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Fluid Flow and Heat Transfer Analysis in AaParallel Plate Heat Sink Using a Commercial CFD Software

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Abstract

Heat dissipation becomes a significant issue in efficiency promotion and stable operation of air cooled electronics components and assemblies. The use of finned heat sinks increases the effective surface area for convective heat transfer thereby reducing the operating temperatures of electronic devices. The objective of a heat sink is to achieve maximum heat dissipation, while restricting the consumption of valuable resources such as mass, fan power, pressure drop and space. Optimal design of the heat sink is a significant task. Therefore preliminary studies on the heat transfer characteristics of a parallel plate heat sink have been carried. In this research work, the geometric parameters considered are number of fins, fin length, fin height and base height. Studies have been performed through design of experiments (DOE) methodology in conjunction with simulation results. The simulation is carried out with a commercial package provided by Fluent Inc. The results are analyzed using analysis of variance and response graphs. In this study, the geometric parameters namely number of fins, fin height and base height are found to be significant at low (20 Nos), high (30 mm) and high level (7.5 mm) respectively for an efficient heat sink design.

Keywords: Parallel plate heat sink, Thermal resistance, CFD solver, Analysis of variance, Design of Experiments.

Introduction

The most common method for cooling electronic devices is by finned heat sinks made of aluminum. These heat sinks provide a large surface area for the dissipation of heat and effectively reduce the thermal resistance. Chen et al (2004) have estimated that the future cooling in computers and electronic applications, require more efficient compact heat exchangers employing active heat transfer methods in combination with ambient air. Cohen and Iyengar (2002) have concluded that air cooling in conjunction with traditional heat-sinks will continue be the method of choice for heat dissipation due to the ease of application, reliability and low cost.

Unfortunately, heat sinks often take up much space and contribute to the weight and cost of the product. Consequently, the need for new design and more effective ways to dissipate this energy is becoming increasingly urgent.

Because of compelling market requirements, design optimization of new electronic devices, is often found to be prohibitive. Teertstra et al(1999) have concluded that techniques, such as one-variable at a time is useful for simple designs, however often fall short for real-world applications.

To achieve an optimum design of heat sink for an effective heat transfer, newer methodologies or techniques are to be identified. Lee (1995) concluded that the cooling performance of a heat sink depends on a number of parameters including thermal conduction resistance, dimensions, location and concentration of heat sources as well as the airflow bypass conditions. These parameters make the optimal design of a heat sink very difficult. Also he has reported that the option of having excessive fins to improve the performance is a very dangerous way. Because, in most cases, having excessive fins induce a higher pressure drop across the heat sink, resulting in a severe reduction in flow velocity and/or a significant increase in flow bypass over the heat sink.

Traditionally, the performance of heat sinks is measured experimentally and the results are made available in the form of design graphs in heat sink catalogues. C.W. Leung and S.D. Probert (1988) have experimentally investigated and reported about the effect of optimal fin thickness, fin length and fin height for a better heat dissipation from an array of rectangular fins protruding from a base.

Copeland (2000) concluded that the traditional characterization method for a heat sink has been the topic of much debate as vendors have applied different standards or interpretations to determine the characterization of heat sinks. Analytical and empirical formulations for the fin efficiency, pressure drop and the heat transfer coefficient have also been used in the design process to determine the optimal heat sink design. Stewart and Stiver (2004) concluded that optimal heat sink design for an electronic system is extremely time-consuming.

In recent years, maturation of computational fluid dynamics (CFD) software codes tailored for applications in the electronics industry and the availability of powerful low cost workstations have made possible the simultaneous solution of both the heat transfer and fluid dynamic problems in undertaking thermal design of electronic devices.

Therefore, in this work, we have adapted an approach that combines heat sink's numerical model with DOE methodology, thereby incorporating the influence of the design variables automatically. This approach considered geometric parameters of the heat sink that have the individual and interaction effects on the target heat dissipation.

Modelling and Simulation

A typical parallel plate heat sink considered in this present work is shown in Fig. 1. The important geometric variables considered are number of fins, fin length, fin height, and base height. The range of geometric parameters of the chosen heat sink for the present study is given in Table 1.

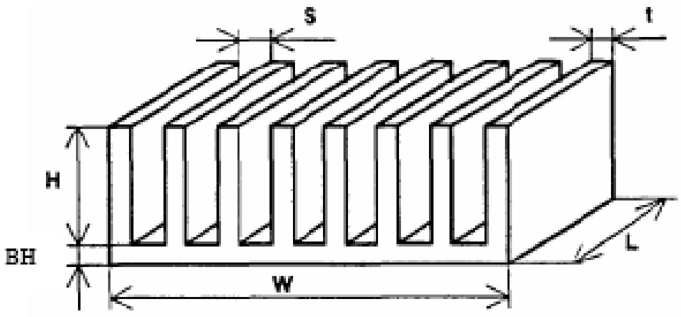

Figure: 1 A typical Heat Sink

Table 1: Range of geometric parameters.

