

# Optimum Design and Selection of Heat Sink for Air Cooled I.C Engine by Varying Geometry and Material

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**ABSTRACT:** The sole aim of any design optimization technique is price reduction and performance enhancement. In case of fins used in IC Engines, the optimization of price is concerned with minimum material requirement and optimization of performance is in terms of improved heat transfer rate. In this paper the effects of fin material, thickness and geometry on the performance of air cooled IC engine fins is analyzed using ANSYS and Taguchi method of design of experiment (DOE), the analysis of variance (ANOVA) is employed to efficiently seek the combination of optimized design parameters.

**KEYWORDS:** Fin material, geometry, thickness, ANSYS, Taguchi, ANOVA.

## I. INTRODUCTION

When an internal combustion engine begins to burn the fuel in its combustion chamber, due to combustion of fuel nearly 70% of the heat is lost into the atmosphere and only around 30% of the total heat generated is successfully utilized. This heat if not removed adequately and properly in time may cause several problems and even cease the engine [1]. Thus to prevent these thermal damages the heat must be properly removed out of the engine. Generally there are two types of heat dissipation techniques i.e. liquid cooling and air cooling, but considering the complexity factors such as more space, maintenance and high cost the air cooled engines are preferred for smaller vehicles. Thus the fins play a pivotal role in the dissipation of heat and hence these are expected to be highly efficient in the dissipation of the heat. There are several factors which find a significant effect on the efficiency of the fin such as the geometry, material, size, roughness, etc [2]. In the present research the effect of the different geometry is analyzed along with the reduction in thickness of the fins by using three different materials.

## II. RELATED WORK

G. Babu, and M. Lavakumar et al. [3] designed rectangular fin body made of Al 204, replaced it with Al 6061 and Mg materials, they had also done theoretical calculations to determine the heat lost effectiveness and efficiency of the fins. Chandrakant SS et.al [4] conducted experiments for rectangular and triangular fin profiles for air velocities ranging from 0 to 11 m/s. Experimental and CFD simulated result proves that annular fins with rectangular fin profiles are more suitable for heat transfer enhancement as compared to triangular fin profiles. G.Bahadur Vali & Krishna Veni et al. [5] have designed fins used in cylinder head, they used two different Aluminum alloys 6061 and 7475 and performed thermal analysis on the cylinder to determine the thermal behavior for aluminum alloys and they further explained that by reducing the thickness, the weight of the component reduces, by observing the thermal analysis results heat flux is more for the modified model than for original model.

N. Phani Raja Rao and T. Vishnu Vardhan et al [6] compared Al 6061 and Mg Alloy with AA204 the various parameters (i.e., shape & geometry) are considered in the study, by reducing the thickness the heat transfer rate and

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efficiency of the fin increases. Kobus et al. [7] determined the optimized fin geometry to find minimum fin volume in the certain heat transfer. Molen et al. [8] obtained temperate profile in a pin fin with both convection and radiation heat transfer experimentally and compared the results with a simple heat transfer model. Faberi [9] determined optimum fin geometry using generic algorithm. Mohsin A. Ali1, Prof. (Dr.) S.M Kherde et al [10] , studied various researches done in past to improve heat transfer rate of cooling fins by changing cylinder block fin geometry and climate condition. From the literature study it is understood that there is a scope of improvement in heat transfer of air cooled engine cylinder fin, if mounted fin's shape varied from conventional one.

In this paper, the objective is to investigate the performance of fins with novel configurations under the influences of convection. Two unique fin profiles namely circular and angular of standard thickness 3.0 mm, reduced fin thickness 2.5 mm have been analyzed in terms of the total amount of heat loss, fin effectiveness and fin efficiency, and the results have been compared with that of a conventional rectangular fin (CRF) for three different materials namely cast iron, Aluminum alloy AL 7075 and ALUSIL. Optimum fin geometry and material has been analyzed in order to maximize the heat dissipation from the fin to the ambient for the same volume of the fin and fin length. The design development has been done in the Pro-E whereas the analysis has been performed in ANSYS software and selection of optimum profile is achieved by Taguchi optimization method.

