MULTI-OBJECTIVE OPTIMIZATION OF GRAPHITE HEAT SPREADER FOR PORTABLE SYSTEMS APPLICATION

by

ARIJIT BANERJEE

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ABSTRACT

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Arijit Banerjee, M.S.

The University of Texas at Arlington, 2009

Supervising Professor: Dereje Agonafer

The advancement made in portable electronic systems has primarily been due to miniaturization of electronic systems. This in turn leads to an increase in power density which leads to higher temperatures and formation of hot spots. There is a temperature specification of system surfaces for human comfort (such as the surface close to a keyboard on laptops). Challenge in cooling portable devices is that there is not enough room to accommodate heat sinks. It is therefore important to have heat spreaders that can transfer the heat from critical devices to regions where cooling is available. Traditionally, copper has been the best heat spreader due to its high thermal conductivity. However, copper has a relatively high density and correspondingly high weight. Graphite is a suitable alternative. Recent advances in graphite technology have

resulted in fairly high conductivity in the planar directions. In spite of these advances, the cost of graphite is an issue. There are many methods for solving these problems, and depends on the type of the system used. The two basic types of methods to analyze the system are:

1) Experimental method, 2) Simulation using a computer aided tool.

In this research project simulation using the thermal modeling tool, Icepak; is considered. The prototype model of the laptop is designed, boundary conditions are applied and analysis is done. The results so obtained in this simulation give a detailed idea of the amount of the heat to be dissipated from the system and the locations of the hotspots. Graphite heat spreader is included in the design and simulated, the results interpret that the graphite heat spreader improves the thermal performance of the system. Graphite heat spreader forces the heat flow only through the plane which decreases the overall global temperature and also it reduces the hotspots in the system as heat spreader acts almost like insulator through the thickness. Graphite is very expensive so the size and shape of the heat spreader has to be optimized.

Thus, this research project contributes to the enhancement of thermal performance of the laptop. Though this may not be the final solution but definitely can be considered for further studies which may lead to a more efficient design.

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CHAPTER 1

INTRODUCTION

1.1 Introduction to Thermal Challenges in Laptop

The modern technologies have tremendous urge for high performance laptops as they use new software and complex designs to be analyzed, this indeed arises a major problem for the thermal management engineers and this problem has been more difficult as the size of the laptop is reducing with time. In this process of increasing performance of these laptops, thermal engineers have a great challenge in improving the cooling systems. In high performance laptop the power density is very high resulting in high global temperatures and at few points the heating is localized resulting in the hotspots.

Thermal engineers continue to investigate better methods to improve the performance of the system by maintaining its global temperature lower to the critical temperature. Certain methods are being implemented in this long run of time to overcome the above mentioned problems are stated below

1. Using a Heat sink directly on the chip; this can be used only in the traditional laptops where size was not a constraint and improves only the chip performance but the heat from other components will not be efficiently removed.

2. Using a Heat sink with exhaust fan and heat pipes which has an advantage over the method used previously as the heat pipe is used for transferring heat from chip to heat sink adiabatically to the heat sink and heat sink size can be increased as that is not located on the chip rather it is located closer to fan so the overall chip temperature will be reduced to level where the system performance will be better than former.
3. Using Heat spreaders, for conducting heat from chip to heat sink giving path for heat flow i.e. replacing the heat pipe. It can also be used to spread out heat at the surface as it again increases the in-plane surface area to reduce heat spots.

1.2 Brief account of Thermal Optimization

The present market requires developed and faster notebook computers at cheaper prices. This need for high performance laptops demand thermal engineers to design, develop and optimize the cooling devices so that they have high performance factor and inexpensive compared to past. Effective thermal management facilitates efficient removal of heat from device to the ambient environment. The ever shrinking size has also increased the burden placed on today’s thermal management devices [1].

Engineering optimization can best be classified as a rigorous mathematical approach to identify and select a best candidate from a set of probable design alternatives [2].

A number of optimization methods are available to solve such problems. However, for engineers to apply optimization for their problem they need to understand the theory, the algorithm and the techniques behind these methods. This is because practical problems may require modifying algorithmic parameters, even scaling and adapting the existing methods to suit the specific application. Above all, the user may have to try out a number of optimization methods to find one that can be successfully applied. These methods are being used in the different fields of study, such as Electronics, Automotives, Buildings, Data centers. As the design complexity has been an issue of the optimization but the thermal modeling tools use computers to solve complex designs [3].

1.3 Introduction to Graphite Heat Spreader

As discussed in the previous section, there are certain complex problems that also have a weight constraint where the power density is increasing and the size, weight cannot be changed. Thermal management of the laptops is essential to have high performance. This challenge forces the thermal management engineers to go in search of a most efficient cooling system which has good conductivity and also is lighter in weight. This urge yields the requirement of heat spreaders which conduct heat laterally so there will be no localized heating and also it helps in directing the flow of heat

Graphite is an anisotropic material. The material most often used for heat spreaders are copper and aluminum if graphite is compared with these materials, its has almost the same conductivity as copper and in fact double to that of aluminum and graphite’s density is much less. The other reason for selecting graphite is its anisotropic property as it has its thermal conductivity through the thickness almost 5% of the thermal conductivity in lateral, so almost it acts like an insulator through thickness. The only dis-advantage is that graphite is expensive.

1.4 Approach to the problem

This research study makes an attempt to improve upon the technical paper by Martin [1]in which the method used is experimental and the simulation of the similar model with exactly same boundary conditions, same constraints and same design variables, which is done in a thermal design tool, Icepak.

Study initially parameterizes the heat spreader by exchanging the positions of different heat sources and reducing the size of the spreader in an orderly fashion, to obtain a case in which size of the heat spreader is reduced and global maximum temperature was almost same.

However due to concerns like practical application and structural strength of the spreader, a true optimization approach was further undertaken. The objectives are to optimize the size and shape of the Graphite Heat Spreader. Optimal surface temperature is the constraint. The chip power, laptop size, airflow rate are kept constant. A standard model of laptop is designed; boundary conditions are applied and thermal analysis is done.

CHAPTER 2

OPTIMIZATION AND GRAPHITE HEAT SPREADERS

2.1 Definition and Applications

Optimization may be defined as the process of maximizing or minimizing a desired objective function while satisfying the prevailing constraints [5]. Decisions are made in every stage of design and modeling of engineering systems either to minimize the effort required or maximize the desired benefit. Since either of these goals in any physical situation can be expressed as a function of certain design variables, *optimization* may also be defined as the process of finding the conditions that give the maximum or minimum value of a function [2].

As there is no single method for solving all optimization problems efficiently so the engineers are compelled to develop a number of optimization methods for solving different types of optimization problem. But finally it is the decision of the design engineer to select which method is appropriate for his problem so as to get accurate and efficient solution.

The ever-increasing demand to lower the production costs due to increased competition has prompted engineers to look for rigorous methods of decision making such as optimization. As a result engineering optimization was developed to help engineers design systems that are both more efficient and less expensive and to develop innovative methods to improve the performance of the existing systems. Computer based simulation and analysis is used extensively in engineering for a wide variety of tasks. Despite the steady and continuing growth of computing power and speed, the computational cost of complex engineering analysis and simulations maintain pace.

2.1.1 Statement of an Optimization Problem

Majority of problems often involve constrained minimization. An example of such constrained minimization problem is finding the minimum resistance of the spreader subject to constraints on temperature and weight of heat spreader. Constrained problems may be expressed in the following general nonlinear programming form [6]:

$$\begin{aligned} &\text{minimize} && f(\mathbf{x}) && \\ &\text{subject to} && g_i(\mathbf{x}) \leq 0 && i = 1,......., m \\ &\text{and} && h_j(\mathbf{x}) = 0 && j = 1,......., l \end{aligned} \qquad (1)$$

where $\mathbf{x} = (x_1, x_2, ..., x_n)^T$ is a column vector of n real-valued design variables. f is the objective function, g’s are inequality constraints, and h’s are equality constraints. The inequality constraints in Eq. (1) include explicit lower and upper bounds on the design variables. We may also express Eq. (1) in the form: minimize $f(\mathbf{x})$, $\mathbf{x} \in \mathbf{\Omega}$ where

$$\mathbf{\Omega} = \{\mathbf{x}: \mathbf{g} \leq 0, \mathbf{h} = \mathbf{0}\} \qquad (2)$$

$\mathbf{\Omega}$ is the feasible region or feasible set. For unconstrained problems the feasible region is the entire space or $\mathbf{x} \in \mathbf{R}^n$. Objective function and constraints of linear programming problems involve linear functions of **x**, where as objective function in quadratic programming problems is a quadratic function of the variables while the constraints are linear.

The *design space or design variable space* in an optimization problem can be considered as an n-dimensional Cartesian coordinate space where each coordinate axis represents a design variable x_i (i=1,…..n). A design point is a point on the design space that may represent a possible or an impossible solution. Design variables cannot be chosen arbitrarily; they have to satisfy certain specific functional requirements to produce an acceptable design. These restrictions that must be satisfied in a design are called *design constraints*.

Design constraints are classified into two; one that represent limitations on the behavior or performance of the system and one that pose physical limitations on the design variables such as availability ,fabric ability, transportability etc. While the former is referred to as behavior or functional constraint, the latter is known as geometric or side constraints.

