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Thermal Analysis of Engine Cylinder with Fins

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Abstract- The engine cylinder is a critical component in automobiles, withstanding extreme temperature fluctuations and thermal stress. Fins on the cylinder's surface improve heat transfer, allowing it to cool more efficiently. Conducting a thermal analysis on both the cylinder and the fins provides critical information about heat dissipation rates and temperature distribution within it. Increasing the surface area achieved with these fins improves heat dissipation. However, designing such a complex engine poses significant challenges. Our project's primary goal is to investigate thermal properties such as directional heat flux, total heat flux, and temperature distribution. This analysis involves varying parameters such as geometry (circular or rectangular), material (Aluminium Alloy 6061 T6, Structutal Steel), and fin thickness (2mm) of a square cylinder model created in SOLIDWORKS 2020. This model is then imported into ANSYS WORKBENCH-2024 to perform steady state thermal analysis. In this analysis, we use an average internal temperature and stagnant air as the cooling medium for the outer surface. We also use a reasonable Film Coefficient as our boundary condition.

Key words: Solid works, Ansys, Heat Flux, Direction Heat Flux

I. INTRODUCTION

Engine Cylinder and Combustion Chamber:
In the realm of Internal Combustion engines, the combustion process occurs within the engine cylinder, generating hot gasses with temperatures ranging from 1200-1500°C. This extreme heat can potentially lead to the burning of the oil film between moving parts, resulting in issues like piston seizure and damage to components like piston rings, compression rings, and oil rings. Excessive temperatures can also harm the cylinder material. To maintain optimal efficiency, it's crucial to reduce this temperature to approximately 150-200°C, the temperature at which the engine functions most effectively. Striking the right balance is essential since excessive cooling can reduce thermal efficiency. Therefore, the cooling system's goal is to maintain the engine at its ideal operating temperature. It's worth noting that engines are notably inefficient when cold, so the cooling system is designed to prevent cooling during the warm-up phase, only initiating cooling once the engine reaches its peak operating temperature. To prevent overheating and its associated problems, excess heat in engine components must be rapidly dissipated and released into the surrounding atmosphere. Essentially, the cooling system acts as a temperature regulation mechanism. It's important to recognize that extracting heat from the working medium through engine component cooling represents a direct thermodynamic loss. The rate of heat transfer hinges on factors such as wind velocity, engine surface geometry, external surface area, and ambient temperature. This analysis focuses on engine block fins, considering temperature control via convection, with no consideration for air velocity.

1.1. Natural Air Cooling:

Typically, a significant portion of an engine is exposed to the surrounding atmosphere. As vehicles move, the air rushes over the engine's surfaces at a relative velocity, carrying away the generated heat. This method relies on natural convection, and hence it is termed Natural Air Cooling. Two-wheeler engines, in particular, are often cooled using natural air circulation. Since heat dissipation is related to the frontal cross-sectional area of the engine, there is a need to increase this area for effective cooling. However, expanding the engine's frontal area can make it bulkier and reduce the power-to-weight ratio.

1.2. Fins:

Fins, in essence, are extended surfaces connected to an object to enhance heat transfer rates to or from the surroundings by amplifying convection. The quantity of heat an object transfer is contingent upon the combination of conduction, convection, and radiation processes. To augment heat transfer, one can elevate the temperature difference between the object and its environment, enhance the convection heat transfer coefficient, or increase the object's surface area. While altering the first two factors might not always be feasible or economical, the addition of fins serves as a practical solution. Fins effectively enlarge the surface area, offering a cost-effective means to address heat transfer challenges. Familiar examples include the circumferential fins encircling the cylinder of a motorcycle engine and the fins attached to condenser tubes in a refrigerator. These fins play a vital role in managing temperature within a spark-ignition (SI) engine, ensuring it operates at specific thermal conditions. This controlled thermal regime is instrumental in preventing thermal failure and the associated detrimental effects on both the engine and its lubricant. Fins are integrated into engine design as they provide a crucial pathway for cooling the engine when it becomes excessively hot, thus preventing engine overheating. The number of fins present on the engine cylinder varies according to the engine's capacity, with larger engines featuring a greater quantity of fins on the engine block. In the realm of fin terminology and types, we have various terms to describe them, including fin base, fin tip, straight fin, variable cross-sectional area fin, spine or pin fin, and annular or cylindrical fins. Each of these fin types has specific characteristics and applications in the context of engine cooling.

