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Research Article

Design Modification and Heat Transfer Analysis of different Geometry Fins

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Abstract

Heat transfer is a notable constraining variable for the effectiveness of internal combustion engines. The capacity to anticipate heat transfer in engine concludes a significant role in engine advancement. The heat transfer rate optimization increases the efficiency and reflects the saving in the power supplied of the automobile engine. The cylinder surfaces are extended to dissipate more amount of heat, and these extended surfaces are known as fins. Fins are a necessary part of the engine cylinder which aides in expanding heat dissipation rate produced by the engine. The heat dissipation relies on the speed of the air, surrounding temperature, geometry, and surface of the fin. The main objective of this research study is to analyse the new design and heat transfer properties of the fins to increase the fin efficiency, effectiveness and heat transfer rate by simulating the different geometry fins (as rectangular, circular, annular, zigzag and curved). The 3-D modelling of fins was done in CAD software and the CFD analysis was carried out to determine the heat dissipation flow through the fins. The analysis of the fins was carried out using material aluminium alloy 6061 which has a higher thermal conductivity.

Keywords: *Heat Transfer Rate, Design of Fins, Effectiveness of fins, CFD, Finite Element Analysis, Convection*

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1. Introduction

The I.C. engine is in which the fuel burn with an oxidizer (usually air) in the engine cylinder during the combustion stroke. The chemical energy of the fuel is converted into mechanical energy (Heat Transfer Analysis and Optimization of Engine Cylinder Fins of Varying Geometry and Material , Jul. - Aug. 2013). Only 25 to 35 percent of the total generated thermal energy converts into useful work and rest of it rejected into the surrounding.

It is necessary to remove the excessive heat for avoiding the damaging effects of overheating or burning of engine components (Cooling Effect Improvement by Dimensional Modification of Annular Fins in Two Stage Reciprocating Compressor, 2014). By increasing the heat transfer coefficient, the transfer rate of heat can be increased between the surface and its surrounding, or the area of the surface can be increased, or by both (Thermal and hydraulic performance analysis of rectangular fin arrays with perforation size and number., 2014). To enhance the heat transfer, commonly the extended surfaces are used which are known as fins. The concern of this paper is to dissipate the heat by the application of cooling fins (through an extended surface. Conduction and convection are the two methods of heat transfer which needs to understand to know the phenomena of fins. Radiation mode is not significant as the temperature is too low (An Experimental Investigation into the Cooling of Finned Metal Cylinders, in a Free Air Stream, 1999). The process of convection is mainly used to cool the different type of machines through fins (Design Modification and Thermal Analysis of IC, June 2017). Due to the design of the system, the fin shape design is limited, yet at the same time geometry and parameters could be changed to enhance the heat transfer (Design and Analysis of Engine Fins , 2016). Surface heat-transfer coefficient is mainly expressed as the rate of transfer from the surface of an object through air stream. To calculate the coefficient of surface heat-transfer a various theoretical method are used for the air flow over a simple surface.

For finned cylinders (complex bodies), the velocity field is extremely complicated over the surface of the fins, especially in the region at the rear half of the cylinder where the flow is vortical (Pinkel, 1934).

1.1 Necessity of Cooling System

The combustion of fuel inside the combustion cylinder produced a lot amount of heat which is not completely convert into useful power at the crankshaft. Mainly a 25% of heat is used to transfer the useful work through

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the crankshaft. An approximate distribution of the fuel energy losses is mentioned below (Design and Analysis of Engine Fins , 2016).

Friction losses = 10%
Cylinders wall losses = 30%
Exhaust gas losses = 35%

A comprehensive study by Kern and Kraus about the extended surface heat transfer was published in 1972. More recently various number of papers have been published addressing the cooling of free air cooled engines. Comprehensive data on surface heat transfer coefficient is scarce which ultimately determines the effectiveness of the fins. Although many studies, scattered throughout the research journals, provide some information, little compares with that from the body of the work undertaken between 1932 and 1938 at the Langley Memorial Aeronautical Laboratory. This work was described in NACA papers for free air cooled cylinders (Comparison of Experimental and CFD Analysis of Fin Array, Apr-2018).

