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Optimal Fin Planting of a Side-Inlet-Side-Outlet Heat Sink Using a Multiobjective Evolutionary Algorithm

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Abstract

This research is aimed at demonstration of the optimal geometrical design of side-inlet-side-outlet pin-fin heat sinks (SISOPFHS) using a multiobjective evolutionary algorithm. A multiobjective real-code Pareto envelope-based selection algorithm (MORPESA) is assigned to explore Pareto optimal solutions. Two objective functions are minimization of junction temperature and fan pumping power of a heat sink. Function evaluation can be achieved by using computational fluid dynamics (CFD) software. Design variables include pin cross-sectional area, number of fins, fin pitch, base thickness, inlet air velocity and fin heights. Design constraints are defined in such a way that the heat sink can practically be used and manufactured. The results show that MORPESA is a powerful tool for the optimal design of such a heat sink.

***Keywords**:* multiobjective evolutionary algorithms, side-inlet-side-outlet heat sink, Pareto optimal solutions, computational fluid dynamics, heat transfer

1. Introduction

Air-cooled heat sinks have been widely used in electronics cooling for decades. The heat sink integrated with a fan for generating air flow is an efficient means for dissipating heat from electronics device due to its capability of minimizing ducting and leakage problems, low cost, and high reliability. A heat sink performance depends on conduction from the electronic package to the heat sink base, followed by conduction into the extended surfaces and convection to air flow. This can be enhanced by optimal design of a heat sink. Design optimization of plate-fin [3, 10] and pin-fin [4, 9] heat sinks with air impinging from the heat sink top has been demonstrated in the literature. The shortcoming of such systems is that the fan impingement can cause undesirable pressure on the cooling target. This can be avoided by using a heat sink with air flow from its side, which is herein called a side-inlet-side-outlet (SISO) heat sink. With such flow situation, the design space of the heat sink is different from those presented in [8] Investigation on optimization of SISO heat sinks is important in order to get the best idea to form this type of heat sink.

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Therefore, this research is aimed at demonstrating the optimal geometrical design of pin-fin heat sinks using a multiobjective real-code Pareto envelope-based selection algorithm (MORPESA) [3] technique. Two objective functions (to be minimized) include junction temperature (T_j) and fan pumping power (P_F). The design constraints are heat sink usability and manufacturing feasibility. Design variables consist of pin cross-sectional area, number of fins, fin pitch, base thickness, inlet air velocity and fin heights. The objective functions are evaluated by using Computational Fluid Dynamics (CFD) software.

2. Multiobjective Optimization

A typical optimization problem is assigned to minimize a design objective subject to constraints. Often in reality, there are more than one objective functions in one problem. This is called a multiobjective optimization, which can be expressed as:

$$\text{Min } \mathbf{F}(\mathbf{x}) = \{f_1(\mathbf{x}), .., f_m(\mathbf{x})\} \quad (1)$$

Subject to

$$g_i(\mathbf{x}) \leq 0,\ i \in I.$$

If there is one objective function, there will be one global optimum solution. However, if there are two or more objectives, the problem has countless optimum solutions. The set of such optimal solution is called a Pareto optimum set. If viewed one the objective function domain, it is called a Pareto front (Fig 1). To solve problem (1), it means to explore its Pareto front. Recently, the most popular methods used solving such a problem is multiobjective evolutionary algorithms (MOEAs). This type of optimizers has some certain advantages over the others as they are robust, simple to use, capable of solving almost any kind of problems, and capable of exploring a Pareto front within one optimization run. The last feature is what makes those MOEAs popular. MOEAs exploit the population-based search strategy for this task. As the use a group of design solutions for iteratively searching Pareto solutions, the numerical scheme called non-dominated sorting can be used to find a set non-dominated solutions, which is an approximate Pareto solutions.