The values of the design variable belonging to the set $\mathbf{x}$ that satisfy $g_i(\mathbf{x}) = 0$ forms a hyper-surface on the design space called the *constraint surface*. This is an (n-1) dimensional subspace where n represents the number of design variables. The constraint surface divides the design space into two; one where $g_i(\mathbf{x}) < 0$ and the other in which $g_i(\mathbf{x}) >0$. Design points on the hyper-surface i.e. points that satisfy $g_i(\mathbf{x}) = 0$ satisfy the constraint $g_i(\mathbf{x})$ critically. Those lying on the region where $g_i(\mathbf{x}) >0$ are infeasible and unacceptable while those on the region belonging to $g_i(\mathbf{x}) <0$ are feasible and acceptable. The collection of all constraint surfaces i.e. $g_i(\mathbf{x}) = 0$, i=1,….m that separates the acceptable region is known as the *composite constraint surface*. A design point that lies on one or more constraint surfaces is known as a node point and its associated constraint as an *active constraint*. Those points that do not lie on the constraint surface are known as *free points*. Depending on the location of a design point on the design space, it can be classified into four as:

1. A free and acceptable point
2. A free and unacceptable point
3. A bound and acceptable point and
4. A bound and unacceptable point.

In general there will be more than one acceptable design point and our objective is to choose the best from the lot. This is obtained by specifying a criterion to compare the acceptable design and choosing the best one from it. This criteria or function is known as the *cost or objective function* of the optimization problem. When there are more than one objective function then the problem is known as a *multi-objective programming* problem. Like constraint surfaces, objective functions also form hyper-surfaces known as *objective function surfaces*. Once the objective function surfaces are drawn along with constraint surfaces on the design space, the optimum point can be easily located graphically as shown below [3].

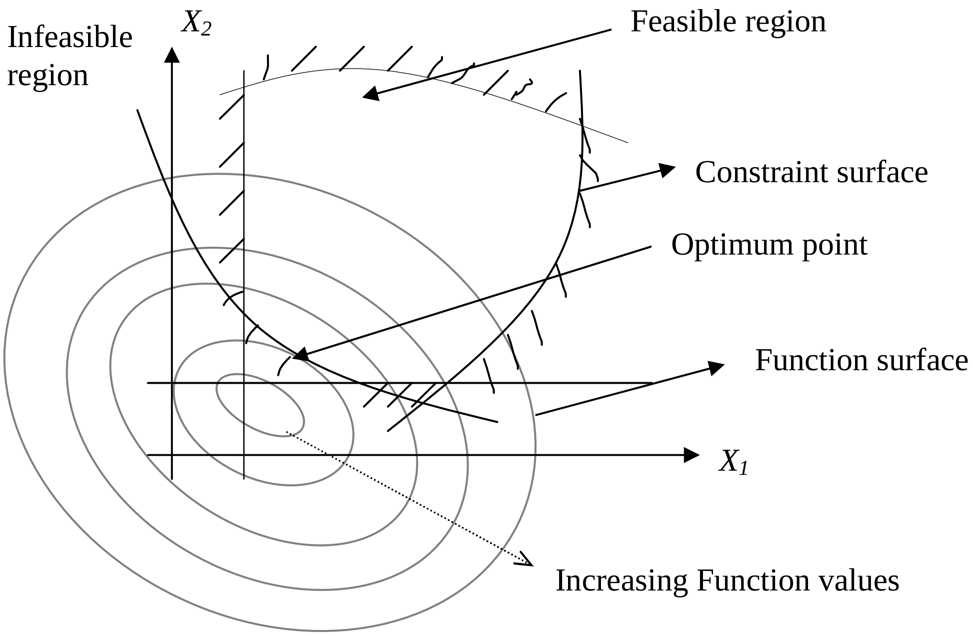

Figure 1: Function plot depicting optimum solution for a 2 design variable set

2.2 Graphite Heat Spreaders

Heat spreader is a sheet of a material which can conduct heat laterally and has high conductivity and lighter in weight.

Thermal management technology remains a vital part of electronics innovations as advanced electronic systems become faster, shrinking in size and weight. Increasingly sophisticated high-density electronics demand higher thermal efficiencies, better performance, lighter in weight, greater reliability and inexpensive. Now a day’s multi-chip packaging has its density increasing day by day and due to fast processors the heat produced is lot more compared to traditional single chip modules so that conventional heat sinks and coolants are becoming inadequate. As the heat is produced from an electronic chip so it is highly concentrated in localized areas. This is the situation where heat spreaders are used for efficiently dissipated the heat by creating the maximum effective surface area where heat is transferred into and carried away by the external cooling medium.

Heat spreaders are used at die level packaging to spread heat from the microprocessor chip into the packaging. Heat spreader can help to eliminate the need of fans, heat sinks, and heat pipes for thermal management. It also reduces the overall cost and weight of the system. Various methods of spreading heat are widely used in today's electronics. Spreaders are commonly used within electronic enclosures to move heat from discrete components to the walls of the enclosure. In some cases, a natural graphite heat spreader can replace a conventional thermal management system consisting of a heat sink and cooling fan in a low performance laptop [7]. To reduce the noise from the cooling fan and by keeping it from coming on for a certain time. This improves the working environment for people frequently using a laptop computer as the noise from the fan can be distracting at times.

The reliability and performance of these systems can be drastically decreased if heat is not properly removed from electronic systems. The reliability of electronic systems decreases 50% for every 20° C increase in junction temperature. When system's thermal densities and electronic packaging complexities increase the weight of the laptop will be a constraint so the heat sink size cannot be changed here the necessity for a lighter cooling system which has good heat conductivity arises.

2.2.1 Natural Graphite

Natural graphite is an anisotropic material which exhibits a high thermal conductivity in the plane of the sheet combined with a much lower thermal conductivity through the thickness of the sheet. Natural graphite sheet can be used as heat spreader to direct the flow of the heat from chip to the heat sink and it can also be used as insulator to eliminate localized hot spots decreasing the touch temperature in electronic components. The ability to direct heat in a preferred direction is an additional advantage of an anisotropic material [4].

When the heat dissipater is a thermally anisotropic material, the heat spreading coefficient has to be considered. Carbon and graphite based materials are attracting interest as anisotropic heat spreaders, with an additional advantage being their low density. A high degree of thermal anisotropy reduces the temperature gradient in the plane of the part and increases the effective heat transfer area, characteristics that are most desirable for electronics with high heat-intensity components. Most carbon and graphite-based materials used to date are based around carbon fibers. These are high cost by virtue of the need to conduct high temperature graphitization processes to develop the required thermal properties in the fiber [8].

Natural graphite flakes are a polycrystalline form of carbon comprised of layer planes containing hexagonal arrays of carbon atoms. These layer planes, referred to as graphene layers, are ordered so as to be substantially parallel to one another. The bonding forces holding the graphene layers together are only weak Vander Waals forces and hence the layers can be readily separated. Natural graphite flakes can be chemically treated to insert an intercalant ion into the interlayer spacing. The graphene layers can then be exfoliated by thermally vaporizing the intercalant in the graphite lattice. The intercalant within the graphite decomposes and volatilizes, which generates internal pressure between the graphene layers and forces the layers to separate as the intercalant escapes the graphite structure. The particles of intercalated graphite expand 100 times their original volume in an accordion-like fashion in the direction perpendicular to the graphene layers. The exfoliated graphite particles are vermiform in appearance, and are commonly referred to as worms. These expanded graphite flakes can then be consolidated together and mechanically formed, without binders, into a cohesive, flexible sheet of graphite material. Typically, continuous rolling operations are used to form the worms in sheets. [4]

Table 1, shows properties of different materials used to manufacture heat spreader. Density of natural graphite is 50% of aluminum and 20% of cooper ,so it is much lighter but the in-plane thermal conductivity of natural graphite is twice as of aluminum and almost equal as copper. Thermal conductivity of graphite through thickness is almost negligible compare to its in-plane conductivity so it acts like insulator through thickness avoiding hot spots.

Table 1: Thermal properties of heat spreader materials

Property	Direction	Natural Graphite sheet	Aluminum alloy	Copper alloy
Density (g/cm3)		1.1-1.7	2.71	8.89
Thermal Conductivity (W/mK)	In- Plane	140-500	220	388
Thermal Conductivity (W/mK)	Thickness	3-10	220	388
Specific Heat Capacity (J/kgK)		846	904	385

There is another advantage of Graphite is the conversion of acoustic energy into heat as a result of the viscosity is the most important mechanism of sound absorption as sound propagation through the porous media is dominated by viscous forces and is proportional to the velocity of the fluid relative to the solid surface. The induced mass and friction drag lowers the sound speed relative to the free field. This indirect effect of heat transfer is accompanied by the direct effect of conversion of acoustic energy into heat. [9]

2.3 Graftech International Ltd.

The heat spreaders taken in this research are manufactured by Graftech International Ltd., which is one of the world's largest manufacturers of high quality synthetic and natural graphite and carbon products. It is the first company to offer heat spreaders manufactured from natural graphite materials. Compared to typical thermal management materials, eGraf materials offer thermal conductivities twice as effective as aluminum and rival the thermal conductivity of copper at substantially reduced weights. eGraf is one of the line of electronic thermal management products to meet the increasing thermal management demands created by the need for smaller, highly integrated and higher performing electronic devices. eGraf SpreaderShield is a natural graphite solution that distributes heat evenly in two dimensions, eliminating “hot spots”, shielding components from heat sources and improving performance in consumer electronics. SpreaderShield thermal management products are custom designed for use in applications such as laptop computers, flat panel displays, portable projectors, digital video-cameras, wireless phones, and personal digital assistant devices. SpreaderShield is ideal for products where space for other cooling solutions is limited and weight is a critical factor. In many cases, SpreaderShield can eliminate the need for other thermal management solutions such as fans, heat sinks, and heat pipes resulting in both reduced cost and weight for the device.” [7]

CHAPTER 3

PARAMETERIZATION OF HEAT SPREADER

3.1 Introduction

A *simulation* is an imitation of some real thing, state of affairs, or process. The act of simulating something generally entails representing certain key characteristics of a selected physical system. The formal modeling of systems has been by a mathematical model, which attempts to find analytical solutions to problems which enable the prediction of the behavior of the system from a set of parameters and initial conditions. Computer simulation is often used as a substitution for, modeling systems for which simple closed form analytical solutions are not possible. There are many different types of computer simulation; the common feature they all share is the attempt to generate a sample of representative scenarios for a model in which a complete enumeration of all possible states of the model would be prohibitive or impossible. Several software packages exist for running computer-based simulation modeling that makes the modeling almost effortless and simple.

