PARAMETRIC OPTIMIZATION OF HEAT SINK USING MULTI-OBJECTIVE OPTIMIZATION METHOD

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Abstract:
In the present study, Optimizing the design of Heat sink in the electronics cooling assembly is investigated using Computational fluid dynamics and Numerical parametric optimization techniques. Objective of this optimization is to decrease the maximum temperature on the heat sink surface by varying the different input design parameters such as number of fins, Distance between the fins and length of the heat sink base plate. Multi-objective numerical optimization method is used to drive and decide the input parameter values without any user interaction to arrive at the best possible solution with least amount of time. Optimized results obtained from this numerical optimization is compared with base design results for performance improvements.

1. INTRODUCTION

The increased power dissipation and shrinking dimensions of microelectronics devices have accentuated the need for highly effective compact cooling technologies. Heat sinks and heat exchanger are of particular interest due to very high rates of heat transfer. The need to develop optimization methodologies in order to design efficient cooling systems is drawing the attention of a large number of industrial and university researchers. Due to the large number of design parameters, optimization is based on numerical methods. Sizing, shape and topology optimization methods have great potential to advance cooling structure design. These automated optimization processes speed up the design process and reduce development cost. Hence, there is a need to use of automated and computerized design optimization approaches, which automatically determine a design change and furthermore guarantee the improvement of the structure design with least human interaction. This thesis focuses on parametric optimization which is a systematic design technique that aims at arriving at an optimal distribution of solution within a given design constraints to minimize an objective function while satisfying constraints. Computational simulations of heat sink will be carried out with design optimization algorithm to arrive at the best possible design with given constraints using multi-objective optimization method.

The goal of topology optimization is to determine the optimal distribution of materials for minimizing design objectives. The topology optimization was initiated by Bensøe and Kikuchi [5]; it has been successfully adopted to the structural optimization of solid mechanics problems. Along with the successful introduction of the topology optimization method to solid mechanics problems, topology optimization problems for fluid systems were initiated by the work of Borrvall and Petersson [6]. They added the Darcy friction force term which is the multiplication of the Darcy friction coefficient and velocity [7], to the original fluid equation such as Stokes equation. Then, they represent the structural topology by the distribution of two-phase material having different material properties: solids ($\alpha s \approx \infty$) and fluids ($\alpha f = 0$), where α is the Darcy friction coefficient. Following this idea, numerous studies have been performed. Wikeret al. added effective viscosity variation as an additional property control of two-phase material [8-9]. Gersborg-Hansen et al. suggested a topology optimization method for Navier-Stokes flow [10], which is similar to the Borrvall and Petersson‟s work [6]. Besides the successful utilization of topology optimization for fluid systems, heat transfer problems have also been an issue of great concern as applications of the topology optimization method. Topology optimization is first applied to pure heat conduction problems by Donoso and Sigmund [11]. In addition to heat conduction, heat convection physics is also taken into consideration by employing convection the coefficient „h‟ [12-14]. In conventional topology optimization methods, it is not easy to clearly define boundary locations in the middle of the process, since they are blurry and constantly changing. Therefore, previous research assumed that the heat convection coefficient was constant without considering fluid motion, which varies significantly according to the geometry. Subsequently, these approaches may be infeasible for designing cooling channels that prevent re-circulation areas and hot spots. At present the work of Van Oevelen [15] has shown that the solid-fluid interface can accurately be handled both for pressure drop and heat transfer in a 2D topology for laminar flows. This opens the possibility to further explore the approach. Therefore, this study will contribute to the further work on the parametric optimization of heat sink using numerical optimization techniques.

2. PROBLEM DESCRIPTION AND METHODOLOGY

In this work, design optimization with application to heat sink will be carried out using the parametric optimization approach with Multi-objective optimization technique. This optimization approach has been applied to various physics problems such as electromagnetic, heat conduction, and fluidics. Yet, the parametric optimization approach for conjugate heat transfer problems is still in the initial stage and has not been well established. In this study, Conjugate Heat transfer analysis will be carried out for parametric optimization to produce better optimization results.

2.1 Mathematical Modelling of Governing Equations

For a Newtonian fluid, the governing equations of fluid flow describing the Conservation of mass (Continuity equation), conservation of momentum and conservation of energy in three-dimensional Cartesian coordinate systems are considered and Flow is modelled as turbulent by transforming governing equations into time averaged Reynolds Averaged Navier-Stokes equations.

