Study of Effect of Fin Geometry on Rate of Heat transfer for a 150cc, 4-stroke IC Engine

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Abstract— The heat transfer rate from air-cooled extended surfaces from an IC engine primarily depends upon the velocity of the vehicle, air stream velocity, fin geometry, material and the ambient temperature. Insufficient removal of heat from engine leads to high thermal stresses and lower engine efficiency. The cooling fins allow the wind to move the heat away from the engine. Low rate of heat transfer through fins is the main problem of air-cooling system, sometimes leading to piston seizure. Different designs of fin geometries are used in commercial 4-stroke engines to augment the rate of heat transfer through convection. The fin geometry plays a major role in augmenting the rate of heat transfer. A detailed Finite Element heat transfer study is conducted to study the effect of heat transfer on the rate of heat transfer from an IC engine. It is found that S shaped or wavy fins have the maximum effectiveness as they increase the air flow turbulence and hence the coefficient of heat transfer *h*, thus increasing the rate of heat transfer.

Keywords— IC Engine,Fins, Heat Transfer, Fin effectiveness, FE analysis

I. INTRODUCTION

When the combustion of air-fuel mixture takes place inside the engine cylinder, a temperature as high as 2600^{O}C is generated by the combustion gases. Out of total heat generated by internal combustion engine due to combustion of fuel, only 38% of heat is converted in useful work, out of remaining 62% about 33% is carried by exhaust gases into the atmosphere during exhaust stroke. The rest of 29% must be passed to atmosphere by some suitable arrangement.For an IC engine, the fins are designed for material, geometry (length, Distance between two fins (pitch), cross sectional area) and the heat transfer coefficient of the surrounding fluid etc. Out of all the above parameters the fin geometry plays the maximum role in deciding the rate of heat transfer from the engine. The choice of fin geometry apart from the rate of heat transfer also depends on fabrication feasibility, material availability, and cost of fabrication and manufacturing limitations amongst others.

Kumbhar D.G et.al. [5] studied the effect of perforations in IC engine fin geometry and concluded that the heat transfer rate increases with perforation in fins as compared to fins of similar dimensions without perforation. The perforation of the fin enhances the heat dissipation rates at the same time decreases the expenditure for fin materials also.

N. Nagarani et.al. [6] Analyzed the heat transfer rate and efficiency for circular and elliptical annular fins for different environmental conditions. Elliptical fin efficiency is more than circular fin. If space restriction is there along one particular direction while the perpendicular direction is relatively unrestricted elliptical fins could be a good choice. Normally heat transfer co-efficient depends upon the space, time, flow conditions and fluid properties. If there are changes in environmental conditions, there is changes in heat transfer co-efficient and efficiency also.

R.P. Patil and H.M. Dange [7] conducted CFD and experimental analysis of elliptical fins for heat transfer parameters, heat transfer coefficient and tube efficiency by forced convection. The experiment is carried for different air flow rate with varying heat input. The CFD temperature distribution for all cases verifies experimental results. At air flow rate of 3.7 m/s, the heat transfer rate decreases as heat input increases. Also h is higher at above atmospheric temperature and lower at below atm. Temperature. At air flow rate of 3.7 m/s the efficiency, increases as heat input increases.

J.Ajay Paul, SagarChavanVijay [8] Parametric Study of Extended Fins in the Optimization of Internal Combustion Engine they found for high speed vehicles thicker fins provide better efficiency. When fin thickness was increased, the reduced gap between the fins resulted in swirls being created which helped in increasing the heat transfer. Large number of fins with less thickness can be preferred in high speed vehicles than thick fins with less numbers as it helps inducing greater turbulence.

G.Raju, Dr. Bhramara Panitapu, S. C. V. Ramana Murty Naidu. “Optimal Design of an I C engine cylinder fin array using a binary coded genetic algorithm”.[9]This study also includes the effect of spacing between fins on various parameters like total surface area, heat transfer coefficient and total heat transfer .The aspect rations of a single fin and their corresponding array of these two profiles were also determined. Finally the heat transfer through both arrays was compared on their weight basis. Results show the advantage of triangular profile fin array.

