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Technical Note

An impingement heat sink module design problem in determining simultaneously the optimal non-uniform fin widths and heights

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ABSTRACT

The Levenberg–Marquardt Method (LMM) is applied in the present study to determine the optimal fin widths and heights of an impingement cooling heat sink module using a general purpose commercial code (CFD-ACE+). In this optimal heat sink design problem, the non-uniform fin widths and heights are chosen as the design variables. The objective of the present study is to minimize the system thermal resistance (R_{th}) of the fin array and to obtain the optimal dimensions of heat sink. The results obtained by numerical experiments demonstrate that by utilizing the optimal heat sink and operating at the design condition $Re = 15{,}000$, R_{th} can be decreased by 3.10% and 1.20% when compared with the original and Yang and Peng's (2008) [1] heat sinks, respectively. Nu and COE can be increased by 3.20% and 3.20%, respectively, when compared with the original heat sink, and these parameters can be increased by 1.22% and 1.18%, respectively, when compared with the optimal heat sink proposed by Yang and Peng (2008) [1]. Consequently, the thermal performances of optimal impingement heat sink can be improved.

1. Introduction

The hydraulic and thermal characteristics of various impinging heat sinks have extensively studied, due to its favorable unit price, weight and reliability, by many researchers. For instance, Sansoucy et al. [2] experimentally studied the heat transfer from a parallel flat-plate heat sink under a turbulent air jet impingement. Brignoni and Garimella [3] examined experimentally the optimization of confined impinging air jets used in conjunction with a pin-fin heat sink. The ranges of enhancement factors for the heat sink were found to be between 2.8 and 9.7 relative to a bare surface. Li et al. [4] and Li and Chen [5] investigated the thermal performance of pin-fin and plate-fin heat sinks with confined impingement cooling by using infrared thermography.

Yang and Peng [1] numerically investigated the thermal performance of a heat sink with a non-uniform fin heights design with impingement cooling. In their work, they intuitively and without any theoretical basis designed four groups of heat sink with non-uniform fin heights. Along with the original design, the Nusselt numbers and coefficients of performance for the four groups of impingement heat sinks were calculated and compared. Based on their research outcomes they concluded that group IV of type-k design had the best thermal performance when operating at $Re = 15{,}000$. The above study is not related to any design problem because no design algorithm was applied.

An effective heat sink design algorithm improves the efficiency of heat sink modules and reduces the duration and cost of the design process. Many investigations have proposed high-performance heat removal characteristics. For instance, Park et al. [6] used numerical optimization to estimate the shape of pin-fins for a heat sink to improve the cooling efficiency. Iyengar and Bar-Cohen [7] utilized the least-energy optimization algorithm to design plate fin heat sinks in the forced convection problem. The Taguchi experimental design method was utilized by Sahin et al. [8] to examine the effects of changes in the design parameters on the heat transfer and pressure drop characteristics of a heat exchanger.

Recently, Huang et al. [9] examined the impingement heat sink design problem studied by Yang and Peng [10] by utilizing the LMM. In reference [10], they investigated the thermal performance of a heat sink with a non-uniform fin width design with impingement cooling. The objective of the study by Huang et al. [9] is to further reduce the thermal resistance of their optimal heat sink by employing the optimal design algorithm to determine the optimal widths of fin in an impingement heat sink and to further improve the thermal performance of the heat sink module proposed by [10]. Results indicated that under the design operating condition $Re = 5000$, R_{th} can be decreased by 12.98% and 4.81% compared to the original and to Yang and Peng's optimal heat sinks, respectively.

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Nomenclature

A_b	bottom surface, mm^2
A_h	heating surface, mm^2
B_i	design variables, mm
b	the thickness of heat sink base, mm
COE	coefficient of enhancement
G	fin pitch, mm
H_i	fin height, mm
J	functional defined by Eq. (7)
k	thermal conductivity of fin, W/(m-K)
L	the width of heat sink base, mm
$L1, L2, L3$	the width, depth and height of the computational domain, mm
Nu	Nusselt number
P	number of design variables
q	applied heat flux, W/m^2
R_{th}	thermal resistance, °C/W
T_∞	ambient temperature, °C
V	specified fin array volume, mm^3
W_i	fin widths, mm
Greek symbols	
Ω	total computational domain

The purpose of the present work is to examine the impingement heat sink design problem studied by Yang and Peng [1] again. The objective is to further reduce the thermal resistance and improve the thermal performance of their optimal heat sink by employing our optimal design algorithm to determine simultaneously the optimal fin widths and heights of an impingement heat sink.