Parameter	Minimum value	Maximum value	Increment value
Number of Fins (N)	20	40	10
Fin Length (L)	50 mm	100 mm	25 mm
Fin Height (H)	10 mm	30 mm	10 mm
Base Height (BH)	2.5 mm	7.5 mm	2.5 mm

Considering the various geometric variables present in the modelling and simulation, the design of experiments (DOE) approach with L_{27} orthogonal array, has been applied to reduce the simulation time and costs involved. Three levels in these input geometric parameters are chosen such that the differences are large enough to measure changes in the responses. If the levels are too close to each other, the change might not be large enough to detect and the opportunity for optimization could be lost. If the levels are too far apart, the design space of interest may not be able to be optimized due to non-linear or discontinuous response between the values.

Modeling and simulation of the heat sink have been carried out using Commercial software provided by fluent Inc. The solver engine in this package, uses a systems CFD solver for fluid flow and a full three dimensional (3D) conduction solver. This solver features include conservation of mass, conservation of momentum and conservation of energy. A typical computational model of the parallel plate heat sink created is shown in Fig. 2. Various specifications/constant parameters used in the modeling and simulation of the heat sink, are given Table 2.

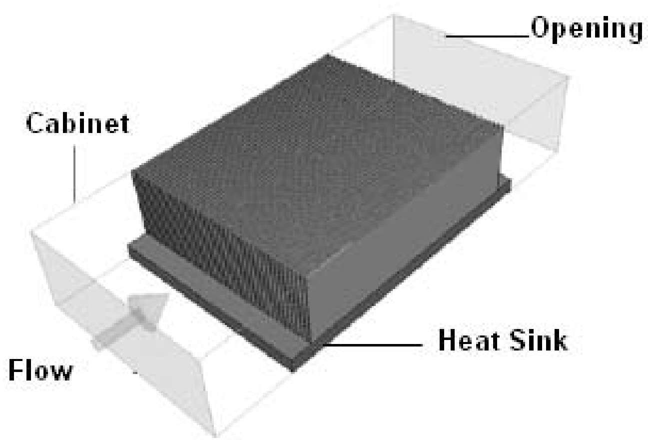

Figure 2: Computational model of Heat sink.

Table 2: Other parameters used in the model.

Heat sink type	Parallel plate heat sink
Heat sink material	Aluminium
Maximum thermal load in the heat sink	100.0 W
Ambient temperature	$25\ ^{0}$ C
Maximum velocity of the air flow	2.38 m/s

Results and Discussions

The results from the simulation of heat sink are shown in Table 3. The results obtained through this simulation are analyzed using analysis of variance (Table 4) and response graphs Figure 3. Analysis of variance has shown the significant parameters and their levels for the output parameter namely low thermal resistance.

For the selection of optimum geometric parameters for a low thermal resistance in the heat sink, many trade-offs between the fin length, fin height and number of fins have to be considered carefully.

Table 3: Simulation results.

	Number of fins	**Fin Length mm**	**Fin Height mm**	**Base Height mm**	**Average velocity in Heat Sink m/s**	**Thermal resistance in Heat Sink C/W**
1	20	50	10	2.5	0.338	5.4080
2	20	50	20	5.0	0.516	1.1520
3	20	50	30	7.5	0.643	0.6510
4	20	75	10	5.0	0.275	4.8440
5	20	75	20	7.5	0.469	1.1100
6	20	75	30	2.5	0.499	0.7360
7	20	100	10	7.5	0.274	3.8210
8	20	100	20	2.5	0.328	1.6250
9	20	100	30	5.0	0.474	0.6980
10	30	50	10	5.0	0.241	7.8940
11	30	50	20	7.5	0.335	1.9440
12	30	50	30	2.5	0.388	1.1720
13	30	75	10	7.5	0.208	6.0330
14	30	75	20	2.5	0.234	3.0840
15	30	75	30	5.0	0.322	1.2270
16	30	100	10	2.5	0.107	9.7840
17	30	100	20	5.0	0.172	2.9140
18	30	100	30	7.5	0.283	1.2200
19	40	50	10	7.5	0.154	8.4700
20	40	50	20	2.5	0.202	5.2400
21	40	50	30	5.0	0.225	2.2850
22	40	75	10	2.5	0.0713	13.1790
23	40	75	20	5.0	0.133	4.4420
24	40	75	30	7.5	0.174	2.2230
25	40	100	10	5.0	0.0679	8.6590
26	40	100	20	7.5	0.112	3.6500
27	40	100	30	2.5	0.117	2.9110

By keeping a minimum number of fins, maximum possible fin pitch can be maintained so that the pressure drop will be minimum and air flow will be maximum for an improved heat transfer in the heat sink. Similarly, to increase the heat transfer area of the heat sink, many aspects have to be considered. In the case of increasing the fin length, the flow length cannot be increased beyond the optimal length because of system level space constrains and possible pressure drops. Because of the manufacturability and flow velocity or flow bypass constrains, the designer cannot decrease the fin thickness beyond the limits to have excessive number of fins to enhance the heat transfer area.