3.2 Temperature Distribution in a Typical Laptop

Fig. 2 shows the internal layout of components directly below the keyboard and case. Major components include the heat sink, the heat pipe above the CPU chip, the fan, the slot for the PCMIA card, the hard drive, the battery, and the bay for the DVD drive. There is a well-designed thermal solution cooling the CPU, but there is no explicit thermal solution employed to cool the hard drive. Because of economic factors, standardization is widespread and the layout of this unit is typical of many laptops. A particular feature of this design is the placement of the hard drive under the left palm rest and the battery under the right. High hard drive operating temperatures can result in uncomfortable palm rest touch temperatures [1].

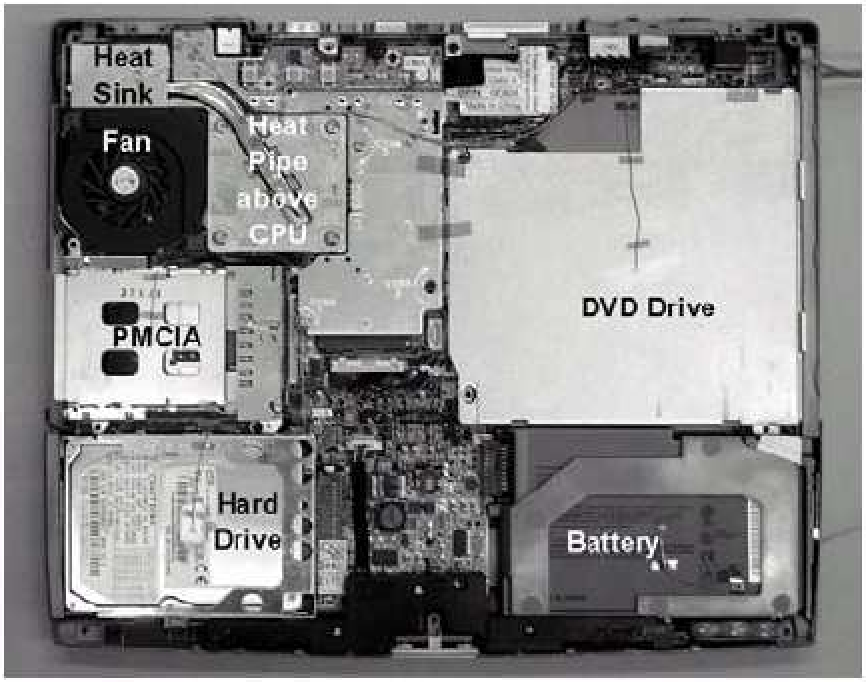

Figure 2: Typical layout of components in a laptop computer [1]

Researchers in reference1 did experiments using temperature sensors and developed a thermal image of laptop as shown in fig 3. Reference 1 reports that the hard drive reached a temperature of 30^oC above ambient. This is similar to data obtained by vichare et.al [10]. This increase in hard drive temperature is caused the average temperature of left palm rest to increase to 14.1^oC above ambient while that of the right palm rest has increased only 3°C. This results in uncomfortable surface temperatures above the palm rest. Two references [11] and [12] report similar results.

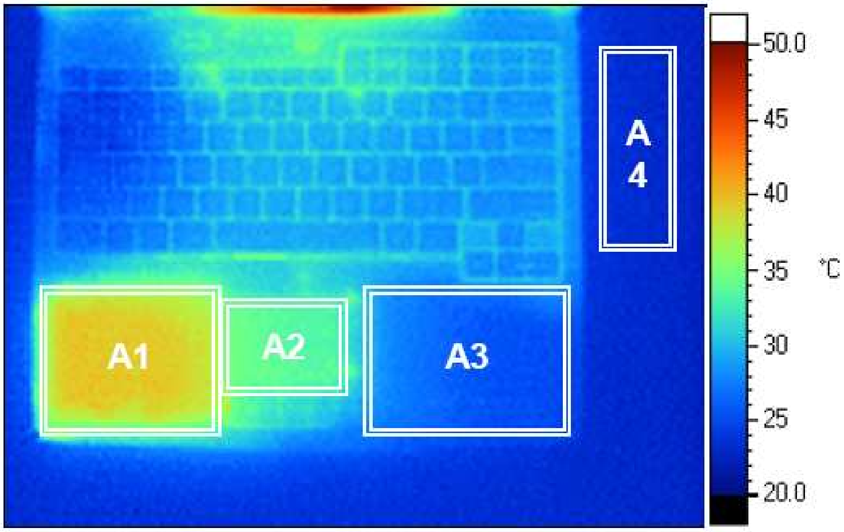

Figure 3: Thermal image of the laptop cover and keyboard [1]

Above references and observations suggest the non-uniform temperature gradient in the interior of laptop. This stresses the importance of heat spreader even more. In this study, a heat spreader was considered and parameterized using Icepak™ a commercial CFD tool provided by ANSYS Inc.

3.3 ICEPAK Modeling

The ICEPAK model was developed considering the thickness graphite thickness of 0.51 mm thick natural graphite spreader that had an in-plane thermal conductivity of 369 W/mK. Installed in a laptop, the natural graphite spreader was able to conform easily to the height differences of the components it contacted. This spreader reduced the overall temperature gradient within the laptop and on the outer case [1].

Heat was transferred from the hard drive, which generated an estimated 16 watts of heat, to other areas of the laptop and reduced the temperature rise of the hard drive above ambient by 21%, from 27.8 °C above ambient to 21.9 °C [1].

The heat spreader was modeled in ICEPAK using all the points of the edges and the thickness was developed as conducting thin plate, they have the same properties as conducting thick plates, except that they have no physical thickness [13]. They can possess only an effective thickness. The spreader is modeled as a 20 point polygon, where the spreader has 4 steps on the right hand top. As a part of weight reduction, these steps were reduced one by one and changes were monitored in temperature gradient across the spreader. The model has four primary heat sources hard disk, PCMCIA, Battery (Power supply) and DVD drive. These are modeled as blocks. The blocks are placed under the heat spreader at places considering the layout in figure 2. Power is supplied to them. A detailed list of boundary conditions can be found in table 2.

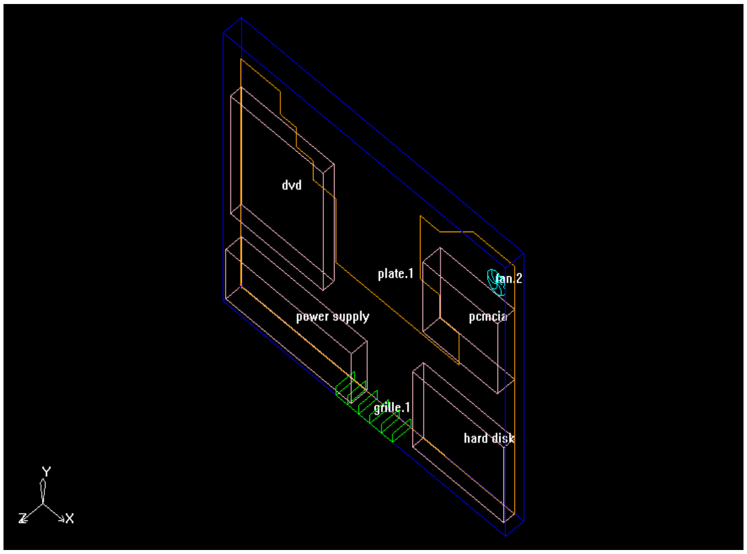

Figure 4: Baseline model

As shown in the figure the four primary blocks which supply the heat to the spreader were considered. Apart from that a grille and exhaust fan with mass flow rate of 12 CFM was also considered.

The air flows from grille to the exhaust fan to reduce the heat in laptop for cooling it. A favorable temperature gradient was observed. However, no velocity boundary condition was applied to it.

3.4 Boundary Condition

The boundary condition considered for the blocks and the heat spreader are as follows.

For the heat spreader the thermal conductivity is 369 W/m-k, with a thickness of 0.51mm. The material considered is natural graphite. The thermal conductivity of casing for the power supply is considered to be 19W/m-k and heat dissipated from it is 10 W. Thermal conductivity of the hard drive is 140W/m-k, heat dissipated from it 10W. Thermal conductivity of DVD drive is 22 W/m-k, heat dissipated from it is 0.5

W. Thermal conductivity of PCMCIA is 1W/m-k, heat dissipated 0.25 W. The thermal conductivity and the heat dissipated from each component could be summarized as follows.

Table 2: Boundary conditions applied in the model

	Conductivity	Heat dissipated
Power supply	19W/m-k	10W
Hard Drive	22W/m-k	16W
DVD drive	22W/m-k	0.5W
PCMCIA	1W/m-k	0.25W

3.5 Different Configuration Considered in the Study

Five cases for the study were considered which are as follows.

1. Base line case.
2. Revised Case.
3. Exchanging positions of PCMCIA and DVD drive.
4. Exchanging positions of hard drive and power supply.
5. Exchanging positions of hard drive and PCMCIA

3.5.1 Base Line

Here in this case all the blocks were considered to be in their original places and boundary conditions were applied, keeping in view the results obtained by smalc et.al [1], running the simulations the following results were obtained.