The aim of the present investigation was to study comparative analysis of the various fin geometries for the rate of heat transfer w.r.t the fin weight and the fin effectiveness. The various result parameters are tabulated and graphically represented.

II. ANALYSIS

A. Base Engine Specifications

The engine used for the study is a 150cc four stroke air-cooled IC engine with the following specifications:

- Engine 4 Stroke, 1 Cylinder, Air Cooled
- Displacement 149.01 cc
- Bore and Stroke 57 × 56.4 mm
- Compression Ratio 9.8:1
- Max. Power 10.35 KW @ 8500rpm
- Fin Material Al. Alloy
- No. of fins 12
- Fin Pitch 10
- Fin Thickness 2mm
- Fin Profile Rectangular
- Max. Fin Height 35mm
- Min. Fin Height 10mm

Different fin geometries for the same engine and thermal environment are studied for the rate of heat transfer.

B. Geometries

The following fin geometry configurations are studied for the rate of heat transfer:

1. Parallel Fin: 12 No.
2. Parallel Fin: 12 No. - Tapered Configuration
3. Parallel Fin: 24 No.
4. Circular Rectangular Fin
5. Circular Rectangular Fin – Tapered Configuration
6. Circular conical Fin
7. S shaped Wavy Fin
8. S shaped Wavy Fin – Tapered configuration

The geometries are drawn in commercially available Solidworks software and imported in Ansys14.0 for 2-D thermal analysis. After the geometries are modeled in Solid works, they are imported in Ansys 14.0 and meshed using SOLID87 - 3-D 10-Node Tetrahedral Thermal Solid element. The element is applicable to a three-dimensional, steady-state or transient thermal analysis. The element is well suited to model irregular meshes (such as produced from various CAD/CAM systems). The element has one degree of freedom, temperature, at each node.The elements are made finer (increase in the number of elements) till the error in reduced to unit place of decimal.

C. Boundary conditions and Solving Methodology

Material Properties	**Al. alloy AA 6061**
Thermal conductivity (W/m K)	210
Specific heat (KJ/kg ^{o}C)	0.9
Density (kg/m^3)	2780
ID wall Temperature (K)	500
Ambient Temperature (K)	300
Convective heat transfer coeff.(W/m^{2}K)	40

The properties of Al alloy AA6061 and boundary conditions are given below:

Table: 1: Material Properties of AA 6061 & boundary conditions

The following assumptions are made in all analysis:

1. The heat flow through the fin is considered as in steady state, so that the temperature of the fin does not vary with time. The temperature of the inner cylinder is constant.
2. The thermal conductivity of the fin material is uniform and constant.
3. The radiation heat transfer of the fin is neglected.
4. Uniform ambient temperature of 300 K is considered

The value of *h* as computed from [1] & [2] for different wind velocities and a pitch of 10 mm and fin height of 35 mm is tabulated below:

Relative Wind Velocity (Km/hr)	Thornhill et al. [1] h (W/m^2K)	Gibson [2] h (W/m^2K)
10	18.1	18.9
20	29.6	31.4
30	**39.5**	**42.2**
40	48.5	52
50	56.8	61.2
60	64.7	70

Table 2: Different values of convective heat transfer coefficient (h) as per Thornhill et al. [1] & Gibson [2] equations

From the above table, the convective heat transfer coefficient is taken as 40 W/m^2K, for vehicle velocity of 30km/hr, for this study.

The different configurations are analyzed for Al. alloy AA6061, having coefficient of thermal conductivity is 210 W/mK. The convective heat transfer coefficient is 40W/m^2K. The combustion chamber ID temperature is 500K and the ambient temperature is 300K.After the application of boundary conditions, the problem is solved in Ansys14.0. The solution after convergence, the temperature distribution, the thermal flux and the temperature gradient are plotted.

The methodology used for solving the problem statement is:

Step A: Modelling of 2-D fin geometries in Solid Works.
Step B: Importing Iges file in Ansys 14.0 and meshing using triangular element (Triangle 6 node 35)
Step C: Application of Boundary conditions on the model
Step D: Solving
Step E: Post-processing and data generation.

