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Transient Thermal Analysis of Rectangular IC Engine Cylinder Fin

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Abstract: Engine performance depends on various parameters such as types of material used for making engine, number of fins used, thickness of fins, and fins shape which escort thermal effect on it. Presently, material used for manufacturing cylinder fin body is Aluminium Alloy 356. One of the key parts of a car that is subjected to significant thermal stresses and high temperature variations is the engine cylinder. To enhance the quantity of heat expelled by convection, fins are installed on the cylinder surface. In order to optimize the improvement in heat transfer efficiency, the current research describes the enhancing assessments of heat dissipation and the consequent stress reductions across a flat surface in various cylinder types. The thermal conductivity of the material and the geometry of the fins both promote heat transmission. The primary goal of the current article is to use the ANSYS workbench to alter the shape and thickness of cylinder fins in order to investigate the temperature distribution.

Keywords: Rectangular fin, AutoCAD 2022, Ansys workbench 2022 academic Software, temperature distribution, and heat flux.

I. INTRODUCTION

Fins are the extended surfaces designed to Increase heat transfer rate for a fixed surface temperature, or lower surface temperature for a fixed heat transfer rate. As per the formula of convective heat transfer, the rate of heat transfer is directly proportional to the area exposed to the convective medium. Therefore, the fins help to increase the area exposed to the circulating medium. Firstly, the heat is transferred from the body to the fins by means of conduction, then this heat from the fins is transferred away by convection. The Engine cylinder is one of the major automobile components, which is subjected to high temperature variations and thermal stresses. In order to cool the cylinder, fins are provided on the cylinder to increase the rate of heat transfer.

In Air cooled engines, extended surface i.e., fins are facilitated covering outside of cylinder head which results in increase in area on which air can act. When fuel is burned in an engine, heat is produced. Additional heat is also generated by friction between the moving parts. Fins are provided at the periphery of engine cylinder to increase heat transfer rate which is why the analysis of fin is important to increase the heat transfer rate. The present work is aimed to demonstrate the thermal performance of fins. A parametric model of piston bore fins is created in 2D modelling software AutoCAD and developed in 3D modelling software ANSYS to predict the transient thermal behaviour. Thermal analysis is done on the fins to determine variation of temperature distribution over time. Analysis is conducted by varying size and introducing slots using ANSYS. Presently, Material used for manufacturing fin body is Cast Iron. In this thesis, it is replaced by Aluminium alloy (AL356) because of its high thermal conductivity (188.75 W/m-k) and specific heat capacity (894.21 j/kg-k).

II. LITERATURE REVIEW

For increasing the rate of heat transfer we require either large surface area or high value of convective heat transfer coefficient, but increasing heat transfer area is easy and effective method. This is accompanied by using extended surfaces or Fins. Kummitha and Reddy [1] analysed fins made up of different materials like aluminium alloys, magnesium alloys and grey cast iron and compared them on parameters like strength, weight, and concluded that aluminium A 380 is better among selected materials.
Kanna [2] have numerically studied thermal performance of straight fin and wavy fin of different pitch for motorcycle engine. They found that 8mm pitch straight fin is a better choice over wavy fins in heat transfer point of view.
Thornhill et al. [3] conducted experiments for heat transfer from aluminium alloy engine cylinders with fins in to a free air. They found heat transfer enhancement with air velocity in the range 2 – 20 m/s with separated and shortened fins.

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Dubey et al. [4] studied thermal analysis of engine cylinder with thick tip fin having varying slot sizes and material. They found that 75mm slotted fins have maximum heat transfer and Aluminium alloy 2014 having 75mm slotted fin engine with thick tip fin have maximum heat transfer rate.

Rajvinder et al. [5] illustrated that the heat energy transfer in two different materials, such as Cast Iron and Aluminium alloy 6061. From the results obtained, they found a high heat flow rate in Aluminium alloy 6061 than those of materials. The literature survey unveiled that research works associated with fins are limited and there were no studies based on varying fin parameters, introducing slots in fins and its variation in slot numbers, locations etc. Hence in this work, an attempt has been made to analyse the impact on the introduction of slots on the IC engine cylinder by performing transient thermal analysis. A plot of temperature and total heat flux distribution on rectangular engine cylinder fin is obtained and slots are introduced to improve the heat transfer rate, reducing the material usage and cost as well. Finally, the recommended upon inference.

