Analytical Comparison of Cylinder Cooling Using Rectangular and Triangular Fins

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Abstract- **Engine life and performance can be improved with effective cooling. The cooling mechanism of the air cooled engine is mostly dependent on the fin design of the cylinder head and block. The heat is conducted through the engine parts and convected to air through the surfaces of the fins. Insufficient removal of heat from engine will lead to high thermal stresses and lower engine efficiency. As the air-cooled engine builds heat, the cooling fins allow the air to move the heat away from the engine. Low rate of heat transfer through cooling fins is the main problem in this type of cooling. In the present work, an attempt is made through analytical calculation to calculate temperature distribution, heat transfer through the fin, heat transfer without the fin and effectiveness. The results obtained for rectangular and triangular profile geometries are tabulated and discussed.**

Keywords- **circumferential fins, Heat transfer, Analytical calculations.**

I. INTRODUCTION

Most internal combustion engines [1] are fluid cooled using either air or a liquid coolant run through a heat exchanger (radiator) cooled by air. In air cooling system, heat is carried away by the air flowing over and around the cylinder. Here fins are cast on the cylinder head and cylinder barrel which provide additional conductive and convective surface. We know that in case of Internal Combustion engines, combustion of air and fuel takes place inside the engine cylinder and hot gases are generated. The temperature of gases will be around 2300-2500°C. This is a very high temperature and may result into burning of oil film between the moving parts and may result into seizing or welding of the same. So, this temperature must be reduced to about 150-200°C at which the engine will work most efficiently. Too much cooling is also not desirable since it reduces the thermal efficiency. So, the object of cooling system is to keep the engine running at its most operating temperature. It is to be noted that the engine is quite inefficient when it is cold and hence the cooling system is designed in such a way that it prevents cooling when the engine is warming up and till it attains to maximum efficient operating temperature, then it starts cooling.

Extended surfaces or fins [2] are widely used in many engineering applications which include, but are not limited to, air conditioning, refrigeration, automobile and chemical processing equipment. The primary objective of using fins is to enhance the heat transfer between the base surface and its convective environment.

As per the literature survey [3], it is established that Effectiveness of the circumferential fin with material aluminum alloy 6061 is better than the fin with material aluminum alloy A204,which is used as fin material for I.C. Engines.

Hence, circumferential fin of rectangular and triangular profiles with material aluminum alloy 6061 is used in the henceforth work.

II. ENGINE SPECIFICATION

Table 1: Engine Specification

No of cylinders	1
bore	57.3mm
stroke	57.8mm
Piston displacement	149.2 cm^3
Compression ratio	9.1:1
Fuel used	petrol
Engine position	vertical

III. ANALYTICAL CALCULATIONS

Circumferential fin of rectangular profile

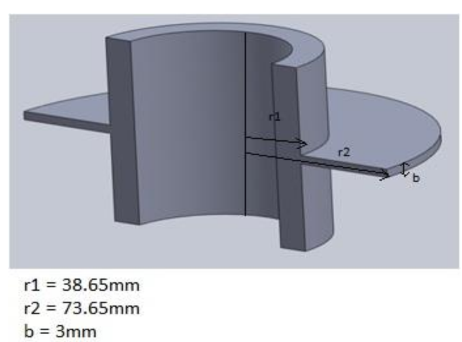

Figure 1: Solid works model of circumferential fin of rectangular geometry.

Making energy balance over annular element of radius ‘r’ and thickness dr

$$\frac{d^2T}{dr^2}+\frac{1}{r}\frac{dT}{dr}-\frac{2h}{kb}\left(T-T\alpha\right)=0$$

Let $\theta = T - T_{\alpha}$

$$\frac{d^2\theta}{dr^2}+\frac{1}{r}\frac{d\theta}{dr}-\left(\frac{2h}{kb}\right)\theta=0$$

Let $m^2=\frac{2h}{kb}$

$$\frac{d^2\theta}{dr^2}+\frac{1}{r}\frac{d\theta}{dr}-m^2\theta=0 \qquad (1)$$

Equation (1), is Bessel’s equation of zero order, on solving

1. Temperature distribution

$$\frac{\theta}{\theta_0}=\frac{I_0(mr)\,k_1(mr_2)+k_o\,(mr)\,I_1(mr_2)}{I_0(mr_1)\,k_1\,(mr_2)+k_0(mr_1)I_1\,(mr_2)}$$

2. The rate of heat transfer

$$\theta_{fin}=2\Pi Kmb\theta_0 r_1$$

$$\frac{K_1(mr_1)\,I_1(mr_2)-I_1\,(mr_1)\,K_1(mr_2)}{K_0\,(mr_1)\,I_1\,(mr_2)+I_0\,(mr_1)\,k_1\,(mr_2)}$$