1.3 Thermal analysis:

A vital branch of materials science, delves into the examination of material properties as they undergo transformations with varying temperatures. Thermal analysis plays a pivotal role in calculating temperature and heat transfer dynamics within and between components in the design and its operating environment. This aspect is crucial in the design process, as many products and materials exhibit properties that are influenced by temperature. Additionally, ensuring product safety is a key consideration; excessive heat may necessitate the implementation of safeguards or protective measures. The flow of heat through components can exist in two fundamental states: steady-state, where the heat flow remains constant over time, and transient, characterized by changing heat flow patterns. Drawing an analogy from the field of structural analysis, a steady-state thermal analysis is akin to a linear static analysis, whereas a transient thermal analysis aligns with the principles of dynamic structural analysis. Solving heat transfer problems involves the utilization of structural and fluid flow analysis techniques:

1. In a thermal structural analysis, the influence of moving air or liquid is approximated by defining a set of boundary conditions or loads. This approach simplifies the analysis by treating the structural aspects of the problem.
2. In a thermal fluid analysis, the impact of air or liquid movement is directly calculated, which may extend the computation time but significantly enhances the overall accuracy of the solution. This approach offers a more comprehensive and detailed understanding of how heat is transferred within the system by accounting for the fluid dynamics.

The choice between these methods depends on the specific problem and the level of precision required, with thermal fluid analysis offering a more in-depth and accurate depiction of heat transfer phenomena.

II. LITERATURE SURVEY

[1] "Heat Transfer Enhancement in Engine Cylinder Fins Using Swirl Flow" by Smith et al.

Key Findings: This study explored the use of swirl flow to enhance heat transfer in engine cylinder fins, demonstrating improved cooling efficiency.

[2] "Numerical Analysis of Convective Heat Transfer in Engine Cylinder Fins" by Johnson and Brown.

Key Findings: The authors employed numerical simulations to analyze convective heat transfer within engine cylinder fins, highlighting the influence of fin geometry on performance.

[3] "Experimental Investigation of Heat Transfer in Ribbed Engine Cylinder Fins" by Lee and Kim.

Key Findings: Ribbed fins were investigated, revealing enhanced heat transfer due to increased surface area, but also higher pressure drop.

[4] "Heat Transfer Enhancement in Engine Cylinder Fins Using Nanofluids" by Wang and Liu.

Key Findings: The use of nanofluids within engine cylinder fins improved heat transfer, with notable implications for engine cooling.

[5] "Comparative Analysis of Straight and Helical Fins in Engine Cylinders" by Garcia et al.

Key Findings: This study compared straight and helical fins, showing that helical fins can offer improved heat transfer performance but with added complexity in manufacturing.

[6] "Effect of Fin Thickness on Heat Transfer in Engine Cylinder Fins" by Patel and Sharma.

Key Findings: The research demonstrated that varying fin thickness can significantly impact heat transfer, with thinner fins showing improved performance.

[7] "Heat Transfer Enhancement in Engine Cylinder Fins Using Phase Change Materials" by Li et al.

Key Findings: The incorporation of phase change materials in fins was found to enhance heat transfer while maintaining consistent engine temperature.

[8] "Analytical Modeling of Heat Transfer in Wavy Engine Cylinder Fins" by Chen and Zhang.

Key Findings: Wavy fins were analyzed using analytical models, showcasing enhanced heat transfer due to increased surface area.

[9] "Transient Heat Transfer Analysis in Engine Cylinder Fins During Start-Up" by Das and Dutta.

Key Findings: The study focused on transient heat transfer during engine start-up, offering insights into the critical initial phases of engine operation.

[10] “Thermal Analysis of Engine Cylinder with Fins by using ANSYS Workbench” by Mulukuntla Vidya Sagar and Nalla Suresh.

III. METHODOLOGY

The primary objective of this project is to enhance the heat dissipation rate of a given engine cylinder while analyzing various properties such as temperature, total heat flux, and directional heat flux. This is achieved by altering the material used for the cylinder, adjusting the cylinder's geometry, and modifying its linear dimensions.