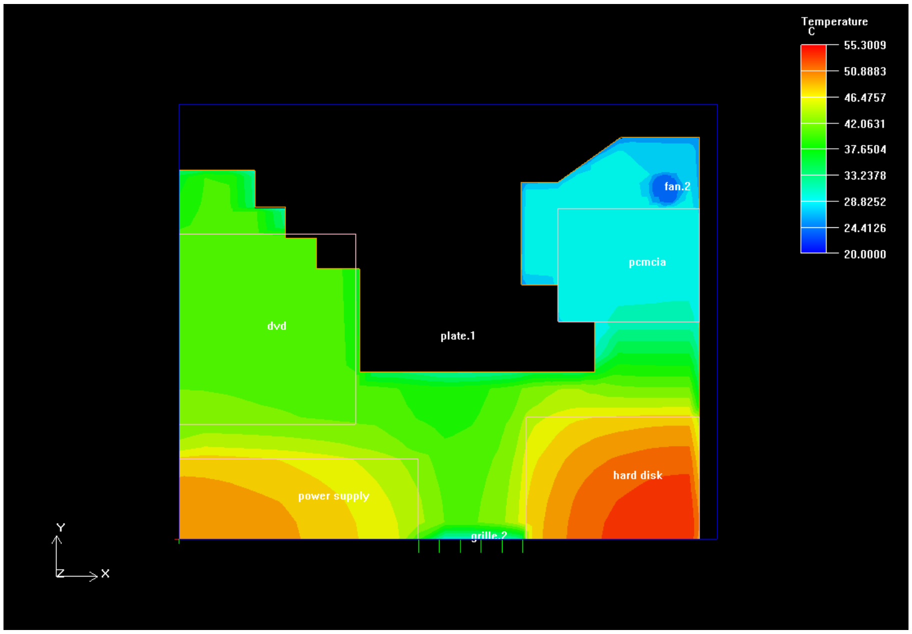

Figure 5: Temperature contours in base line case

The temperature gradient obtained was between 20 to 50 degrees, with maximum temperature obtained on the hard drive.

3.5.2 Revised Case

In this case new boundary conditions were considered and solved. The thermal conductivity of hard drive case was considered to be 140W/m-k and heat dissipated from it 10W [7]. The results obtained are as follows. All other boundary conditions were kept the same.

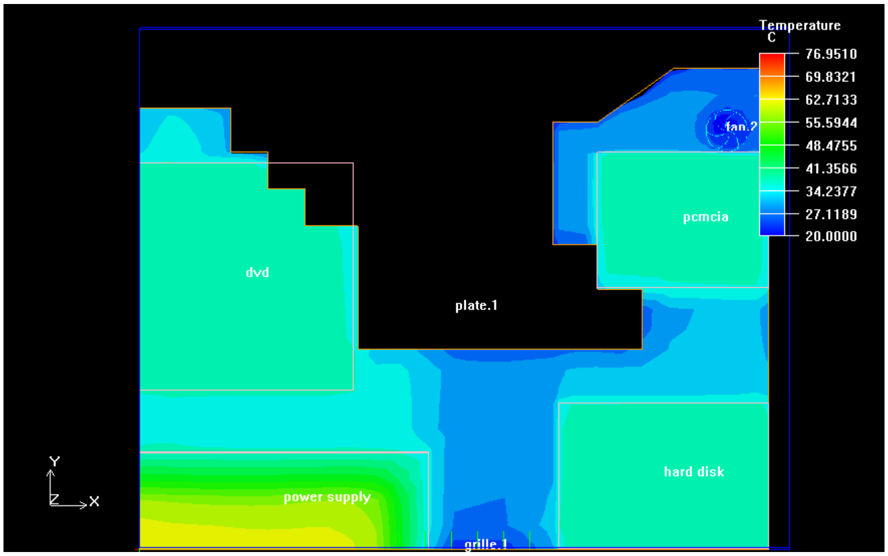

Figure 6: Temperature contours in revised baseline case

The temperature gradient was obtained as shown in the diagram varies between 20 to 76.95 degrees. The maximum temperature was observed in power supply. This case was further considered for parameterization. In parameterization, positions of all the blocks were changed with respect to one another. The specific cases where a significant temperature difference was observed are described below.

3.5.3 Exchanging positions of DVD and PCMCIA

Exchanging the positions of DVD and PCMCIA the changes in temperature contours were observed. The DVD and PCMCIA are exchanged in exactly in each other’s places and the changes in their temperature gradient are noted as follows. In this analysis reduction of area was done by cutting one of the steps of the heat spreader intuitively above PCMCIA.

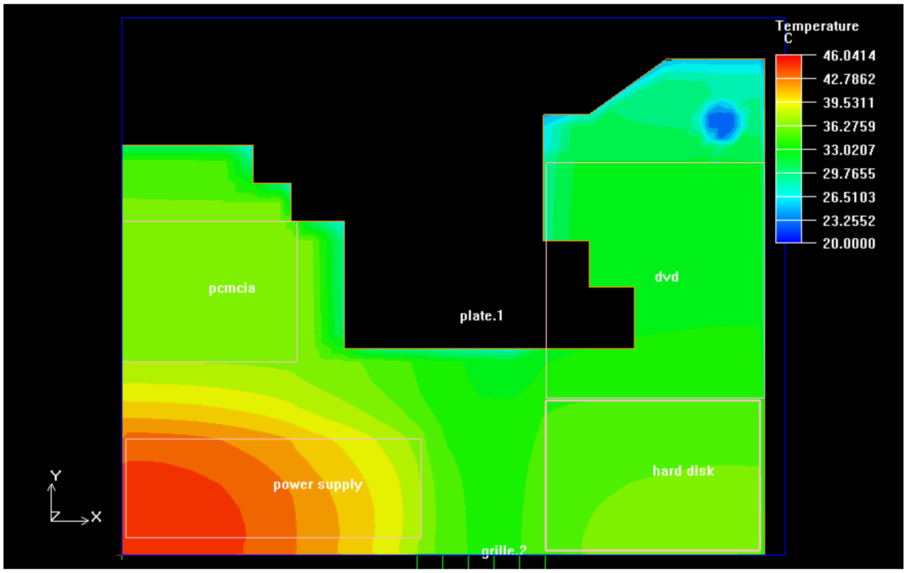

Figure 7: Temperature contours with DVD and PCMCIA position exchanged

It was observed that the temperature gradient across the heat spreader was from 20 to 46 degrees, the heat distribution was more uniform than the revised baseline case which can be observed from the figure 7. A change noteworthy, in the temperature contours is that the spot of maximum temperature shifted from left to right. This could be because of the change in spreader area.

3.5.4 Exchanging the positions of hard drive and power supply

In this case the position of hard drive and power supply were exchanged and the changes in temperature contours were noted. Figure 8 shows the temperature contour that was taken over the heat spreader.

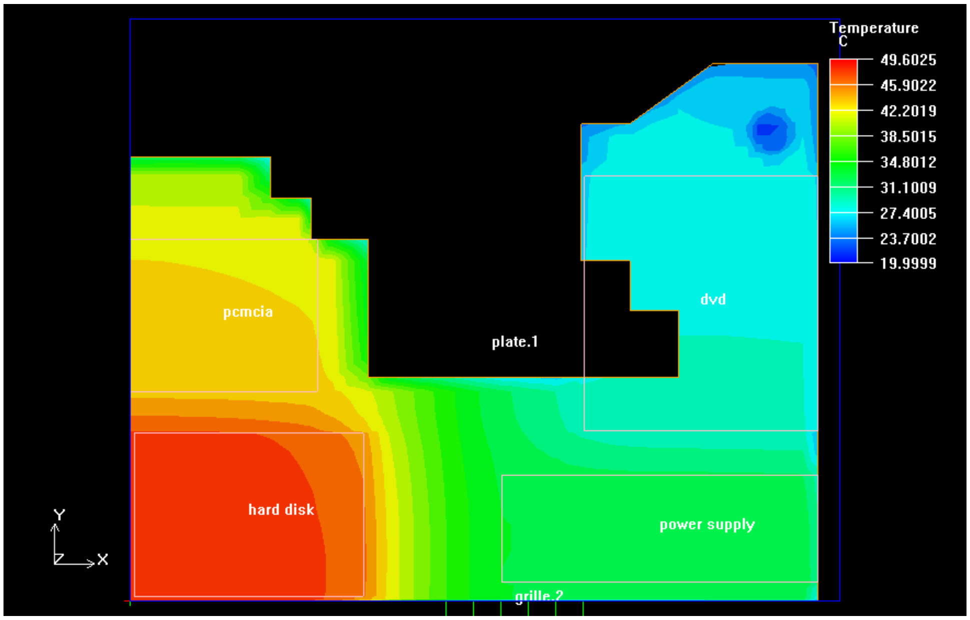

Figure 8: Temperature contours in exchange of hard drive and power supply

The temperature gradient was 20 to 49 degrees centigrade. The maximum temperature dissipation was observed on hard disk. The spot of maximum temperature was on hard disk as expected.

3.5.5 Exchanging the position of PCMCIA and Hard Drive

The position of PCMCIA and hard drive were exchanged and changes in temperature gradient were observed as follows.

