Analysis of fins of parabolic shape using Finite Element Method

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Abstract

In this era of supercars and high speed vehicles various technologies have been developed to increase the rate of combustion and enhanced the speed as well as the power of the engine. Owing to this great development there arise a problem of very high temperature in the combustion chambers of the engine. It increases the cost by using the material that have high hot hardness and properties that can with stand high temperature range. To bring a solution to this problem, fins are attached to the outer wall of engine which acts as extended surface to increase the surface area for heat transfer. Now the question arises in which form they are attached. To ensure this we would consider the HMT in which we studied that it can be of various geometry depending upon the application. So to cope up with the challenge of heat transfer we will investigate the effect of geometry on heat transfer and for this the model would be created and simulated in ANSYS 2019 and obtain an authentic work.

Introduction

Energy between two substances at different temperature is known as Heat. It generally flows from the upper temperature to the lower temperature of a substance. It is measured in units of energy; The SI unit of heat is in joules. Heat transfer could even be a discipline of thermal engineering which deals with the interchange of thermal energy between physical systems. It is assessed into various mechanisms, like thermal conduction, thermal convection, thermal radiation, and transfer of energy by phase changes. Fins is that the exchanging device which is employed to transfer heat by increasing the cross section area. Fins having different geometry like plain, wavy, oval tube and plenty of more. Fins are primarily wont to increased extent when the fluid having low heat transfer coefficient. It may be wont to increase the full rate of warmth transfer. To calculate this the term fin efficiency is extremely important. Fin efficiency is defined as the ratio of actual heat transfer rate by the highest possible heat transfer rate. Since most of the fins having one-dimension fin efficiency which is that the function of fin geometry, fin material thermal conductivity. \( \eta_{\text{fin}} = \frac{\text{Actual heat transferred by the fin (Q_{\text{fin}})}}{\text{Maximum heat that would be transferred if whole surface of the fin is maintained at the base temperature (Q_{\text{max}})}} \).

Types of Fin refer Fig.1

(a) Rectangular Profile
(b) Rectangular Longitudinal Profile
(c) Trapezoidal Profile
(d) Concave Parabolic Profile
(e) Rectangular Radial Profile
(f) Triangular Radial Profile
(g) Cylindrical Pin Profile
(h) Tapered Pin Profile
(i) Concave parabolic Pin Profile
Heat Transfer Through Fins

Heat is conducted from the bottom in to the fin at its root and so while simultaneously conducting along the length of the fin, heat is additionally convected from the surface of the fin to the ambient fluid heat transfer coefficient of $h$ in W/m$^2$–Kelvin.

Consider a differential element of the fin of length $dx$. Let $Q$ is the heat conducted in to the element along $x$-direction given by

$$Q = -kA \frac{dT}{dx}$$

Type of Heat Transfer Through Fins

Heat Transfer depends on second law of thermodynamics which states that heat transfers from an object at a higher temperature to the object at a lower temperature. The molecules at higher temperature moves towards the surroundings of the lower temperature in order to achieve equilibrium and gain stability. Here the heat flows from the surface of the fin to the surroundings that is at the ambient temperature.

Heat Transfer Through Fins by Conduction

In conduction process the heat transfer takes place due to the vibrations of the molecules of the material of fin. As the atoms of the fin material attached to the engine cylinder gains sufficient energy, they start vibrating and transfer the energy to the neighboring atoms and thus the heat flows from the base of the fin to the end surface according to the profile.

Heat Transfer Through Fins by Convection

Convection heat transfer takes place from the surface of fin which is in contact with the fluid (air). The molecule of air which is in contact with the surface of the fin gains sufficient energy and become lighter and moves away from the surface of fin. In order to replace or fill the vacant space more of dense air comes in contact with the fin and thus the convectional current is set up. In this way the heat is lost from convection. The main thing is that the high temperature develops in the engine cylinder when it is operating at high speeds so this also changes the ambient conditions outside that of cylinder. Now the convection dominating will be the Forced convection and heat will be dissipated more due to high speed of the fluid in contact with the fin.

We are going to analyses the heat transfer through a parabolic fin which is being manufactured by 3D printing technique in which the fin is produced through the layer by layer deposition of the material. Owing to this technique it may or may not be inferior as compared to other manufacturing processes such as casting and thereby can degrade the quality of the fin produced which can directly or indirectly affect the heat transfer capacity of the fin. The surface finish of the fin can also be affected by 3D printing; the surface may
not be as smooth as can be obtained by the machining processes. However, the heat transfer is analyzed at various points on the geometry by applying thermocouples at different points from the base and the effective temperature can be determined.

- To simulate the conditions in the computational software.
- To visualize the temperature contours across the surface of the fin.

