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Thermal Analysis and Performance Evaluation of Heat Sink with Slender Square Fin Geometry for Application of Electronic Cooling

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Abstract

This research paper focuses on a development of a heat sink with slender square fins for the application of relay circuit cooling where in the device shall be used to cool inline snatch relays that are used as circuit breakers in PLC boards. The geometrical layout and thermal analysis of the heat sink is discussed in this paper. The relay circuits need effective heat sinks in order to dissipate the hot side heat from the chip to the atmosphere. This encourages designing a heat sink in which heat transfer enhancement is carried out by designing of slender fins with plain and skewed profile fins that have a three layer concentric triangular layout. With this geometrical layout, the thermal analysis and heat transfer enhancement from plain profile fins configuration is carried out.

Keywords:*Thermal Analysis,Heat Dissipation, Pressure Drop, Electronic Devices*

1. Introduction

Heat sinks are devices that allows the heat dissipation from hot surface, mostly the case of heat generating surfaces to the atmosphere. In most situations the heat transfer across interface between the solid surface and the coolant air is the lead efficient within the system, and the solid air interface represents the greatest barrier for heat dissipation. A heat sink reduces this problem by increasing the surface area that is in direct contact with the fluid or surrounding air. This allows more heat to be dissipated and reduces the device operating temperature. Thus, the electronic devices which dissipate large heat can be equipped with proper heat sink so as to maintain the device temperature.

Electronic devices like relay circuits generates excess heat during their operation and thus require thermal management to improve reliability and prevent premature failure of the device. The amount of heat generated from electronic devices is almost equal to the amount of power input if there are no energy interactions. The relay circuits with very high current capability may need to dissipate as much as 80 to 100 watts. To dissipate such high amount of heat it becomes necessary to design heat sink with enhanced heat transfer rate from the device.

The present model study is to be conducted for the application of heat sink in relay circuit cooling where the purpose is to cool in-line snatch relays that are used as circuit breakers in PLC boards. The size of the device is constraint due to the fact that the device is to be used in control panel, hence has to be compact. Thus the study is focused on design development and testing of heat sink with slender square fins that has generic progressive transverse layout. The surface area enhancement and cross flow heat dissipation is planned through skew pattern fins in direction normal to the air flow. Fins to dissipate approximately 35-40 watt of energy is planned to get desired cooling effect of the relay circuits. The role of fin geometry in heat sink plays an important role in effect on overall thermal and fluid performance associated with different fin geometries.

2. Overview

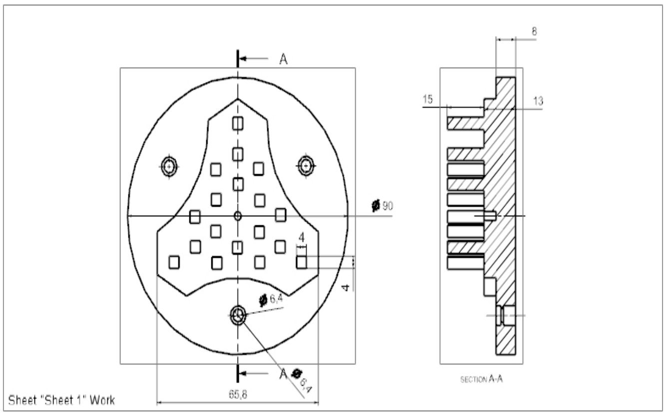

Fig. 1 Schematic of Heat Sink Model

To reduce excess heating of relay circuits was the main objective of the paper. In this paper, based on size of the control panel it is necessary to design and development of heat sink setup with plain and skewed slender square fins. Thermal analysis of the heat sink structure is done using ANSYS software simulation and various contours are obtained. Also the overall heat transfer coefficient is achieved from theoretical as well as from the experimentation.

