DESIGN AND ANALYSIS OF NORMAL FIN FOR AN ENHANCED THERMAL ENERGY STORAGE SYSTEM

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Abstract- The engine system is regarded as a significant automobile component imposed to increased variations in temperature as well as thermal stress. For cooling the engine, fins are utilized which further increases the transfer of heat rate. The principle of this article is to maintain an energy storage system in steady state condition by adding fins. The task of thermal analysis is performed on engine fins which identifies the amount of dissipated heat. The modeling and meshing of fins are carried out along with the analysis of conductive as well as convective cooling.The simulation is performed utilizing ANSYS software and the generated results showed improved thermal behaviour as well as optimized shape.

Keywords: Engine fin, FEA, convective cooling, ANSYS, notch.

1 INTRODUCTION

A need for high thermal system efficiency in a variety of engineering applications has sparked a lot of interest in finding improved methods for increasing transfer of heat rates in thermal engineering models. The development of compact thermal devices to achieve high performance, reduced price, low weight, as well as small size is also required. Heat exchanger is a collection of equipments which joins two or more fluids as well as contacts a fluid by a solid surface in diverse temperatures to provide simpler and more effective thermal energy transmission [1-4].Heat exchangers are widely utilized by broad chemical reactions as well as other applications commercial in nature [5-8], including radiation, evaporation, condensation, as well as air-conditioner systems. When most engineering systems are turned on, they generate heat.

The overheating of system produces heat, which becomes a major cause of system failure. Processes for removing unnecessary heat from a device or part are critical in order to avoid damaging effects as well as overheating issues. As a result, several experiments or product inventions have been carried out by researchers in order to find the most efficient manner for heat dissipation from a device or object. Fins are a form of devices utilized for dissipation of heat in heat transfer enhancement system [9]. It was designed by various researches examining the impact of complicated geometries of fin on thermal efficiency, and it has a relative high heat transfer rate as well as a portable design [10]. Theheat exchangers, which are used in a variety of applications, transfer a significant amount of energy utilizing fins. Since the heat exchangers used in these applications require a considerable amount of power, increasing their performance would save a significant amount of energy [11].

The low thermal conductivity, on the other hand, restricts how much energy to be accumulated and recovered in a considerable time duration. As a result, the range of real-world implementations is narrowed. Most applications necessitate rapid response to transients arising from generation [12] or demand peaks. Utilizing high conductivity fins to improve the storage unit's efficiency is a possibility. In comparison to other heat transfer enhancement methods, this alternative has a lower construction cost and is easier to fabricate and maintain [13]. Mounting specially shaped fins on the tubes is the general framework of a fin tube within heat exchanger. The best technique is that the fin base is to be laid down in a manner and so the tube is connected to the fin material in an integral manner, giving the fin as well as tube a larger thermal contact region. To join the tubes with the fins, various mechanical methods such as galvanising, aluminium are used. The most of fin as well as tube heat exchangers are designed to operate within some temperature of operation as well as pressure restrictions of the device fluid along with equipment needed for a particular application. The tube material as well as fin, and perhaps even the mechanical system utilized for securing the fin base with tube, determine the fin's contact with the tube. Inappropriate fin-to-tube contact produces resistance that is hard to gauge and has an effect on heat transfer between the fins and tubes of the heat exchanger [14, 15].Considering support of the fins, the extraction of heat is easily performed from thermal systems due to the extended surfaces. Fins with suitable structures aid for improving heat transfer efficiency (HTP); Consequently, fins with unsuitable structures will limit HTP [16]. The enhancement of the thermal efficiency of the fin and tube heat exchanger has an effect on global conserving energy, as well as protecting the environment from pollution created by the generation of energy. The air side has the most thermal resistance and hence the air side heat transfer enhancement is often chosen [17].

