International Journal of Engineering & Technology, 7 (2) (2018) 605-608

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10.14419/ijet.v7i2.9800
Research paper

Comparative analysis on toroidal fins with variable thickness rectangular splines for heat transfer enhancement

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Abstract

In the present situation, there is a need for devices to carry the thermal energy generated in the system. Fins are the efficient devices which are going to carry the heat generated in the system. In the present work, we have chosen a special shape of fins by choosing two different materials. Toroidal fins have been considered. By varying its shapes heat transfer analysis has been carried out. In the present work, we have considered the toroidal fins having Aluminium and Gunmetal materials. The thicknesses of the spline are reduced from 7 mm to 3mm. The effectiveness for Aluminium 3mm is 3.28 and for 7mm is 3.3723. The effectiveness of Gun metal 3mm is 2.02 and for 7mm is 2.7895.

Keywords:*Convection; Effectiveness; Efficiency; Heat Transfer; Thickness; and Toroidal.*

1. Introduction

In the study of heat transfer, a fin is a surface that it extends from an object to increase the rate of heat transfer to or from the environment by increasing convection. The amount of conduction, convection or radiation of an object determines the amount of heat transfer. Adding a fin to an object, however, increases the surface area and can sometimes be an economical solution to heat transfer problems. The reason of designing is common to analyze the effect of the heat transfer wherein the type of design is one of the factors that gave effect. The purpose of designing fin is to obtain the effectiveness of the fin. Although the fins significantly increase heat transfer from the cylinder, considerable improvement could still be obtained by increasing the number of fins [1].Besides that, the thickness of fin, the gap between fins are also[2]. Besides that, the thickness of fin, the gap between fins are also important in the designing of the engine [3]. In this report, we have performed the experimental investigation on the toroidal fins. During this project, our initial goals were to change the fin material, dimensions and to find out the amount of heat transfer rate occurring through the newly modelled fins in the CREO Parametric.

The objective of present work is as follows Selection of suitable fin material and fin geometry for the present work, Geometric modelling of the fins with different dimensions and different fin Materials, Experimental setup for the fins,Analysis of experimental results. High capacity motors and pumps will be having fins on the surfaces having more thickness but due to this thickness we cannot place number of fins. Due to this practical issue, we have decided to reduce the thickness from 7mm to 3mm by which we can accommodate more number of fins along across the surface.

2. Experimentation details

Thermocouple positions on toroidal fins

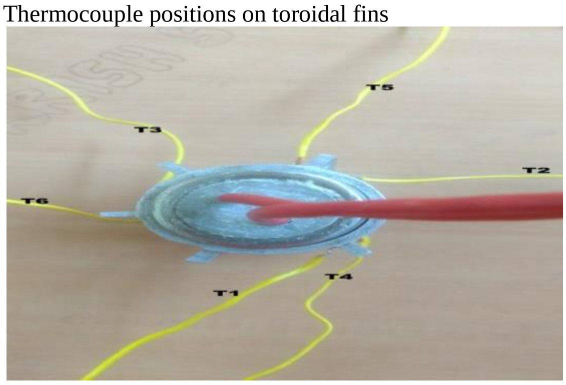

Fig. 2.1: Thermocouple Positions on Toroidal Fins.

Fig. 2.2: Thermocouple Attachment on Splines of Fins.

Fig. 2.3: Experimental Set Up.

Fig.2.4: Mica Heater.

Fig. 2.5: AluminiumToroidal Fin.

Fig. 2.6: Gun Metal Toroidal Fin.

Fig 2.4 shows the heater is used to heat the cylindrical wall of the toroidal fins to the desired temperature. This desired temperature is achieved with the help of varying voltage parameter which changes its power parameter and hence it's emitting temperature [4]. The heater is made up of mica material to isolate the electric current from passing through the heater to the toroidal fins.

3. Methodology of calculations

1) Perimeter of Fin:

x= Thickness of fin= 7 mm, y= length of fin= 96 mm

P= 0.206 m

2) Area of the Fins:

A= 0.672 ×10^{-3}m^{2}

3) Constant m:

h = convective heat transfer coefficient, P = perimeter of the fin, K= Thermal Conductivity of alluminium= 265 W/mk.