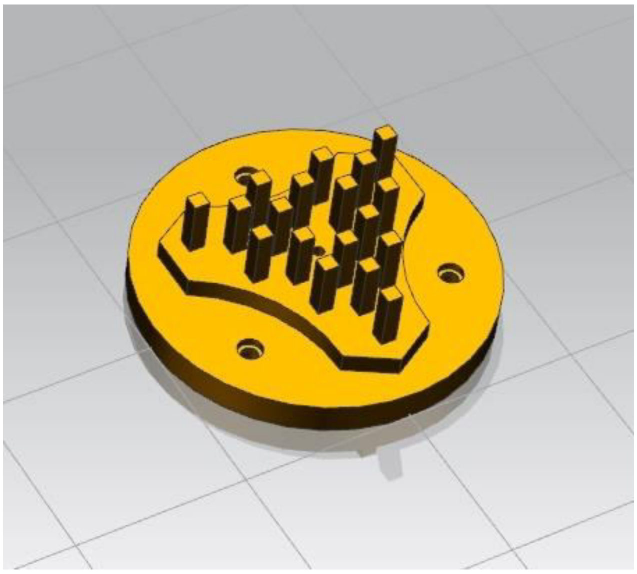

Fig.2 3-D Model of Heat Sink

The figure above shows the 3D model of the heat sink using CATIA software. Basically, considering the aspect of size of relay circuit in control panel it has been considered that the circular base plate of 90 mm in diameter and pin fin arrays are uniformly distributed on this metal frame of aluminium from the flow passage, the aluminium block used to form the test model has high conductivity (K = 201W/mK). This block is milled on one side forming array of small pin fins and the empty space between the square pin fins becomes the flow path.

3. Experimental set up layout

The experimental set-up consists of u-tube manometer, axial blower, duct, fin patter or test model and heater assembly. Heat sink thermal performance and pressure drop experiments were conducted at a wind-tunnel system as shown in figure.
The test section is shown in Fig.2.

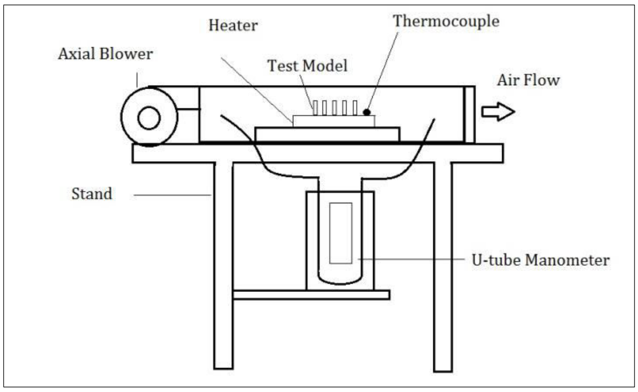

Fig.3 Experimental Setup

The experimental setup above shows the rectangular duct air flow chamber which is developed for enhanced directed flow of air over the test fin structure, also the u-tube manometer arrangement will get the desired pressure drop across the fin structure, which can be used to determine the nature of air flow above the fin structure. Axial blower with variable speed is used to regulate the air flow inside the chamber. Temperature measurement will be done using J-type thermocouples with multi-channel display.A Bakelite sheet with thermal conductivity K=0.233W/mKwhich acts as an insulator is placed to cover the back of the heater which allows the heat to travel only in the fin array direction. Measurement of the temperature on the fin array and the surrounding is taken by thermocouple.

Table 1 Instruments Specifications

Name of Parts	Specification	Quantity
Blower	1 hp, 2 amp, 230V, 0-3000rpm variable	1
Thermocouple	J-Type	1
U-Tube Manometer	Water as a manometric fluid	1
Bakelite Sheet	As Insulation(K=0.232)	1
Heater	Power=100 W, 230 V, AC	1
Duct	160x160 mm & 120x120 mm Central Cross section	1

4. Heat Transfer Calculations& Thermal Analysis

Diameter of orifice = 16mm
Coefficient of discharge (Cd) = 0.64
Density of water ρ_w = 1000 kg/m^3
Density of air ρ_a = 1.275 kg/m^3

i.Velocity of air in the duct can be obtained by calculating the volume flow rate through the
$Q = C_d \frac{\pi}{4} d^2 \times \sqrt{2.g\ (H \frac{\rho_w}{\rho_a}})(1)$
where, H = Difference of levels in manometer
ii. The heat gain from the air is calculated from
$Q = mC_p(T_{in} - T_{out})$ (2)

To obtain the overall heat transfer coefficient initially it is necessary to determine heat transfer through the test model setup. Therefore, heat transfer through the test model is given by
Q = h.A (ΔT) (3)
Where, Q is the heat transfer in watts, h is heat transfer coefficient, area of fins as per geometry is 0.28 m^2

For laminar flow,
h = 0.64 ${R_e}^{1/2}(\mu C_p/K)^{1/3}$(K/L) (4)
where, Re = V/v
V = Velocity of air in m/s, and
v = kinematic viscosity of air = 20 x $10^{-6} m^2/sec$

Thermal analysis of heat sink is to bedetermined by ANSYS software simulation.