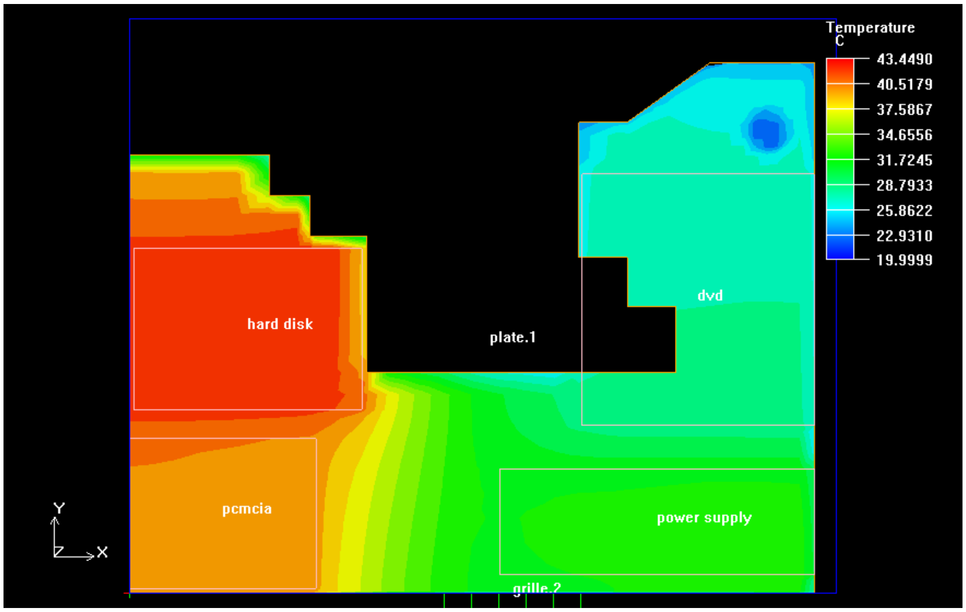

Figure 9: Temperature contours with PCMCIA and hard drive positions exchanged

It was observed that this was the best case so far because the temperature gradient obtained was between 20 to 43.44 degree and the heat distribution was uniform all over the spreader compared to previous cases. One more step was reduced to study the changes in temperature gradient.

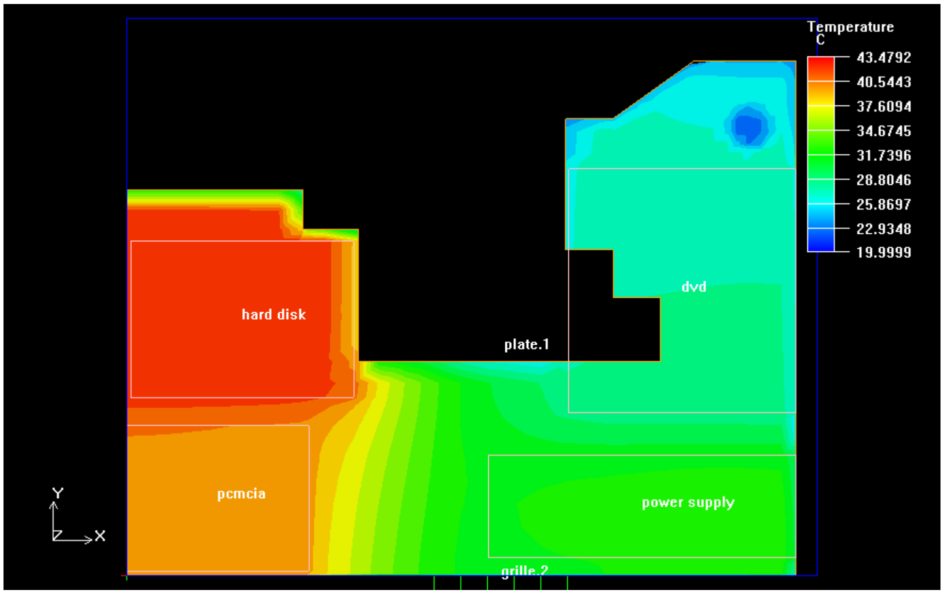

Figure 10: Temperature contours with one step less

It was observed that the change in temperature gradient is not significant it varies between 20 to 43.47 degrees. The hot spot is at the hard drive. Hence the area was further reduced.

3.5.6 Reducing Second step from the Spreader

One more step was reduced from the heat spreader to check the temperature gradient difference and determined an approximate area for parameterization. The results are as follows.

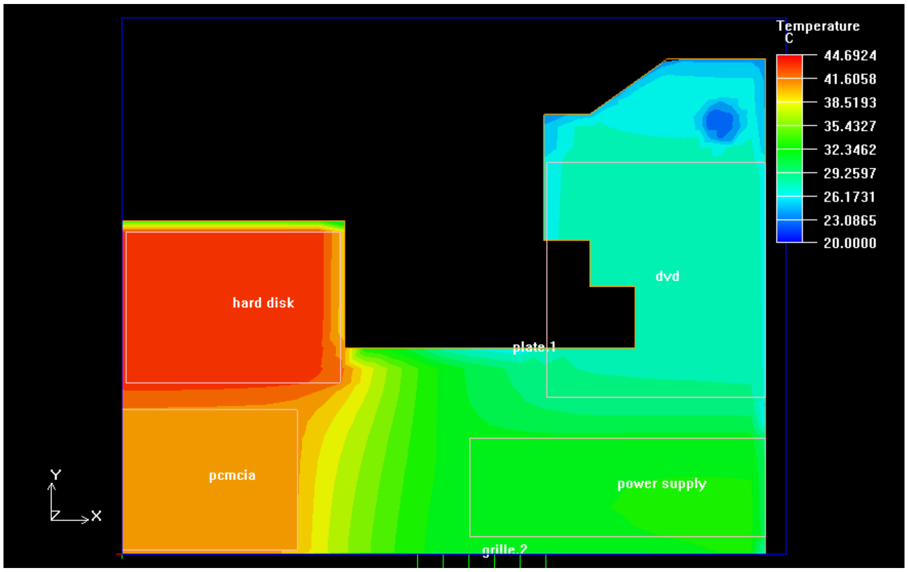

Figure 11: Temperature contour

A sudden increase of temperature was observed which is not acceptable for cooling the laptop. The temperature gradient varied from 20 to 44.69 degree. However, there was an increase in global maximum temperature.

3.6 Mesh Sensitivity Analysis

The baseline model was solved from a minimum of 35,000 elements to a maximum of 65,000 elements. Temperature of hard drive was a parameter considered in the monitored in the study. It was observed that the temperature of hard drive varies between 41.98°C to 42.31°C which is one percent variation overall. Thus, it can be said that the solution is independent of mesh.

CHAPTER 4

OPTIMIZATION OF THE HEAT SPREADER

4.1 Introduction

In this section the optimization of the graphite heat spreader of a laptop computer is discussed. An ICEPAK model is developed then boundary conditions are applied, the model is also checked for structural strength using a simulation in ANSYS workbench. The simulation in ANSYS also helps verify the results obtained from ICEPAK modeling.

4.2 ICEPAK Modeling

The Icepak model was developed considering the graphite thickness of 0.51 mm-thick natural graphite spreader that had an in-plane thermal conductivity of 369 W/mK. Installed in a laptop, the natural graphite spreader was able to conform easily to the height differences of the components it contacted. This spreader reduced the overall temperature gradient within the laptop and on the outer case by as much as 8°C [1]. The heat spreader was modeled in Icepak using the exact same dimensions as the original. Heat spreader was developed as a conducting thin plate. Conducting thin plates have same properties as conducting thick plates except that they have no physical thickness. In this study, only hard disk, Battery, DVD drive and PCMCIA card are considered and are modeled as blocks.

The blocks are placed on the heat spreader at the appropriate places and power is applied to them. Figure 12 shows the initial model of heat spreader.

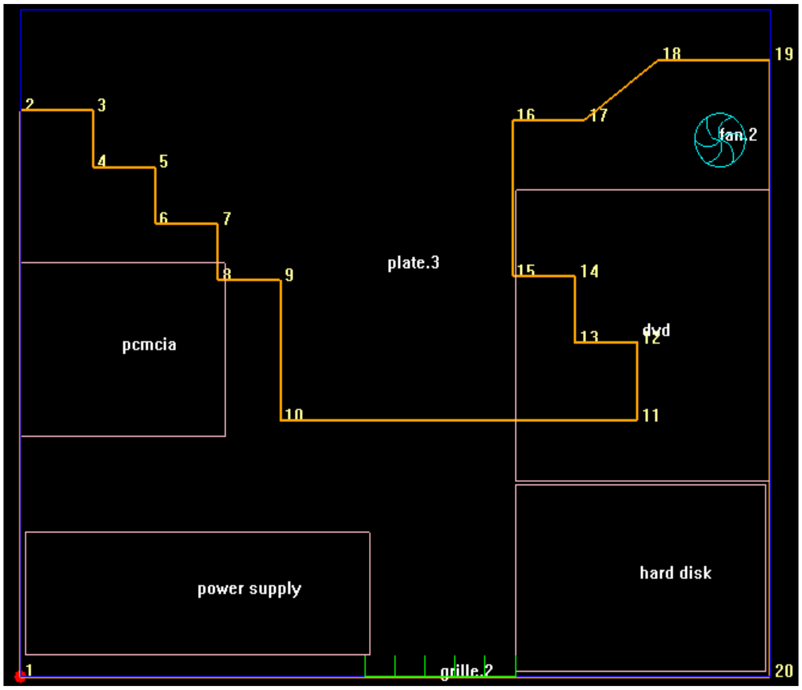

Figure 12: Initial heat spreader model developed with ICEPAK

The model is solved as a forced convection controlled model and contains a free opening through which air enters under the influence of an exhaust fan that has sucks air at a mass flow rate of 12 CFM.

4.3 Boundary Condition

The boundary condition considered for the heat spreader is thermal conductivity of 369 W/m-k with a thickness of 0.51mm. The material considered is natural graphite. Table 2 summarizes the boundary conditions for the blocks.

4.4 Baseline Case

In this case, all the blocks are considered to be in their original places and boundary conditions are applied, running the simulations, following results were obtained as shown in Figure 13.