D. Results and Discussions

The problem statement is solved and the various parameters are plotted for analysis. Thermal gradient is a physical quantity that describes in which direction and at what rate the temperature changes the most rapidly around a particular location. The temperature gradient is a dimensional quantity expressed in units of degrees (on a particular temperature scale) per unit length. The SI unit is kelvin per meter (k/m).

Heat flux or thermal flux is the rate of heat energy transfer through a given surface, per unit surface. The SI derived unit of heat rate is joule per second, or watt. Heat flux density is the heat rate per unit area. In SI units, heat flux density is measured in [W/m^2]. Heat rate is a scalar quantity, while heat flux is a vector quantity. To define the heat flux at a certain point in space, one takes the limiting case where the size of the surface becomes infinitesimally small.Fin effectiveness (ε is defined as the ratio of heat transfer rate with fin to the heat transfer rate without fin

$$\varepsilon_f = \frac{Heat\ transfer\ rate\ with\ fin}{Heat\ transfer\ rate\ without\ fin} = \frac{Q}{h\ A_b \theta_b}$$

Here, A_b is the cross sectional area of the fin at the base.

For an adiabatic fin where fin tip loss is negligible:

$$\varepsilon_f = \frac{\sqrt{hPkA_c}\,\theta_b \tanh mL}{h\, A_b \theta_b} = \sqrt{\frac{kP}{h\, A_b}} \tanh mL$$

for a uniform cross-section fin (A_c=A_b)
Further if , $mL > 2;\ \tanh mL \approx$
Therefore

$$\varepsilon_f = \sqrt{\frac{kP}{h\, A_b}}$$

The physical significance of effectiveness of fin can be summarized below:

- An effectiveness of (ε_f) = indicates that the addition of fins to the surface does not affect heat transfer at all. That is, heat conducted to the fin through the base area A_b is equal to the heat transferred from the same area A_b to the surrounding medium
- An effectiveness of (ε_f) < indicates that the fin actually acts as insulation, slowing down the heat transfer from the surface. This situation can occur when fins made of low thermal conductivity materials are used.
- An effectiveness of (ε_f) > indicates that the fins are enhancing heat transfer from the surface, as they should. However, the use of fins cannot be justified unless (ε is sufficiently larger than 1i.e. ($\varepsilon_f >$. Finned surfaces are designed on the basis of maximizing effectiveness of a specified cost or minimizing cost for a desired effectiveness.

Fin effectiveness is enhanced by:

a) Using material with high thermal conductivity like Copper, Aluminum etc.
b) Increasing the ratio of perimeter to the cross-sectional area of the fin; *P/A*. Therefore the use of thin, but closely spaced fins is preferred to that of thick ones.

Fin Configuration	**Heat transfer (W)**	**Fin Weight (kg)**	**Effectiveness**
Parallel fin -12 No.	736.7	0.252	2.54
Parallel fin -12 No. Tapered	683.9	0.210	2.36
Parallel fin -24 No (10 mm pitch)	1170.8	0.490	4.03
Circular Rectangular	1982.4	0.760	6.83
Circular Rectangular Tapered	1729.3	0.590	5.96
Circular Conical	1871.4	0.340	6.45
S shaped Wavy Fin	2030.9	0.780	7
S shaped Wavy Fin – Tapered	1817.3	0.610	6.26

configuration			
Cylinder without fin	290.3	0	1

c) Lower value of heat transfer coefficient *h.* The fins are preferable when the fluid is a gas rather than a liquid, particularly when the heat transfer from surface is by natural convection. If fins are to be used on surfaces separating gas and liquid. Fins are usually placed on the gas side. Therefore, it is no coincidence that in liquid-to-gas heat exchangers such as the car radiator, fins are placed on the gas side.