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There are many research works about the heat transfer through fins and also there are number of diverse research journals published that includes the study and analysis of the fins by varying geometry, annular passage and the properties of the fluid in contact with the fins. Therefore we have tried to practically change the geometry and manufacture the fin of parabolic shape through 3D printing technique that creates an edge over the others. In this paper we will try to simulate the conditions in the computational software like ANSYS.
We will also determine the actual heat transfer through fins by experimentally determining the value of temperatures at different points from the base viz the point of attachment from the heat source towards the ambient conditions.

**Methodology**

We will begin our work by selecting a reference fin, for say, a fin of an IC Engine. The chemical composition of the fin is going to be tested so compared with a regular aluminum alloy fin.

**Mechanical Properties**


The values of various properties are found to be:

1. Melting Point: 582 - 652 °C
2. Thermal Conductivity: 167 W/m°C
3. Specific Heat Capacity: 0.896 J/g°C

**MODELLING and SIMULATION**

Models of the reference fin will be developed using modelling software and then the model will be modified for various geometrical shapes.

**PARABOLIC FIN**

Parabolic fin may be convex or concave depending upon the curvature. We have selected the parabolic geometry for our research work because in parabolic shape as we move along the X-axis the thickness of the fin decreases thereby allowing more of the fluid to come in contact with the fin surface and which increasing the rate of heat transfer. The space between the two consecutive fins will be more at the edge as compared to base. However, we don’t know whether the concave or the convex, which will be more effective? so in order to find out we will perform analysis on both the convex as well as concave.

![Figure Models of fins](image)

**FIN PERFORMANCE**

Fin Performance can be described in two different ways

Effectiveness and Efficiency
**EFFECTIVENESS (€)**

It is defined as the ratio of actual heat transferred from fin area to the heat which would be transferred if entire fin area was at base temperature. By above definition € for infinite length is given by,

\[
\epsilon_{\text{fin}} = h \cdot P \cdot k \cdot A_c \frac{Ac(ts-a)}{hAc(ts-ta)}
\]

Factors affecting fin effectiveness-

1. \(P \cdot Kh \cdot Ac\) should be greater than unity.
2. Effectiveness of fin is increased by increasing the ration of \(P\) and \(Ac\).

**EFFICIENCY**

The is defined as the ratio of actual heat transfer rate from the fin to the ideal heat transfer rate from the fin if it is at base temperature.

\[
\eta_{\text{fin}} = \frac{Q_{\text{fin}}}{Q_{\text{max}}}
\]

In the standard experiment of pin fin apparatus, we use pin fin. But in this we would like to determine the temperature distribution of a parabolic fin as shown in the picture. By replacing the pin fin with the parabolic fin in the same apparatus. We will Determine the value of Distribution, effectiveness and efficiency with the help of the experiment as well as the theoretical value. And compare the experimental and theoretical value. We will also determine the most effective of the two curvatures.

Temperature distribution along the length of a fin is given by

\[
\frac{\alpha}{\alpha_0} = \frac{T-T_1}{T_0-T_1} = \frac{\cosh[m(l-x)]}{\cosh(ml)}
\]

In this equation the unknown is ‘m’. Now determine the value of ‘m’ using

\[
m=\sqrt{\frac{h_p}{k\cdot a}}
\]

In the equation \(h\) and \(k\) are unknown,

\[
h = \frac{Nu \cdot k}{d}
\]

\[
Nu = c \cdot Re^n \cdot Pr.
\]

\[
Re = \frac{V \cdot D}{\nu}
\]

After creating the 3D model in modelling software, we’ll import the part move into ANSYS for the thermal analysis. We’ll begin our analysis by defining the fabric from material library and its properties and therefore the various constant like convective heat transfer coefficient (as calculated above in Calculations) of the system. Next step is to define the bottom temperature of the fin and therefore the ambient temperature. The answer then generated by the ANSYS will give the overall temperature drop and therefore the gradient over the fins.
Conclusion

After a thorough analysis of both the shapes of the parabolic fins in the ANSYS software and obtaining the thermal analysis simulation it can be concluded that the convex parabolic fin has a greater heat transfer rate due to the more exposure of the surface to the surroundings along the longitudinal axis. 

\( \varepsilon_{\text{fin}} \) depends upon the surface area of the fin exposed to the surroundings.

The thermal analysis of fins by modifying its certain parameters like geometry is our main aim during this project. By using ANSYS, we checked the thermal behavior of various models. Appropriate material was selected and models of fins of varying geometry like parabolic fin of convex and concave were made.

There after the information was recorded and was compared for optimum heat transfer density. The results obtained after the completion of this project, may be generalized and may be applied for various large scale applications like fins for IC Engines, which might help in considerable increase within the it’s efficiency and life. the aim of this project is to require a step towards a whole analysis of the warmth dissipation through fins. Ideally it should prevent overheating for all its applications.

References