III. METHODOLOGY

The methodology followed in the present work is given in flow chart in Fig. 1

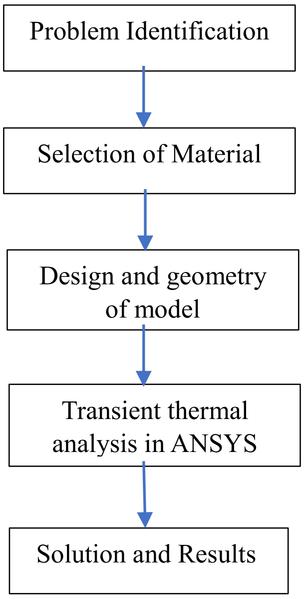

Fig 1: Flow chart showing methodology used in the study

A. Selection of Material

There are various kinds of engineering materials used to suit the respective needs but the material used for fins should fulfil the following desires which is – it should have high thermal conductivity, low specific heat capacity, easy availability, low cost & density and easily machined. By comparing Thermo physical properties of various materials, Aluminium alloy AL356 is taken as the material for fin. The chemical composition of Aluminium alloy AL356 is 92.05% Aluminium with 0.35% Magnesium, 7% Silicon, 0.2% Iron, 0.1% Manganese and 0.1% Zinc.

Table 1: Thermo physical properties of various materials

Properties	Al alloy- 6061	Al alloy – 356	Gray cast iron
Density, kg/m^3	2713	2685	7200
Ultimate tensile Strength, MPa	313.1	246.7	240
Yield tensile Strength, MPa	259.2	172.8	230
Young's modulus, GPa	69.1	72.1	110
Specific Heat capacity, J/kg k	914.71	894.21	447
Thermal conductivity, W/mk	155.12	158.75	52

B. Modelling of Rectangular fin

Rectangular fin profiles bearing 2.5mm thickness is modelled. The number of fins for the model is 5. The distance between the two top surfaces of the fins is maintained at 12mm. The engine cylinder's length is 85mm, and the outer and inner bore diameters are

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110 and 70mm, respectively. Further, slots were introduced at the centre and the corners. AutoCAD software is used to accomplish this work. The detailed fin parameters are shown in Table 2.

Table 2: Fin Parameters

Fin Parameters	**Fin model: Rectangular (in mm)**
Fin Thickness	2.5
Distance Between Fins	12
Length of Cylinder	85
Outer Bore Diameter	110
Inner Bore Diameter	70
Number of Fins	5
Slot Dimensions	20×10
Slot Location	Centre and Corner

Initial design of 3D Rectangular fin is done using Ansys workbench. To create the model, open ANSYS workbench, drag and drop Geometry to Project Schematic. Now, Open design modeller from project schematic and start sketching. The dimensions for the rectangular fin with slots are shown in the table above. Select the sketch and give revolve. Then, click generate and update after each modification.