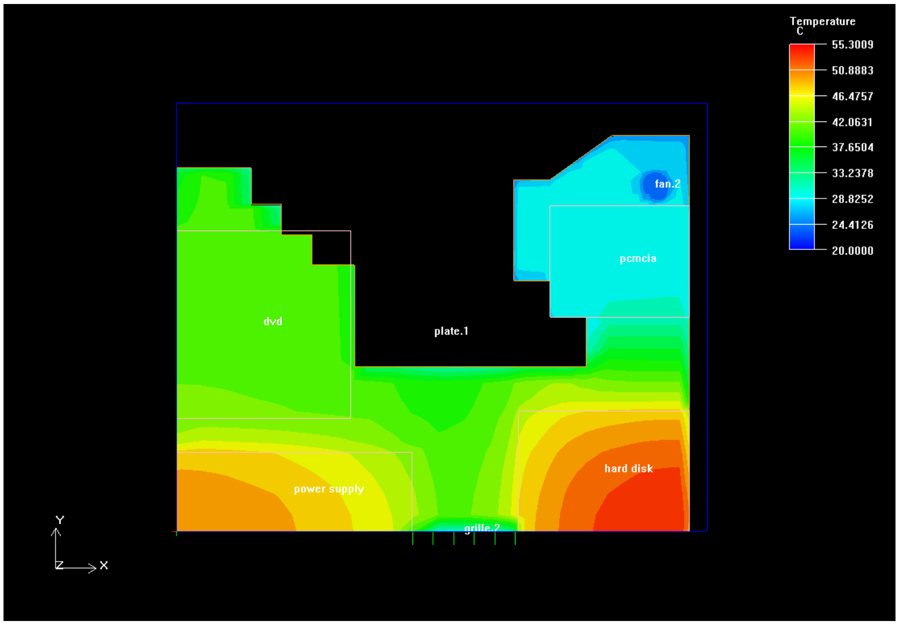

Figure 13: Temperature plots for baseline model

The temperature gradient obtained was between 20 and 55^{o}C degrees, with maximum temperature obtained on the hard disk which is underneath the right palm.

4.5 Structural Design

In order for the spreader design to be implemented it is important that is strong structurally too. Hence, a thermal stress analysis of the same design was done in a ANSYS workbench. A solid model of the spreader with four components is created in Pro/E as assembly. The model was imported into ANSYS Workbench as IGES.

Thermal boundary conditions applied to this model are heat transfer coefficient on top surface of spreader. There are two aims of this analysis. As there is no experimental work in this paper the software model is validated using another code. The second aim is to check the structural integrity of the spreader design. Mechanical boundary conditions in design are fixed support on lower face of all components and equivalent load of 5lb$_f$ was applied on model to simulate the pinning down of heat spreader. Figure 6 and 7 shows the thermal and mechanical boundary conditions respectively.

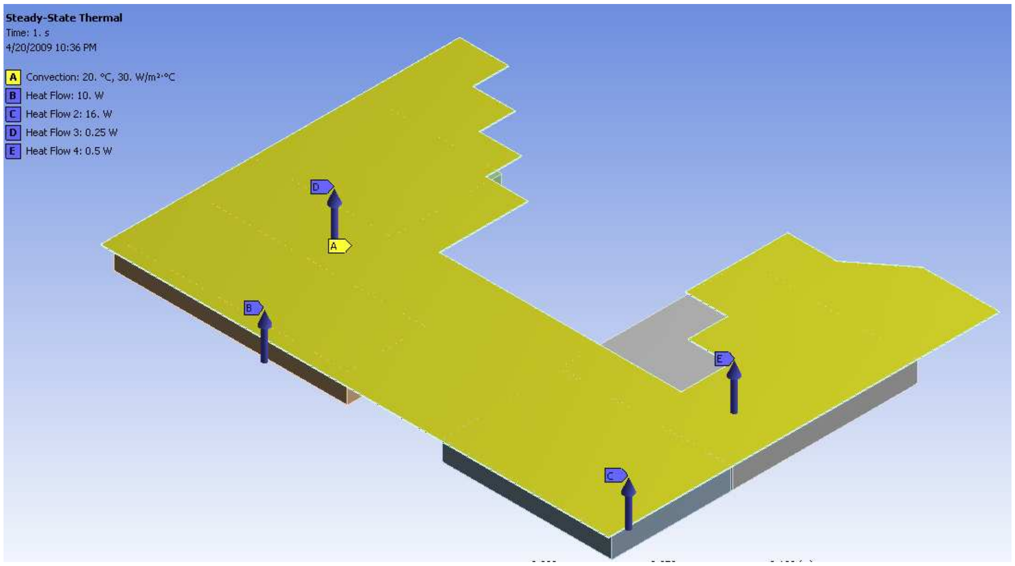

Figure 14: Thermal boundary conditions applied to model

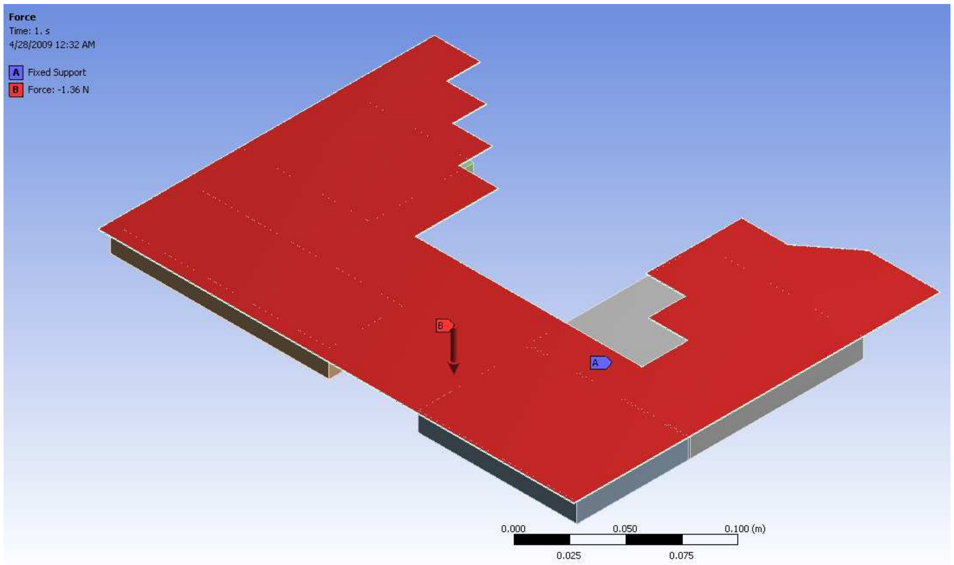

Figure 15: Mechanical boundary conditions applied to model

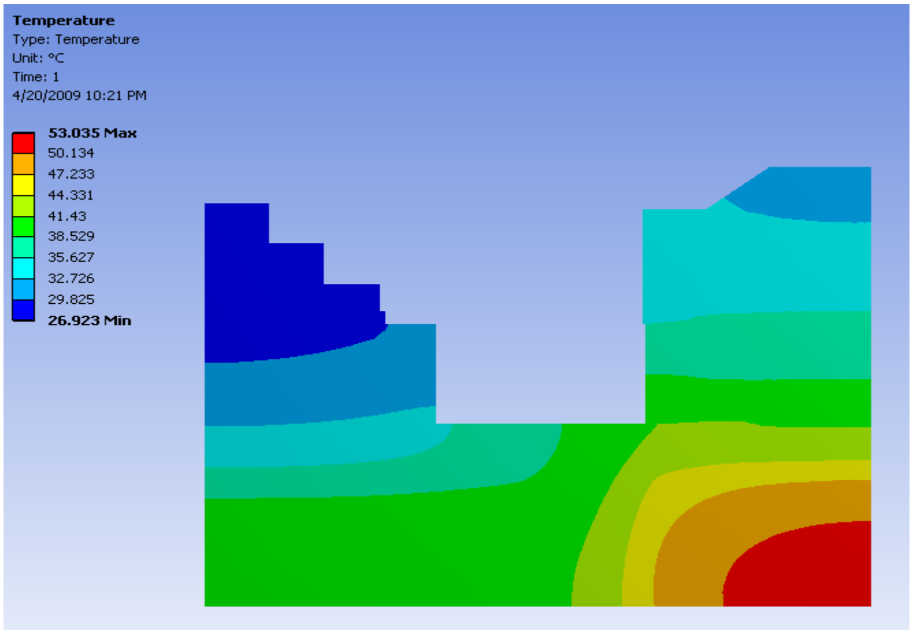

Figure 16: Temperature contours in heat spreader

It is evident that highest temperature occurs in hard disk and is 53°C. The temperature obtained in this case is within 5% of the temperature obtained in baseline case solved in Icepak. Thus the computational model is validated.