Two fundamental approaches can be employed to augment the rate of heat transfer for dissipating heat from the cylinder walls:

1. Increasing the Surface Heat Transfer Coefficient (h value):

To boost the surface heat transfer coefficient, it's essential to enhance the velocity of the fluid through which heat is transferred. The heat transfer coefficient is directly proportional to the fluid's velocity. Achieving this requires artificial means, such as installing a pump or blower to induce forced convection. Another strategy involves replacing the existing material with one that possesses a higher heat transfer coefficient. However, this approach may impact the product's cost and structural properties. For instance, if the material needs to be both ductile and possess a high heat transfer coefficient, a dilemma arises. Material-1 may be ductile but with a moderate heat transfer coefficient, while material-2 might have a superior heat transfer coefficient but lack ductility, potentially being harder and brittle. In such cases, the solution often involves alloys or composite materials that fulfill both structural and thermal requirements. Creating such alloys can be costly and time-consuming. Consequently, an alternative method favored by industrialists and designers is the use of extended surfaces, commonly known as fins.

2. Increasing the Surface Area of the Component:

Fins, in the context of heat transfer, refer to surfaces that protrude from an object, thereby amplifying the rate of heat transfer to or from the environment by intensifying convection. The heat transferred by an object is determined by conduction, convection, and radiation processes. Augmenting the temperature gradient between the object and its surroundings while increasing the object's surface area enhances heat transfer. However, in certain cases, modifying the first option (heat transfer coefficient) might not be practical or economical. Therefore, the more cost-effective and convenient approach is to append fins to the object, as this effectively increases the surface area, offering a practical solution for efficient heat dissipation. This method is particularly favored when compared to the first approach of enhancing the heat transfer coefficient.

Several compelling reasons underscore the importance of utilizing fins in various applications:

1. High Thermal Conductivity Material ("K"):

The thermal conductivity of the material used for the fins, denoted as "K," should ideally be as high as possible. Materials like copper, aluminum, and iron are preferred due to their relatively high thermal conductivity. Among these options, aluminum is often favored for its low cost, lightweight nature, and resistance to corrosion. This makes it an economical and practical choice for many heat transfer applications.

2. Maximizing p/Ac Ratio:

To optimize heat transfer efficiency, it's essential to maximize the ratio of p/Ac. This ratio can be enhanced by using fins with thin plate configurations and slender pin-like structures. Increasing p/Ac ensures a greater surface area relative to the volume, which in turn facilitates efficient heat transfer.

3. Effective in Low Heat Transfer Coefficient Scenarios:

Fins are most effective in situations where the convective heat transfer coefficient ("h") is relatively low. This is particularly evident in scenarios where the heat transfer medium is a gas, and heat transfer predominantly occurs through natural convection. In such cases, the use of fins is not only justified but highly advantageous.

3.1. Fins Approach:

When implementing fins, selecting the appropriate fin length ("L") is a crucial consideration. It's important to note that increasing the fin length beyond a certain point may not be justified unless the added benefits clearly outweigh the associated costs. Additionally, the efficiency of most fins used in practical applications tends to exceed 90 percent, underscoring their effectiveness in enhancing heat transfer. This high level of efficiency is a key attribute of fins, making them a valuable component in thermal engineering and design.

3.2. Problem Definition:

The project investigation focuses on thermal issues related to automobile fins, particularly concerning Temperature Distribution, Total Heat flux, and Directional heat flux within the cylinder fins due to the high temperatures in the combustion chamber. ANSYS WORKBENCH-2024 serves as the platform for this analysis. The study involves a model of nearly square engine, with variations in geometry, fin thickness, and material to enhance the heat transfer rate.

3.3. The ANSYS Workbench Interface:

The ANSYS Workbench interface comprises several key elements, including the Toolbox region, the Project Schematic, the Toolbar, and the Menu bar. Depending on the analysis type, application, or workspace, additional windows, tables, charts, etc., may be present. Actions in ANSYS Workbench involve dragging components or analysis systems from the Toolbox to the Project Schematic or initiating actions by double-clicking on items. Context menus, accessible via a right-mouse click, provide supplementary options. The Project Schematic visually represents analysis systems, displaying all connections and links between them. Individual applications operate independently from the ANSYS Workbench GUI, but the results of actions in these applications may be reflected in the Project Schematic.

