Optimization of Rectangular Fins Cooled by Force Convection Using Computational Fluid Dynamics.

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Abstract: The trends in electronics are toward decreasing size and cost, while increasing speed. Performance and reliability of operating devices can be achieved by increasing heat dissipated. As heat loads increase, the thermal management to keep junction temperatures within safe operating limits is becoming more critical. The heat sink optimization study allowed for a determination of the heat sink geometry, which would produce a minimum thermal resistance, while producing the highest heat dissipation. A flat plate heat sink with 50 mm x 58mm with different configurations was modeled using Solidworks and a thermal analysis was performed. The result of the thermal analysis was used to optimize the fin geometries. The fin geometries considered are the pitch, fin height, numbers of fin and fin thickness. An Aluminum alloy was used as fin material to cool a motor driver (IRFP150N) with a heat power of 50W. It is found from the results that the best design with larger heat dissipation capacity is when fin thickness is small, wider pitch and taller fin height. And this consists of (7) fins with (0.3 mm) fin thickness and 7mm pitch

Key words: (heat Sink, Flat plate, CFD, cooling, optimization, fin thickness).

INTRODUCTION

One of the challenges of electronic devices is thermal management, because overheating of electronic devices has become a major issue especially in devices and a Metal-Oxide Semi-Conductor Field Effect Transistor (MOSFET) drive electronics. This problem is also witness by many home, office and industrial appliance such as power inverters, stabilizers, personal computers, cellular phones etc. therefore, most of these devices require effective means of extracting the excess heat from the electronic device. Heat sink dissipates the heat from the electronic devices. Air-cooled heat sinks have been commonly used as a means for overseeing heat-related issues of electronics because of their adequacy and cost effectiveness. Air-cooled heat sinks are susceptible to relatively low heat transfer coefficients and have large base temperature variations (Mohan & Govindarajan, 2011).

Heat sink is a passive heat exchanger which transfers generated heat by an electronic or a mechanical device to a fluid medium that are often air or liquid coolant, the heat is then dissipated away from the device thereby allowing temperature control of the device. In personal computers, heat sinks are used to cool the central processing units, some chipsets and RAM modules. Heat sinks are designed to maximize its surface area in contact with the cooling medium around it which is sometimes air. Velocity of air, material choice, extrusion design and surface treatment are factors affecting the performance of heat sink. There are several design and arrangement of heat sink which are but not limited to the following;

- Straight rectangular uninterrupted fins
- Straight rectangular interrupted fins
- Inclined rectangular fins
- Knurled fins
- Triangular fins
- Pinned fins

In this study, a straight rectangular uninterrupted fin is considered with varying parameters of fin height, fin width; inter fin spacing as well as air flow rate to determine the performance of the fin. Recently in electronics a very complicated designs of air cooled heat sinks are used which dissipates heat to the surrounding by flow of large volume of air. The major challenges associated with heat sinks are; due to constraint in space, air should be blown at very high velocities and to maintain such velocities, big size fan has to be employed. Also air flowing at a very high velocity creates noise. More so, in air cooled units, there is no active cooling device so temperature below ambient condition is unattainable. Therefore, working at high speeds in the high ambient conditions had become extremely difficult. Processor and chips cooling is one of the bottlenecks in many electronics, so there is need for the design of effective cooling techniques. (Paulo & Heitor, 2011)

The study of rectangular fin by varying geometric parameters using numerical analysis as well as simulation will reveal the optimum and effective design techniques which will provides effective passive cooling and mitigate damaged caused by excess heat generated in electronic devices as well as other engineering applications

John et al. (2010) observed that heat sinks with circular pin fins perform better than heat sinks with square pin fins at low Reynolds number. Consequently, at high Reynolds number, heat sinks with square pin fins perform better than that with circular pin-fin. Further (Rubio-Jimenez et al., 2012) concluded that heat sinks with offset micro pin fin are good option for cooling the IC chips. John et al. (2010) observed that at low Reynolds number, the heat sinks with circular pin-fins shows better performance compared with heat sinks having square pin-fins and vice versa. (Rubio-Jimenez et al., 2012) concluded that the heat sink having offset micro pin fin is a good option for cooling the IC chips. Tullius et al. (2012) studied numerically the effect of fin shapes in mini channels and established that the optimal fins shape is dependent on the flow rate of the fluid through the channel. Jadhav et al (2019) investigated geometrically enhanced heat sinks through experiment by using water and concluded that water has many potential to cool the high heat generating microprocessors. Shyu et al., (2017) numerical study concluded that by locating a rectangular pin fin in a microchannel heat sink, a reasonable heat transfer could be achieved (Jadhav et al., 2018).

