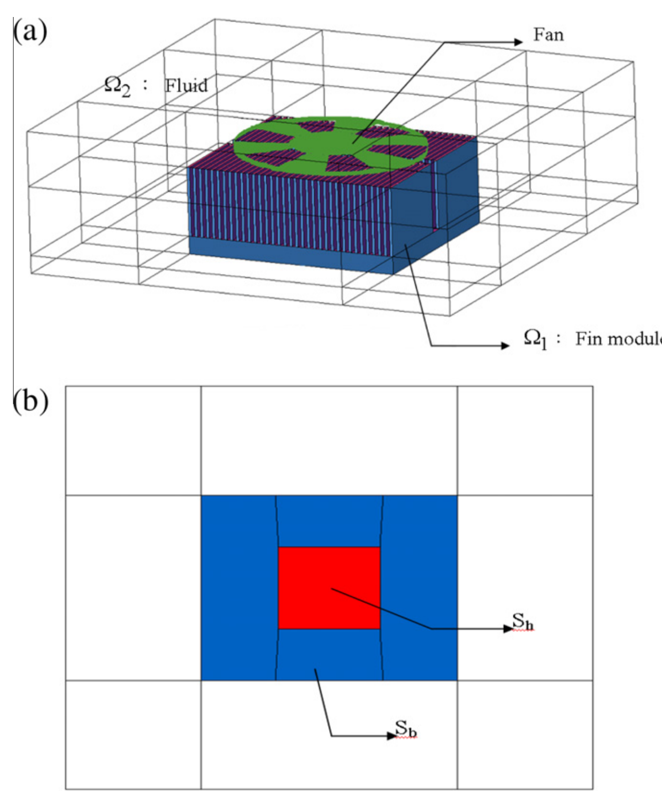

Fig. 1. The (a) geometry of the computational domain of heat sink module and (b) bottom and heating surfaces of the fin array.