## III.MATERIALS AND METHODS

Presently used material for cylinder fin body is Cast Iron. Cast iron is basically an alloy of carbon and silicon with iron used for manufacturing fins. It consists 2.4 – 3.7 % C, 1.1 – 2.8% Si, 0.3 – 1.1% Mn, 0.16% P and 0.11% S. Cast iron possess high fluidity and hence it can cast any complex shapes and thin sections, makes it as a most attractive choice for fins and also it has an excellent wear resistance, and possesses high damping capacity but when we consider the mass properties aluminium alloy seems to be a best choice.

Table.1. Material Properties

Sl. no	Material	Thermal conductivity W/m k	Density Kg/m <sup>3</sup>	Thermal diffusivity m <sup>2</sup> /s	Specific heat J/kg k
1	Cast Iron	52.3	7272	17.03 x 10 <sup>-6</sup>	420
2	Al 7075	194	2770	73.00 x 10 <sup>-6</sup>	880
3	ALUSIL	161	2627	71.72 x 10 <sup>-6</sup>	854

Aluminium alloy possess characteristics such as Light weight, good conductivity, higher resistance to corrosion and ductile in behavior. The reason for choice becomes obvious when one compares the weight requirements of aluminum and material such as cast iron, approximately 90.76% of fin weight can be saved and hence ALUSIL and AA 7075 is considered as alternative material for cast iron.

### Design of Experiments

There are many input parameters to be considered for optimum fin design, but in this paper we have selected three most influencing parameters, one parameter with two levels and other two parameters with three levels. The process parameters and their levels are depicted in Table 2.

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Table.2. Process parameters and their levels

Process parameters	Level 1	Level 2	Level 3
Thickness (mm)	3.0	2.5	--
Geometry	AA 7075	ALUSIL	CAST IRON
Material	CIRRCULAR	CURVED	RECTANGULAR

The analysis was carried out as per L18 orthogonal array shown in Table 3. The output responses were selected as Heat lost effectiveness and Mass of the fin. The measured and calculated output values and their S/N ratios are obtained.

Table.3. L 18 Orthogonal Array

THICKNESS (mm)	GEOMETRY	MATERIAL	THICKNESS (mm)	GEOMETRY	MATERIAL
1	1	1	2.5	Rectangular	CI
1	1	2	2.5	Rectangular	ALUSIL
1	1	3	2.5	Rectangular	AA 7075
1	2	1	2.5	Circular	CI
1	2	2	2.5	Circular	ALUSIL
1	2	3	2.5	Circular	AA 7075
1	3	1	2.5	Curved	CI
1	3	2	2.5	Curved	ALUSIL
1	3	3	2.5	Curved	AA 7075
2	1	1	3	Rectangular	CI
2	1	2	3	Rectangular	ALUSIL
2	1	3	3	Rectangular	AA 7075
2	2	1	3	Circular	CI
2	2	2	3	Circular	ALUSIL
2	2	3	3	Circular	AA 7075
2	3	1	3	Curved	CI
2	3	2	3	Curved	ALUSIL
2	3	3	3	Curved	AA 7075

### Taguchi method

Taguchi method involves three stages: system design, parameter design, and tolerance design. The Taguchi method is a statistical method used to improve the product quality. The Taguchi process helps to select and determine the optimum fin design for air cooled IC engines. Taguchi developed a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal-to-noise (S/N) ratio. It uses the S/N ratio as a measure of quality characteristics deviating from or nearing to the desired values. There are three categories of quality characteristics in the analysis of the S/N ratio, i.e. the lower the better, the higher the better, and the nominal the better.

