Steady State Thermal Analysis on Heat Sinks by Varying Fin Configuration Using ANSYS

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Abstract:

A heat sink is a passive heat exchanger, which is designed to have large surface area in contact with the surrounding (cooling) medium like air. Heat generated by every element or component of electronic circuit must be dissipated for improving its reliability and preventing the premature failure of the component. Heat sinks provide heat dissipation thereby increasing the life of the electronic devices. In this study, a comparative thermal analysis on heat sinks of different configurations is performed. The purpose of this study is to determine the optimal design for a heat sink (among the considered design configurations) with maximum possible natural convection. The heat sinks are designed using Solid Works software. These designed models have been analyzed using ANSYS WORKBENCH software. The results obtained suggest the Rectangular flat plate heat sink as optimum design among the considered heat sink models.

Keywords: Heat sink, Fin configuration, Heat dissipation, Solid works, ANSYS workbench

1. Introduction:

Heat sinks function by efficiently transferring thermal energy ("heat") from an object at high temperature to a second object at a lower temperature with a much greater heat capacity. This rapid transfer of thermal energy quickly brings the first object into thermal equilibrium with the second, lowering the temperature of the first object, fulfilling the heat sink's role as a cooling device. Efficient function of a heat sink relies on rapid transfer of thermal energy from the first object to the heat sink, and the heat sink to the second object. The most common design of a heat sink is a metal device with many fins. The high thermal conductivity of the metal combined with its large surface area result in the rapid transfer of thermal energy to the surrounding, cooler, air. This cools the heat sink and whatever it is in direct thermal contact with. Use of fluids and thermal interface material ensures good transfer of thermal energy to
the heat sink. Similarly, a fan may improve the transfer of thermal energy from the heat sink to the air [18].

2. Literature Review:

Akshendra soni et al [17] performed a comparative analysis on heat sinks based on total heat dissipation using Ansys. The study involves comparison of plate, circular and elliptical fin. It is concluded from analysis that plate fin dissipated larger amount of heat compared to others.

Amit Md. EstiaqueArefin et al [13] modified the pin design where the pins are expanded outward. Thermal analysis of the conventional model and the modified model was conducted and compared successfully. It is clear from the numerical analysis of the paper that in the practical environment the modified pin fin heat sink will perform better than the conventional one.

Arularasan R. et al [4] worked out to select an optimal heat sink design, based on preliminary studies on the fluid flow and heat transfer characteristics of a parallel plate heat sink through CFD modeling and simulations. This paper explains the choice of selecting various parameters in optimizing by considering various constraints in the heat sink design, with optimum geometric parameters such as optimum fin thickness, optimum fin height, and optimum base height and optimum gap between the fins, etc.

R. Sam et al [18] designed an optimal heat sink by considering heat sinks which contain continuous rectangular fins, interrupted rectangular fins and above models with through holes. Based on the result obtained it was concluded that the interrupted fins are more efficient than the continuous. The paper also explains that the through holes for the interrupted fins has better performance than the interrupted rectangular fins with an advantage of reduction in weight due to material removal from the standard.

V. Himachandra Raju et al [1] conducted steady state thermal analysis to extract the temperature and heat flux distribution for a given heat input. Further, using cfd analysis, dynamic pressure variation, turbulence kinetic variation and Nusselt number at the tip of fin for varying velocities have been calculated.

Ahmed F. Khudheyer et al [6] conducted natural convection heat transfer for heat sink with rectangular fins for five different geometries (continuous fins, 1-interrupted fins, 4-interrupted fins, inclined fins and V-fins) at different heat flux values experimentally. This paper provides information that validates the facts that the average heat transfer coefficient increases with the increase in the value of the fins height, heat transfer coefficient increases by increasing spacing up to certain limit and it starts to decrease with the increasing in spacing more than the limit, increased length of fins (continuous case) causes a decrease in heat transfer coefficient.

Christian Alvin et al [19] held experimental tests and numerical simulations to investigate the thermal management of LED lamps with a variety of geometrical configurations of extruded-fin heat sinks. This paper also includes the usage of two kinds of interface heat transfer materials to determine their effectiveness in dissipating heat. The paper also deals with the effect of thermal conductivity of thermal interface material on the overall heat transfer rate of a heat sink.
Varun R Yadav et al [16] carried out steady state thermal analysis of fins by modifying its certain parameters such as geometry. In this study it is observed that triangular fins allow a great temperature distribution when compared to pin fin or rectangular fins.