3.4. Toolbox:

The ANSYS Workbench Toolbox offers various types of data that can be added to your project. The Toolbox is context-sensitive, adjusting its content based on your selections in the Project Schematic or other workspaces. You can easily switch between workspaces, such as Engineering Data or Parameters, and return to the Project Workspace by clicking the "Return to Project" button on the Toolbar.

As discussed earlier, there are two primary types of thermal analysis commonly employed:

1. Transient Thermal Analysis:

Transient thermal analysis follows similar procedures to steady-state analysis, with the primary difference lying in the nature of applied loads, which are functions of time. To specify time-dependent loads, you divide the load-versus-time curve into distinct load steps, where each "corner" on the load-time curve represents one load step. Considering the definitions and characteristics of both steady-state and transient thermal analysis, it becomes evident that each has its unique advantages and is suited for specific applications. However, the present scenario necessitates the assessment of how properties evolve with time, either linearly or non-linearly.

2. Steady State Thermal Analysis:

A steady-state thermal analysis is instrumental in evaluating the impact of constant thermal loads on a system or component. It is often used as a precursor to transient thermal analysis. This type of analysis allows us to determine temperature distributions, thermal gradients, heat flow rates, and heat flux within an object, with the key characteristic that these parameters remain constant over time. Steady state thermal analysis can be either linear, assuming material properties are constant, or nonlinear, accounting for material properties that vary with temperature. Since most materials exhibit temperature-dependent properties, the analysis is typically nonlinear in nature. Therefore, in the context of analyzing the model created in SOLIDWORKS-2020 for a square engine, where changes are made to material (Structural Steel, Aluminum alloy 6061 T6) geometry (Rectangular), and fin thickness (2mm), steady state thermal analysis is the preferred choice. This method allows us to investigate the effects of these variations on the time required to achieve a steady state. The analysis involves plotting the time versus a property and assessing the impact on various properties such as temperature, directional heat flux, and total heat flux.

3.5. Assumptions for Analysis:

1. The temperature of the surrounding air remains relatively constant.
2. A constant heat transfer coefficient is considered on the air side.
3. Heat generation within the system is neglected.
4. Loads applied to the system remain constant.
5. Most of the physical properties, including material properties, are treated as constant throughout the analysis.

3.6. Design Details:

4.1. Modeling of Cylinder Fin:

The cylinder, along with the fin, was modeled using SOLIDWORKS-2020 The dimensions were chosen to represent a square engine with a stroke ratio of unity. Various fin geometries, including fins, were modeled using SOLIDWORKS-2020.

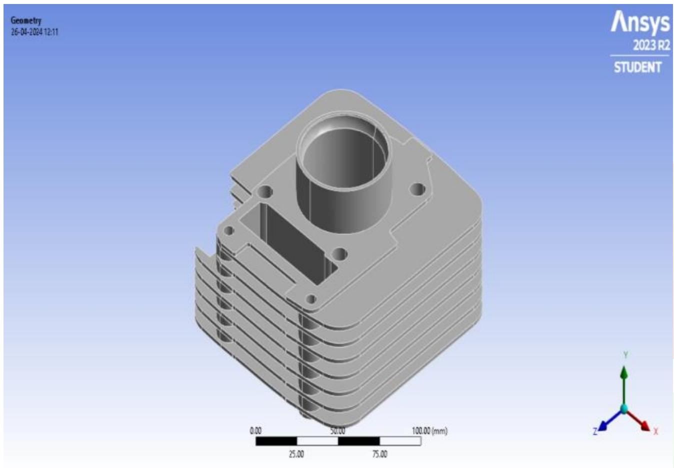


Fig.1 CAD model of Bajaj 125cc engine cylinder with fins.