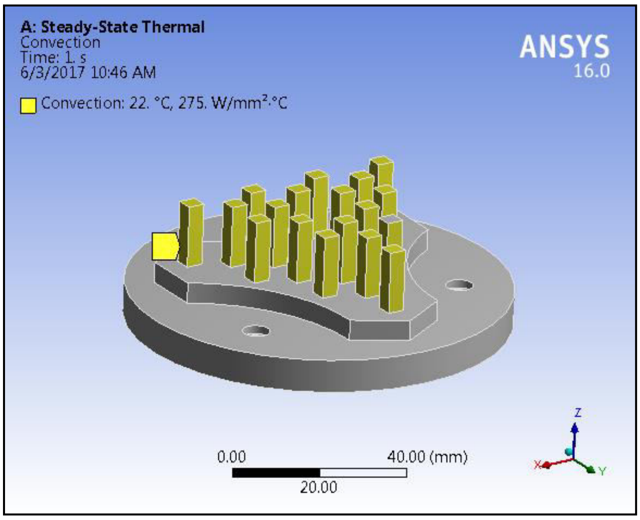

Fig.4 Steady State Thermal Convection

The figure above shows steady state thermal analysis. The steady state thermal analysis gives the effect of steady thermal loads on the heat sink by establishing the initial conditions. From the ANSYS software simulation, the test model with plain slender square fins gives the convection heat transfer coefficient as 275 W/mm^2°C.

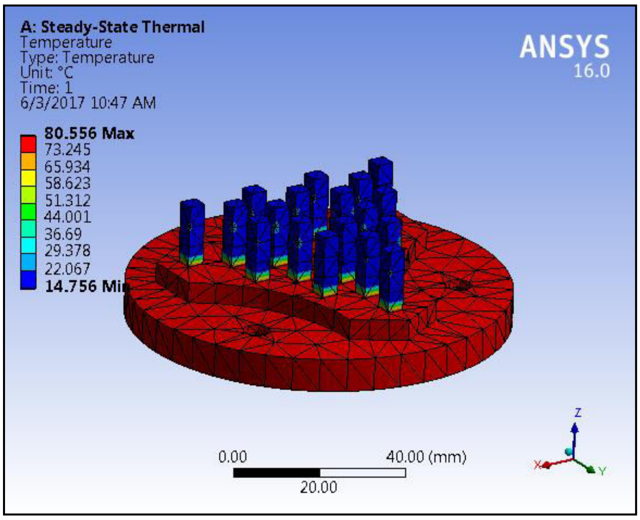

Fig.5 Temperature Variation Contour

Temperature variation contour is obtained when the given boundary conditions are applied to the problem. The results obtained from the ANSYS software simulation for temperature contour is shown in figure.

An inner portion of fin holder displays elevated temperature. From the figure above it can be said that the temperature goes on decreasing as we go away from the center of heat sink towards the tips of the fins.

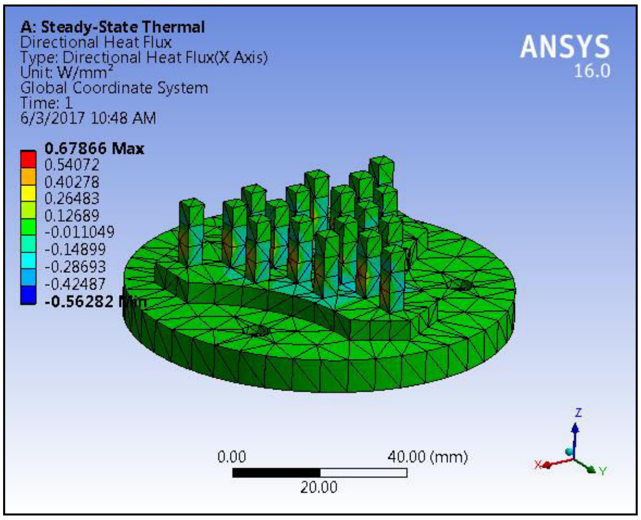

Fig.6 Directional Heat Flux Contour

Heat flux or thermal flux is the rate of heat energy transfer through a given surface per unit time. The results obtained from ANSYS software simulation for heat flux contour is shown in figure. From figure we can say that the heat flux is maximum at the inner portion of fins. It is also observed that heat is maximum at the outer periphery of the fins because this portion comes in direct contact with the air.