For the minimization cases, two definitions associated with non-domination are given as:

Definition 1: **Dominance** Given $f_i(x)$ for $i = 1,\ldots,m$ are objective functions, if $f_i(x_1) \leq f_i(x_2)$ for every

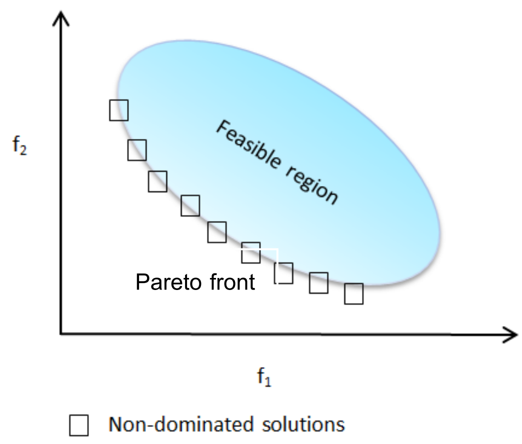

Fig.1 Non-dominated concept

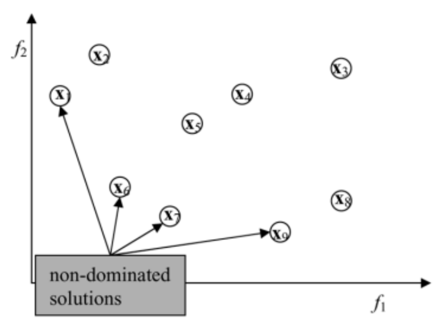

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Fig.2 Non-dominated solutions.

Definition 2: **Non-Dominated Solutions** (Local Pareto Set) Given a set of solutions or population ***P*** size *N*, a solution $x_e \in P$ is a non-dominated solution in ***P*** if there does not exist $x \in P$ such that x dominate x_e . Fig. 2 depicts a plot of 9 design solutions on the domain of objective functions. The non-dominated solutions are $x_1, x_6, x_7,$ and x_9 [3]. The search procedure of most MOEAs uses this non-dominated sorting scheme to find the set of Pareto optima. Starting with an empty set called a Pareto archive, an initial population (a set of randomly generated solutions) is created. Then, a new population is created by means of evolutionary operation. The archive will be used to collect non-dominated solutions sorted from the new population iteratively and the non-dominated set at the final iteration is regarded as a Pareto optimal set.

3. Design Problem

The schematics of the pin fin heat sinks used in this study are shown in Fig. 3. The heat sinks were fabricated from aluminum (k_{Al} =202 W/m K) with base dimensions of 25 mm × 25 mm where the pin height ranges from 0.001 to 0.05 mm. The pin fin heat sink viewed from the side and the top subject to bypass flow is shown in Fig. 4 and 5 respectively where it is installed in the L × W × H rectangular duct and mounted on the top of the heat source.

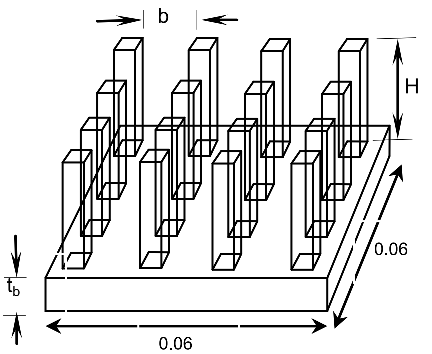

Fig.3 Schematic of design problems

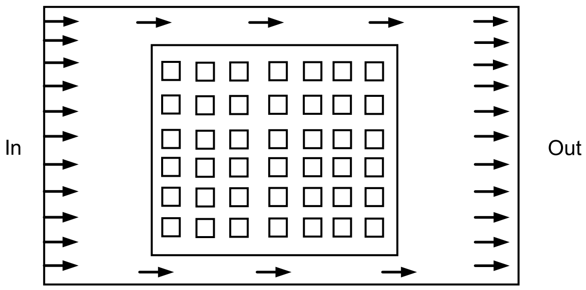

Fig.4 Top View of a Side-Inlet-Side-Outlet Heat Sink

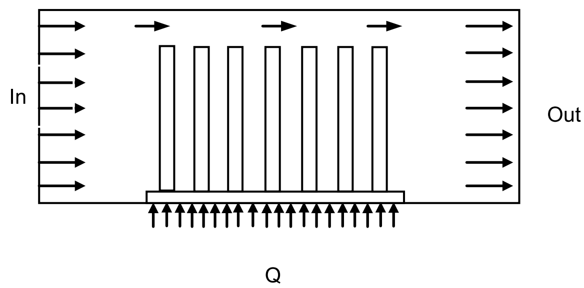

Fig.5 Side View of a Side-Inlet-Side-Outlet Heat Sink

A multiobjective design problem can be defined as follows:

Min: f = {f_1(x), f_2(x)} (2)

Subject to

$0.0025 \leq a \leq 0.008$ (3)

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$0.025 \le b \le 0.004$ (4)

$4 \le n \le 16$ (5)

$0.0025 \le t_b \le 0.009$ (6)