In [18], an approach was proposed with a procedure for analysing the geometry of fins of a hot-side heat exchanger on the output attributes of a Thermoelectric generator (TEG) using Computational Fluid Dynamics (CFD) and some simpler mathematic equations. The thermal as well as electrical efficiency of a TEG device consisting of a coolant, heat exchanger, and a thermoelectric module was also investigated using a similar method [19]. Experiments, on the other hand, have not confirmed these methods. [20] presented a numerical simulation approach for evaluating the thermal as well as electrical efficiency of a TEG with single thermoelectric module using CFD and a finite element (FE) model. The method's reliability is also verified by additional tests. The design of FE models for a wide-scale TEG device with numerous thermoelectric modules, on the other hand, it was tedious, and the cost of computational resources is very high [21]. The most popular types of fins are radial as well as longitudinal fins, though several other forms, along with some other unusual ones, have been proposed. The use of latent heat thermal storage units including radial arrays of fins for both solidification as well as melting has been thoroughly investigated in the past [22]. Different heat transfer resistances exist in the heat transfer phase within the fluid in the tubes as well as the air flowing across the tube bank. Transfer of convective heat across fluid within the tubes, touch resistance between the fins and tubes, conduction across tubes as well as fins, and convective transfer of heat in the air are the means of convective transfer of heat. Since the heat exchanger’s air portion has been shown to have the highest covering of total resistance, heat transfer enhancement techniques have historically concentrated on the air side [23, 24].

Henceforth, an efficient design and analysis of normal fins is proposed with the contributions given as,

- Thermal analysis of engine fins to identify heat dissipation.
- Modeling and meshing of fins along with baseline, conductive and convective cooling analysis.
- FEA and ANSYS software is utilized for simulation.

The arrangement of paper is: Section 2 elucidates the relevant works. Proposed framework is detailed in section 3. Results as well as discussion are explained in section 4. Finally, work summary is given in section 5.

2 RELATED WORKS

Min et al [25] described a method for cooling which improved the degraded ventilation as well as the dissipation of heat in a sink with a horizontal fin. This sink was affixed on a naturally convected LED module. Response surface methodology was utilized for optimizing the geometry and the performance of cooling was analysed in comparison with the traditional methodologies.

Lihua et al [26] presented an approach in which the deviated fins are analyzed and the variation occurred within the original value as well as the theoretically obtained value was determined. A device was designed for directly measuring the variation and the relation between the variation and the displaced area was estimated. The effective ad accurate functioning were verified with the contrast of calculating as well as simulating depending on original parameters for design.

Mohammad et al [27] dealt with optimizing the shape of an inverted fin which was penetrated within a model generating heat which was further extracted towards the cool surrounding. An optimal geometric structure was obtained due to which the peak temperature is minimized. The increased range of excessively existing temperature was calculated and a numerical solution was performed for delivering the temperature field.

Syed et al [28] analysed transfer of heat in a heat exchanger with a finned double-pipe. It comprised of longitudinal fins with varying thickness and the boundary conditions required for the transfer of heat were investigated. A friction factor was employed for considering the complete performance of the proposed approach. The obtained results denoted the efficient functioning with minimization of weight, cost as well as frictional loss.

Rao et al [29] presented a design for optimizing a heat sink with plate-fin utilizing a design of multi-objective in nature. The rate of entropy generating as well as the cost of material with several restrictions were considered for measuring the heat sink performance. The performance of dissipation of heat was estimated using a finite elemet software and resulted in a competitive performance when compared to existing algorithms.

Karima et al [30] performed numerical simulations of three dimensions for exploring the vortex generator performance in plate fin heat exchanger. The functioning of the introduced approach in the presence as well as absence of baffles was compared and the effects regarding the perfolation shape was analysed. The case with the presence of baffles revealed excellent results.

3 PROPOSED METHODOLOGY

In order to maintain the system in a condition of steady state, the generated heat in the system gets conducted across the walls and boundaries and suffers continuous dissipation. The dissipated heat amount has to be large with the transfer of heat through convection