Flow velocities, fluid type selection, material choice for heat sinks with different channel surface modifications are some of the related areas of heat sink where research is being carried out. It was observed by many researchers that the use of fins in micro channel enhances the thermal performance. Most researchers reported that elliptical pin fins usually exhibit poor thermal performance, but the pressure drop offered by the elliptical pin fins is minimum among the different pin fin shapes under consideration (Jadhav et al., 2018).

MATERIAL AND METHODS

Model Description

The geometry flat plate heat sink used for cooling in the research is shown in Figure 1. The work seeks to optimize the fin parameters such as the height, fin thickness, the pitch and numbers of fin. The heat sink is used for cooling IRFP150N which generate up to 50W and can operate at a maximum temperature of 150^{o}C. The heat sinks are produced from an Aluminum alloy (AL6061). A thermal simulation of the heat sinks was carried out using Solidworks with difference configuration shown in Table 1.

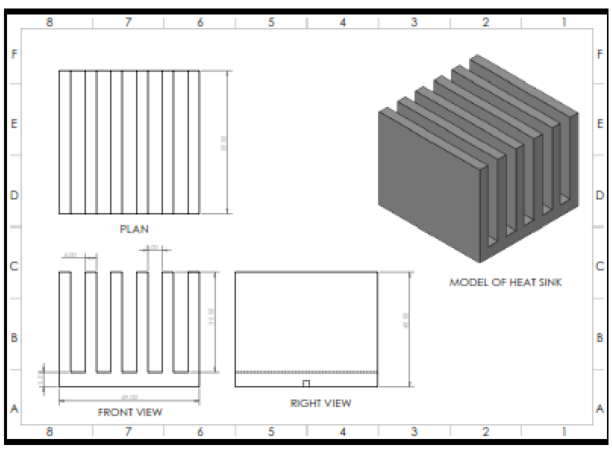

Figure 1: Geometry of the Heat Sink

Governing Equations

The Conservation of Mass, Momentum and Energy within an infinitesimal small fluid element are the fundamental governing equations of all Computational Fluid Dynamics simulations. The Conservation of Momentum laws (equation) are also known as Navier-Stokes equations, (Piyush, Bhushan, & Praveen, 2016). The governing equations for heat transfer and fluid flow are often formulated in a general form for the simplification of discretization and programming, which has achieved great success in thermal science and engineering. These equations speak physics. They are the mathematical statements of three fundamental physical principles upon which all of fluid dynamics are based:(1) mass is conserved;(2) F = ma (Newton's second law); (3) energy is conserved. The purpose of this section is to present basic equations of fluid motion.

Continuity equation

$\frac{D\rho}{Dt} + \rho\nabla.\overline{V} = 0$ (1) (Hansa, et. al, 2019)

The fluid density remains unchanged for all compressible flows, i.e. independent of time and space. And hence $\frac{D\rho}{Dt} = 0$and therefore, the continuity equation is given as $\nabla.\overline{V = 0}$. (2)

Momentum equation;

The momentum of the moving fluid in x,y and z directions are expressed by equation 3 – 5.

$$for\ x - component: \frac{\partial\rho(\rho u)}{\partial t} + \nabla.(\rho u.\overline{V}) = \frac{\partial p}{\partial x} + \frac{\partial\tau_{xx}}{\partial x} + \frac{\partial\tau_{xy}}{\partial y} + \frac{\partial\tau_{zx}}{\partial z} + \rho f_x \quad (3)$$

$$for\ y - component: \frac{\partial\rho(\rho v)}{\partial t} + \nabla.(\rho v.\overline{V}) = \frac{\partial p}{\partial y} + \frac{\partial\tau_{xy}}{\partial x} + \frac{\partial\tau_{yy}}{\partial y} + \frac{\partial\tau_{zy}}{\partial z} + \rho f_y \quad (4)$$

$$for\ z - component: \frac{\partial\rho(\rho w)}{\partial t} + \nabla.(\rho w.\overline{V}) = \frac{\partial p}{\partial z} + \frac{\partial\tau_{xz}}{\partial x} + \frac{\partial\tau_{yz}}{\partial y} + \frac{\partial\tau_{zz}}{\partial z} + \rho f_z \quad (5)$$