IV. EXPERIMENTAL DETAILS

Table 1. The Boundary Conditions

Density	7.85 kg/mm³
Specific Heat	4.34 mJ/kg °C
Thermal Conductivity	0.0605 W/mm °C

Table 2. Material Data for Structural Steel

Density	2.713 kg/mm³
Specific Heat	9.157 mJ/kg °C
Thermal Conductivity	0.1553 W/mm °C

Table 3. Material Data for AA6061 T6

V. RESULTS:

Materials	Total Heat flux (W/mm²)	Directional Heat flux (W/mm²)
Structural Steel	0.23523	0.10769
AA6061 T6	4.3685	2.9905

Table 4. Results

Loads	Units	Values
Inlet Temperature	°C	300
Film coefficient	W/mm² °C	5
Ambient Temperature	°C	22

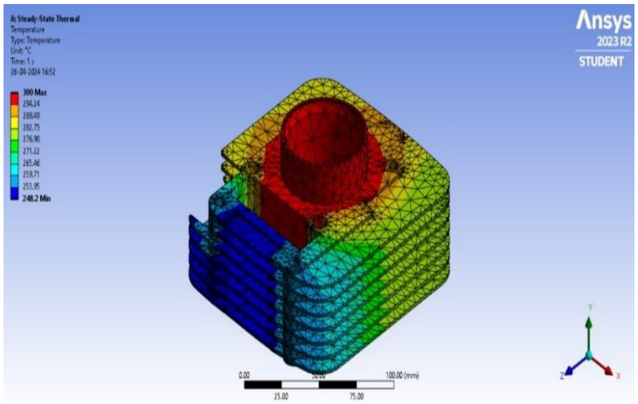
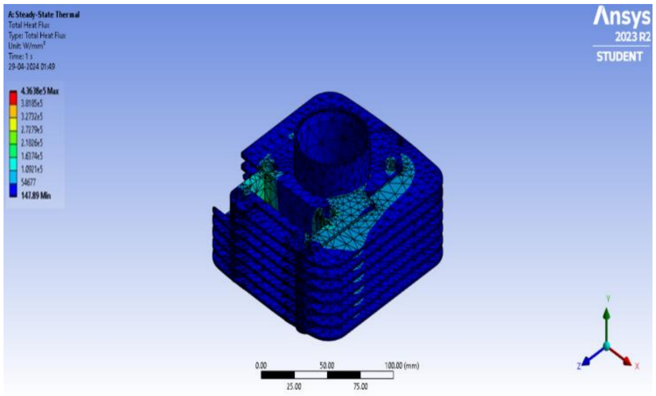