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## IV. RESULTS AND DISCUSSIONS

### PRO E MODEL

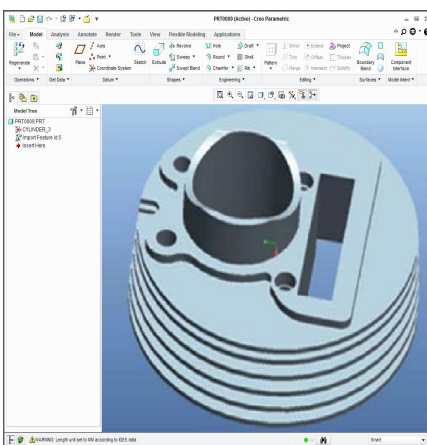


Fig.1. Circular fin profile

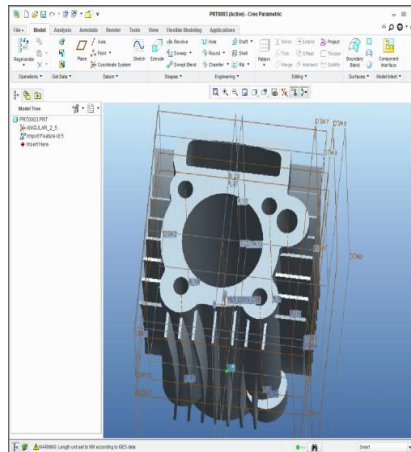


Fig.2. Angular profile

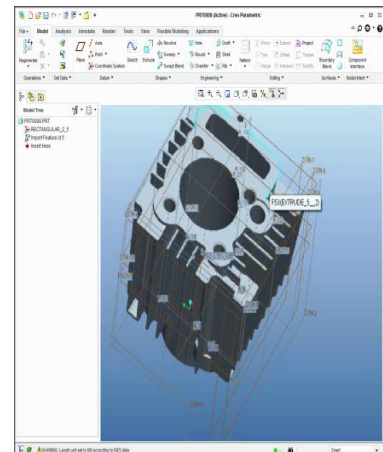


Fig.3. Rectangular profile

### CFD Analysis

Heat flux or thermal flux is the rate of heat energy transfer through a given surface per unit time. 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. So the heat flux of the fins must be in maximum value. As on our paper heat flux produced by the circular fins is more than the other fins types. A temperature gradient is a physical quantity that describes in which direction and at what rate the temperature changes the most rapidly around a particular location. As well as the thermal flux of the fins the thermal gradient also had maximum value. The contours are such that they give us the idea about at what place, the value of that parameter ranges, which is indicated by the colour legend in the results. It is observed from the steady state thermal analysis the circular fins showing good temperature distribution along the fin length.