(Ejehson, et. al, 2016)

Energy equation

$$\rho\frac{D}{Dt}\left(e + \frac{V^2}{2}\right) = \rho q + \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right) - \frac{\partial(up)}{\partial x} - \frac{\partial(vp)}{\partial y} - \frac{\partial(wp)}{\partial z} + \frac{\partial(u\tau_{xx})}{\partial x} + \frac{\partial(u\tau_{yx})}{\partial y} + \frac{\partial(u\tau_{zx})}{\partial z} + \frac{\partial(v\tau_{xy})}{\partial x} + \frac{\partial(v\tau_{yy})}{\partial y} + \frac{\partial(v\tau_{zy})}{\partial z} + \frac{\partial(w\tau_{xz})}{\partial x} + \frac{\partial(w\tau_{yz})}{\partial y} + \frac{\partial(w\tau_{zz})}{\partial z} + \rho\vec{f}.\vec{V} \quad (6)$$

Design of Experiment/Optimization Technique

Design of experiments (DOE) is a statistical technique for quickly optimizing performance of systems with known input variables such as an electronics cooling system. Use of DOE in the heat sink design is to obtain optimum thermal characteristics. In the design of the heat sink there must be identified factors having the greatest impact on improving the capacity for heat dissipation. The geometrical factors of the structure of the heat sink, which are selected as design parameters, are the height of the fins, the fin thickness, the number of fins and pitch of the heat sink. Full Factorial Experiment for four factors for each one on two levels is used as a tool for the realization of DOE. Table 1 shows the four design parameters, whose influence is analyzed.

Table 1: Design Variables

S/No	**Factors**	**Level 1**	**Level 2**
1	No of Fin	6	7
2.	Fin Thickness (mm)	3	4
3.	Fin Height (mm)	35	40
4	Pitch (mm)	5	6

Thermal Simulation method

1. 3D model of the Heat sinks having different configurations was created.
2. A thermal study was from the simulation icon.
3. Materials were defined for both the heat source and the heat sink.
4. And thermal loads/restraints were defined, i.e. the power source (50W) and the mode of heat transfer (convection).
5. Contact settings were also defined between the heat sink and the heat source.
6. For assemblies and multi body parts, the proper contact settings were defined.
7. Fine mesh was created for the model and then the study was run.

RESULTS AND DISCUSSION

CFD Results

Table 2, shows sixteen (16) different configurations used for the thermal analysis of the heat sink and the responses recorded from the CFD results. i.e. the heat sink total surface area, the minimum and maximum temperature of the heat sink and total heat dissipated by the heat sinks. The results were extracted from the color plots in Figure 2. From results configuration run number 1 has the heat sink highest temperature, while run number 16 has the heat sink lowest temperature. This two heat sinks also have the smallest and largest surface area for dissipating the heat.

Table 2: Responses from the CFD analysis results

Run	**No of Fin**	**Fin Thickness (mm)**	**Fin Height (mm)**	**Pitch (mm)**	**Area (m^2)**	**Tmin (^oC)**	**Tmax (^oC)**	**U ($W/m^{2o}C$)**	**Q=UCT**
1	6.000	3.000	35.000	5.000	2.748	79.100	151.000	14.294	2824.233
2	6.000	3.000	35.000	7.000	2.859	86.600	120.000	14.294	1364.946
3	6.000	3.000	40.000	5.000	3.067	82.600	115.000	14.307	1421.718
4	6.000	3.000	40.000	7.000	3.177	80.400	114.000	14.307	1527.253
5	6.000	4.000	35.000	5.000	2.858	87.600	104.000	14.294	670.039
6	6.000	4.000	35.000	7.000	2.967	84.700	117.000	14.294	1369.856
7	6.000	4.000	40.000	5.000	2.858	87.500	119.000	14.307	1288.124
8	6.000	4.000	40.000	7.000	2.964	84.800	122.000	14.307	1577.568