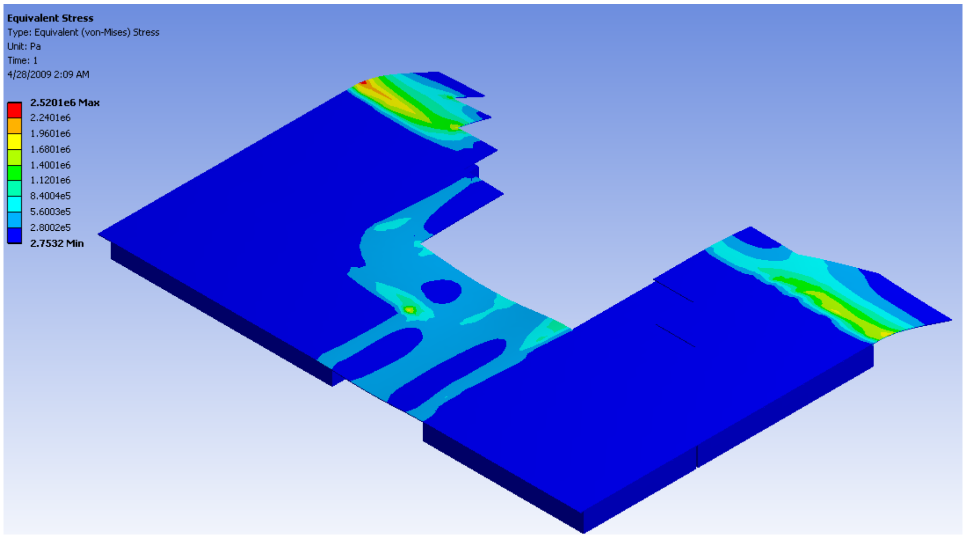

Figure 17: Von-Mises stress induced in spreader due to heat generation

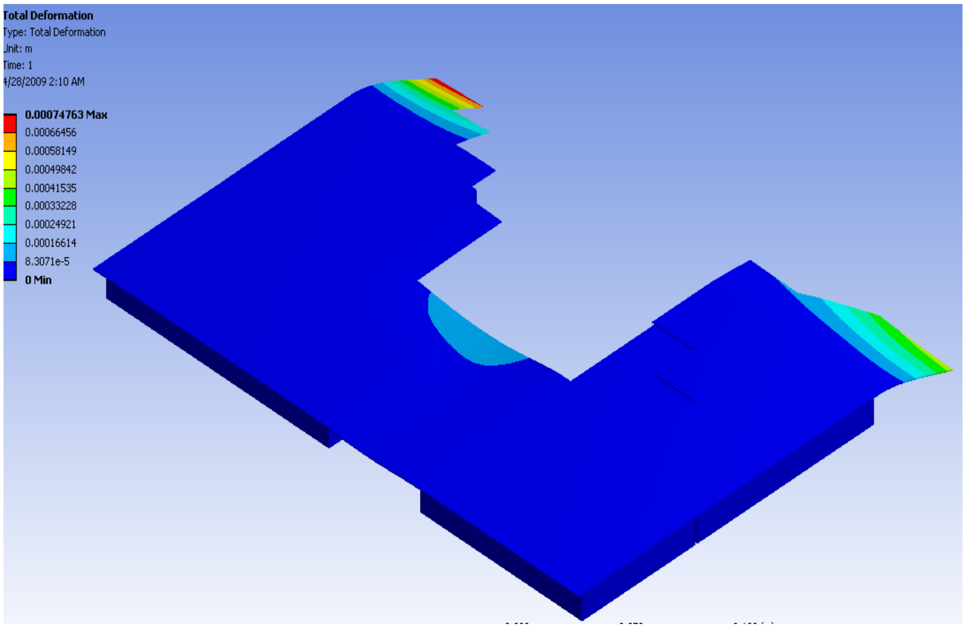

Figure 18: Deformation of graphite heat spreader

Figure 17, shows the mechanical stresses induced in graphite heat spreader. Maximum stresses are on the edges of heat spreader, these are mechanical stresses that will be induced because of the deformation of graphite. The stresses that are induced in the middle are the ones that are induced because of the heat generation from components underneath it. One can infer from figure 18 that the maximum deformation induced in graphite heat spreader is 0.7 mm. This deformation can add tremendous contact resistance between the components and spreader and can be responsible for increase in temperature.

4.6 Optimization of Heat Spreader

The use of a heat spreader made a tremendous impact on cooling performance. However, a careful look at the temperature plot obtained in Figure 13 reveals that a significant portion of spreader, starting on right underneath the DVD drive, doesn’t show any appreciable temperature gradient. Similarly, near the fan, air is exiting system at 20°C one can observe that the spreader also has a temperature also 20°C. Literally speaking, if the temperature of the spreader is 20°C, the spreader there is redundant.

Every square millimeter of graphite is costly; there is a need to minimize the spreader area by not sacrificing the maximum temperature across the spreader.

For the purpose of optimization, the heat spreader was divided into 11 parts. Each part contains one X and one Y dimension, which are considered optimization variables, yielding 22 design variables in all (Z dimension was considered fixed and hence not considered in optimization). The purpose of 22 design variables is that it gives very good control for optimizing geometry of the spreader. Initial values of the variables are assigned in such a way that the baseline case of optimized model of the spreader replicates the original design. Figure 19 shows the optimization model.

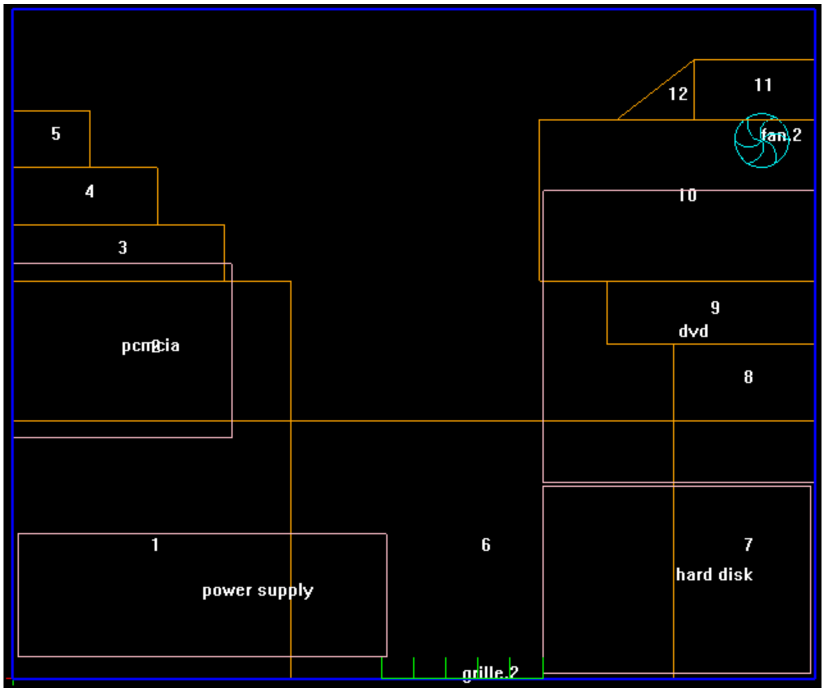

Figure 19: Optimization model of heat spreader

Table 3 gives the dimensions of the different parts and the total area of heat spreader; the total area of which is 48591.01 mm^2. This corresponds to a net weight of 42 grams.

Table 3: Non-Optimized (Original) dimensions of the heat spreader

Block	X Length (mm)	Y Length (mm)
1	104	96
2	104	52.4
3	79	21.2
4	54	21.2
5	29	21.2
6	143	96
7	53	96
8	53	28.95
9	78	23.45
10	103	60.46
11	45.56	22.14
12	28.49	22.14

Constraints on the design variables depends on the location of part (*e.g.*, parts that are placed on high heat dissipating components, such as power supply and hard disk, will have smaller constraints compared to the parts located underneath PCMCIA, DVD, and near the fan). Equation 3 gives the optimization function

$$Totalarea = \sum_{n=1}^{12} X * Y \quad \text{------------------------} \ (3)$$

The monitor variable for optimization is the global temperature. The constraint on temperature is 56°C. This algorithm generated over 100 scenarios. But the scenario wherein, the area of spreader was least is shown in figure 20.

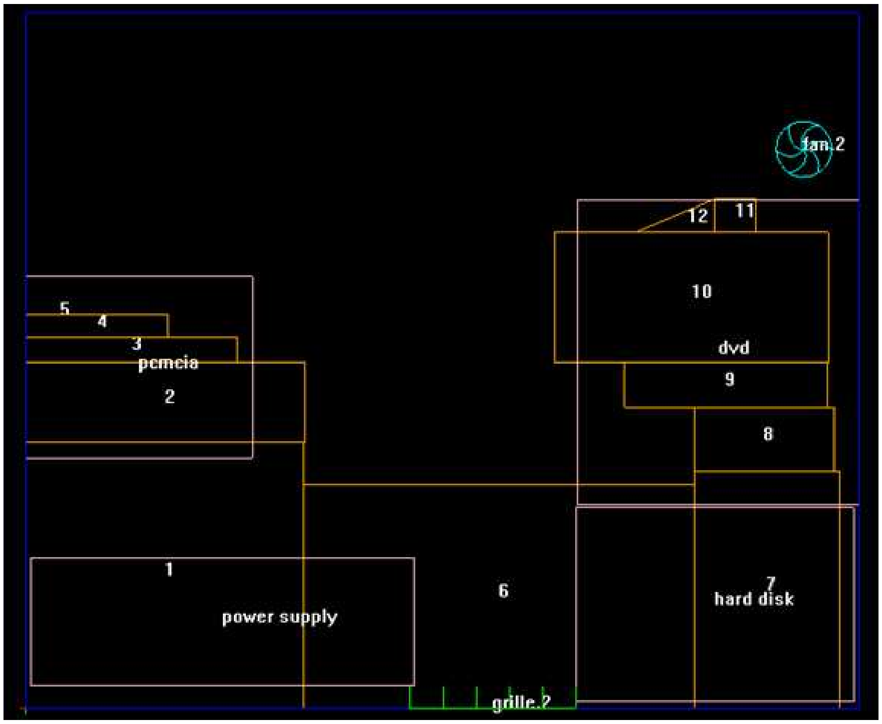

Figure 20: Optimized dimensions of heat spreader

One can assert by comparing figure 12 and figure 20 that there is a significant change in dimensions of heat spreader. Figure 13 shows the temperature contours associated with the model. The maximum temperature obtained in the model was 55.9°C. Thus, by sacrificing 1°C temperature globally, a huge reduction in net cross-section area of the spreader was obtained. The new dimensions of spreader are listed in Table 4. Figure 22 shows the different scenarios that were solved with the optimization routine.