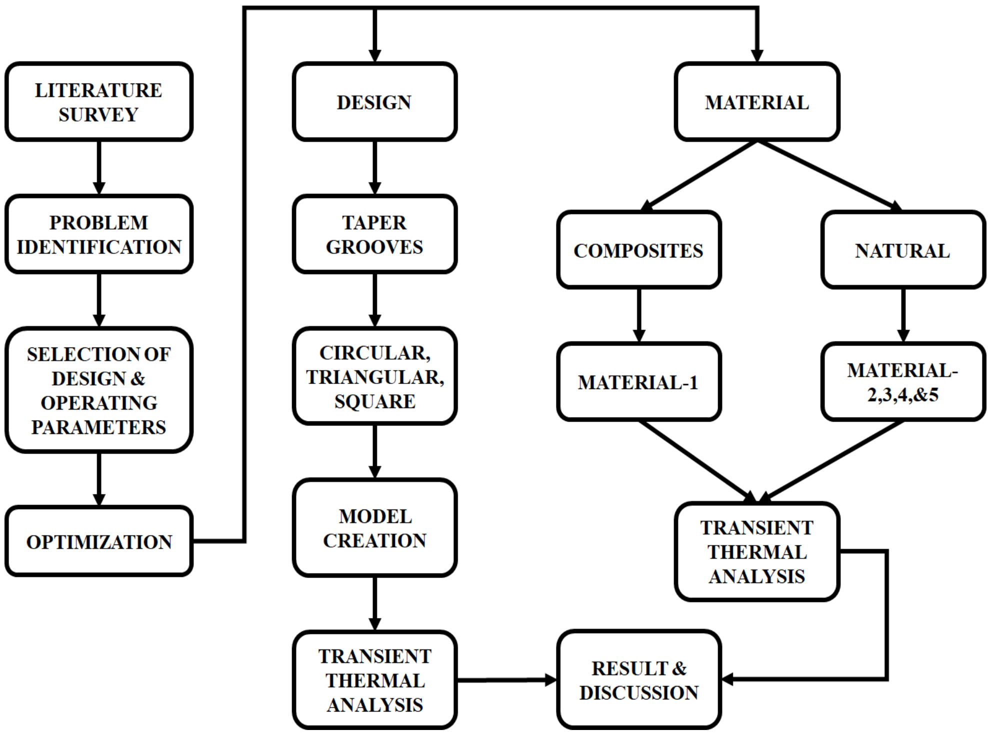

Figure 1 Proposed process flow

within the surface as well as the surroundings of fluid. The increase of heat is performed by the attachment of fins to the system surface. These fins are the metals of thin strips. The flow diagram of the proposed method is given in figure 1.

Initially, the survey related to the research as well as the problems are to be identified. The parameters to be utilized are then selected and designed. The optimization of parameters and materials is performed. The design of the fin is of any shape according to the requirement and the corresponding model is created. The material is also choosen and its thermal analysis is performed.

3.1 Modeling

Generally, the temperature of ambient air is regulated at 25^{o}C as well as the evaluation of thermophysical properties are performed at the temperature of fin and is given by,

$$T_F = \frac{1}{2(T_A+T_B)} \quad (1)$$

Where, T_F→ temperature of fin
T_A → ambient temperature
T_B→ temperature of base plate

The original rate of heat transfer is given by,

$$Q_T = Q_I - Q_L \quad (2)$$

Where, Q_I→ input heat
Q_L→ loss of heat

And

$$Q_L = \frac{K_B A_B (T_B - T_A)}{X} \quad (3)$$

Where, K_B→thermal conductivity of the material
A_B→ cross sectional area of the material
X→ material thickness

The average value of heat coefficient is estimated from,

$$H = \frac{Q_T}{A(T_B - T_A)} \quad (4)$$

Where A→ fin cross sectional area.

The transfer of heat is improved with the help of fins by two ways. They are,

- Creation of turbulent flow across the geometry of the fin thus degrading the thermal resistance in the film which is stagnant. This film occurs due to the parallel flow of fluid in the surface of the solid.
- Fin density increase which further improves the area of heat transfer that contacts the fluid.

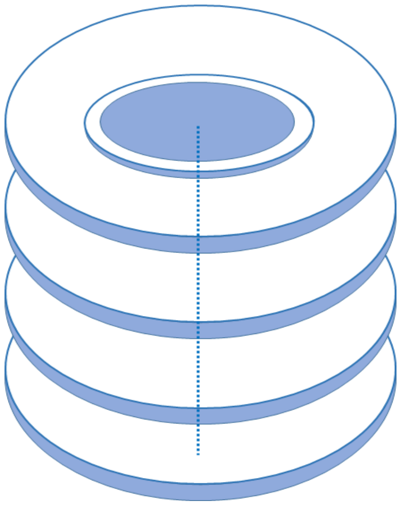

Figure 2 Isometric model

The isometric model of the fin is shown in figure 2. The geometry of fin as well as density which generate the flow of turbulent as well as increase the performance further improves pressure drop. This is considered as a critical requirement in majority of applications with improved performance. The optimal geometry of fin as well as combination of fin density is regarded as a concession of pressure drop, size, performance and weight. Apart from the geometry of fin, the parameters like height, spacing, thickness and pitch are also varied to increase the performance. Generally, the thickness of fin ranges from 0.005 mm to 0.01 mm, height ranges from 0.03 mm to 0.5 mm and density ranges from 8 to 30 fins per inch.