m = 7.3735

ml=0.70785m

1) Actual heat flux Q_{act}=

$$\sqrt{hpkA \times \theta^{o}} \times \tanh ml$$

θ^0= T- T_a = 140.216 - 34 = 106.216°C

Q_{act}= 84.9831W

2) Theoretical or Maximum heat flux $Q = V \times I$

V= Voltage regulated for the heater= 72 v

I= Current supplied= 0.35 A

Q_{max} = 25.2W

3) Fin Effectiveness $\varepsilon = \dfrac{Q_{act}}{Q_{max}}$

ε = 3.3723

Fin efficiency $\eta = \dfrac{\tanh ml}{ml}$ where tanhml= 0.60933, ml= 0.70785

η = 86.08 %

Calculation for Natural Convection

1) Grashoff Number: $Gr = \dfrac{g\beta\Delta T l^3}{\nu^2}$ where ύ= kinematic viscosity of air= 1.46 × 10^{-5} m^2/sec, T_{avg} = Average temperature of the experimental readings= 155.28 ^{0}C

l = 0.096 m, $\beta = \dfrac{1}{T_f + 273}$ Tf = (Tavg + Ta) / 2 Tf = 95.64 °C

β = 0.00271 K^{-1}

Gr =17.1510×10^6^

2) Prandtl number: $P_r = \frac{\mu C_P}{K}$ where μ = dynamic viscosity of air, Cp = specific heat of air and k = thermal conductivity of engine material.

Pr =0.743

3) Nusselt Number: $Nu = \frac{hl}{k} = .59 \times (Gr \times \Pr)^{0.25}$

Where, Nu = Nusselt's number, Gr = Greshoff's number, Pr = Prandlt number, h = convective heat transfer coefficient, L = length of fin and k = thermal conductivity of air.

Nu= 35.25

h = 8.886W/m^{2}K

4. Results & discussion

Bar Chart for Q_{act}Bar Chart for Effectiveness.

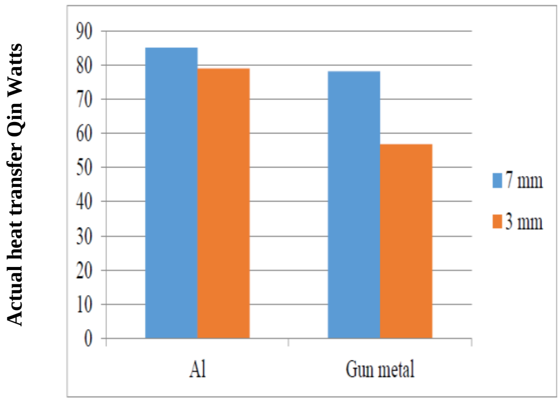

Fig.4.1: Bar Chart for Actual Heat Transfer $Q_{act.}$

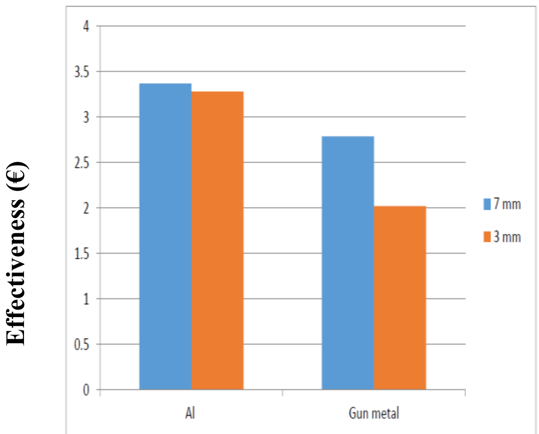

Fig. 4.2: Bar Chart for Effectiveness.

Bar Chart for Efficiency Bar Chart for Temperature difference $\boldsymbol{\theta}$in ^{0}C.

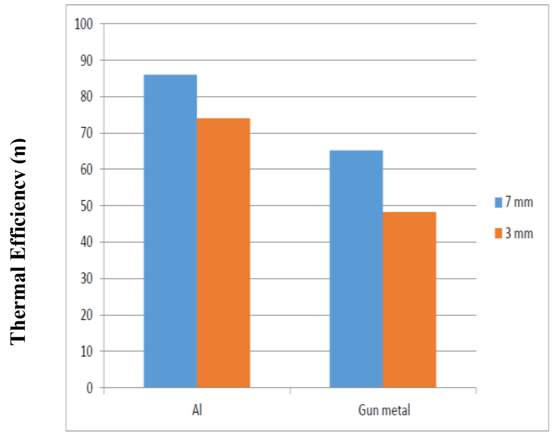

Fig. 4.3: Bar Chart for Efficiency.

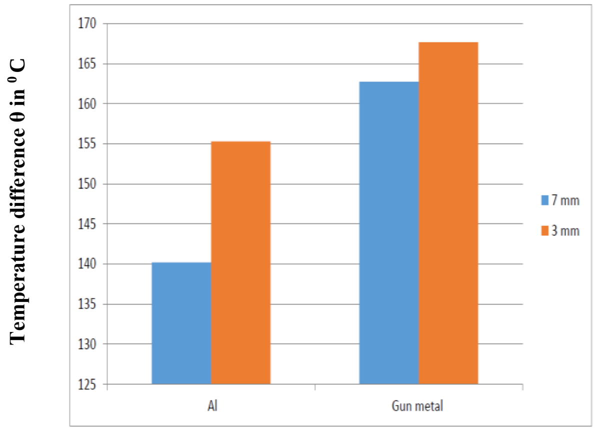

Fig. 4.4: Bar Chart for Temperature Difference $\theta°$.