Conservation of Mass

$$\frac{\partial(\rho\overline{u})}{\partial x}+\frac{\partial(\rho\overline{v})}{\partial y}+\frac{\partial(\rho\overline{w})}{\partial z}=0 \qquad (1)$$

Conservation of Momentum

X-Momentum Equation

$$\frac{\partial}{\partial t}(\rho\overline{u})+\frac{\partial}{\partial x}(\rho\overline{u}\,\overline{u})+\frac{\partial}{\partial y}(\rho\overline{v}\,\overline{u})+\frac{\partial}{\partial z}(\rho\overline{w}\,\overline{u})$$
$$=-\frac{\partial\overline{P}}{\partial x}+(\mu+\mu_t)(\frac{\partial^2\overline{u}}{\partial x^2}+\frac{\partial^2\overline{u}}{\partial y^2}+\frac{\partial^2\overline{u}}{\partial z^2}) \qquad (2)$$

Y-Momentum Equation

$$\frac{\partial}{\partial t}(\rho\overline{v})+\frac{\partial}{\partial x}(\rho\overline{u}\,\overline{v})+\frac{\partial}{\partial y}(\rho\overline{v}\,\overline{v})+\frac{\partial}{\partial z}(\rho\overline{w}\,\overline{v})=$$
$$-\frac{\partial\overline{P}}{\partial y}+(\mu+\mu_t)(\frac{\partial^2\overline{w}}{\partial x^2}+\frac{\partial^2\overline{w}}{\partial y^2}+\frac{\partial^2\overline{w}}{\partial z^2})-\rho g\beta(T_\infty-T) \qquad (3)$$

Z-Momentum Equation

$$\frac{\partial}{\partial t}(\rho\overline{w})+\frac{\partial}{\partial x}(\rho\overline{u}\,\overline{w})+\frac{\partial}{\partial y}(\rho\overline{v}\,\overline{w})+\frac{\partial}{\partial z}(\rho\overline{w}\,\overline{w})$$
$$=-\frac{\partial\overline{P}}{\partial z}+(\mu+\mu_t)(\frac{\partial^2\overline{w}}{\partial x^2}+\frac{\partial^2\overline{w}}{\partial y^2}+\frac{\partial^2\overline{w}}{\partial z^2}) \qquad (4)$$

Conservation of Energy

$$\frac{\partial}{\partial t}(\rho c_p\overline{T})+\frac{\partial}{\partial x}(\rho\overline{u}c_p\overline{T})+\frac{\partial}{\partial y}(\rho\overline{v}c_p\overline{T})+\frac{\partial}{\partial z}(\rho\overline{w}c_p\overline{T})=$$
$$k(\frac{\partial^2\overline{T}}{\partial x^2}+\frac{\partial^2\overline{T}}{\partial y^2}+\frac{\partial^2\overline{T}}{\partial z^2})+\frac{\partial}{\partial x_t}(\frac{\partial\overline{T}}{\partial x_t}\frac{c_p\mu_t}{\sigma_t})+q'' \qquad (5)$$

Heat Transfer in solids and Fluids is modelled using conjugate Heat transfer approach in which conduction in solid is coupled with convection heat transfer in fluids. Both Solid and Fluid domains are modelled using steady state simulations.

2.2 CAD Geometry and Computational Domain

Geometry of Electronics chipset assembly consists of a PCB, Chip and heat sink is used for this investigation. Chip is placed on the center of the PCB and the heat sink with square fins is placed on top of Chip. Figure 1 shows 2D view of the geometry. Computational domain covering the entire assembly is created around the geometry. Extend of this domain is limited to 2 times the length of the PCB. Domain dimension is chosen in such a way that, it would not affect the flow near the electronic components assembly. Figure shows the domain created around the fluid region of interest.