1.2 *Material properties*

Table 1 Material properties of Aluminium Alloy 6061

S. No	Parameters	Values
1	Melting temperature ©	585 °C (1,085 °F)
2	Linear thermal expansion coefficient (α)	2.32×10−5 K−1
3	Thermal conductivity (k)	151–202 W/(m·K)
4	Specific heat capacity ©	897 J/(kg·K)

2. Methodology

A fin is defined as the surface which increase the rate of heat transfer by extending the surface from an object or through the environment, increasing convection. However, adding a fin configuration with the object, slightly increases the area of surface and can also be an economical solution for heat transfer problems (Kern, 1972). Circumferential fins around the cylinder, square, rectangular shape of a motorcycle engine are a few familiar examples (Design and analysis of different types of fin configurations using ANSYS, 2018).

The different fin configuration with their respective dimensions which are taken into account for the calculation of heat transfer rate are as follows.

3. Fin configuration

3.1 *Rectangular Fin*

Table 2 The dimensions of rectangular fin

S. No.	Fin Length	110 mm
1	Fin Thickness	4 mm
2	Fin Pitch	7.78 mm
3	Fin height	30 mm
4	Number of fins	10 mm

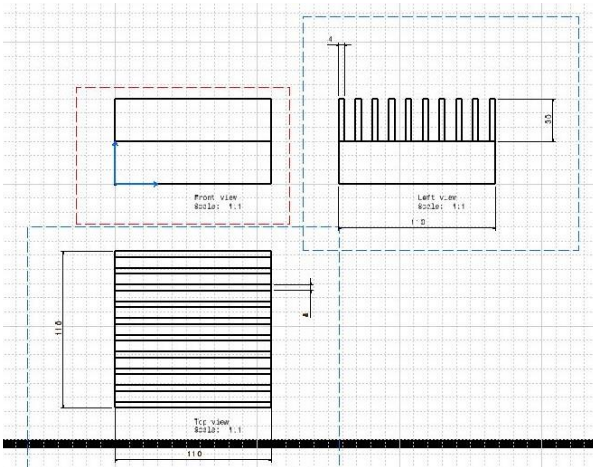

Fig. 1 Drafting of rectangular fin

3.2 *Annular Fin*

Table 3 The dimensions of Annular fin

S. No	Parameters	Values
1	Cylinder Diameter	35 mm
2	Fin height (fin radius)	30 mm
3	Fin Pitch	7.78 mm
4	Fin Thickness	4 mm
5	Number of Fins	10 mm

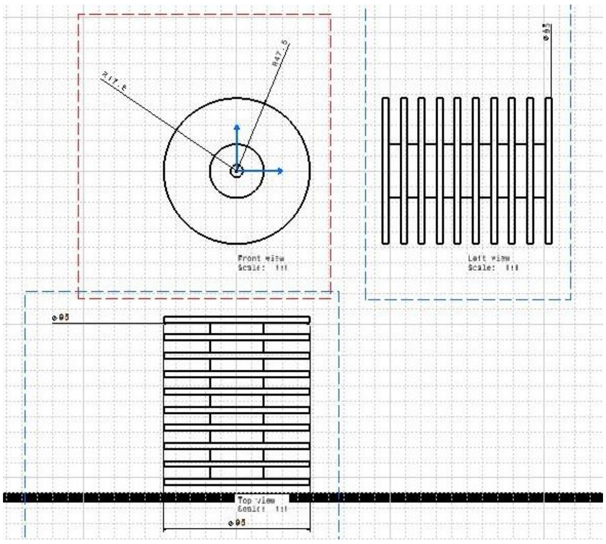

Fig. 2 Drafting of annular fin

3.3 *Zigzag Fin*

Table 4 The dimensions of zigzag fin

S. No	Parameters	Values
1	Fin Length	110 mm
2	Fin Thickness	4 mm
3	Fin Height	30 mm
4	Step length (zigzag)	20 mm
5	Number of step	10 mm
6	Fin pitch	7.78 mm