$0 \le H \le 0.05$ (7)

$0.5 \le V_f \le 1.7$ (8)

where f_1 is junction temperature, and f_2 is fan pumping power. The objective functions can be expressed as [3]

$$f_1(x) = T_f = T_a + QR_{HS} \quad (9)$$

and

$$f_2(x) = P_f = \frac{\dot{m}\Delta P}{\rho_a} \quad (10)$$

The other parameters are defined as follows:

T_a= ambient air temperature set as 298 K

Q = heat load set as 120 W

R_{HS} = heat sink thermal resistant (K/W)

a = fin cross-sectional area (m^2)

b = fin pitch (m)

n = number of fins in each row

t_b= heat sink base thickness (m)

H = fin heights (m)

$\dot{m}_a$ = an air flow rate (kg/s)

V_f = inlet air velocity (m/s)

ΔP = pressure drop across the heat sink (N/m^2)

ρ_a = air density set as 1.177 kg/m^3

Computational Fluid Dynamics software is assigned to compute the values of pressure and temperature.

3.1 Encoding/decoding design variables

The most difficult part in design optimization of the heat sink is the decoding design variables process. In this work, the heat sink has square cross-section fins and base. Initially, the design vector **x** sized 20×1 is assigned to have lower and upper bounds as $\mathbf{0} \le \mathbf{x} \le \mathbf{1}$. Then, the parameters used to generate a fin geometry are extracted as:

$d = 0.001 + 0.007x_1$ (m)

$n = ceil(4 + 11x_2)$

$ceil(x)$ rounds x towards $+\infty$

$t_b = 0.001+0.004x_3$ (m)

H_1-$H_{16} = 0.05x_4 - 0.05x_{19}$ (m)

$V_f = 0.5 + 5.5x_{20}$ (m/s).

According to the above parameters, H_1-H_{16} determine the distribution of fin heights throughout the base. The control points are equally spaced on the heat sink base as shown in Fig 6 while those 16 fin height values are distributed as shown. The radial-basis interpolation is employed. Fig. 7 shows a sample of planting n×n square pin fins on the heat sink base where the interpolation surface control their heights. For more details of the surface spline interpolation, see [7].

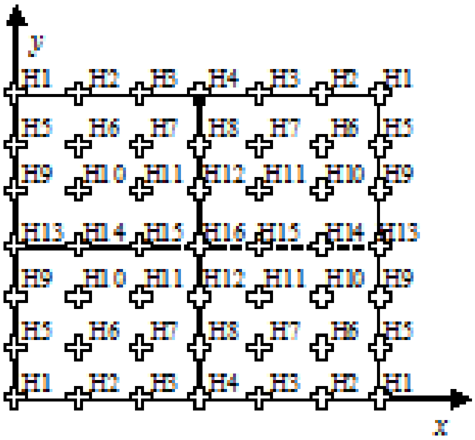

Fig. 6 interpolation points

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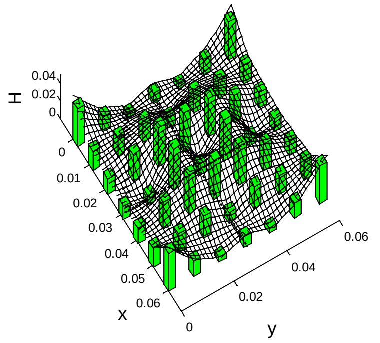

Fig. 7 sample of fin height distribution

4. Design Results

In this pilot study, A multiobjective real-code Pareto envelope-based selection algorithm (MORPESA) is employed to find the Pareto optimal solutions of the design problem. One optimization run is performed with the population size of 30 and the number of generation of 30. The Pareto front obtained is shown in Fig. 8 while the corresponding heat sink geometries are illustrated in Fig. 9. 12 Pareto optimal solutions are found and their objective values are given in Table 1. What can be seen from the results is that the junction temperature and fan power of the heat sink are lower than that obtained by the optimum pin-fin heat sink subject to air impinging from the top [7] with the same base dimension. This implies that the design strategy proposed in this paper can result in an efficient heat sink.

