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Analysis & Optimization of Processor Cooling Fins

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Abstract—In this study, thermal analysis of electronic processor fins is proposed and an effort is made to decrease the maximum temperature in processor by employing rectangular fins which aid in rapid heat removal to the surroundings for ensuring the optimal working of the processor. Removal of heat generated in the processor gets augmented by the application of fins to it. Comparative study is presented by selecting particular material for electronic processor, rectangular in shape, enclosed by a steel casing to which aluminum fins are attached. Modeling and Analysis is carried out using the Finite Element Method (FEM) based software, ANSYS. Heat flows out from the processor to the surrounding through the casing and then to fins attached to it. Convective boundary condition is applied to the casing and fins except the bottom, which is insulated. Increase in number of fins leads to decrease in maximum temperature and increase in heat flux of the processor proportionally. The results report the temperature distribution and heat flux contour for variation in number of fins. Conclusion is drawn from the results pertaining using the appropriate number of fins to be used to optimize the maximum temperature in processor. Results show that ANSYS can be used effectively and efficiently to solve the challenge of heat transfer problem.

I. INTRODUCTION

We need to go far back in time to remember a CPU that was able to operate completely without a heat sink. The first Intel processors were already producing considerable amount of heat, but the low specifications allowed operation without any heat removal mechanism. A little later, as the processing speed increased, these processors required at least a passive heat sink for trouble free operation. However, for the last few years, as the processors got more and more powerful, it has become mandatory that a CPU requires a multi-fin heat sink as well as a fan that ensures reasonable air flow through the cooling fins as the overheated processors exhibit a shorter maximum life span and often results in problems like system freezes or crashes. A heat sink is a device used in computers to remove the large amount of heat generated by components, including ICs such as CPUs, chipsets and graphic cards, during their operation. A heat sink is used to increase the surface area which dissipates the heat faster n keeps the ICs under safe operating temperature. Fans are also used to speed up this process. It usually consists of a base with one or more flat surfaces and an array of fin like protrusions to increase the heat sink's surface area contacting the air, and thus increasing the heat dissipating rate. A combination of a heat sink and a fan is widely used which maintains a larger temperature gradient by replacing warmed air more quickly. Heat sinks are made from good thermal conductors such as copper or aluminum alloy. Copper is significantly heavier and more expensive than aluminum but it is also roughly twice as efficient. The most common of a heat sink is a metal device (Cu or Al) with many fins. In this paper, section 2 describes the heat sink types and its thermal resistance. Section 3 explains the least square model for estimating the parameters and predicting the best fit of the proposed heat sink in different loads of a microprocessor. In electronic systems, a heat sink is a passive heat exchanger that cools a device by dissipating heat into the surrounding medium. In computers, heat sinks are used to cool central processing units or graphics processors. Heat sinks are used with high-power semiconductor devices such as power transistors and optoelectronics such as lasers and light emitting diodes (LEDs), where the heat dissipation ability of the basic device is insufficient to moderate its temperature. A heat sink is designed to maximize its surface area in contact with the cooling medium surrounding it, such as the air. Air velocity, choice of material, protrusion design and surface treatment are factors that affect the performance of a heat sink. Heat sink attachment methods and thermal interface materials also affect the die temperature of the integrated circuit. Thermal adhesive or thermal grease improve the heat sink's performance by filling air gaps between the heat sink and the heat spreader on the device.

A. Heat transfer principal

A heat sink transfers thermal energy from a higher temperature device to a lower temperature fluid medium. The fluid medium is frequently air, but can also be water, refrigerants or oil. If the fluid medium is water, the heat sink is frequently called a cold plate. In thermodynamics a heat sink is a heat reservoir that can absorb an arbitrary amount of heat without significantly changing temperature. Practical heat sinks for electronic devices must have a temperature higher than the surroundings to transfer heat by convection, radiation, and conduction. The power supplies of electronics are not 100% efficient, so extra heat is produced that may be detrimental to the function of the device. As such, a heat sink is included in the design to disperse heat to improve efficient energy use. Fig. 1 shows how the heat sink looks. With the same image principle of heat transfer can be understood easily.