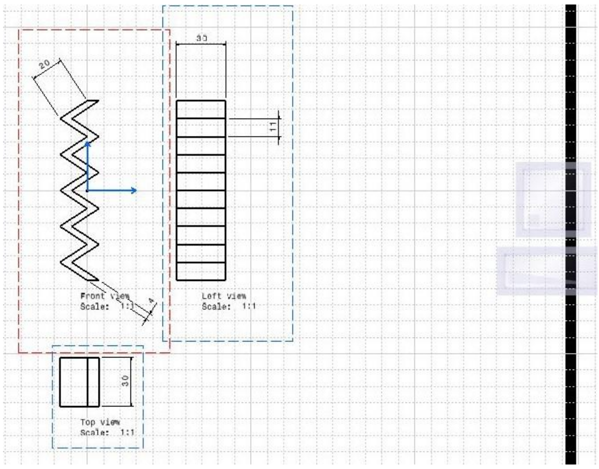

Fig. 3 Drafting of zigzag fin

4. Hand calculations

4.1 Nomenclature

$\dot{Q}$= Heat transfer rate	W
h = Heat transfer coefficient	$W/_{m^2K}$
A_c= Fin contact area	m^2
T_s= Fin surface temperature	K
T_a= Ambient temperature	K
$q"$= Heat flux	$W/_{m^2}$
P= Perimeter of fin	m
T_b= Fin base temperature	K
w= Width of fin	m
t= Thickness of fin	m
A_s= Surface area of fin	m^2
K= Thermal conductivity (Al Alloy 6061)	$W/_{mK}$

4.2 Formula used

Heat transfer Rate

$$\dot{Q} = hA_s(T_s - T_a) \tag{1}$$

Convection at fin tip for rectangular and zigzag fins

$$\dot{Q} = M\theta_b \tanh[m\left(w + \frac{t}{2}\right)] \tag{2}$$

Convection at fin tip for annular fins

$$\dot{Q} = \sqrt{hPKA_c}(T_b - T_a)\{\frac{\tanh(\sqrt{\frac{hP}{KA_c}}L)+\frac{h}{\sqrt{\frac{hP}{KA_c}}K})}{1+\frac{h}{\sqrt{\frac{hP}{KA_c}}K}*\tanh\sqrt{\frac{hP}{KA_c}}L}\} \tag{3}$$