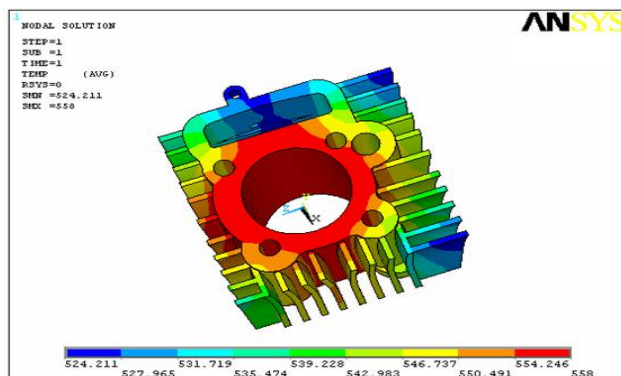


Fig.4. Nodal temperature- Angular

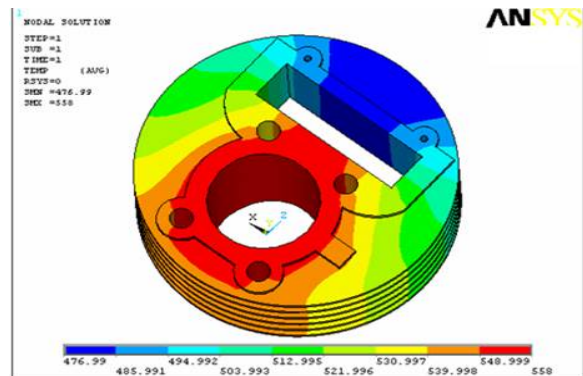


Fig.5. Nodal temperature- circular

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Table.4. Analysis Results

THICKNESS mm	GEOMETRY	MATERIAL	Heat lost w	Effectiveness	Mass kg
2.5	Rectangular	CI	40.69	33.83	2.21
2.5	Rectangular	ALUSIL	57.73	58.36	0.85
2.5	Rectangular	AA 7075	58.49	56.16	0.91
2.5	Circular	CI	178.2	22.85	1.70
2.5	Circular	ALUSIL	206.72	40.09	0.66
2.5	Circular	AA 7075	208.94	44.01	0.70
2.5	Curved	CI	44.92	32.98	2.04
2.5	Curved	ALUSIL	61.05	57.89	0.79
2.5	Curved	AA 7075	63.11	58.56	0.84
3	Rectangular	CI	43.10	30.37	2.65
3	Rectangular	ALUSIL	56.92	53.24	1.02
3	Rectangular	AA 7075	60.31	58.44	1.09
3	Circular	CI	185.43	20.86	2.04
3	Circular	ALUSIL	210.3	36.61	0.79
3	Circular	AA 7075	213.52	40.19	0.84
3	Curved	CI	48.13	30.24	2.45
3	Curved	ALUSIL	63.63	53.05	0.95
3	Curved	AA 7075	65.42	58.54	1.01

Table 4. Illustrates the temperature distribution of circular fins with different materials. It is seen from the table Alusil showing more temperature distribution compared to that of Aluminum Alloy 7075 and cast iron.

All the materials are showing linear distribution of temperature along the length of fins. Result comparison shows that circular fins are having more heat flux for Alusil alloy.

### S/N Ratio Analysis

In this study, the objective is to produce optimum fin design with higher heat transfer rate and effectiveness, lower the mass of the fins. Thus for S/N ratio analysis the higher-the-better criteria of quality characteristic can be suitable for heat lost and effectiveness of fin, while the lower-the-better criteria of quality characteristic can be suitable for Mass of the fin.

Table.5. Signal to Noise Ratio response for heat lost

Level	Thickness (mm)	Geometry	Material
1	38.36	46.02	39.38
2	38.65	35.13	39.15
3		34.36	36.99
<b>Delta</b>	<b>0.29</b>	<b>11.66</b>	<b>2.38</b>
<b>Rank</b>	<b>3</b>	<b>1</b>	<b>2</b>

Table.6. Response Table for Means

Level	Thickness (mm)	Geometry	Material
1	102.21	200.52	111.63
2	105.2	57.71	109.39
3		52.87	90.08
<b>Delta</b>	<b>2.99</b>	<b>147.64</b>	<b>21.55</b>
<b>Rank</b>	<b>3</b>	<b>1</b>	<b>2</b>

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From the response Table.6 and Fig.6 it is clear that geometry is the most influencing factor followed by material and thickness for transient heat loss in fin. The optimum parameters for Maximum heat lost are thickness 3.0 mm, circular geometry and AA 7075 Material.