3.2 Meshing

The analysis of the models of the engine fins is performed by ANSYS software. The meshing of the models are carried out utilizing the default settings with a value of 0.5 corresponding to a measuring scale of -100 to 100. If the mesh relevance is set to higher value of 100, the mesh is refined to 185236 nodes as well as 95421 elements and an increase of three-times the mesh node count. When the mesh parameters considered as default are accepted, these parameters are utilized for generating increased number of results which are accurate. During the cooling analysis of convection type, which involves assembly fins, the complicated geometry model as well as computable resources demand reduction of models to quarter part of actual geometry. The model is sectioned in a conservative manner and hence the quarter geometry consists of minimal surface area for cooling related to possible four quarters. With ANSYS, initially the meshing of model occurs followed by the application of boundary conditions and finally analysis is carried out.

3.3 Model Inputs of FEA

The boundary conditions of the engine fins in the normal plant operation are to be influenced. The coefficients for the transfer of heat are estimated for,

- Inner region of pressure housing.
- Outer region of pressure housing under engine fins.
- Outer region of engine fins.
- Outer region of pressure housing over the engine fins.

The heat transfer coefficient of engine fins is estimated with the treatment of engine fin as flat plate, hence the engine fin surfaces possess similar heat transfer coefficient. In general, the data related to testing as well as operating plant reveals an increase in temperature of cooling air when it flows over the engine fin. This temperature increase is approximately of 50^{o}F and is integrated into the models of FEA.

3.4 Analysis of Baseline Cooling

The analysis of baseline cooling in engine fins is carried out with the application of loads to several FEA model components. The heat loads are termed as the attributes experienced by the pressure housing as well as engine fins while in normal stepping functions.

3.5 Conductive Cooling Analysis

The analysis of conductive cooling is carried out by the initial application of heat loads towards pressure housing as well as components of engine fins. The application of cooling convection loads is replaced with the holding of surfaces at particular temperature equal to 100^{o}F. This process of surface holding at particular temperature intends a conductive apparatus to remove heat from the engine fins. A normal component cooling water is generally present, anyway a temperature of 100^{o}F related to water is considered for the analysis. This is for the accounting of potentially imposed heat loads over the cooling water due to its flow along the reactor to every fin.The component cooling water's flow rate is regarded as appropriate for maintaining the conductive pooling model at fixed temperature under increased heat flux which is potential in nature. The thermal conductivity of each engine fin which constitute various internal groove system are referred as the inputs of the analysis of heat transfer. The analysis of conductive cooling assumes the following conditions.

- The flat sides of the engine fins are to be maintained at fixed temperature, this further performs correlation towards straight-sided apparatus which is utilized on engine fins.

- The flat side as well as the angle surface of the engine fin are to be cooled conductively. This performs correlation towards an apparatus and is described within flat edges as well as inside angle of engine fins.

3.6 Convective Cooling Analysis

The analysis of convective cooling is carried out by the application of heat loads as well as convective cooling loads in the ANSYS model along with engine fins added. Since the convective cooling amount depends on the area of the surface, the cooling convective transfer of heat increases with the increase in area which further results in minimal component temperature of engine fins.A turbulent cooling air flow occurs over the surface of the engine fins and the air flow is assumed completely over the external engine fin surface.

3.7 Modeling and Properties of Material

The design of the cooling fin utilizes aluminium material and the three various notch types choosen for the analysis are given as,

- Holed fins
- Rectangular notch fins
- V-shaped notch fins

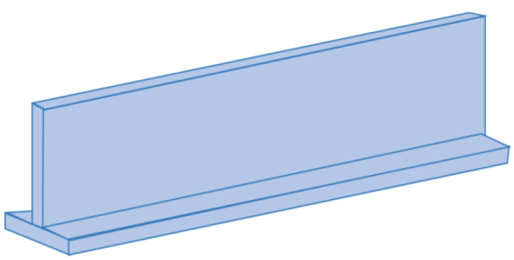

Figure 3 Fin without notch

The design of fins without any notch is indicated in figure 3.

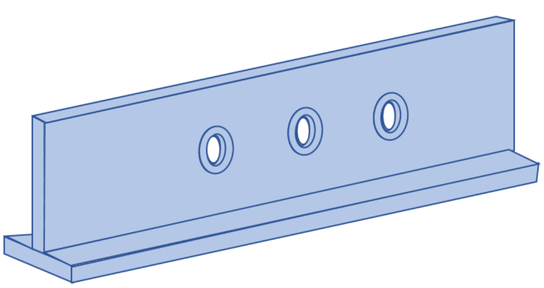

Figure 4 Fin with holes

The design of fins with holes is indicated in figure 4.