Heat Flux

$$q" = \frac{\dot{Q}}{A_c} \tag{4}$$

Efficiency

$$\eta = \frac{\dot{Q}}{hA_s(T_s - T_a)} \tag{5}$$

Effectiveness

$$\varepsilon = \sqrt{\frac{PK}{hA_c}} \tag{6}$$

$$M=\sqrt{hPKA_c} \tag{7}$$

$$m=\sqrt{\frac{hP}{KA_c}} \tag{8}$$

$$\theta_b=T_b - T_a \tag{9}$$

5. Steady State Thermal Analysis

5.1 Rectangular Fin

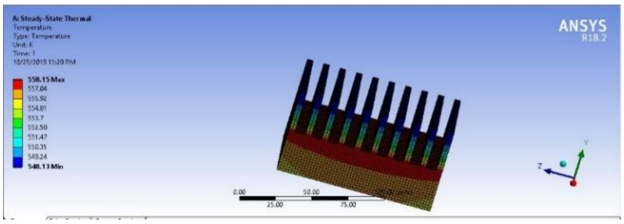

Fig. 4 Steady state thermal temperature of rectangular fins

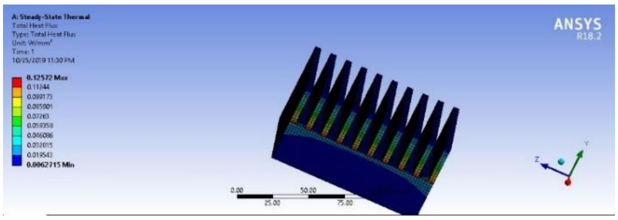

Fig. 5 Steady state thermal heat flux of rectangular fins

5.2 Annular Fin

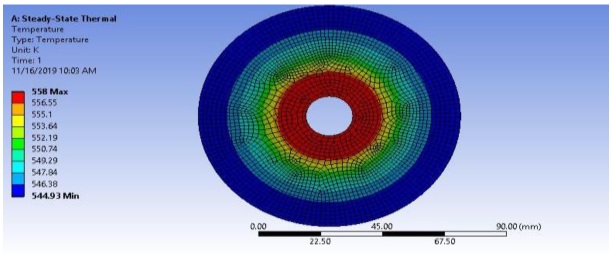

Fig. 6 Steady state thermal temperature of Annular fins

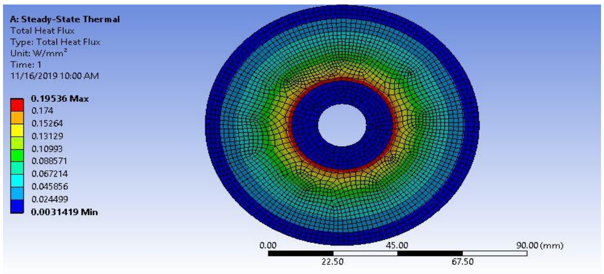

Fig. 7 Steady state thermal heat flux of annular fins

5.3 Zigzag Fin

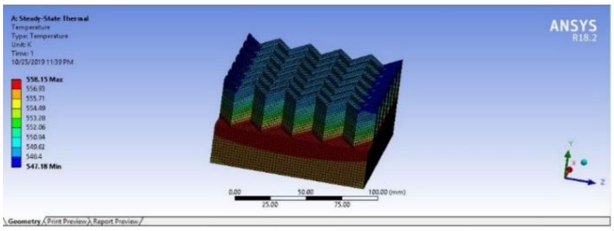

Fig. 8 Steady state thermal temperature of zigzag fins

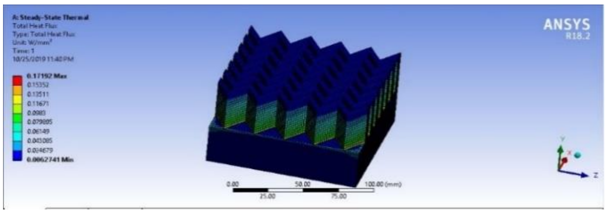

Fig. 9 Steady state thermal heat flux of zigzag fins

6. CFD Analysis

Ansys Fluent Solver is used for the CFD analysis. Steady state simulations are performed. Conservation equations for momentum, mass, and energy are the governing equations for fluid dynamics (Comparison of Experimental and CFD Analysis of Fin Array, Apr-2018). The following governing equations are considered which are suitable for the current model and simulations. The mass, energy, momentum are conserved in these equations which work by finite volume approach.

6.1 Assumptions in CFD Analysis

- The fluid, air is assumed to be incompressible throughout the process.
- Air properties were taken at the film temperature.
- The flow was considered as steady.
- The fin itself doesn't have any heat source.
- The radiation heat transfer was negligible.
- The temperature was assumed to be uniform at the base of the.
- The heat flow in the fin and its temperature remain constant with time.