2. The direct problem

Fig. 1 shows a three-dimensional model of impingement heat sink module and will be considered in the present study to illustrate the methodology in designing the optimal fin shape by using the LMM to minimize the thermal resistance of the heat sink module.

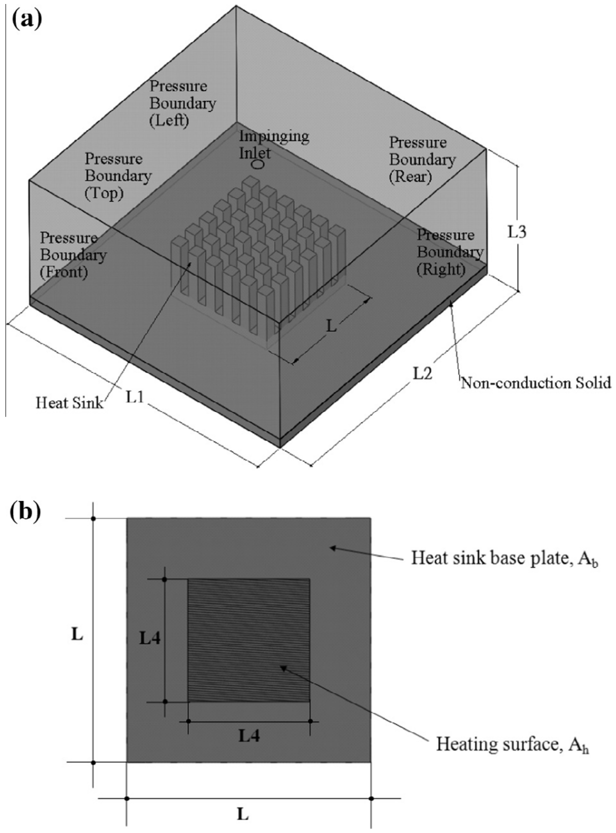

Fig. 1. The (a) geometry of the computational domain of the impingement cooling heat sink module and (b) the bottom and heating surfaces of the fin array.

Let Ω represents the computation domain and $\{\Omega\} = \{\Omega_1 \cup \Omega_2\}$, where Ω_1 represents the heat sink fin array region and Ω_2 represents the air flow region. All outer boundary fin surfaces are subjected to Robin-type boundary conditions with heat transfer coefficient h and ambient temperature T_∞. A heat flux q is imposed on heating surface A_h of the bottom surface of heat sink module A_b, while the remainder of the bottom surface of the fin array remains insulated. Fig. 1(a) shows the geometry of the computational domain of the impingement heat sink module, and Fig. 1(b) illustrates its bottom and heating surfaces.

The three-dimensional motion of the fluid is an incompressible and unsteady flow and is calculated by using the three-dimensional Reynolds-Averaged Navier–Stokes (RANS) equations. In addition, the fluid is in a state of turbulence and thus the standard $k - \varepsilon$ equation was selected for turbulence modeling, and the standard wall function was used near the wall. The velocity-inlet and pressure-outlet are chosen as the fluid boundary conditions in this study. The solution for the above three-dimensional impingement heat sink module is obtained using CFD-ACE+ [11] since Huang et al. [9] have examined its validity.

The direct problem considered here is the determination of the velocity and temperature distributions for the air and heat sink when all the boundary conditions and the heat flux on A_h are known.

3. The design problem: obtain minimum thermal resistance

The objective of this study is to utilize the Levenberg–Marquardt Method (LMM) design algorithm to re-examine the same impingement heat sink design problem that was recently studied by Yang and Peng [1]. The goal is to further reduce the thermal resistance of their optimal heat sink by determining the optimal fin heights and widths of the impingement heat sink.

The design variables for a 6 by 6 squared fins heat sink module is illustrated in Fig. 2. The fin width and height can vary from fin to fin, and the fin pitch and volume are fixed. The fin array volume V can be calculated using the following equation:

$$V = [W_1^2 \times H_1 + W_2 \times H_2(W_2 + 2W_1) + W_3 \times H_3(W_3 + 2W_1 + 2W_2)] \times 4 + (L^2 \times b)\ \text{mm}^3 \tag{1}$$

$$L = 2 \times W_1 + 2 \times W_2 + 2 \times W_3 + 5 \times G\ \text{mm} \tag{2}$$

where L and b are the width and thickness of the heat sink base, respectively. W_1 to W_3 and H_1 to H_3 are the fin widths and fin