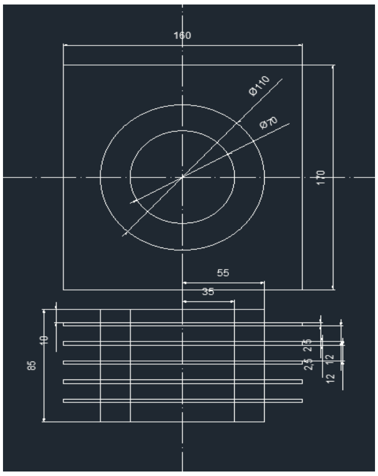

Fig 2: 2D model of 2.5mm Rectangular fin without slots

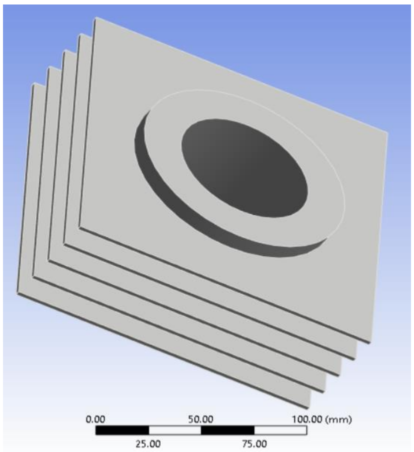

Fig 3: Rectangular fin model of 2.5mm thickness without slots

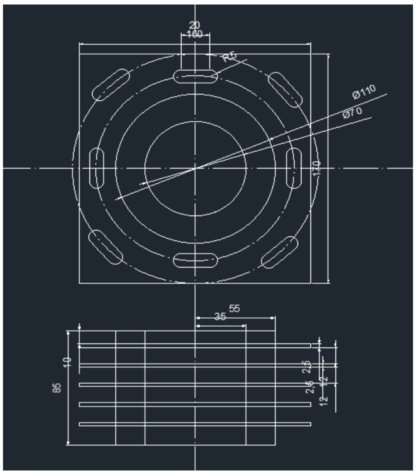

Fig 4: 2D model of 2.5mm Rectangular fin with slots

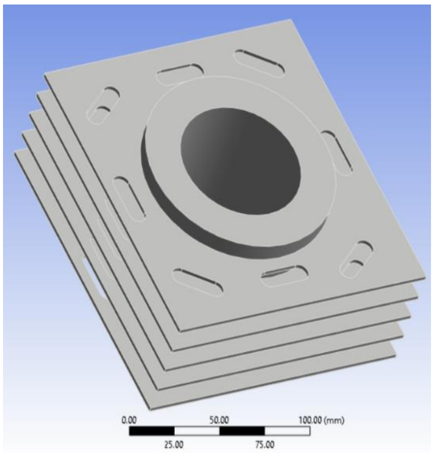

Fig 5: Rectangular fin model of 2.5mm thickness with slots

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IV. ANALYSIS OF MODELLED FINS

Here, Transient thermal analysis is a type of thermal analysis that involves simulating the temperature distribution and heat transfer within a system over time. It is the evaluation of how a system responds to fixed and varying boundary conditions over time. For fixed boundary conditions, the time to reach a steady state temperature can be evaluated, as well as how long operating conditions can be sustained before reaching a threshold temperature. For time-varying boundary conditions, transient analysis can show you the resulting thermal response of the system. This type of analysis is commonly used to evaluate the thermal behaviour and also understand the thermal stresses of components, systems, and processes.
The pre- and post- processings of fin models are discussed below.

- **Pre-processing**

Ansys workbench was used as a modelling tool for the analysis for different fin geometries. The fundamental fin design was done in Autocad, and further exported to Ansys workbench to carry out meshing and performance analysis. For meshing Triangular mesh is generated due to its high mesh quality. The meshing of different fins are reported in figures 5 and 6. As it is mentioned earlier thermal analysis is carried out to identify thermal stresses that cause failure. The loads and boundary conditions used to analyze the fin are:

Maximum and Minimum temperatures are 1500ºC and 200ºC,
Ambient temperature is assumed to be 22ºC,
Convection coefficient is 0.000005 W/mm² ºc,
The material used for the analysis is aluminium alloy 356.

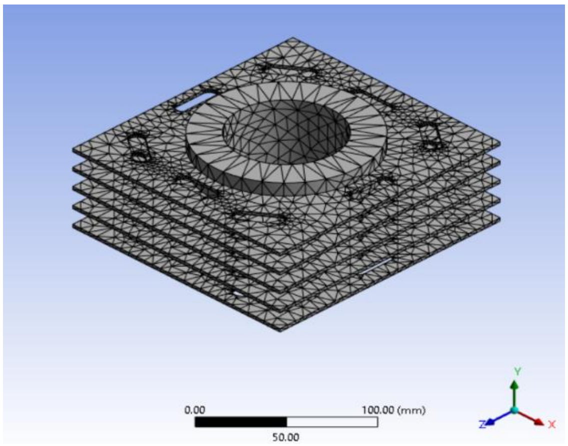

Fig 5: Mesh model of rectangular fin with slots.