4.1. Comparison

From above experimental results, we came to know that fins with two different materials and different cross-sectional areas (variation in thickness) will lead to the following points:

4.1.1.Aluminium fins with 7 mm thickness

As we know Al is one of the excellent material, which has better thermal properties as compared to remaining materials. As Al is having the conductivity of 265 W/mK it will transfer the heat rapidly that's why in the observation table average temperature is around 140^0 C has been observed. This is due to higher values in conductivity observed [5]. Also due to the spline section of the fins which is one of the unique design on which we have carried out experimentation.

4.1.2. Aluminium fins with 3 mm thickness

In this work the same toroidal shape of the fin has been considered by decreasing its thickness from 7mm to 3mm. During experimentation, we have observed that average temperature is around 155.28^{0}C. This increase in average temperature is due to reduced thickness of 4mm. From the literature survey and expert suggestion we have reduced the thickness from 7mm to 3mm which has given us better heat transfer [6]
Characteristics compared to 7mm.
By comparing the results like maximum heat transfer, effectiveness and efficiency, we came to the conclusion that fins with spline thickness in between 3mm to 7mm will give us the maximum efficiency. In our results, we have observed that spline with 7mm thickness has given 86% efficiency leading to an effectiveness of 3.372 and fin with 3mm spline thickness has given us effectiveness of 3.28 which is nearer to the 7mm thickness of this spline and temperature variations between these two is nearly

same but 3mm thickness fin will carry the maximum heat at its tip surface [7]. By decreasing the thickness of fins on the toroidal shape we can increase the number of splines leading to the better heat transfer properties.

4.1.3. Gunmetal fins with 7 mm thickness

From literature survey, we have observed that all the researchers have carried out experiments on Al and Cu types. Due to this, we have considered unique material namely Gunmetal which is the composition of Cu and Zn having lesser thermal conductivity and higher specific heat rate [8]. Similar to above experiments we have supplied heat to the Gunmetal around 78 W. The average temperature observed was around 162 ^{0}C with the effectiveness of 2.78 leading to efficiency of 66%. These observations are due to the content of zinc in Gunmetal, which offers resistance to flow of heat, as it is the insulating material.

4.1.4. Gunmetal fins with 3 mm thickness

In this experimental work, we have decreased the thickness of spline from 7mm to 3 mm. The average temperature has been raised to 5^{0}C compared to 7 mm thickness and we have observed the effectiveness of 2.02 with 50% efficiency. As Gunmetal is having the density 8.72* 10^{3} kg/m^{3}, by reducing the cross-sectional area of the Gun metal the actual heat transfer supplied is reduced and the temperature is increased. From experimentation, we have observed the effectiveness of 2.02 which is less than that of 7 mm thickness of spline which is 2.78. This observation is due to the decreased cross-sectional area.

4.2. Comparison of Al and gunmetal

By comparing both metals we came to a conclusion that Aluminium is having higher thermal conductivity value, less specific heat and less density. We have seen that heat required to raise its temperature is more compared to gunmetal whereas, the transfer of heat in the aluminium fins takes place rapidly due to its higher thermal conductivity value observed. In case of gunmetal, the specific heat required to raise its temperature is more thereby to transfer the heat energy to raise its temperature is more compared to aluminium. In this experimental work, we have varied the thickness of spline from 7mm to 3mm for both metals [9]. By observations, we have seen that by decreasing the thickness of spline difference in temperature observed is more due to the exchange of heat with the atmosphere. This value indicates that by reducing the thickness the temperature difference observed will increase [10-11]. Similar results have been observed for the gunmetal but the temperature difference is around 8^{0}C- 10^{0}C. This is due to higher specific heat, decreased the conductivity of gunmetal.

5. Conclusion

The experimental work carried out with convection phenomenon by considering natural convection. The thickness of the fin has been varied from 7mm to 3mm and results were observed. For aluminium with 7mm thickness, we have obtained effectiveness of 3.37 and for 3mm spline we have obtained 3.28. This variation is due to decrease in the thickness leading to the better temperature variation. For gunmetal similar phenomenon's were observed and results are given as For 7mm thickness, obtained value is 2.78 and for 3mm thickness, it is 2.02. By observing results of both the metal and by optimisingaluminium with 3mm thickness will give better heat transfer characteristics compared to others. These observations are due to the change in metallic properties in gunmetal and aluminium.

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