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Synthesis of multiple cross-section pin fin heat sinks using multiobjective evolutionary algorithms

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ABSTRACT

This paper demonstrates multiobjective optimization of a multi cross-section pin fin heat sink (MCSPFHS) for use in electronic devices. The design problem is assigned to optimize junction temperature and fan pumping power of the heat sink. Design variables are encoded to shape the fin geometry with several pin fin cross-sections. The heat sink is set to be side-inlet-side-outlet (SISO) while several multiobjective evolutionary algorithms (MOEAs) including hybrid real code population-based incremental learning and differential evolution (PBIL-DE), second version of strength Pareto evolutionary algorithm (SPEA2), and unrestricted population size evolutionary multiobjective optimization algorithm (UPSEMOA) are applied to solve the bi-objective optimization problem. The results obtained are superior to those conventional pin fin heat sinks.

1. Introduction

The trend of electronic equipment toward denser and more powerful products has led to its use with higher power densities. It is common that high power densities result in increased junction temperatures between a heat sink and an electronic device which simultaneously requires higher fan pumping power [1]. Such heat buildup can cause damage to electronic devices. The fan pumping power, on the other hand, is an indicator for heat dissipation operating cost. Much work has been conducted to explore new cooling techniques [2]. Air cooled heat sinks (HSs) are some of the most prominent devices used for dissipating heat from the electronic devices due to their capability of avoiding leakage problems, low cost and high reliability. Heat sink performance to great extent depends on fin geometry [3]. The heat transfer process starts from heat conduction from the electronic equipment to the heat sink base, and then it is followed by conduction into the surfaces of the heat sink fins and convection to air flow. Over the years, many researchers around the world have contributed their work related to heat sink optimization. Two common types of heat sinks are plate fin [2] and pin fin [3,4] heat sinks. By planting pins in between plate fins, it is called plate-pin fin heat sinks [5]. Other types can be honeycomb [6–10] and micro-channel [11–15] heat sinks. Heat sink bases can be squared [3,4,16], rectangular [2,17], or circular [18]. The heat sinks are subject to impinging [2–4,8,19–23] and side-inlet-side-outlet [1,5,9,10,24–31] flows.

Similarly to design of other types of heat exchangers, two inevitable design objectives are set to measure system thermal performance and operating cost. The bi-objective design with junction temperature and fan pumping power minimization was presented in [2–4]. Minimization of entropy generation is an alternative choice, which was studied in [28,30,32] while the simultaneous minimization of thermal resistance and heat sink mass was presented in [18,23,33]. Design variables are assigned to optimize HS dimensions [3] and geometries [2–4]. Some recent work [34] employed topology optimization to generate heat sink geometries for optimal natural free convection, nevertheless, this is still far from being implemented in practice since the manufacturing cost will be too high. In computing objective and constraint functions, computational fluid dynamic (CFD) simulation is traditionally used. Flow inside the heat sink is said to be conjugate heat transfer where flow behaviors are described by a laminar flow model [2,3,17,18,31,32], and turbulent models [22,28,29,35]. Mostly for the latter, the k–ε turbulence model is used to describe the characteristics of air flow through heat sinks.

The optimization methods used are usually meta-heuristics or evolutionary algorithms. Using such methods is advantageous because they are simple to understand, code, and use. The methods are derivative-free enabling heat sink designers to assign

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Nomenclature

C_p	heat capacity at constant pressure of air
C_μ	turbulent model parameters
$C_{\varepsilon 1}, C_{\varepsilon 2}$	turbulent model parameters
$\mathbf{f}, f_i$	objective functions
$\mathbf{F}$	body force vector
H, H_i	fin height
$\mathbf{I}$	the unit tensor
k	turbulent kinetic energy
k_A	thermal conductivity of air
k_s	thermal conductivity of solid
$\dot{m}$	air flow rate
P	pressure
P_f	fan pumping power
P_k	production term
ΔP	pressure drop across the heat sink
Q	heat generated per unit volume
q	heat flux
R_{HS}	heat sink thermal resistance
T	temperature
T_a	ambient air temperature
T_j	junction temperature
t_b	heat sink base thickness
u	averaged velocity vector
w	heat sink width
$\mathbf{x}$	vector of design variables