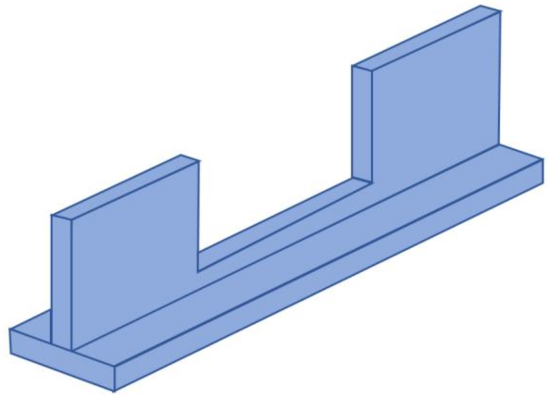

Figure 5 Fin with rectangular notch

The design of fins with rectangular notch is indicated in figure 5.

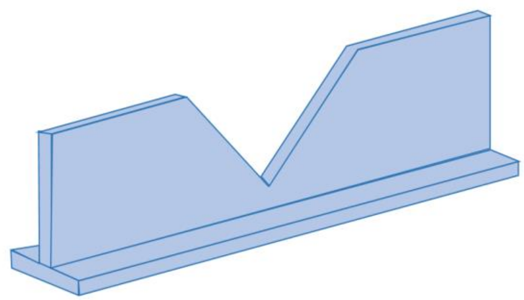

Figure 6 Fin with V-shaped notch

The design of fins with V-shaped notch is indicated in figure 6.

The analysis of cooling fins is performed with the utilization of aluminium since it provides an efficient thermal as well as electrical conductivity. Aluminium has the ability to perform as a superconductor at a temperature of 1.2K which is critical in nature. It also possess the characteristic of less weight.

4 RESULTS AND DISCUSSION

FEA deals with the process of failure prediction because of unaware stress indicating areas with issues in the material as well as permitting the designer to identify the theoretical stress. FEA generally comprises of three steps named as preprocessing, analysis and postprocessing. Initially, in preprocessing, the portion which has to be analysed is constructed by the user and the geometry is portioned ito several discrete regions termed as nodes. The preparation of the models utilize graphical preprocessor for assistance. The preprocessor overlay the mesh and hence FEA is performed efficiently. During analysis, the prepared dataset is utilized as finite elementcode input and this task outlines the functioning for the analysis of linear elastic stress. Finally, in postprocessing, examination is performed by the user across the code generated numbers which results in lists of displacements as well as stress in discrete model location. Generally, the display of postprocessor performs overlay of contours denoting the stress level of model.

Figure 7 denotes the considered engine fin model which is initially meshed followed by the application of boundary conditions and then analysis is performed.

Figure 8 denotes the meshed fin. Meshing is performed to obtain results with improved accuracy and precision. The complete volume of the specimen is covered considering the parameters like outlet, inlet, heat flux and fin surface.

