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THERMAL STUDY AND ANALYSIS OF DIVERSE GEOMETRICAL FINS USING FEA

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Abstract

Fins are extended surfaces used to dissipate heat energy generated in combustion chambers of internal combustion (IC) engines, radiators, condensers, and cooling towers. The heat transfer within fins is primarily due to conduction, while the heat transfer between the fin surface and the surrounding fluid is due to convection. The temperature at the root of the fin is maximum and gradually decreases along its length, reaching the lowest temperature at the tip. Fin efficiency is defined as the ratio of actual heat transfer to the maximum possible heat transfer through the fin. Fin effectiveness is the ratio of heat transfer with fins to heat transfer without fins. This study analyzes the thermal performance of different fin geometries using Finite Element Analysis (FEA). The geometries include annular fins with 3 and 9 discs, perforated fins with elongated holes, and wedge-shaped fins. The materials considered are aluminum alloy and copper alloy. The analysis is performed using CATIA for modeling and ANSYS 14.0 Transient Thermal Workbench for simulation. The results show that wedge-shaped fins exhibit the highest heat flux and efficiency, followed by perforated fins and fins with 9 discs. The study concludes that wedge-shaped fins are the most effective for heat dissipation.

Keywords: Fins, Perforated geometry, Fin effectiveness, Fin efficiency, Heat flux, Film coefficient, CATIA, ANSYS 14.0.

1. Introduction

Heat transfer is a critical aspect of thermal management in various engineering applications, including IC engines, radiators, and cooling towers. Fins are widely used to enhance heat dissipation by increasing the surface area exposed to the surrounding fluid. The efficiency and effectiveness of fins depend on their geometry, material, and the heat transfer mechanisms involved. This study focuses on the thermal analysis of different fin geometries using Finite Element Analysis (FEA) to determine the most effective fin design for heat dissipation.

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1.1 Fins and Their Applications

Fins are extended surfaces that protrude from a body to increase the heat transfer rate between the surface and the surrounding fluid. They are commonly used in:

- Air-cooled IC engines
- Refrigeration condenser tubes
- Electric transformers
- Reciprocating air compressors
- Semiconductor devices
- Automobile radiators

1.2 Types of Fins

Fins can be classified based on their geometry:

1. **Longitudinal fins**: Rectangular, trapezoidal, and concave parabolic profiles.
2. **Radial fins**: Rectangular and triangular profiles.
3. **Pin fins**: Cylindrical, tapered, and concave parabolic profiles.

1.3 Fin Efficiency

Fin efficiency (η) is the ratio of the actual heat transfer rate to the maximum possible heat transfer rate if the entire fin were at the base temperature. It is given by:

η=QactualQmax*η*=*Q*max*Q*actual

1.4 Fin Effectiveness

Fin effectiveness (ε) is the ratio of the heat transfer rate with fins to the heat transfer rate without fins:

ε=QfinQno fin*ε*=*Q*no fin*Q*fin

1.5 Advantages of Numerical Methods

Numerical methods, such as FEA, offer several advantages:

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- **Cost-effectiveness**: Numerical simulations are less expensive than physical experiments.
- **Speed**: Simulations can be performed quickly, allowing for rapid design iterations.
- **Real-world simulation**: Numerical methods can simulate real-world conditions that are difficult to replicate in experiments.
- **Ideal conditions**: Numerical methods allow for the simulation of ideal conditions, isolating specific phenomena for study.

2. Literature Review

Several studies have been conducted on fin performance, focusing on efficiency, effectiveness, and heat transfer characteristics. Key findings from the literature include:

- **Air-side heat transfer characteristics of spiral-type circular fin-tube heat exchangers**: The study found that spiral-type fins improve heat transfer by 13.24% compared to flat fins.
- **Empirical correlations for mixed convection heat transfer**: The study concluded that heat transfer coefficients increase with Reynolds and Grashof numbers.
- **Heat transfer analysis in annular fins with tapered profiles**: Tapered fins showed improved heat transfer compared to rectangular fins.
- **Experimental and numerical analysis of convective heat transfer from notched fin arrays**: Notched fins improved heat transfer by 30% compared to solid fins.
- **Heat transfer analysis of lateral perforated fin heat sinks**: Perforated fins showed higher heat transfer and significant weight reduction compared to solid fins.