6.2 Governing Equations

The Conservation equation of mass is given by:

$$\frac{\partial y}{\partial x}+\frac{\partial v}{\partial x}+\frac{\partial w}{\partial x}=0 \qquad (10)$$

The Conservation equation of momentum in x, y, z directions of Cartesian co-ordinate system respectively is as follows:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial \rho}{\partial x}+v\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right) \qquad (11)$$

$$\frac{\partial u}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial \rho}{\partial y}+v\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \qquad (12)$$

$$\frac{\partial u}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial \rho}{\partial x}+v\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right) \qquad (13)$$

The Conservation equation of energy is given by:

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\frac{k}{\rho C_p}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)+q_g+\emptyset \qquad (14)$$

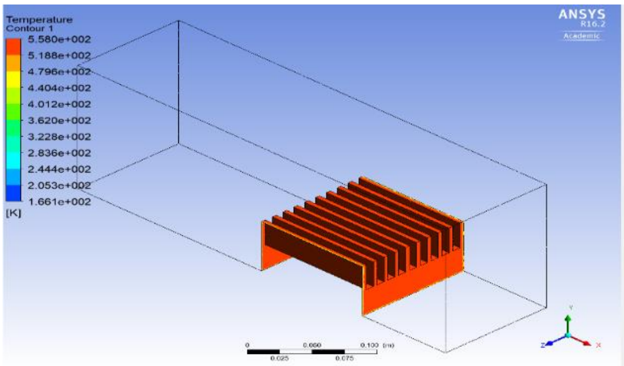

Fig. 10 CFD analysis, temperature contour of rectangular fins

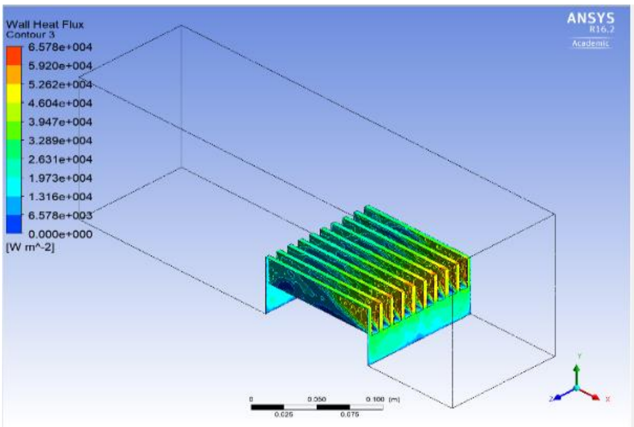

Fig. 11 CFD analysis, Wall heat flux contour of rectangular fins

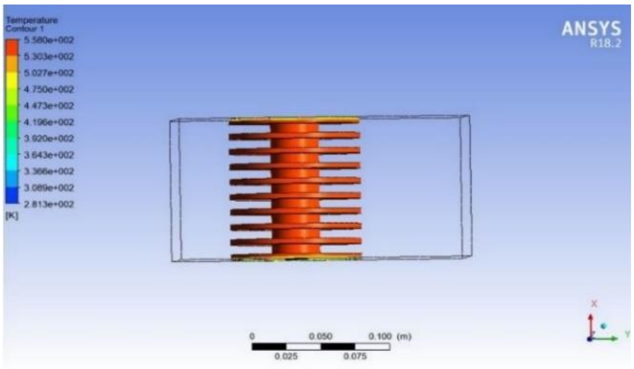

Fig. 12 CFD analysis, temperature contour of annular fins

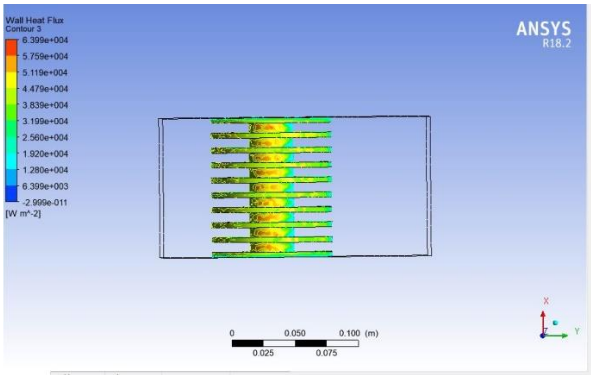

Fig. 13 CFD analysis, Wall heat flux contour of annular fins.