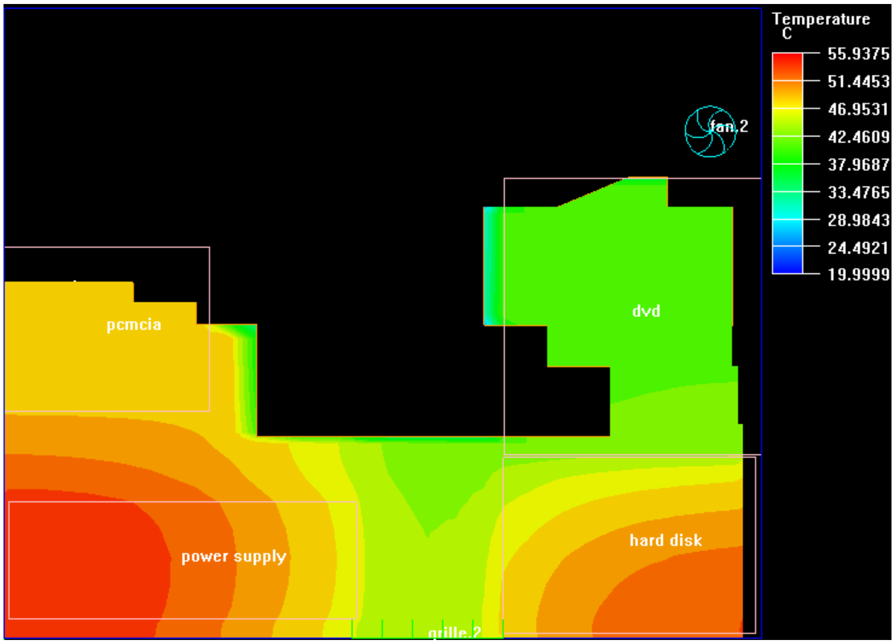

Figure 21: Temperature plot with optimized dimensions of heat spreader

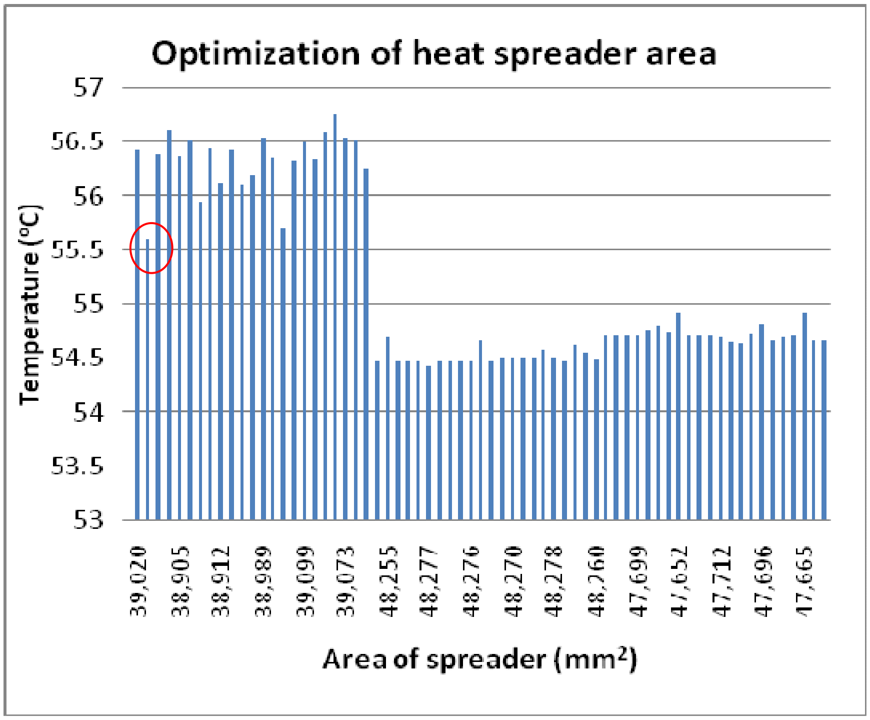

Figure 22: Optimization scenarios for heat spreader

On the X-axis in Figure 22 are the areas of heat spreader obtained in various scenarios that were solved using the optimization algorithm. The optimal scenario is scenario 2, which generates the least area among all different cases. Table 4 gives the optimized dimensions of heat spreader.

Table 4: Optimized dimensions of heat spreader

Block	X length (mm)	Y Length (mm)
1	102	96
2	104	30
3	79	10
4	54	9
5	29	3
6	143	83
7	53	85
8	53	25
9	78	18
10	103	50
11	20	15
12	28.49	22.14

The total area of the optimized spreader is 38828 mm^2. The net saving in area is 48591.01 – 38828 = 9800 mm^2, which is nearly 20% smaller than the original design. This corresponds to a net weight of 34 grams, which is almost 20% reduction in cost of graphite. A structural design simulation of the new optimized heat spreader revealed that maximum deformation induced in spreader is 0.24mm. Primary reason for this is extension of heat spreader is cut off and is pinned down directly onto the PCMCIA card and DVD.

However, the maximum stress induced in the spreader is more than in the original design, but is still less than the maximum strength of graphite and hence can be considered as safe.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction

The main objective of this work was to define and design a thermal management system for a laptop. Optimization of the heat spreader size and cost is another goal of this research study. Icepak, a powerful computational fluid dynamics solver is used in this analysis for simulation and optimization.

5.2 Conclusion

Graphite is the best material for the heat spreader compared to aluminum and copper as graphite conductivity is same as copper and twice as aluminum, and density of Graphite is much less compared to both aluminum and copper. Anisotropic property is also very important characteristic of Graphite which makes it the best of three. The thermal conductivity of the heat spreader will be almost equal to the standard heat sink used in a laptop.

5.2.1 Conclusion from parameterization of heat spreader

The research makes an attempt to study the effect of heat spreaders on the overall performance of a portable device (laptop). All major heat sources were considered in the study. An attempt of reducing the area and in turn weight of heat spreader was made in this study. The reduction of area was achieved by cutting steps from the top right where the temperature was minimum. A change in shape affected the spreading and hence temperature distribution significantly. However, the global maximum temperature was almost the same. Hence, from the study we could satisfactorily conclude that case number five with one step reduced is the best possible parameterization for the heat spreader for cooling the laptop. In this study, we successfully reduced the area of the spreader by 2000 mm square.

5.2.2 Conclusion from optimization of the heat spreader

The optimization of heat spreader to reduce its fabrication cost was considered in this study. The spreader was divided into 12 parts and each part was assigned two variables. Using optimization algorithm, area of the spreader was reduced by almost 9800 mm^2 which corresponds to 20% of the original design area. This particular research was done for a laptop. According to EEtimes a total of 177 million notebooks will be sold in 2009 [14]. If it is assumed that all notebooks have a graphite heat spreader and total cost of installing graphite heat spreader is one dollar then a net reduction of 20% in cost of graphite spreader will correspond to a saving of 79.65 million - 63.72 million = 15.93 million dollars.

5.3 Scope of Future Study

An experimental validation of the analysis presented in the current thesis will provide an insight into the accuracy of the simulation carried out. Manufacturability of the design can also be tested by actually implementing the design suggested.

REFERENCES

[1]. Martin Smalc, Gary Shives, Gary Chen, Shrishail Guggari and Julian Norley, “Thermal Performance Of Natural Graphite Heat Spreaders” IPACK2005-73073, ASME interPACK 2005.

[2]. Bob dehoff, Dr. Chong-Sheng wang and David Fast, “Thermal Optimization of a Radial Folded Fin Heat Sink for Desktop Computer Applications” Tyco Electronics.

[3]. S. Rao, Engineering Optimization – Theory and Practice. NY: John Wiley & Sons, Inc., 1996.

[4]. A. Menon, “Structural Optimization Using ANSYS and Regulated Mulquadratic Response Surface Model” AIAA 2005

[5]. Ashok D Belligundu and Tirupathi R. Chandrupatla, Optimization Concepts And Application in Engineering. Prentice Hall India

[6]. T. W. Simpson, A. J. Booker, D. Ghosh, A. A. Giunta, P. N. Koch and R.-J. Yang, “Approximation Methods in Multidisciplinary Analysis and Optimization-A Panel Discussion,” Structural and Multidisciplinary Optimization, vol. 27, pp. 302-313, July. 2004

[7]. www.egraf.com

[8]. R. J. Gaeta, “The SDound Absorbing Potential of Carbon-Graphite Foam” 12th AIAA/CEAS Aeroacoustics Conference, AIAA 2006-2405

[9]. Ingard, U. Notes on Sound Absorption Technology, Noise Control Foundation, Poughkeepsie, NY, 1994.

[10]. Vichare, N., Rodgers, P., Eveloy, V., Pecht, M.G., 2004, "In Situ Temperature Measurement of a Notebook Computer – A Case Study in Health and Usage Monitoring of Electronics," IEEE Transactions of Device and Materials Reliability, Vol. 4, No. 4, pp 658-663.

[11]. Dell USA Community Forum, 2005, "D600 Palmrest Heat," Online (Available: http://forums.us.dell.com/supportforums/board/message?board.id=latit_harddrive&message.id=6271

[12]. Jose Sandoval .com, 2005, "Hot Dell – D600 or D800 or whatever," Online (Available: http://www.josesandoval.com/hotdells/)

[13]. www.icepak.com

[14]. http://www.eetimes.com/news/latest/showArticle.jhtml?articleID=212701251

BIOGRAPHICAL INFORMATION

Arijit Banerjee completed his B.Tech (Bachelor of Technology) degree in Mechanical Engineering from Nizam Institute of Technology, Andhra Pradesh, India in June 2006. In his senior year; he undertook project work titled "Design, Manufacturing and Analysis of Polymer composite Sandwich Aerofoil and FEM Implementation".

He completed his Master's Degree in Mechanical Engineering from The University of Texas at Arlington, in December 2009. His thesis was based on the development of a design and optimization method for graphite heat spreaders using thermal design tool ICEPAK. His current research interests are electronic packaging, heat transfer, finite elements analysis and computer aided design.