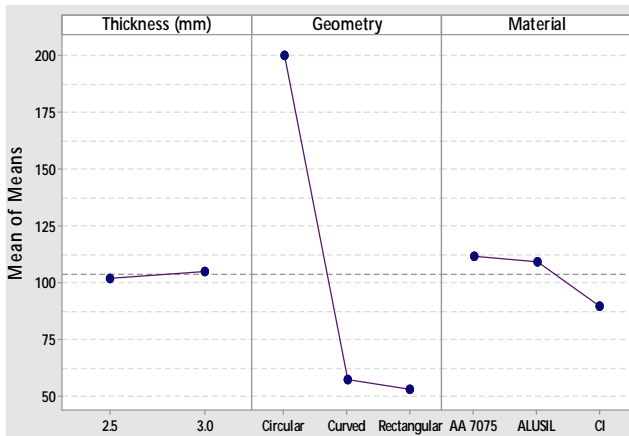


Fig.6. S/N Ratio for heat loss

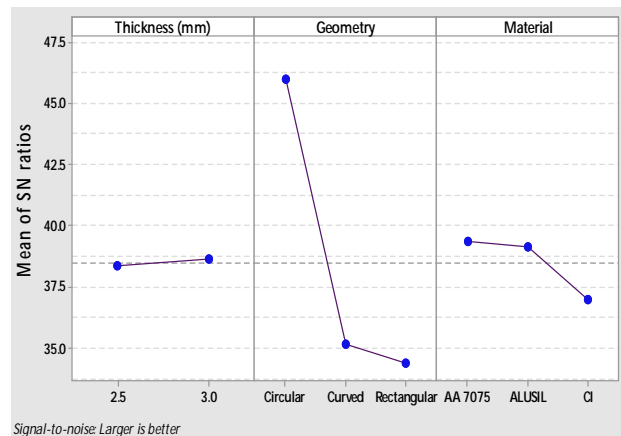


Fig.7. Response for means

From the response Table 7 and Fig.8 it is clear that fin material is the most influencing factor followed by geometry and thickness for effectiveness of fin. The optimum effectiveness is achieved at 2.5 mm thickness, curved geometry and for AA 7075 Material.

Table.7. Signal to Noise Ratio response for effectiveness

Level	Thickness (mm)	Geometry	Material
1	32.66	30.31	34.33
2	32.08	33.4	33.82
3		33.4	28.96
<b>Delta</b>	<b>0.59</b>	<b>3.1</b>	<b>5.37</b>
<b>Rank</b>	<b>3</b>	<b>2</b>	<b>1</b>

Table.8. Response Table for Means

Level	Thickness (mm)	Geometry	Material
1	44.97	34.1	52.65
2	42.39	48.54	49.87
3		48.4	28.52
<b>Delta</b>	<b>2.58</b>	<b>14.44</b>	<b>24.13</b>
<b>Rank</b>	<b>3</b>	<b>2</b>	<b>1</b>

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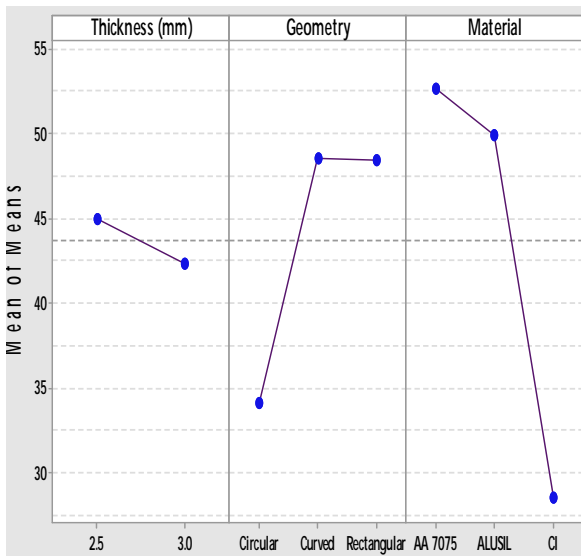
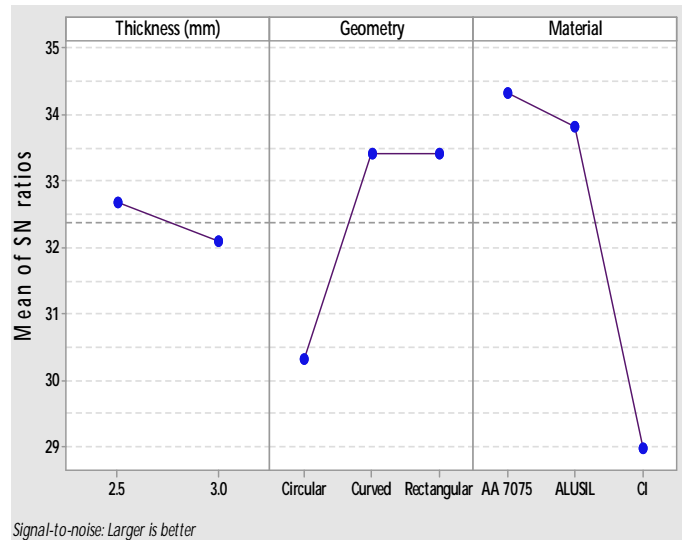