9	7.000	3.000	35.000	5.000	3.208	80.600	113.000	14.294	1485.711
10	7.000	3.000	35.000	7.000	3.340	77.800	111.000	14.294	1585.037
11	7.000	3.000	40.000	5.000	3.579	79.800	113.000	14.307	1700.021
12	7.000	3.000	40.000	7.000	3.711	71.900	107.000	14.307	1863.600
13	7.000	4.000	35.000	5.000	3.334	78.700	110.000	14.294	1491.643
14	7.000	4.000	35.000	7.000	3.466	76.100	109.000	14.294	1629.969
15	7.000	4.000	40.000	5.000	3.844	73.300	105.000	14.307	1743.401
16	7.000	4.000	40.000	7.000	3.840	71.100	105.000	14.307	1864.394

The results of the thermal analysis conducted on the 16 heat sink configuration are shown in Figure 2. The graphs indicate the highest and the lowest temperature recorded for each heat sink configuration.

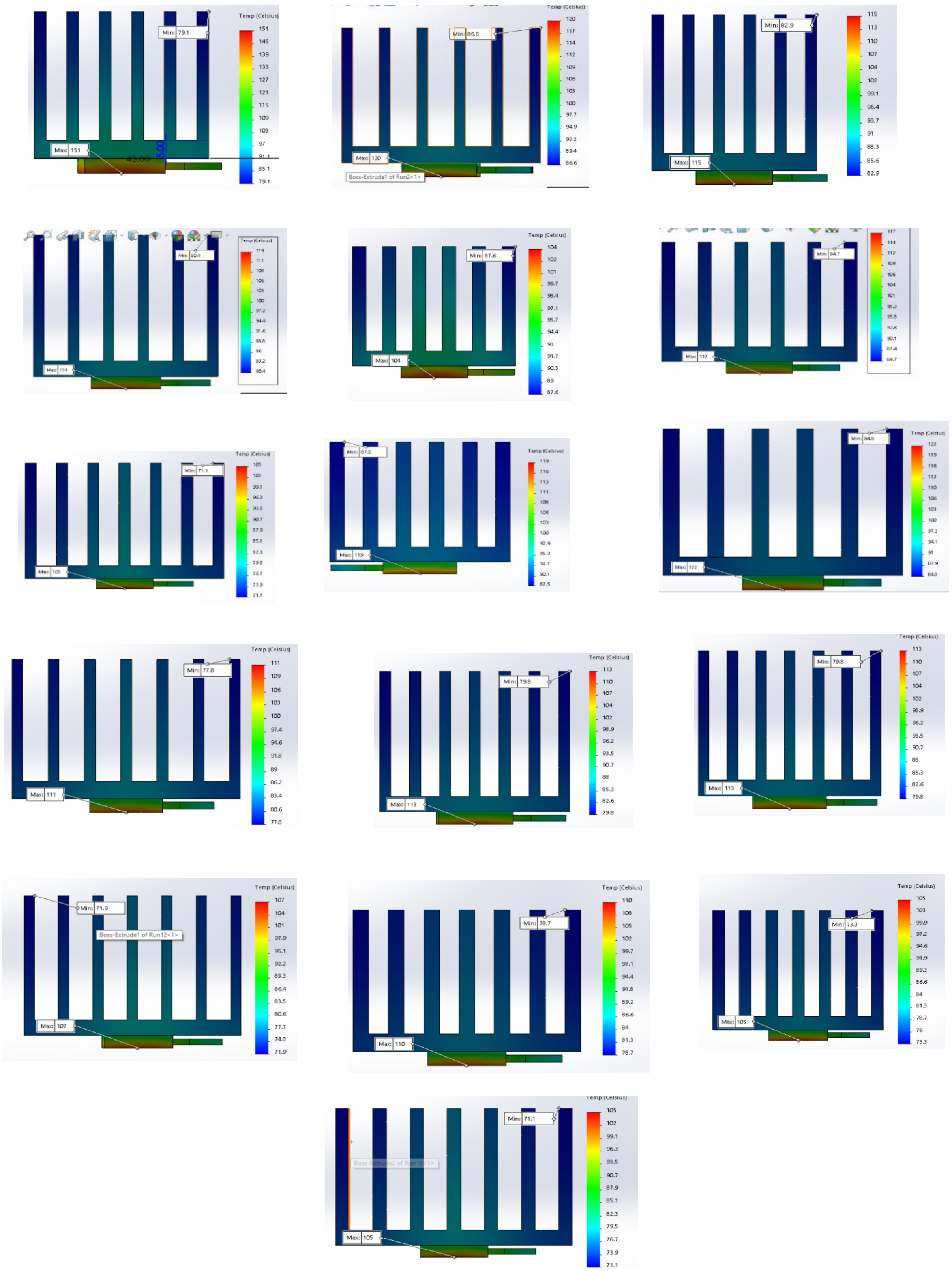

Figure 2: Temperature Color May of the Heat Sinks.

Optimization Results

The optimization of the design variables were carried out using Minitab 17 software and the key results are the main effect plots, interraction plots and contour plots, as shown in Figures 3-5. The graphs (Figure 3) reveals that the heat sinks with 7 numbers of fins dissipate more heat than the heat sinks with 6 numbers of fins. Also, the heat sinks that have 3mm thickness perform better than the heat sinks with 4mm thickness and lastly, the heat sinks with 7mm pitch have higher heat capacity that the heat sinks with 5mm pitch.

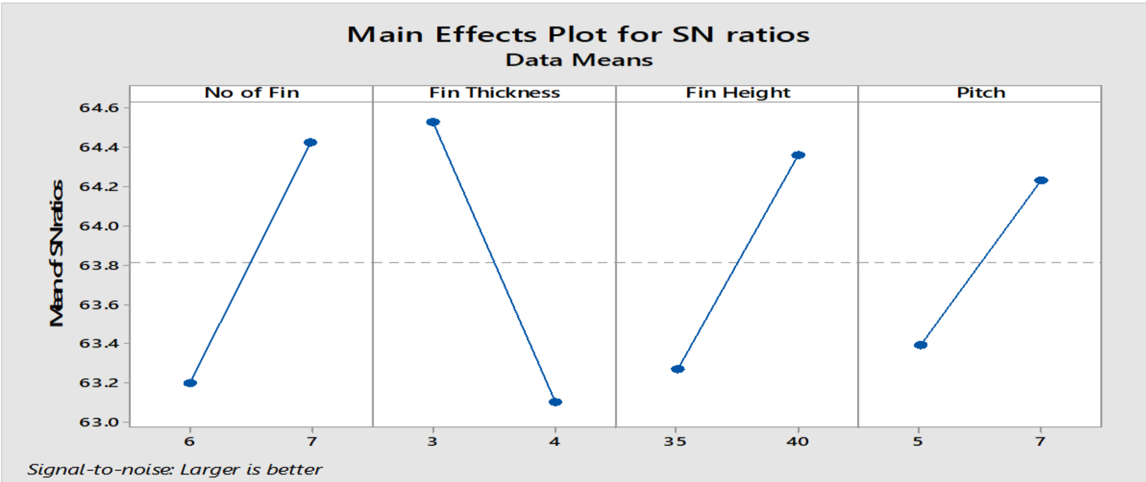

Figure 3: Main effect for SN Ratio.