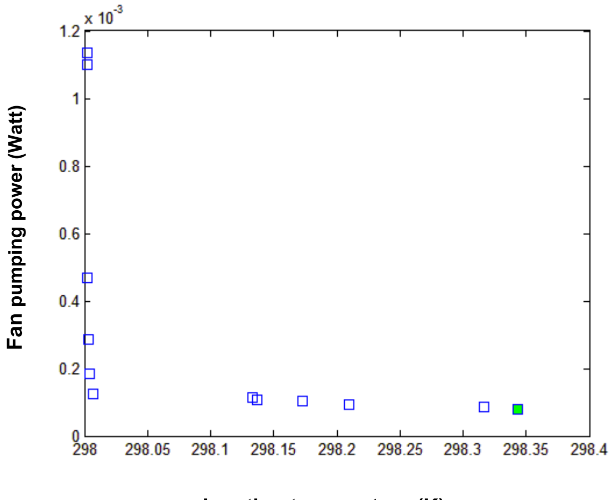

Fig. 8 Pareto front

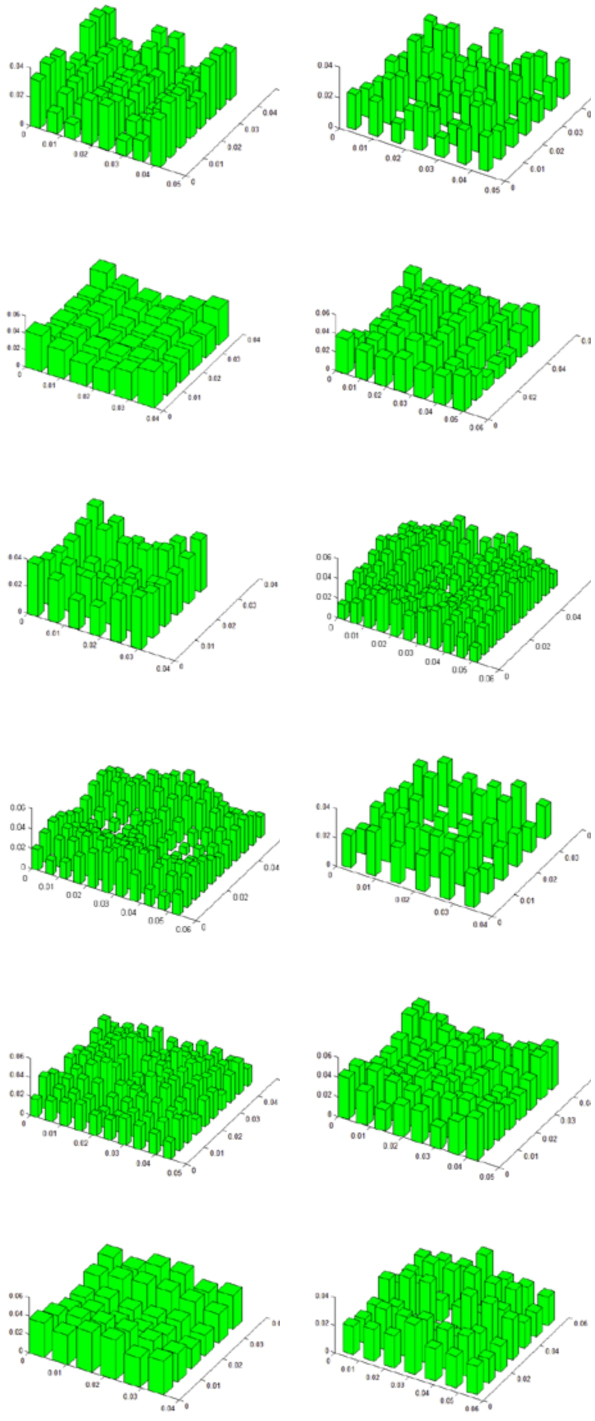

Fig. 9 heat sink according to the Pareto front

Table 1 Results

No	n	f_1	f_2
1	8	298.002	0.001134
2	7	298.0023	0.001099
3	6	298.0024	0.000468
4	7	298.0036	0.000286
5	6	298.0039	0.000183
6	11	298.0071	0.000126
7	11	298.1331	0.000114
8	6	298.1368	0.000107
9	10	298.1726	0.000102
10	8	298.2093	9.19E-05
11	6	298.3163	8.43E-05
12	7	298.3429	7.86E-05

5. Conclusions

In this research, the geometrical design problem of side-inlet-side-outlet pin-fin heat sinks (SISOPFHS) with multiple objective functions is demonstrated. MORPESA is assigned to solve the multiobjective design problem. The results show that optimum SISOPFHS is superior to the optimum pin-fin heat sink subject to air impinging from the top. Future work will be the performance enhancement of MOEA for this design problem.

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