3. $Q_{withoutfin}=hA_s(T_s-T_{\alpha})=h2\Pi r_1 b(T_s-T_{\alpha})$

4. Effectiveness $\in=\frac{Q_{fin}}{Q_{withoutfin}}$

On solving using above formulae

1. $\frac{\theta}{\theta_0}=0.9706$

$T_{TIP}=156.3^{o}C$

2. $Q_{fin}=31\,watts\,(57400\ w/m^2)$

3. $Q_{withoutfin}=0.9175\,Watts\left(1700\ w/m^2\right)$

4. Effectiveness $\in=\frac{Q_{fin}}{Q_{withoutfin}}=33$

Circumferential fin of Triangular Profile

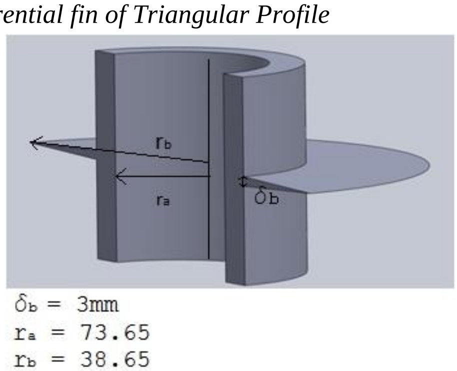

Figure 2: Solid works model of circumferential fin of triangular geometry.

Profile function

$$f_2(r)=\frac{\delta_b}{2b}(r_a-r)$$

$$\frac{df_2(r)}{dr}=\frac{-\delta_b}{2r}$$

On energy balance, General equation for circumferential fin

$$f_2\,(r)\frac{d^2\theta}{dr^2}+\frac{f_2(r)}{r}\frac{d\theta}{dr}+\frac{df_2(r)}{dr}\frac{d\theta}{dr}-\frac{h\theta}{k}=0$$

On substitution of profile function

$$r(r_a-r)\frac{d^2\theta}{dr^2}-(r_a-2r)\frac{d\theta}{dr}-\ bm^2r\theta=0$$

Let $m^2=\frac{2h}{k\delta_b}$

$$v=r_a-r$$

$$v\,(r_a-v)\frac{d^2\theta}{dv^2}-(r_a-2v)\frac{d\theta}{dv}-\ bm^2\,(r_a-v)\,\theta=0$$

Solving by method of frobinius

1. Temperature distribution

$$\theta=C1\sum_{k=0}^{\alpha}a_k\,v^k$$

Where, $a_1 = bm^2a_0$

For $k\geq 2$

$$a_k=\frac{[k(k-1)+br_am^2]a_{k-1}-bm^2a_{k-2}}{k^2r_a}$$

With

$$a_0=\frac{\theta_b}{1+(mb)^2+\sum_{k=2}^{\alpha}(a_k/a_0)\,b^{\,k}}$$

2. $Q_{fin}=-KA\frac{d\theta}{dr}|_{r=r_b}$

3. $Q_{withoutfin}=hA_s(T_s-T_{\alpha})=h2\Pi r_b\delta_b(T_s-T_{\alpha})$

4. Effectiveness $\in=\frac{Q_{fin}}{Q_{withoutfin}}$

1. $T_{Tip}=153^{o}C$
2. $Q_{fin}=37\,Watts\left(68518\ w/m^2\right)$
3. $Q_{withoutfin}=0.91725\,Watts\left(1700\ w/m^2\right)$

4. $\in = \text{Effectiveness} = \dfrac{Q_{fin}}{Q_{withoutfin}} = 40$

IV. RESULTS AND DISCUSSIONS

A. Temperature Tables:

Circumferential fin	**Experimental Results[10]**		
	Temperature at the fin base (^{0}C)	**Temperature at the fin tip (^{0}C)**	**Temperature Difference (^{0}C)**
Rectangular profile	159	153	6
Triangular profile	159	150	9

Circumferential fin	**Ansys Results [10]**		
	Temperature at the fin base (^{0}C)	**Temperature at the fin tip (^{0}C)**	**Temperature Difference (^{0}C)**
Rectangular profile	159.47	155.2	4.27
Triangular profile	159.18	152.64	6.54

Circumferential fin	**Analytical calculations Results**		
	Temperature at the fin base (^{0}C)	**Temperature at the fin tip (^{0}C)**	**Temperature Difference (^{0}C)**
Rectangular profile	159	156	3
Triangular profile	159	153	6

B. Heat Flux Table:

Circumferential fin	**Analytical calculations Results**
	Heat Flux (W/m^2)
Rectangular profile	57400
Triangular profile	68518

C. Effectiveness Table:

Circumferential fin	**Analytical calculations Results**
	Effectiveness
Rectangular profile	33
Triangular profile	40

In triangular profile fins compared to rectangular profile fins

1. The temperature difference at the base and tip of the fin is increased about 50%
2. Rate of heat transfer is increased by about 6 watts
3. Effectiveness is increased to about 7

V. CONCLUSIONS

1. Rate of heat transfer and effectiveness is more for triangular profile fins when compared to rectangular profile fins, when the temperature difference between base and tip of the fin is considered. Therefore it is concluded that triangular profile fins are more effective than rectangular profile fins.
2. By using triangular profile fins, the weight of the fin body reduces, therefore the dead load on engine reduces, which leads to higher fuel efficiency.
3. Hence for effective cooling of cylinder block of an I.C engine, circumferential fins of triangular profile with material Aluminum alloy 6061 is recommended based on research work, as it gives optimum results of heat transfer.

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