To understand the principle of a heat sink, consider Fourier's law of heat conduction. Fourier's law of heat conduction, simplified to a one-dimensional form in the *x*-direction, shows that when there is a temperature

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gradient in a body, heat will be transferred from the higher temperature region to the lower temperature region.

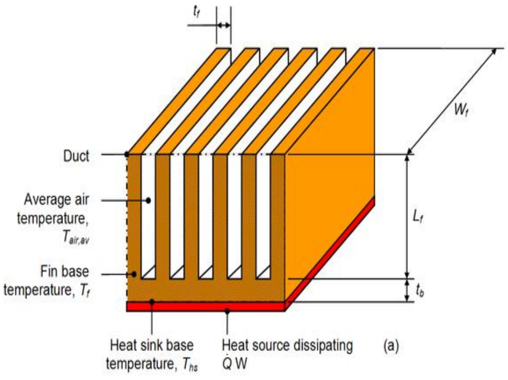

Fig. 1 heat transfer principal

The rate at which heat is transferred by conduction, q_k, is proportional to the product of the temperature gradient and the cross-sectional area through which heat is transferred.

$$q_k = -kA\frac{dT}{dx}$$

Consider a heat sink in a duct, where air flows through the duct, as shown in Figure It is assumed that the heat sink base is higher in temperature than the air. Applying the conservation of energy, for steady-state conditions, and Newton's law of cooling to the temperature nodes gives the following set of equations.

$$\dot{Q} = \dot{m}c_{p,in}(T_{air,out} - T_{air,in}) \quad (1)$$

$$\dot{Q} = \frac{T_{hs} - T_{air,av}}{R_{hs}} \quad (2)$$

B. Design factors to be considered

While designing fins factors to be considered are thermal resistance, fin efficiency, spreading resistance, optimization, fin arrangement and surface color.

II. LITERATURE

Knight et al. (1992) extended previous analysis of micro channel heat sinks for turbulent as well as laminar flow. They demonstrated improvement of previous studies by relaxing constraints on fin thickness/ pitch ratio and allowing turbulent flow. Copeland (1995) modified previous analyses for developing flow and calculated optimum fin thickness and pitch for silicon heat sinks cooled by fluorocarbon liquids. Lee (1995) analysed flow through parallel fin heat sinks in fully ducted and partially ducted flows. Unlike a fully ducted configuration, in partially ducted configuration at a fixed approach velocity, an optimum size of fin existed; thermal performance improves monotonically as fin pitch is decreased. Aranyosi et al. (1997) showed isocurves of pressure drop and fan power at fixed thermal resistance in addition to isocurves of thermal resistance at fixed pressure drop and fan power. As pressure drop or fan/blower power increased, optimum fan thickness and pitch decreased, resulting in reduced thermal resistance. In addition to analysis, experimental and numerical studies were performed. Tasaka et al. (1997) performed experimental studies of compact heat sinks with fin thickness and pitch as small as 0.34mm and 0.70mm. Results correlated well with results from compact heat exchanger data. This compactness factor, defined as thermal conductance per unit volume, was three to seven times that of standard heat sinks. M Bisht and K S Mehra (2014) condecucted number of experiments and published a paper on optimisation of working of processor by fins using FEM in International Journal for Research in Applied Science and Engineering Technology.

III. PROBLEM SPECIFICATION

Processor is made of copper with thermal conductivity of 386 W/m-K and it generates heat at the rate of 1 W. The enclosing container is made of steel with thermal conductivity of 17 W/m-K. The fins are made of aluminium with thermal conductivity of 180 W/m-K. There is convection along all the boundaries except the bottom, which is insulated. The film (convection) coefficient is h=50 W/m2-K and the ambient temperature is 20ºC. An attempt is done to decrease the maximum temperature and increase the heat flux in the electronic component by varying the number of fins to ensure the optimal working of the component.