3. Modelling of Heat sink using SolidWorks:

3.1 Design of Normal Rectangular Plate Fin

Heat Sink of rectangular plate fin is created in SolidWorks and saved in IGES format. A flat platform of 80x50x5mm is common in all designs. The designs of considered heat sinks are done using SolidWorks.

- Draw a rectangle of dimensions 80x50 mm and extrude with 5 mm.
- Click on the top view and draw a corner rectangle of dimensions 50x3 mm.
- Select the linear pattern and keep 9 fins on the top view.
- Extrude 9 fins with dimensions 30 mm

![Fig 1 Top view of the rectangular plate fin design](image1)

![Fig 2 Isometric view of Rectangular plate fin design](image2)
4 Steady State thermal Analysis of heat sink

4.1 ANSYS Work Bench

ANSYS Workbench is the framework upon which the industry’s broadest suite of advanced engineering simulation technology is built. An innovative project schematic view ties together the entire simulation process, guiding the user every step of the way. Even complex multi physics analyses can be performed with drag-and-drop simplicity [4].

4.2 Basic Calculations [14]:

\[ T_s = 80^\circ C, \ T_a = 30^\circ C \]
\[ T = \frac{(T_s + T_a)}{2} = \frac{110}{2} = 55^\circ C \]

At 55°C, properties of dry air
\[ \rho = 1.0765 \text{ kg/m}^3 \]
\[ \mu = 19.855 \times 10^{-6} \text{ Ns/m}^2 \]
\[ \nu = 18.46 \times 10^{-6} \text{ m}^2/\text{s} \]
\[ \beta = \frac{1}{T} \]
\[ Pr = 0.697 \quad \text{(where Pr is Prandtl number)} \]
\[ k = 0.02861 \text{ W/mK} \]

\[ Gr = \frac{g \beta (T_s - T_a) L^3}{\nu^2} \quad \text{(where Grashofs number)} \]
\[ (9.81 \times (1/ (55+273)) \times 50 \times (50 \times 10^{-3})^3 \]
\[ = \frac{(18.46 \times 10^{-6})^2}{(18.46 \times 10^{-6})^2} \]
\[ Gr = 548544.4023 \]
\[ Ra = Gr \times Pr = 382335.4484 \quad \text{(where Ra is Rayleigh number)} \]
\[ S_{opt} = 2.714 \times L / (Ra)^{1/4} = 6.12 \text{ mm} \]
\[ h = 1.31 \times k / \ S_{opt} \ = 6 \text{ w/m}^2\text{K} \]

4.3 Material properties of Aluminium

<table>
<thead>
<tr>
<th>S.No</th>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Density (( \rho ))</td>
<td>2719 kg/m³</td>
</tr>
<tr>
<td>2.</td>
<td>Specific heat (( C_p ))</td>
<td>871 J/KgK</td>
</tr>
<tr>
<td>3.</td>
<td>Thermal conductivity(( k ))</td>
<td>202.4 W/mK</td>
</tr>
</tbody>
</table>

Table 1 Properties of aluminium
4.4 Mesh generation and Boundary conditions:

The heat sink model is imported into the workbench design modeler and meshed with a four node three-dimensional tetrahedron element. The meshed model of the heat sink is shown in the Fig 3 and the mechanical Ansys workbench is used to mesh the heat sink.

![Fig 3 Meshing of heat sink model](image1)

The heat flow of 14W is given to the fin base as initial condition followed by the convective heat transfer coefficient to the remaining part of the sink with a value of $6 \times 10^{-6}$ W/mm$^2$ $^0$C.

![Fig 4 Loading boundary conditions](image2)
5. Results and Discussion:

5.1 Temperature distribution

1. Rectangular plate fin:

Fig 5 Temperature distribution of Rectangular plate fin (Side view)

The temperature distribution is obtained with 103.97°C of maximum temperature at the center of the base plate and minimum temperature of 103.14°C is obtained at the tip of the fins.

2. Staggered rectangular plate fin:

Fig 6 Temperature distribution of Staggered rectangular plate fin (Isometric view)

The temperature distribution is obtained with 105.3°C of maximum temperature at the center of base plate and minimum temperature of 104.37°C is obtained at tip of fins.
3. Circular pin fin:

The temperature distribution is obtained with 117.11°C of maximum temperature at the centre of base plate and minimum temperature of 115.6°C is obtained at the tip of the fins.

4. Elliptical pin fin:

The temperature distribution is obtained with 125.12°C of maximum temperature at the centre of base plate and the minimum temperature of 124.07°C at the tip of fins.
5.2. Heat Flux Distribution:

1. Rectangular plate fin:

Fig 9 Total heat flux of Rectangular plate fin (Front view)

The total heat flux distribution of orientation to X-axis is obtained with a maximum of 0.013763 W/mm² and minimum of 0.00037574 W/mm².