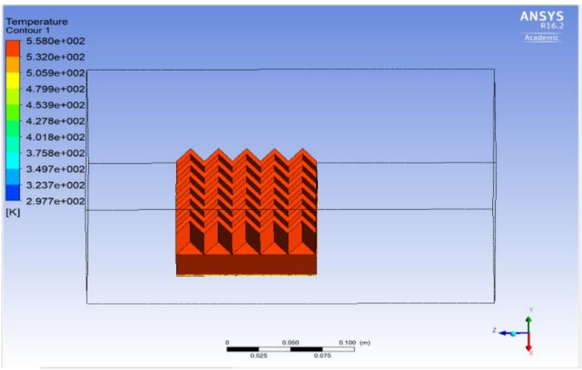

Fig. 14 CFD analysis, temperature contour of zigzag fins

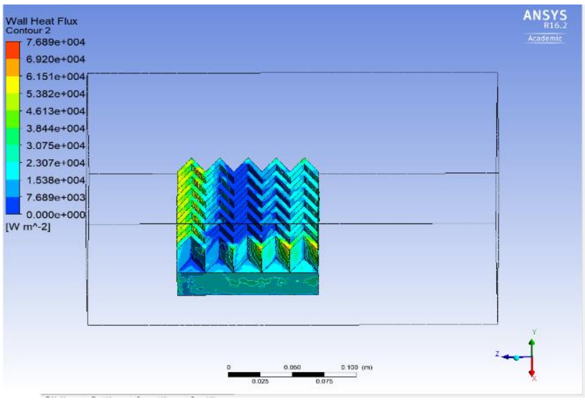

Fig. 15 CFD analysis, Wall heat flux contour of zigzag fins.

7. Results and Discussion

Table 5 Calculated values of variables used in equations

S.No	Fin Configuration	$M=\sqrt{hPKA_c}$	$m=\sqrt{\frac{hP}{KA_c}}$	Perimeter $P(m)$	Surface Area A_s (m^2)	Cross-sectional Area A_c (m^2)	Surface Temperature $T_s\ (K)$	Base Temperature $T_b\ (K)$
1	Rectangular	0.617	9.231	0.228	0.0079	0.00044	553.19	558.13
2	Annular	0.775	7.087	0.219	0.0134	0.00072	538.25	558.13
3	Zigzag	1.120	9.101	0.408	0.0148	0.00081	552.66	558.13

Table 6 Theoretical results

S.No	Fin Configuration	Material	Effectiveness	Efficiency	Heat transfer rate (W)	Heat flux $({}^{W}/_{mm^2})$
1	Rectangular	Aluminium Alloy 6061	56.12	0.91	46	0.104545
2	Annular	Aluminium Alloy 6061	43.09	0.53	46.36	0.064388
3	Zigzag	Aluminium Alloy 6061	55.34	0.87	82.46	0.101802

Conclusions

The fins (extended surface), provides an efficient heat transfer. In this paper three types of different fin configuration have been analysed to determine the heat transfer rate, effectiveness, efficiency and heat flux of the fins. The heat dissipation relies on the speed of the air, heat source temperature and on the surrounding temperature, values of the speed of air and surrounding temperature were taken as 15 m/sec and 25˚C respectively for the finite element analysis. From the results obtained it is found that the zigzag fin geometry has higher heat transfer rate.

The heat transfer rate is maximum in zigzag fin (82.46 W) as compared to other geometry fins. The heat transfer rate of rectangular fin is 46 W and that of annular is 46.36 W. The efficiency of rectangular fin is maximum (0.91) as the surface area of rectangular fin is minimum. As the ratio of perimeter to cross-sectional area of rectangular fin is more as compared to other fins which gives the maximum effectiveness as (56.12). The effectiveness of Zigzag fin is determined as 55.34 and 43.09 for annular fin.

From detailed study of the papers it can be concluded that the geometry, perimeter and cross-sectional area of the fin is the important criteria that decides the efficiency as well as the effectiveness of the fins.

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