Comparative study is done by taking silicon as a material for processor. The properties of silicon material are:

- Bulk modulus : 9.8×10^{11} dyne/cm^2
- Melting point : 1412 °C
- Specific heat : 0.7 J /g -°C
- Thermal conductivity : 130 W /m-°C
- Thermal diffusivity : 0.8cm^2/s
- Thermal expansion : 2.6×10^{-6}/°C

IV. PROCESS METHODOLOGY

The process of solving this in FEM by using ANSYS is as below

A. Solid modeling

Solid modeling is done in solid works so that we can import this model easily in ANSYS. Solid modeling is as shown in the below figure that is Fig. 2.

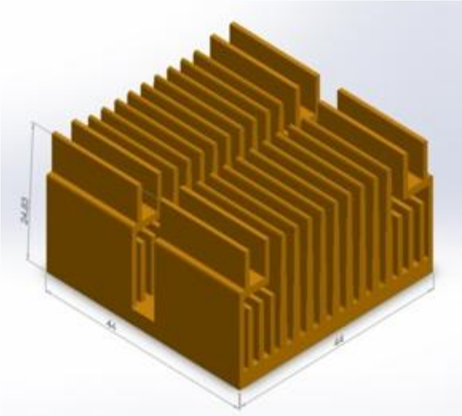

Fig.2 Solid model

B. Pre-processing

Modeling is imported in the pre-processor. Here we define the problem; the major steps in preprocessing are given below:

- Define key points/lines/areas/ volumes
- Define element type: Solid brick 8 node This element can be used as a plane element or as an axisymmetric ring element with a 2-D thermal conduction capability. The element has four nodes with a single degree of freedom, temperature, at each node. The element is applicable to a 2-D, steady-state or transient thermal analysis. The element can also compensate for mass transport heat flow from a constant velocity field.
- Define material/geometric properties: We use the simplest thermal, isotropic, 1D material description. ANSYS has full anisotropic (completely directionally dependent), as well as non-linear material “constitutive laws”. We need to define three different materials (Copper/ Silicon, Aluminium and Steel). At first we are defining Copper then Aluminium and at the end, Steel.
- Define Mesh size and meshing of geometry: Here size of element edge length is 1. Meshed model is as shown in fig. 3.

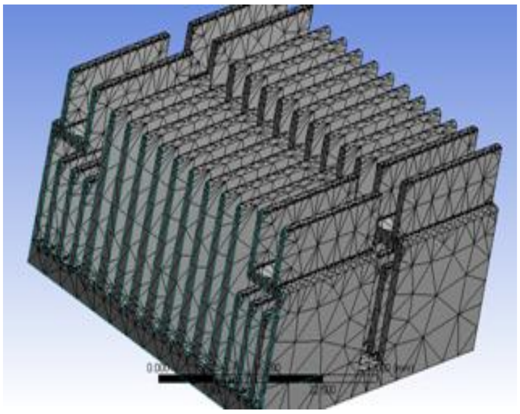

Fig. 3 Meshed model in ANSYS

C. Solution

It includes assigning loads, constraints and solving; here we specify the constraints and finally solve the resulting set of equations. In this problem all sides of block have convection type of boundary condition except the bottom side which is insulated and analysis type is Steady state analysis.

D. Post-processing

After getting solution results are analyzed in post processing. It includes further processing and viewing of the results**.** In this stage we have obtained:

- Heat flux distribution (fig. 4)
- Temperature distribution (fig. 5)