After considering various constrains in the heat sink design, selecting a parallel plate heat sink with optimum geometric parameters such as optimum fin length, optimum fin height, and optimum number of fins or optimum gap between the fins, can improve the effective heat transfer.

From Table 4 and Figure 3, it is evident that for a low thermal resistance in the selected heat sink model, the geometric parameters namely number of fins, fin height and base height are found to be significant at low (20), high (30 mm) and high level (7.5 mm) respectively.

The interaction effects of the geometric parameters namely the number of fins (low level) with fin length (high level) and also fin length (low level) with fin height (high level) are found to significant for a low thermal resistance in the heat sink.

These results obtained in this present approach are found to be in good agreement with conclusions drawn by Lee (1995), and C.W. Leung and S.D. Probert (1988). However, they have not considered the influence of interaction effects in the geometric parameters on the heat transfer characteristics.

Table 4: Anova table for thermal resistance

Source	**Pool**	**DF**	**S**	**V**	**F**	**S'**	**ρ**	**Remarks**
N		2	53.4429	26.7215	151.9503	53.0912	19.31	99%
L		2	0.3989	0.1994	1.1341	0.0472	0.02	NS
H		2	185.5398	92.7699	527.5316	185.1881	67.34	99%
BH		2	11.2163	5.6081	31.8903	10.8645	3.95	99%
E		6	6.4162	1.0694	6.0809	5.3610	1.95	90%
N x L		4	6.2876	1.5719	8.9385	5.5842	2.03	95%
N x H		4	10.9942	2.7486	15.6296	10.2908	3.74	99%
L x H	Y	4	0.7034	0.1759	-	-	-	NS
(e)		4	0.7034	0.1759	-	4.5723	1.66	
Total		26	274.9993	10.5769	-	-	-	-

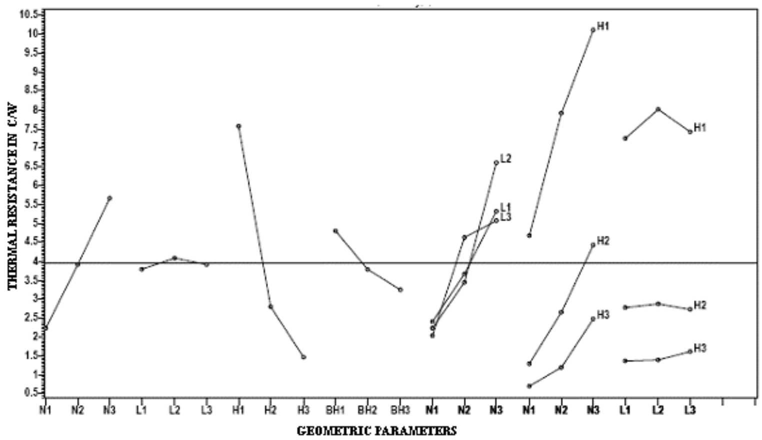

Figure 3: Mean Response graphs for thermal resistance

Conclusion

In this research work, optimal design of the heat sink have been carried out on a parallel plate heat sink considering the geometric parameters such as number of fins, fin length, fin height and base height using design of experiments (DOE) methodology in conjunction with simulation results. The simulation is carried out with the Commercial software provided by fluent Inc. The results are analyzed using analysis of variance and response graphs.

These results and conclusions drawn in this present work are found to be in good agreement with conclusions drawn by Lee (1995), and C.W. Leung and S.D. Probert (1988). However, they have not considered the influence of interaction effects in the geometric parameters on the heat transfer characteristics. This research work has considered the interaction effects of various geometric parameters and they are found to be influencing.

The individual effect of geometric parameters such as number of fins, fin height and base height and interaction effect of number of fins and fin length as well as number of fins and fin height are found to be significant for a low thermal resistance in the heat sink.

This study will benefit the design engineers involved in electronic cooling. Using the approach presented in this research work, the design engineers can carry out optimization of parametric CAD models, for the selection or design of heat sink for effective thermal management in their electronic assemblies.

Nomenclature

ρ - Contribution ratio
BH- Base Height of the heat sink
DF - Degree of freedom
e- Pooled error
F - Variance ratio
H- Fin Height of the heat sink

L- Fin Length of the heat sink
N- Number of Fin in the heat sink
NS - Not Significant
S'- Pure sum of square
SS - Sum of square
V- Error Variance or Mean Square
W- width of the heat sink of the heat sink

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