Table: 3: Heat transfer, Weight and Effectiveness comparison of different fin configurations

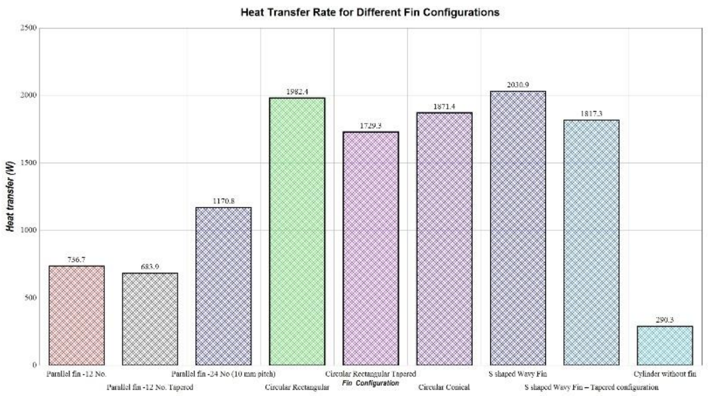

Fig 1: Heat transfer rate comparison of different fin configurations

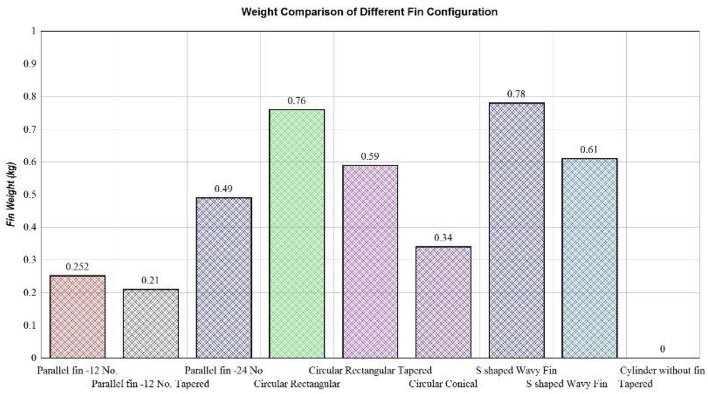

Fig 2: Weight comparison of different fin configurations

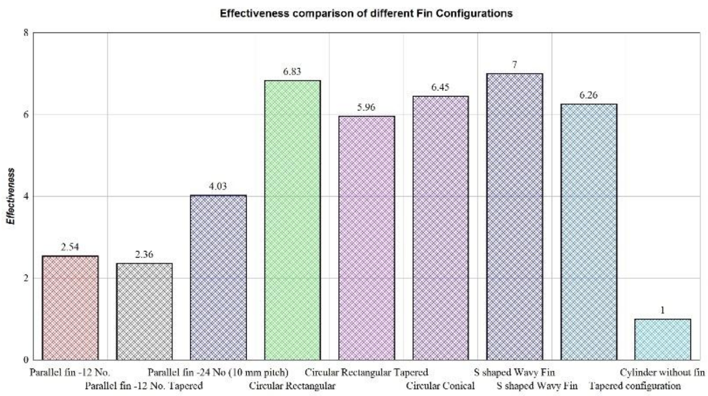

Fig 3: Effectiveness comparison of different fin configurations

The following are the major observations of the above results:

1. The effectiveness of all fin configurations varies from 2.4 to 7.
2. The effectiveness of parallel fins is far lesser than other configuration fins. Hence, Parallel fins should not be chosen for designing the air-cooling systems of IC engines, until due to a configuration constraint.
3. It is advisable to shape the fins in arch shape (S-shape or wavy shapes) to increase the fin effectiveness, as seen in S-shaped Fin configuration. S-shaped fins have the maximum effectiveness.
4. The weight of conical fins is 55.3% lesser than rectangular fins. However, the effectiveness is only 5.6% lower than that of rectangular fins. Hence overall, conical fins are better than rectangular fins.
5. The thermal gradient is maximum in locations of profile change. This will lead to thermal stresses and probably metal cracking in these zones. It is advisable to provide smooth contours in these places to reduce the gradient.

III. CONCLUSION

The effect of fin geometry, is studied for the heat loss for air cooling of an IC engine. The heat transfer rate, weight and effectiveness are plotted and studied for all configurations.It is found that wavy shaped (S-shaped) fin, instead of rectangular cross section have higher rate of heat transfer. The S -shape also increases the turbulence, increasing the h and hence the heat transfer. Also heat transfer per unit weight of fin is larger for conical fin than rectangular fins, hence conical fins are preferred over rectangular cross section fins.

There is further scope to do a 3-D analysis of the configurations to accurately account for the convective heat transfer coefficient. Also the effect of introducing radial holes in fins can be studied for the rate of heat transfer.

IV. ACKNOWLEDGMENT

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