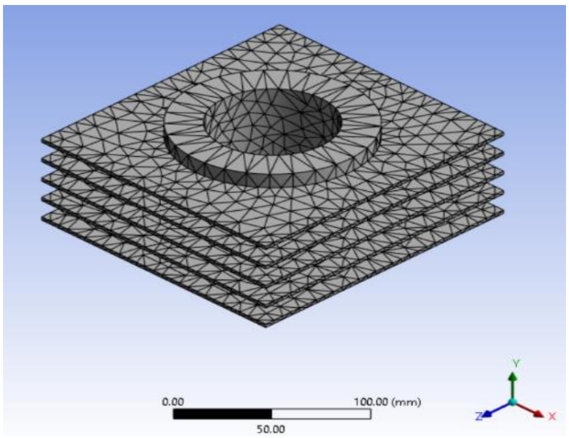

Fig 6: Mesh model of rectangular fin without slots.

- **Post-processing**

All the modelled fin geometries were imported into Ansys workbench tool, and different boundary conditions were employed to carry out virtual simulation to plot the temperature distribution and total heat flux.Temperature values are obtained at the interfaces and total heatflux is calculated from the simulation. The post-processing simulations that are established are reported in below pictures (figure 7 to 10).

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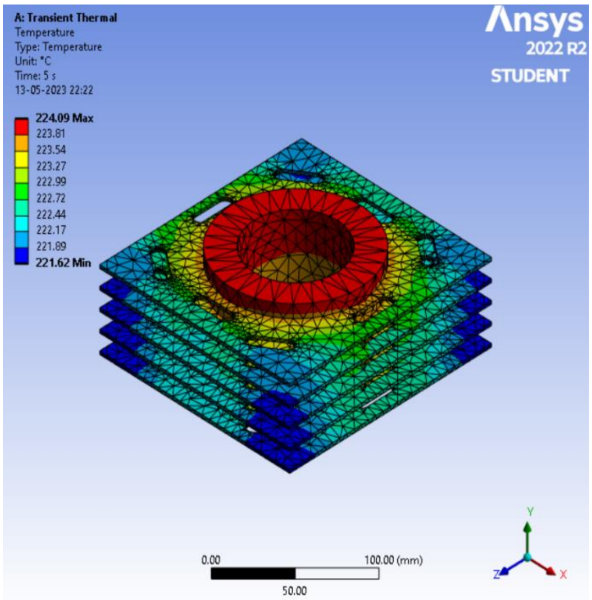

Fig 7: Temperature distribution of rectangular fin with slots.

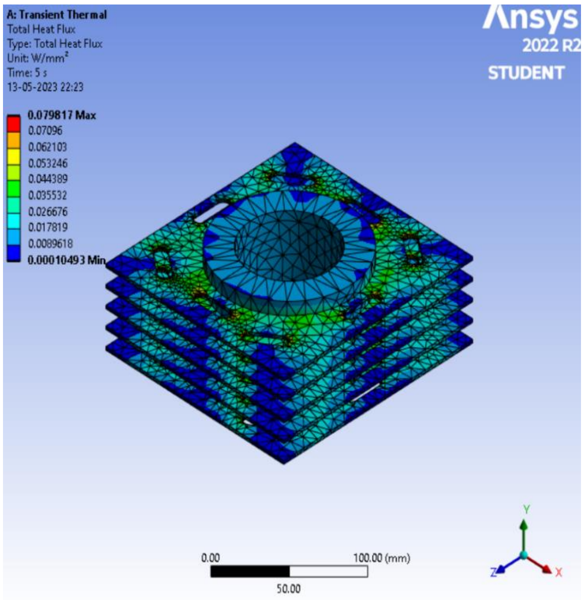

Fig 8: Heat transfer per unit area in rectangular fin with slots.