2.1 Research Gap

While previous studies have explored various fin geometries, there is limited research on perforated fins with elongated holes and wedge-shaped fins. This study aims to fill this gap by analyzing these geometries and comparing their performance with traditional fin designs.

3. Transient Thermal Analysis

3.1 Introduction to Transient Thermal Analysis

Thermal analysis involves studying the effects of temperature changes on material properties. Transient thermal analysis is particularly important for understanding how heat transfer evolves over time in systems such as IC engines and radiators.

3.2 Mechanisms of Heat Transfer

Heat transfer occurs through three mechanisms:

1. **Conduction**: Heat transfer through direct molecular collision.
2. **Convection**: Heat transfer through fluid motion.
3. **Radiation**: Heat transfer through electromagnetic waves.

3.3 Why Thermal Analysis?

Thermal analysis is essential for:

- Determining temperature distribution and heat flow in a system.
- Identifying overheating and thermal stress issues.
- Validating thermal models through empirical testing.

4. Modeling and Simulation

4.1 Objective

The objectives of this study are:

1. To model different fin geometries using CATIA.
2. To perform thermal analysis using ANSYS 14.0 Transient Thermal Workbench.
3. To compare the heat flux and efficiency of different fin geometries.
4. To determine the most effective fin geometry for heat dissipation.

4.2 Fin Geometries

The following fin geometries were analyzed:

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1. **Annular fin with 3 discs**: Standard fin geometry.
2. **Annular fin with 9 discs**: Increased number of discs to study the effect on heat flux.
3. **Perforated fin with elongated holes**: Perforations added to the fin to study their impact on heat transfer.
4. **Wedge-shaped fin**: A different geometry to study its heat dissipation performance.

4.3 Materials

The materials used for the fins are:

- **Aluminum alloy**: Low cost, lightweight, and corrosion-resistant.
- **Copper alloy**: High thermal conductivity, but more expensive and heavier.

4.4 Boundary Conditions

The boundary conditions for the analysis are:

- Ambient temperature: 300 K
- Combustion chamber temperature: 400 K
- Film coefficient: 20 W/m^2K

4.5 Results

The results of the thermal analysis are presented in terms of total heat flux and radial directional heat flux for both aluminum and copper alloys.

5. Results, Conclusions, and Future Scope

5.1 Results

The results show that:

1. **Wedge-shaped fins** exhibit the highest heat flux and efficiency, with a deviation of 56.82% compared to the standard 3-disc fin.
2. **Perforated fins** with elongated holes show a 10.31% improvement in heat flux compared to the standard fin.

3. **Fins with 9 discs** show a 4.347% improvement in heat flux compared to fins with 3 discs.

4. **Copper alloy fins** show slightly higher heat flux compared to aluminum alloy fins, but the difference is not significant.

5.2 Conclusion

The study concludes that:

1. **Wedge-shaped fins** are the most effective for heat dissipation.

2. **Perforated fins** with elongated holes are the next best option.

3. Increasing the number of fins from 3 to 9 improves heat dissipation.

4. The choice of material (aluminum or copper) has a minimal impact on heat flux for the same geometry and boundary conditions.

5.3 Future Scope

Future research could focus on:

1. Analyzing additional fin geometries to further optimize heat dissipation.

2. Using different simulation software to validate the results.

3. Studying temperature distribution across the fin surface.

4. Conducting Computational Fluid Dynamics (CFD) analysis to study the effect of airflow on fin performance.

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International Research Journal of Education and Technology
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