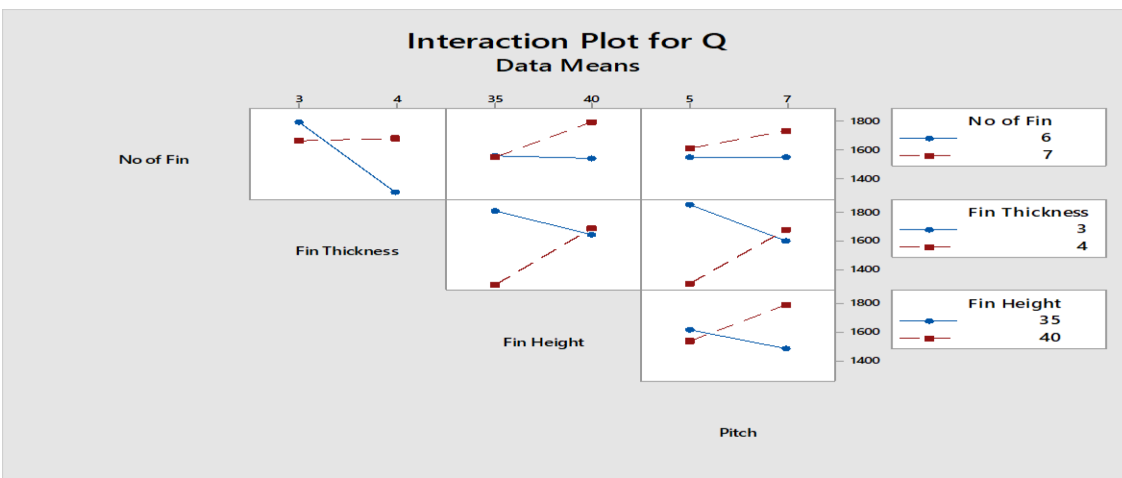

Figure 4: Interaction Plots for Quantity of Heat Dissipated.

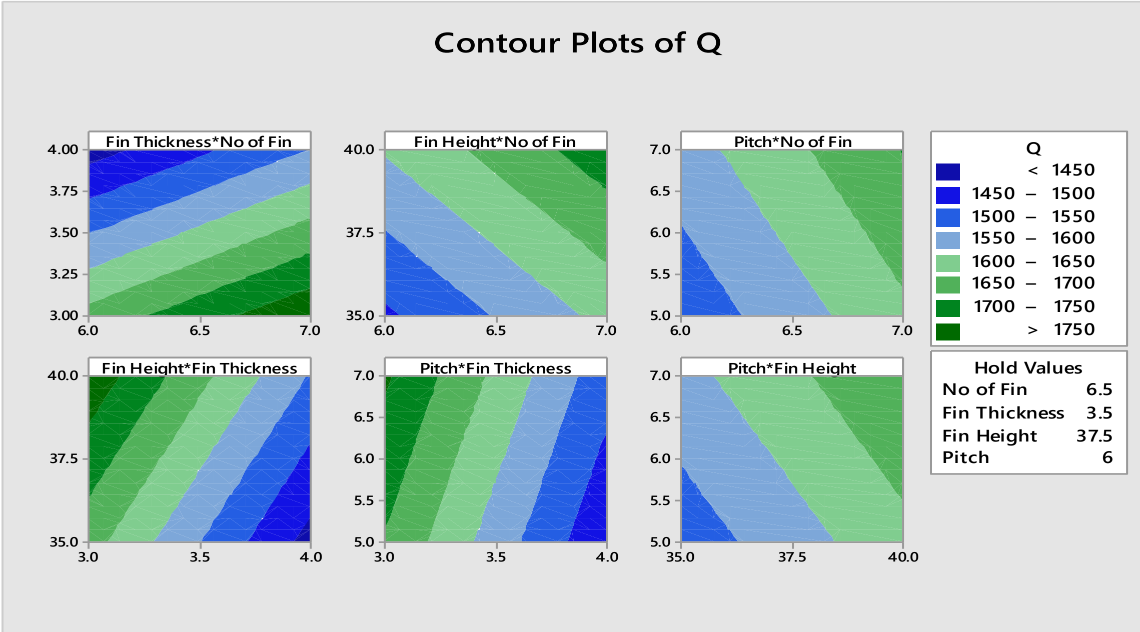

Figure 5: Contour plot the design variables and the Amount of Heat dissipated.

Figure 5, reveals the possible comfort zones for the combinations of the design variables. This shows that the small fin thickness and higher numbers of fins, higher fin height vs higher number of fins and higher number of fins with longer fin height will dissipate more heat than vise visa combinations. Similarly, slimmer fins that are taller, wider pitch with thinner fins and taller and wider fins will produce a cooler heat sink than other configurations.

CONCLUSION

The objective of this paper is to optimize the geometry of the flat plate heat sinks with different configurations for cooling motor drivers like IRFP150N and thereby produce an optimum thermal performance heat sinks by using the design variables from the IRF150N datasheet. The flat plate heat sink model was used to explore the optimal dimensions of heat sink cooled under forced convection. A 2^4 full factorial design was used with CFD thermal analysis to achieve the objectives of the research work. It was found from the results that the best design of a (50 x 50 x 5) mm aluminum heat sink with a temperature input of (50^0C) consists of (7) fins with (0.5 mm) fin widths. The optimum design variable obtain are 3mm fin thickness, 40mm fin height, 7 numbers of fin and 7mm pitch.

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