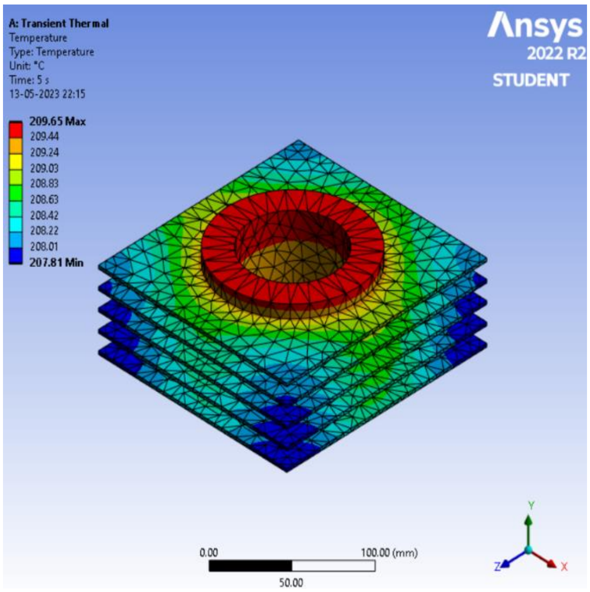

Fig 9: Temperature distribution of rectangular fin without slots.

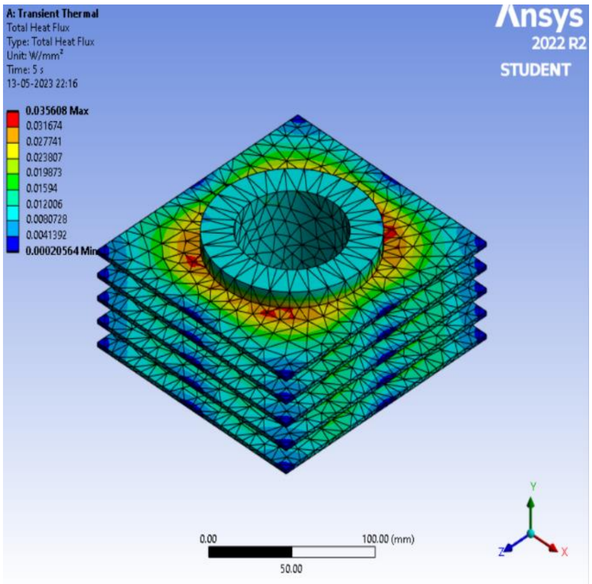

Fig 10: Heat transfer per unit area in rectangular fin without slots.

V. RESULTS AND DISCUSSIONS

Graphs 1 & 2 illustrate the temperature and total heat flux distribution of rectangular fin profiles with 2.5mm thickness and slot considerations. It is seen from the figures; the slotted rectangular fin geometry is showing a higher temperature and heat flux distribution compared to rectangular fin geometry without slots. Commonly used materials for fin geometries such as cast iron etc. have been subjected to thermal analysis over time; however, in this present study, transient thermal analysis was performed for fin models developed from Aluminium alloy al356. This material change was done by considering thermal conductivity and also the overall weight of the fin. Aluminium is light in weight and has higher thermal conductivity, so using Aluminium alloy al356 was considered as a suitable material. It is also inferred that on increasing the fin's thickness, the heat transfer rate is also increased. Further slots in the fin body reduce the fin weight; thereby, resulting in a decrease in the total weight of the engine and an increase

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in the fin efficiency by enhancing the rate of heat energy transfer. The percentage increase in temperature upon the introduction of slots in the rectangular fin model is given in Table 3.