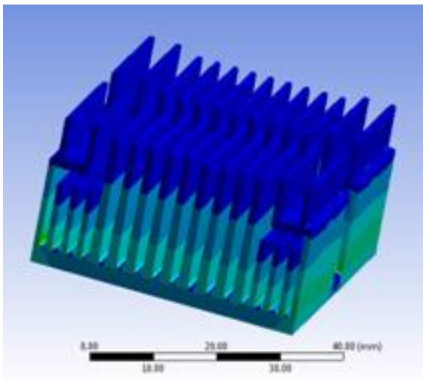

Fig. 4 Heat flux distribution

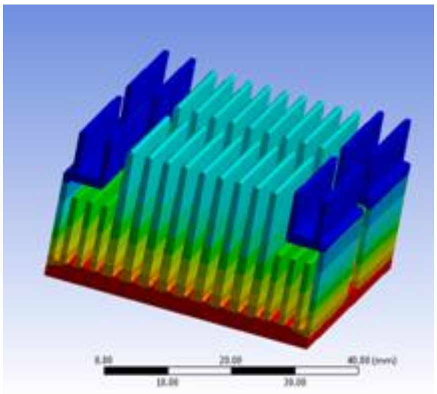

Fig. 5 Temperature distribution

V. RESULTS

Temperature and heat flux contours are plotted for the cases when number of fins is zero, three, seven, nine, eleven, thirteen and fifteen. Results are summarized in the form of graph for Maximum Temperature and Heat flux for different cases of fins. Similarly, temperature and heat flux contours are plotted for the cases when number of fins are increased i.e. zero to fifteen. Results are summarized in the form of graph for Maximum Temperature and Heat flux for different cases of fins.

Table 1. Number of fins v/s maximum temperature

Number of fins	Maximum Temperature (K)
0	491.59
3	425
5	398
7	384
9	372
11	365
13	362
15	360

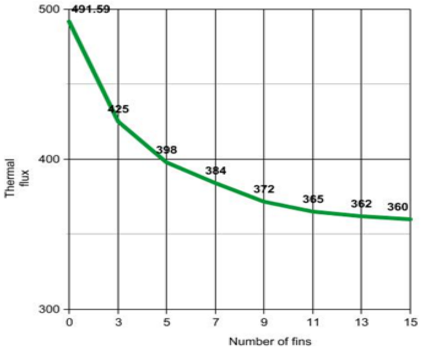

Fig. 6 Number of fins v/s maximum temperature

It is observed from the above fig. 6 maximum temperature decreasing continuously as soon as reached to the higher number of fins. After using thirteen fins in processor, no considerable decrease in the maximum temperature is observed when we further increase the number of fins. Therefore, thirteen fins are sufficient to decrease the maximum temperature of the processor.

Table 1. Number of fins v/s thermal flux

Number of fins	Thermal flux (W/m^2) $(\times 10^4)$
0	7.21
3	8.4
5	8.62
7	8.8
9	8.83
11	8.9
13	8.95
15	9

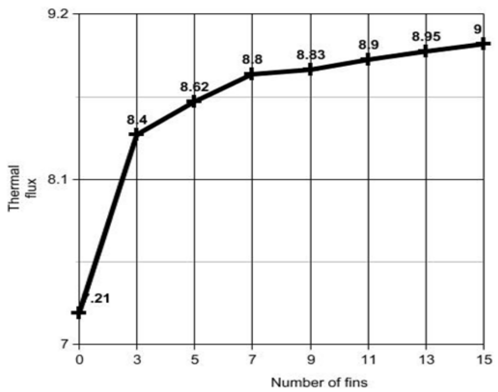

Fig. 7 Number of fins v/s thermal flux

By increasing the number of fins in processor, we can see that as we increase the number of fins, the heat flux increases continuously but after thirteen fins there is no considerable increase in heat flux, as shown in above Fig. 7. Thus, thirteen fins are sufficient to use for heat transfer enhancement.

VI. CONCLUSION

Thermal analysis of processor is done for ensuring its optimal working. Rectangular fins of aluminum are attached to the steel casing enclosing the processor. The results have been obtained by increasing the number of fins. The temperature distribution and heat flux contours with different selection in number of processor fins are obtained. It is observed that the heat flux is increasing and maximum temperature is decreasing with increase in number of fins. But after thirteen fins, there is no considerable increase in heat flux and decrease in maximum temperature as observed. Thus, there is no need to further increase the number of fins keeping cost parameter and effective working of processor in mind.

VII. FUTURE SCOPE

- Thermal analysis for processor cooling system with different shapes of fins and optimization of the same.
- Cost reduction analysis with variable parameters.
- CFD analysis of the fins, to understand air flow around the fins.

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