2. Staggered rectangular fin:

Fig 10 Total heat flux of Staggered rectangular fin (Isometric view)

The total heat flux distribution of orientation to X-axis is obtained with a maximum of 0.15775 W/mm² and a minimum of 0.00013696 W/mm².
3. Circular pin fin:

The total heat flux distribution of orientation to X-axis is obtained with a maximum of 0.028744 W/mm² and a minimum of 0.000339 W/mm².

![Fig 11 Total heat flux of Circular pin fin(Side view)](image)

4. Elliptical pin fin:

The total heat flux distribution of orientation to x-axis is obtained with a maximum of 0.00032633 W/mm².

![Fig 12 Total heat flux of Elliptical pin fin(Isometric view)](image)
5. Graphs:

<table>
<thead>
<tr>
<th>S.No</th>
<th>Type of fin</th>
<th>Temperature (°C)</th>
<th>Heat flux (W/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>1</td>
<td>Rectangular plate fin</td>
<td>103.14</td>
<td>103.97</td>
</tr>
<tr>
<td>2</td>
<td>Staggered fin</td>
<td>104.37</td>
<td>105.3</td>
</tr>
<tr>
<td>3</td>
<td>Circular pin fin</td>
<td>115.73</td>
<td>117.11</td>
</tr>
<tr>
<td>4</td>
<td>Elliptical pin fin</td>
<td>124.07</td>
<td>126.12</td>
</tr>
</tbody>
</table>

Table 2: Results of steady State thermal analysis

A graph is plotted between the maximum temperature obtained on the surface of each heat sink (on x-axis) and the geometric configuration of fins (on y-axis).

Fig 13 Variation of Temperature distribution for different configurations of heat sinks

Another graph is plotted between the maximum heat flux obtained in the surface of each heat sink (on X-axis) and the geometric configuration of fins (on Y-axis).

Fig 14 Variation of Total Heat Flux for different configurations of heat sinks
The graphs obtained above show the superiority of rectangular plate fin in the process of natural convection. From the above graphs, it is clear that the amount of heat dissipated by the rectangular plate fin is the highest when compared to other fin geometrical configurations. This can be evidenced by the minimum possible heat flux and temperature compared to the fins of the other geometric configurations. The elliptical pin fin recorded the highest amount of heat flux and temperature indicating the least amount of heat dissipation among the considered geometric configurations.

From the results obtained by analysis, it has been found that for a particular chosen material of aluminium and a constant convective heat transfer coefficient, the order in which heat dissipation occurs among the considered geometrical configuration is as below:

**Rectangular Plate Fin > Staggered Rectangular Fin> Circular Pin Fin>Elliptical Pin Fin**

6. Conclusions and Future scope:

6.1 Conclusions

In this study, a steady state thermal analysis has been carried out on heat sinks by varying the geometrical configuration of fins. The results are evaluated on the basis of temperature distribution and heat flux distribution which indicate the total heat dissipation from the entire surface under a fixed volume condition. The thermal performance of rectangular plate fin, staggered fin, circular pin fin and elliptical pin fin heat sinks are compared for the fixed base plate dimensions and fin height under fixed volume conditions. According to the results obtained, we can conclude that the rectangular plate fin heat sinks show better thermal performance in the most practical regions, especially in the process of natural convection. Plate fin array usually has larger surface area compared to other considered fins (of different geometries). So therefore, the rectangular plate fin dissipates the most heat from the equipment in the case of total heat dissipation as in the present study (especially in the case of natural convection). Therefore, it is recommended to use rectangular plate fin heat sinks when the total heat dissipation for a given volume of heat sink is to be maximized under a fixed volume condition.

6.2 Future Scope:

In the present study, for the considered optimized dimensions of the heat sink, chosen material of aluminium and a derived constant convective heat transfer coefficient of $6e-6 \text{ W/mm}^2\text{ °C}$, the rectangular plate fin served the purpose of total heat dissipation, way better compared to fins of other considered geometric configurations. The future work of this study may include modifications of design parameters of fins, orientation of heat sink, change of material, application of through holes etc. The considered modifications with respect to design and orientation can be optimized using various optimization techniques and finally a heat sink with desirable fin dimensions, material and properties can be obtained to yield better results (high heat dissipation) to enhance the life of expensive electronic components.

References:


[16] https://heatsinkcalculator.com/