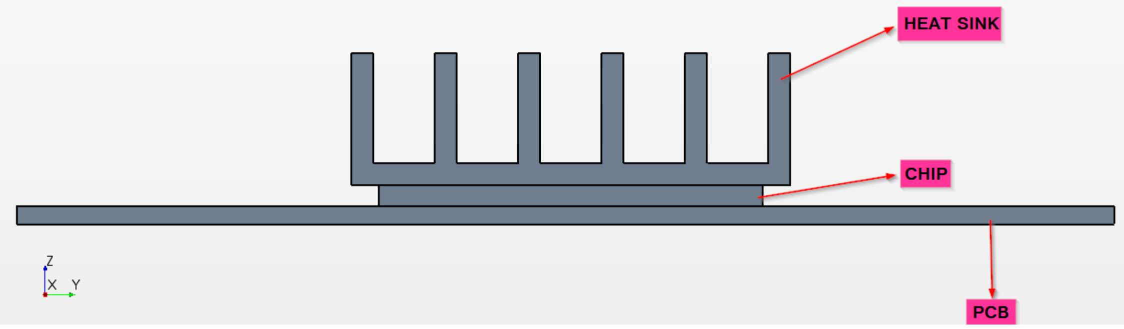

Figure 1: Two-dimensional view of the CAD geometry

2.3 Computational Mesh

3D geometry for solid and Fluid volumes is meshed with Body fitted Hexahedral dominant mesh with prisms cells on wall boundaries of the fluid region. There are no prisms used on the solid region. Mesh is aligned in direction based on a user specified cartesian coordinate system. Mesh on the fluid side has 5 layers of prism to resolve the hydrodynamic and thermal boundary layer. There is also a wall treatment model used to resolve the boundary layer. Solid side mesh has only hexahedral dominated mesh. There are totally 507885 cells generated in both solid and fluid domains. Solid domains have 126271 cells and Fluid domain has 381614 cells.

2.4 Boundary Conditions

Fluid domain has the Velocity inlet boundary condition at the inlet and Pressure outlet boundary condition at the outlet of the domain. Velocity and static temperature are set at the velocity inlet boundary. Static pressure and static temperature is set at the outlet boundary. Top, Bottom and the side surfaces of the fluid domain is set as wall boundary with slip condition. All other surfaces associated with electronic components are considered as a wall boundary with no slip condition.

On the solid domain, all boundaries are set to wall boundaries. Heat Sink and PCB boundaries are set to initial temperature 300K and Chip part is subjected to a heat source of 4W.

2.5 Materials

Air at atmospheric condition is used on the fluid side to model the flow and Heat transfer. On the solid side, Chip is made of silicon, Heat sink is of Aluminum and PCB is of copper clad laminate.

2.6 Weighted Sum Multi-Objective Optimization

Weighted sum of all objectives with multi-objective optimization study allows the design to optimize based on a single objective or based on multi objective. Linear weighing is used that combines all objective into single performance function. In this work, design optimization with application to heat sink will be carried out using the parametric optimization approach. In this study, fluid analysis will be carried out for topology optimization to produce better optimization results.

For getting the optimized design of heat sink for the given electronics cooling system to achieve a lowest maximum temperature possible of the Chip, there are 5 input paraments which are used and varied within the specified range. Following the are the parameters which are varied to obtain the optimum design possible.

1. Fin Dimension X
2. Fin Dimension Y
3. Number of fins in X-Direction
4. Number of fins in Y-direction
5. Length of the Heat Sink base plate.

3. RESULTS AND DISCUSSION

Numerical analysis is performed on a base design by fixing the all the input parameters and for optimization, range has been defined for all the input parameters and objective is set to minimize the maximum temperature of the chip. Optimization algorithm decides and varies the next input design paraments based on the given range and comparing the output with the existing output of maximum temperature from previous designs.

3.1 Conjugate Heat Transfer analysis of baseline design

Baseline design has been considered for doing initial CHT analysis using Computational. Steady state conjugate heat transfer analysis is performed for this design and results are obtained in the form of a Temperature on solid components, velocity inside the computational domain and pressure drop within the computational domain. The maximum temperature on the chip is about 324.05K. Table one shows the performance and input parameter of base design

Table 4.1 Performance and Input parameter of base design

Parameter	Value
Maximum Temperature on the Chip	324.05 K
Pressure drop	0.138 Pa
Surface average temperature at the outlet	300.34 K
Surface area of the heat sink	0.0128 m^2
Heat Transfer through Heat sink	2.4746 W

3.2 Optimization Results

There are 60 designs considered by varying the input parameter values within the specified ranges. Each new design parameters are defined based on the results from the previous design by using a numerical optimization algorithm. Figure 2 shows the plot of design number vs Maximum temperature on the plot. Each design here has a different input parameter decided by weighted sum of multi-objective optimization method.