Greek letters

ρ	air density
μ	dynamic viscosity
μ_T	turbulent viscosity
ε	turbulent dissipation rate
σ_k, σ_ε	turbulent model parameters

Abbreviations

CFD	computational fluid dynamics
MOEA	multiobjective evolutionary algorithm
PBIL-DE	population-based incremental learning - differential evolution
UPS-EMOA	unrestricted population size evolutionary multiobjective optimization algorithm
SPEA2	strength Pareto evolutionary algorithms: version 2

unlimited ideas in the design problem. For multiobjective optimization, the optimizers of this type are usually called multiobjective evolutionary algorithms (MOEAs) and they have a wonderful feature to explore a Pareto optimal front of the designs problem within one optimization run. Some of MOEAs used in heat sink design were the second version of a strength Pareto evolutionary algorithm (SPEA2) [2], population-based incremental learning (PBIL) [3,4], a non-dominated sorting genetic algorithm II (NSGA-II) [36]. On the other hand, a genetic algorithm was used for a single objective design problem [22]. Since CFD simulation is used for function evaluations, the design process of heat sinks is usually considerably time consuming. To deal with such a problem, surrogate-assisted optimization is employed. The idea is to use a design of experiment technique for computer simulation such as a Latin hypercube sampling technique for generating a few design points and then perform CFD function evaluations. The data are then used for construction of surrogate models. An optimizer will be operated by using surrogate model function evaluations which takes significantly less time consumption. If the surrogate models are sufficiently accurate, this idea is very effective and efficient. Up to recently, the surrogate models used for HS design are a Kriging model [4,18], a response surface model [2,4,10,22], radial basis function interpolation [2,4] neural networks [14], and etc.

Most of the investigation in the literature focused on optimum fin sizing with the fin geometries being predefined. However, it has been found that, if the fin sizes and other parameters for HS geometries are simultaneously considered as deign variables [2–4] better heat sinks can be obtained. The main objective of this paper is therefore to propose an innovative idea on planting pin fins on a heat sink of a side-inlet-side-outlet type. The new heat sink is termed multiple cross-section pin fin heat sink (MCSPFHS). The design problem has two objective functions as junction temperature and fan pumping power. Design variables are encoded to shape the heat sink geometry with various fin cross-sections and to be used with multiobjective evolutionary algorithms. Several MOEAs are employed to solve the problem. The results show that the new design process gives superior heat sinks to those traditionally used plate-fin and pin-fin heat sinks.

2. Pin-fin heat sinks

2.1. Physical model

The schematic diagram of a side-inlet-side-outlet pin-fin heat sink is shown in Fig. 1 where the fins are planted on the heat sink base plate. Fig. 2 shows the top view of the HS in cases that the pin fins have various cross-sections. The heat sink is cooled by a horizontal fan with inlet air velocity. For numerical simulation, at the heat sink base which has thickness t_b, constant heat flux (q) is applied on the heat sink base. The heat sink base is a square with the width of w.

In this study, the fluid domain is 57 mm wide, 70 mm high and 220 mm long. The flow is set as three-dimensional, turbulent, incompressible, and steady. The turbulent flow model is used because it was reported in [5] that the flow in their experiment studies, which had similar conditions to this work, is turbulent. Buoyancy and radiation heat transfer effects are negligible. Thermodynamic properties are assumed to be constant. Then the momentum and continuity equations can be respectively written as [37]:

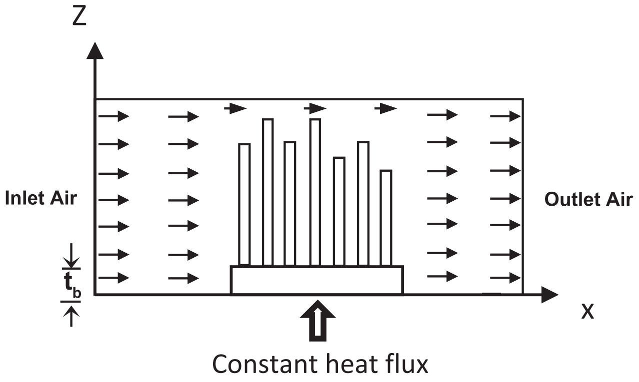

Fig. 1. Side-view of SISOHS.