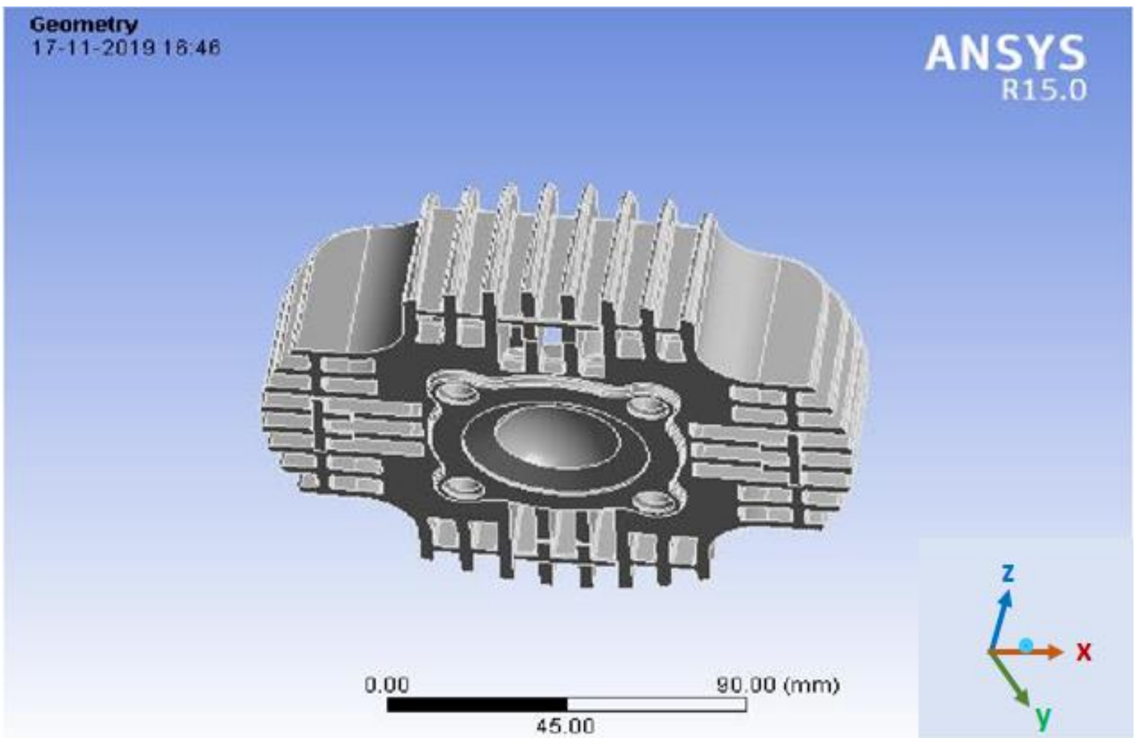

Figure 7 Engine fin

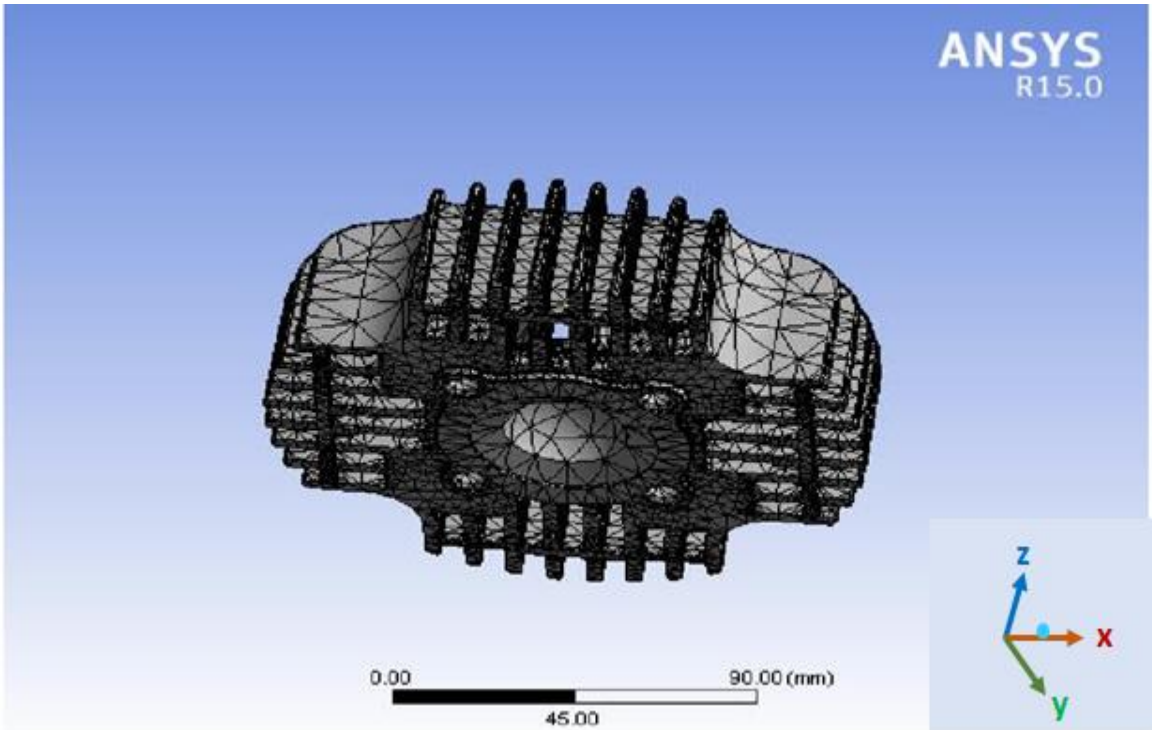

Figure 8 Mesh

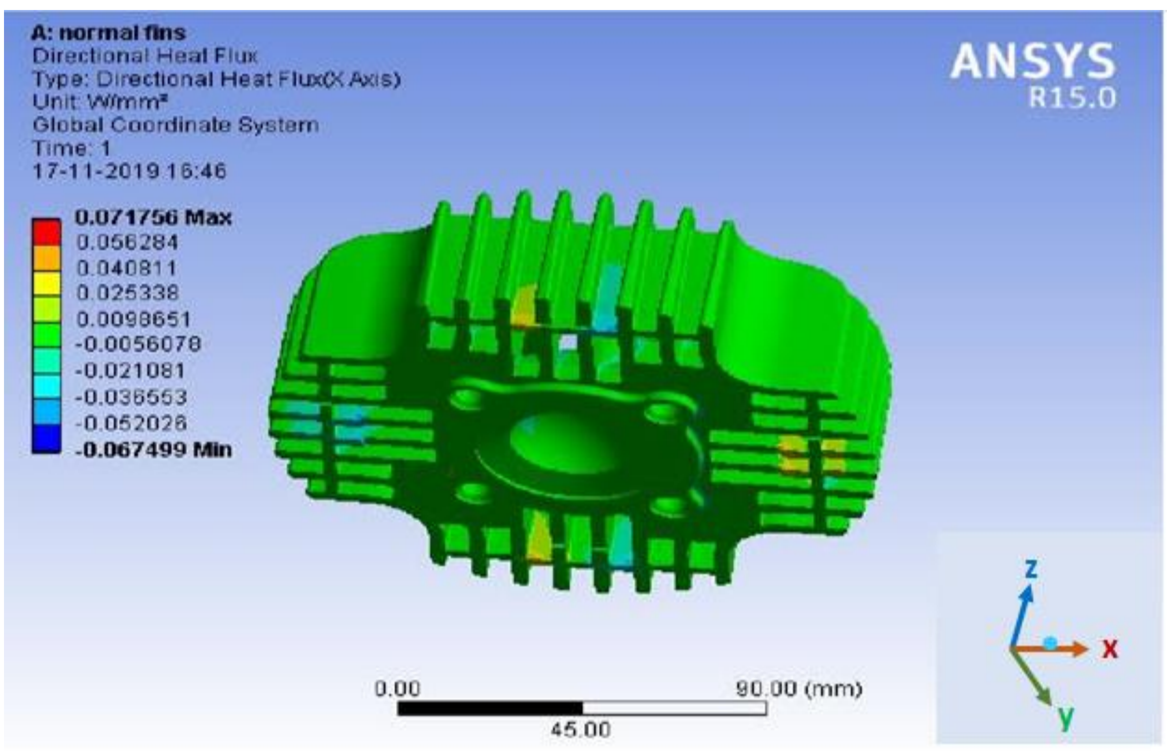

Figure 9 Directional heat flux

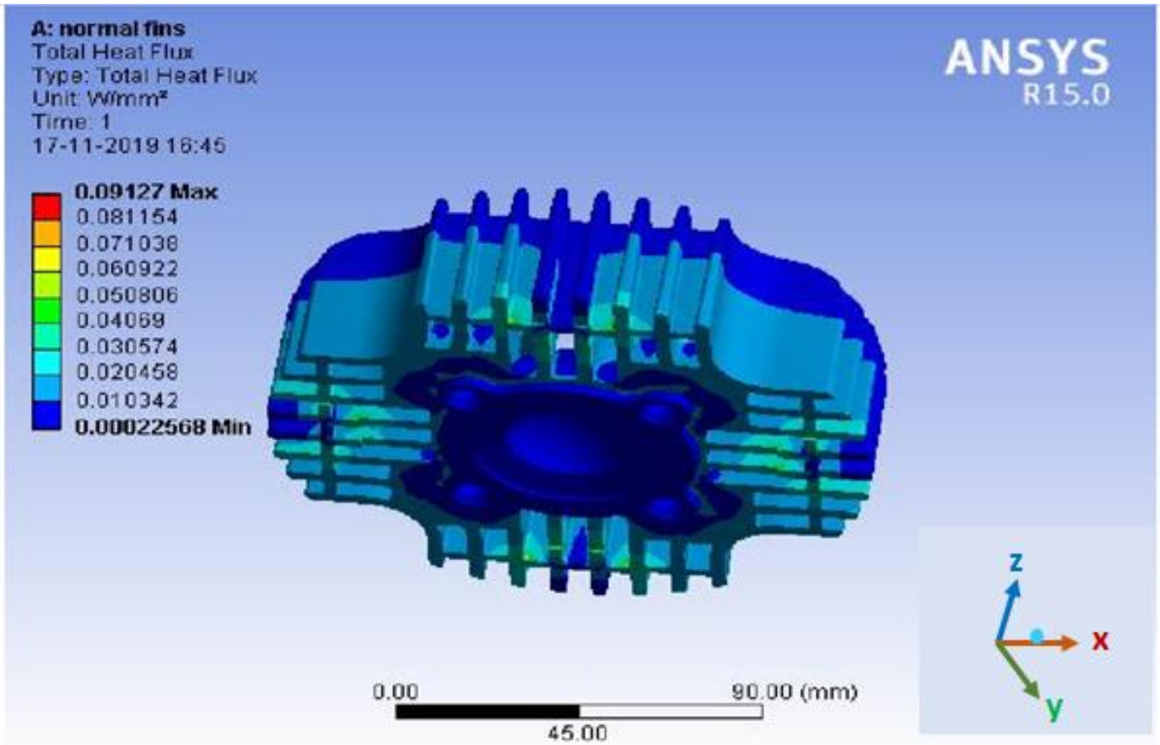

Figure 10 Total heat flux

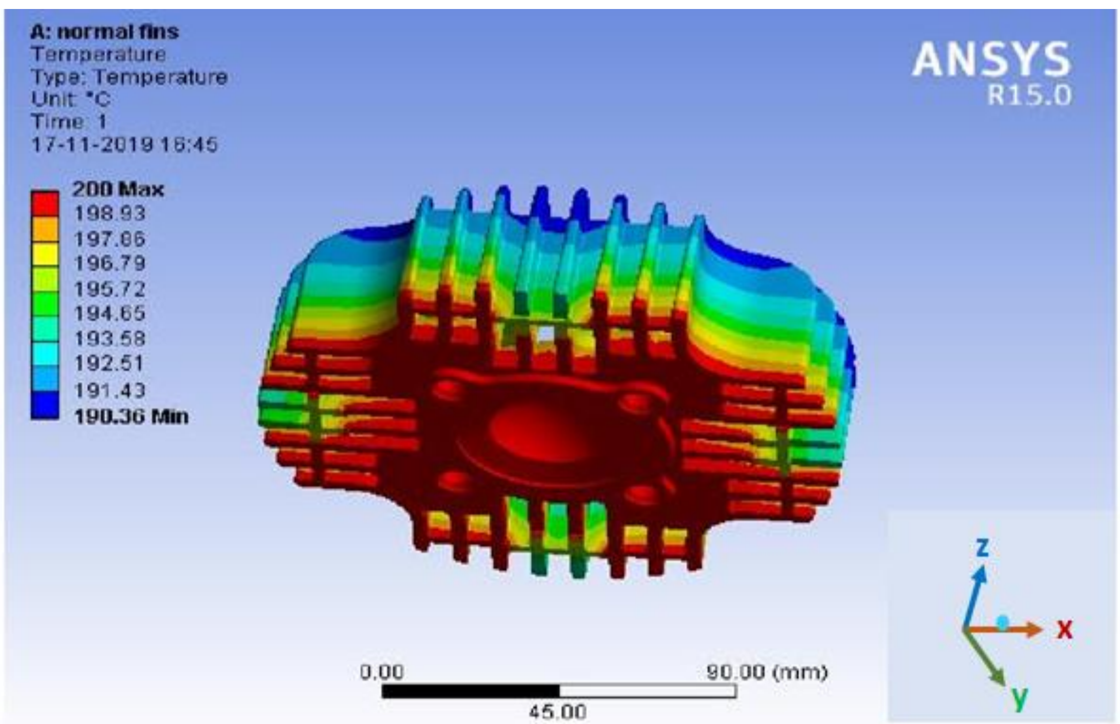

Figure 11 Temperature

Figure 10 indicates the total heat flux of the engine fin. It denotes the overall flow of heat per unit area.

Figure 9 indicates the directional heat flux of the engine fin. ANSYS is utilized for determining temperature, thermal gradient, rate of heat flow as well as heat flux generated by thermal loads which possess the property of invariance with time.

Figure 11 indicates the temperature of the engine fin. The steady state thermal analysis of fixed boundaries of temperature is linear in nature with non varying properties of material. It is nonlinear with the properties of material that varies with temperature.

5 CONCLUSION

The engine fin is considered to be located in a reactor core and is significant for the medium air operation. For ensuring reliability in functioning, a considerable quantity of heat has to be extracted from the engine fin. In this paper, analysis and design of fin utilizing FEA along with ANSYS software is proposed. The analysis of baseline, conductive cooling and convective cooling is performed to determine the effects of engine fin. From the analysis, the designed fin generated improved thermal behavior and a better optimized shape is found out.

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