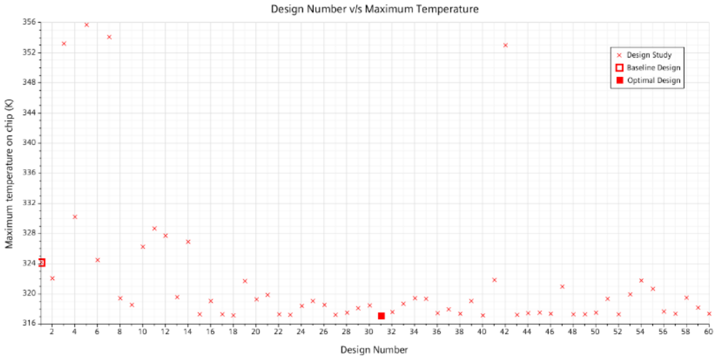

Figure 2: Plot of Design number v/s maximum temperature on Chip

From figure 2, it was found that the optimized design with reduced maximum temperature on the chip was ‘design 31’. This design has a fin spacing of 3mm in each direction, there are 6 fins in the X-direction and 7 fins in the Y direction. Due to this dimension of surface area of the heat sink increases which in turns increase the heat transfer from heat sink. Table 2 shows the output parameter comparison between the baseline design and optimized design. Optimized design has a maximum temperature of 317.04 as compared to 324.05 on base design and Heat transfer from the heat sink is increased from 2.4746 W to 3.065 W with optimized design. Figure 2 shows maximum temperature distribution on the solid components and fluid domain using a section plane. There is very small heat of 0.00604 W carried from the chip directly convection.

Table 2 Baseline and Optimized design comparison

Parameter	**Value (Baseline design)**	**Value (Optimized design)**
Maximum Temperature on the Chip	324.05 K	317.04 K
Pressure drop	0.138 Pa	0.162 Pa
Surface average temperature at the outlet	300.34 K	300.35 K
Surface area of the heat sink	0.0128 m^2	0.02544 m^2
Heat Transfer through Heat sink	2.4746 W	3.065 W
Heat transfer between Chip and Heat sink through conduction	2.4788 W	3.067 W
Heat Transfer from chip side surfaces through Convection	0.01448 W	0.00604 W

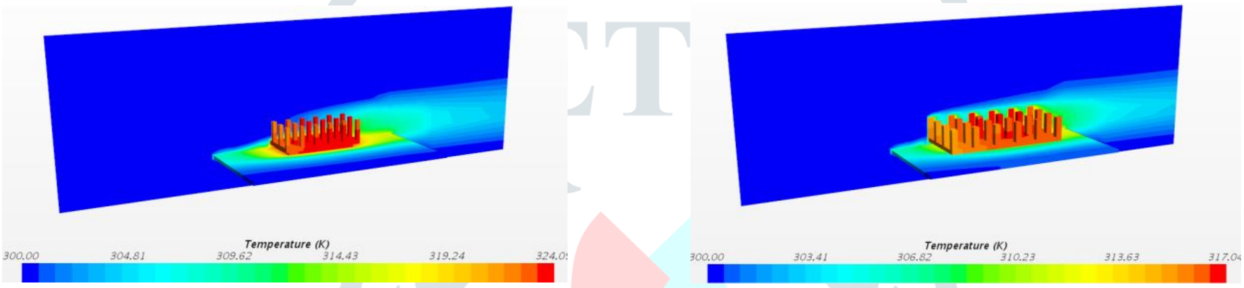

Fig 2 Baseline and Optimized design temperature distribution contours comparison

4. CONCLUSION

Parametric optimization of the heat sink is performed numerically using computational fluid dynamics tools and optimization algorithm. This study was focused on how fast one can obtain optimized design for a given objective by respecting input constraints and ranges and using numerical tools for simulation and optimization. The objective of this optimization study was to minimize the maximum temperature on the heat sink with given constraints. There are 60 designs considered by varying the different input parameters. From this study it is concluded that the ‘Design 31’ provides the least maximum temperature on the heat sink surfaces. This design has optimized dimensions this by increasing the surface area and heat transfer rate in order to reduce the temperature on the heat sink. Out of the 60 design combinations used in this study, the numerical optimization algorithm finds the best design within 31st designs. This saves the considerable amount of time required in finding the optimized design by manually changing the input parameters.

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