Fig.8. S/N Ratio for effectiveness



Signal-to-noise: Larger is better

Fig.9. Response for means

From the response Table9 it is clear that fin material is the most influencing factor followed by geometry and thickness for mass of fin. The lesser weight is achieved at 2.5 mm thickness, circular geometry and for Alusil Material.

Table.9. Signal to Noise Ratio response for Mass

Level	Thickness (mm)	Geometry	Material
1	-0.57381	-0.07813	1.01873
2	-2.15744	-1.66175	1.57269
3		-2.35699	-6.68829
Delta	1.58362	2.27887	8.26098
Rank	3	2	1

Table.10. Response Table for Means

Level	Thickness (mm)	Geometry	Material
1	1.1887	1.1208	0.8983
2	1.4265	1.345	0.8428
3		1.4571	2.1817
Delta	0.2377	0.3362	1.3388
Rank	3	2	1

### Analysis of variance:

Taguchi method cannot judge and determine effect of individual parameters on entire process while percentage contribution of individual parameters can be well determined using ANOVA. The analysis was made using MINITAB 17 one of the popular software specifically used for Taguchi's design of experiment. The significance of each parameter on the responses such as heat lost and effectiveness can be determined through their percent contribution value. The ANOVA results and percentage contribution of each process parameters are found below

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Table.11. Analysis of Variance for Heat lost (w), using Adjusted SS for Tests

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
Thickness (mm)	1	40	40	40	3.56	0.083
Geometry	2	84433	84433	42217	3740.41	0
Material	2	1685	1685	843	74.65	0
Error	12	135	135	11		
Total	17	86294				

Table 11 shows the analysis of variance for heat lost. It is observed that the fin geometry (97.8%) is most significantly influences the rate of heat lost followed by material (2.04%) and least significant of thickness (0.05%).

Table.12. Analysis of Variance for Effectiveness, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Thickness (mm)	1	29.88	29.88	29.88	5.59	0.036
Geometry	2	826.05	826.05	413.02	77.35	0
Material	2	2091.56	2091.56	1045.78	195.84	0
Error	12	64.08	64.08	5.34		
Total	17	3011.56				

In case of effectiveness, material (69.45%) is the most significant parameter followed by geometry (26.20%) and thickness (1.12%). For mass of fin material (90.23%) is the most significant parameter followed by geometry (4.62 %) and thickness (3.34%).

Table.13. Analysis of Variance for Mass (kg), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Thickness (mm)	1	0.2544	0.2544	0.2544	21.94	0.001
Geometry	2	0.3517	0.3517	0.1759	15.17	0.001
Material	2	6.885	6.885	3.4425	296.89	0
Error	12	0.1391	0.1391	0.0116		
Total	17	7.6303				

In all the cases, error contribution (0.156%), (2.12%) and (1.82%) reveals that the inter-action effect of the process parameters is negligible

## V. CONCLUSION

This attempt was made to find the optimal design and selection of heat sink for existing model of 110 cc air cooled IC engine by using Taguchi methodology. The following conclusions are made: The optimum parameters obtained for maximum heat loss: Thickness 3.0 mm, circular geometry and AA 7075 Material. From ANOVA, it is found that fin geometry is the most significant factor affecting heat lost which contributes 97.8 % followed by fin material 2.04%. The optimum parameters obtained for minimum weight: thickness 2.5 mm, circular geometry and Alusil material. The optimum parameters obtained for maximum effectiveness: thickness 2.5 mm, curved geometry and AA 7075 material. The Fin material is most dominant factor affecting the effectiveness and increases the weight of fin thereby reducing the efficiency of engine, which contribute 69.45% & 90.23% respectively.

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