Table 2 Observation Table

Pressure Drop(mm)	Mass flow rate Kg/sec	Temp gradient ΔT ^{0} C	Heat flux watt	Overall HTC (w/m2k)
5	0.1868	**11**	2065.927	46.032
6	0.2333	**12.5**	2932.036	57.490
8	0.2718	**13.7**	3743.576	66.973
9	0.3272	**15.6**	5130.399	80.605
7	0.3689	**16.4**	6080.904	90.879
7	0.4331	**17.2**	7486.669	106.68

6. Results and Discussion

Results thus obtained from various fin structure are plotted and the effectiveness of fin structure as regards to overall heat transfer coefficient. Heat transfer ability, obstruction to air flow, etc. are made as to application of the above structure to various electronic equipment cooling solutions. Derived results helps for selection or suitability of the developed sinks for different electronic cooling applications. From the experimentation it has been observed that with the use of slender square fin heat sink up to 38 watts of heat is dissipated which can be proved from the following graphs plotted based on the observation table.

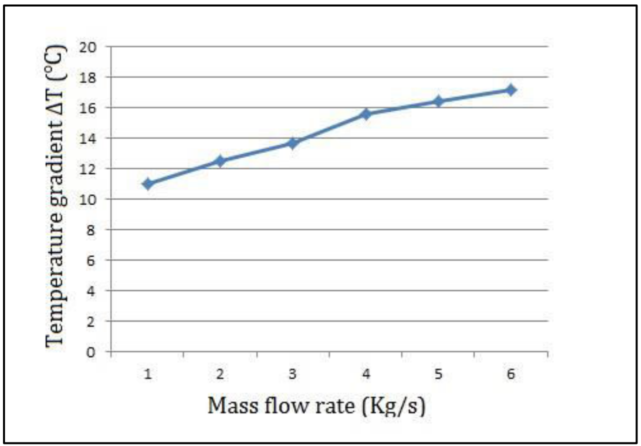

Fig.7 Temperature Gradient Vs. Mass Flow Rate

The above graph shows the temperature gradient versus mass flow rate. From above graph it can be observed that the temperature gradient increases steeply with flow rate up to a particular limit and then stabilizes over the range of flow.

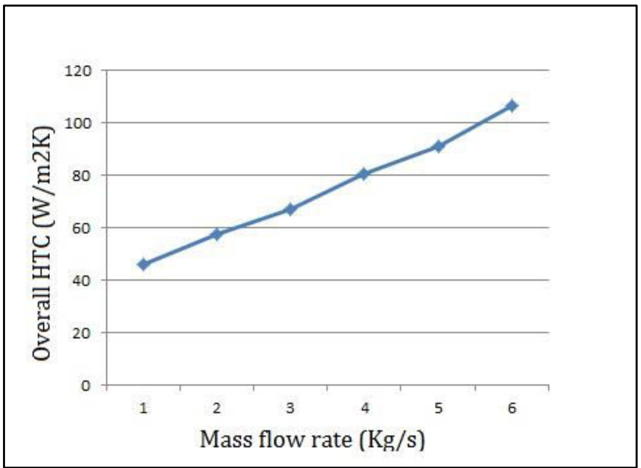

Fig.8 Overall Heat Transfer CoefficientVs. Mass Flow Rate

The above graph shows the Overall heat transfer coefficient versus mass flow rate. From above graph it can be observed that the Overall heat transfer coefficient increases steeply with flow rate up to a particular limit and then stabilizes over the range of flow.

Conclusion:

In this project work testing have been made with variation in mass flow rate of air inside the test chamber. After completing all the tests the following conclusion can be made;

1) From the experimental analysis, it is found that the heat dissipated from the heat sink at different flow rates increases steeply.
2) From the thermal analysis of heat sink it has been observed that the heat flux is maximum at inner portion of fins because the heat is maximum at the center. On the other hand it has been observed that heat flux is minimum at the outer periphery of the fins because this portion comes in contact with air.
3) It is found that as we increase the flow rate at different stages from lowest to highest the temperature gradient is steeply increased.
4) It is found that due to concentric triangulargeometrical layout of heat sink, the flow of air from the fins is uniformly distributed which in turn enhances the heat dissipation from the heat sink.

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