Fig 2. Temperature distribution for Structural Steel

Fig 5. Total Heat flux distribution for AA6061 T6



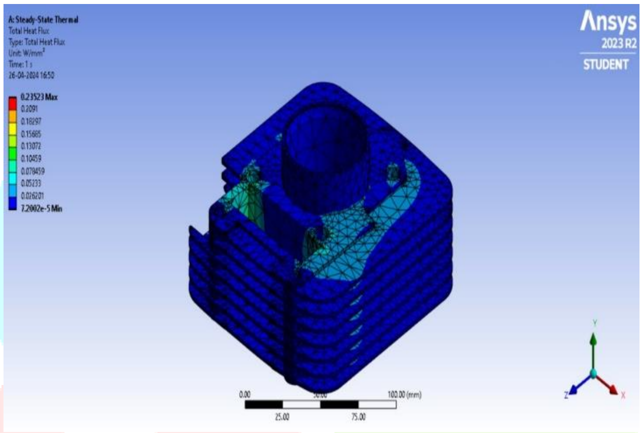


Fig 3. Total heat flux distribution for Structural Steel

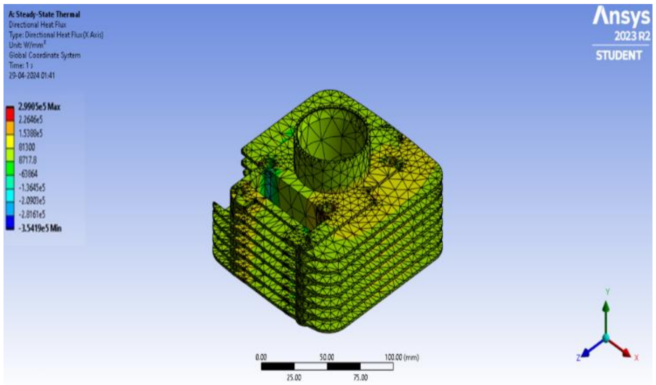


Fig 6. Directional heat flux distribution for AA6061 T6

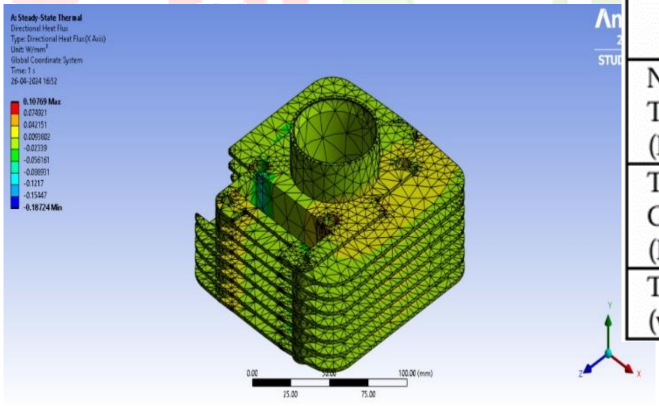
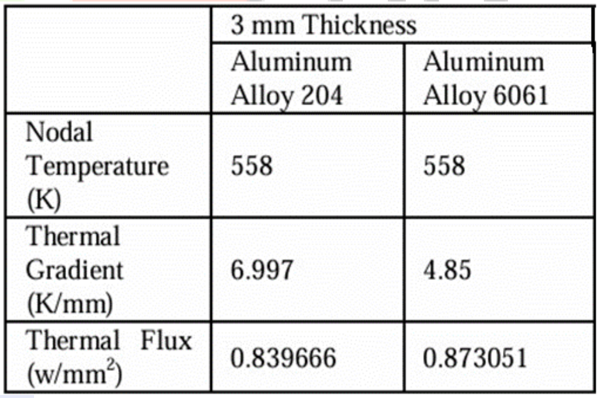
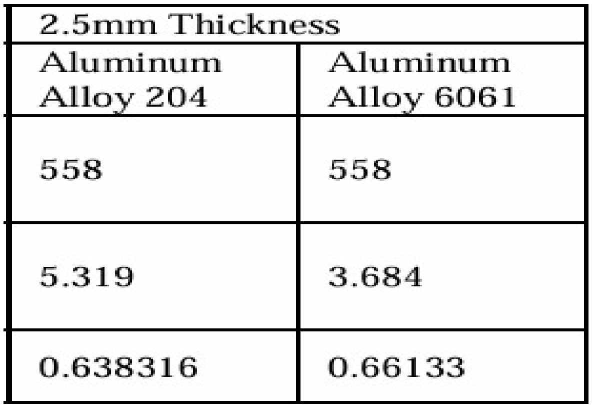


Fig 4. Directional heat flux distribution for Structural Steel



	3 mm Thickness	
	Aluminum Alloy 204	Aluminum Alloy 6061
Nodal Temperature (K)	558	558
Thermal Gradient (K/mm)	6.997	4.85
Thermal Flux (w/mm^2)	0.839666	0.873051

Table 5. Analysis Results



2.5mm Thickness	
Aluminum Alloy 204	Aluminum Alloy 6061
558	558
5.319	3.684
0.638316	0.66133

Table 6. Analysis Results

VI. CONCLUSION

Based on the thermal analysis conducted on the engine cylinder fins, it is evident that material selection plays a critical role in determining the heat dissipation characteristics of the fins. The results indicate that AA6061 T6, a commonly used Aluminum alloy with excellent thermal conductivity and heat dissipation properties, exhibits the highest total heat flux and directional heat flux among the both materials analyzed. This underscores the importance of choosing materials with superior thermal properties to enhance the performance and reliability of engine components. Conversely, Structural Steel, while possessing robust mechanical properties, demonstrates lower values for both total heat flux and directional heat flux. This emphasizes the trade-offs between material strength and thermal conductivity in engineering design. Although steel may offer advantages in terms of structural integrity, its relatively lower thermal conductivity limits its effectiveness in dissipating heat from the engine cylinder fins. Furthermore, the optimization strategy employed, involving the introduction of fillets along the corners of the engine fins, represents a pragmatic approach to enhancing both performance and efficiency. By reducing weight through CAD model modifications, the optimization not only improves the overall thermal management of the engine but also contributes to fuel efficiency and operational longevity.

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