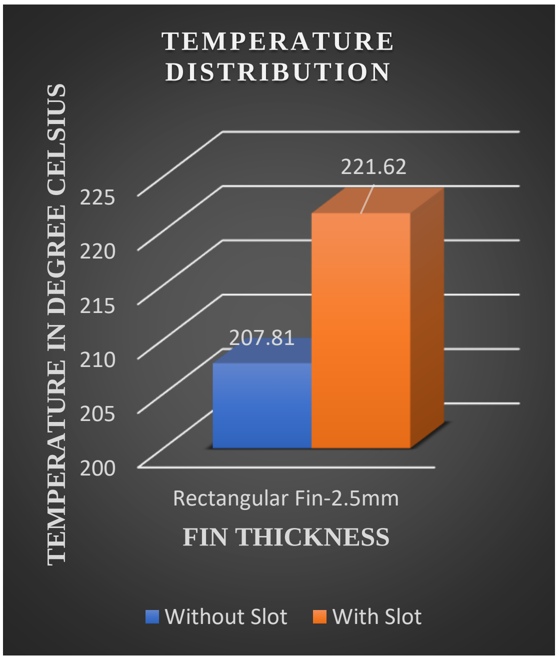
$$\% \text{ Increase is given by } \left[\frac{(\text{With slot} - \text{Without slot})}{\text{With slot}}\right] \times 100$$

From Table 3, it is observed that Slotted rectangular fin of 2.5mm fin thickness is having high temperature i.e., 221.62°C than the non-slotted rectangular fin which is having a temperature of 207.81°C. Thus, the percentage increase in temperature upon slot introduction is 6.23%. This indicates an increase in the heat dissipation rate.

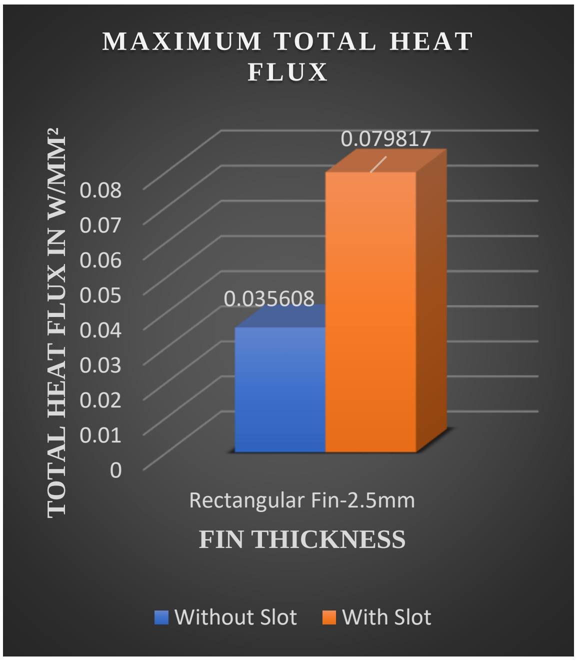
The unwanted heat retained by the engine is reduced by slotting as it causes a temperature descent. Further, on slotting and as the fin thickness enhances an improved convective mode of heat transfer is observed. Thus, the amount of heat dissipated to the surrounding has also improved. On average, there was a considerable reduction in the temperature of the engine parts. The results produced by the analysis software are in the form of coloured contours of required parameters. The contours as such that they give an idea about the value of the parameter ranges, which are indicated in the legend.

Table 3: Percentage increase in temperature for rectangular fin of 2.5mm thickness

Temperature	Rectangular fin (2.5mm thickness)
With Slot	221.62°C
Without Slot	207.81°C
% Increase in temperature upon slot introduction	6.23% gain



Graph 1: Temperature distribution in rectangular fin of 2.5mm thickness



Graph 2: Total heat transfer per unit area in rectangular fin of 2.5mm thickness

VI. CONCLUSION

From the above results and discussion, the following are the conclusions arrived:

Effectiveness of the fin denotes the ratio of the actual heat transfer that takes place from the body having fins to the heat that would be dissipated from the same body without fins. Slotting helps in increasing the effectiveness of the fins. Therefore, the heat transfer rate also increases considerably. There is also a reduction in the usage of materials due to slotting, which leads to lower manufacturing costs and the engine fin component’s weight. Hence, we can achieve an optimum heat transfer rate with less material usage. The observations from the present work are fins with slots show a higher temperature distribution than those fins without slots due to an increase in the convective heat transfer rate, further increasing the overall heat transfer rate. From this work, the use of slots for overall heat transfer enhancement can be justified. Consequently, the introduction of multiple slots on the fin profile

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enhances the overall heat transfer rate and a considerable amount of savings in the mass of the material used, thereby reducing manufacturing costs.

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