Design, Development and Analysis of Hybrid Vortex Cooling System

[#1]Neeta.P. Mathurvaishya, [#2]Sameer.Y.Bhosale

[#1]Mechanical Engineering, Savitribai Phule Pune University, Pune, India.

[#2]Mechanical Engineering, Savitribai Phule Pune University, Pune, India.

ABSTRACT— In the development of the technology and pace of the work the processing speed of the electronic gadgets also increases. This increasing speed and the compact size of the equipment are required. The compact size of the equipment tends to the thermal damage due to high heat generation. An efficient cooling for printed circuit boards with a 12 W input to heat sink to remove the heat. This cooling system design is basically focused on a size reduction factor with priority to high heat removal from PCB's. The hybrid system is designed which consists of air and liquid cooling with the vorticity in the liquid. The high heat dissipation is by heat pipe and radial fins. The efficient cooling performance of the hybrid vortex cooling system was confirmed numerically and experimentally. Finally the optimization of the cooling system was accomplished.

Keywords— Cooling system, Vortex generation, Cooling performance, Heat transfer.

I. INTRODUCTION

Power electronics devices and systems are vital in the efficient generation, transmission and distribution, conversion and a huge variety of end uses of electric power. The printed circuit board consists of power electronics devices, they consume 50% of the applied power as heat. Thus proper temperature performance is required for PCB's to avoid thermal damage to the system (Pounds et al, 2014)[7]. The general methods employed for cooling are natural convection, LHP heat pipe, forced convection. In case of natural convection large size equipment is employed for sufficient cooling whereas in forced convection the fan system has limitations such as noise, vibration, short lifetime and large size, as it consists of moving parts(Angie et al, 2012)[5], (Dong et al, 2015)[8]. For PCB's the active cooling methods may provide better performance but at the expense of higher cost and energy consumption. Passive phase change cooling devices such as heat pipes and thermosyphons, are well established in the electronics industry as a very effective and reliable way of removing excess waste heat at a low thermal resistance (Angie et al,2012)[5]. Thus, hybrid vortex cooling system was suggested by using sintered copper heat pipe as a new cooling device for PCB's and other electronics because it overcomes the demerits of other cooling devices such as large size, higher power input.

The market survey reveals that various cooling systems are using forced convection by using fan which makes the cooling device large of dimension 300 X 300 X 250 mm available in store. The hybrid vortex cooling system was planned to reduce the dimensions but to dissipate heat at average amount.

In heat pipe, phase change cooling is done by using the sintered copper powder as working fluid. The passive phase change cooling is used widely and most preferable for electronics cooling. The sintered copper powder is used for more enhanced cooling effect. This process will provide high power handling, low temperature gradients and high capillary forces for anti-gravity applications (Zhe-Shu et al, 2009) [2], (Seri et al, 1995)[1].

In the present study, the cooling performance of hybrid vortex cooling device was analysed by measuring the temperatures of the coolant and computational analysis was done to verify the temperature gradient, heat flux and overall heat transfer coefficient. The computational analysis of the device was done using ANSYS. The hybrid vortex cooling device is confirmed as an effective cooling for PCB's and other stationary control pannels.

The heat pipe is a highly efficient, proven heat transfer technology. It relies only on the latent heat of vapourization and is completely passive transport of a working fluid sealed within a tubular metal envelope. For the heat pipes embedded in the MCPCB, a copper and water material system is selected for its high performance, low cost and ease of manufacturing (Pounds et al, 2014)[7]. Aluminium is commonly selected as the base material, copper when higher thermal performance is required (Pounds et al, 2014)[7].Design control over this resistance primarily lies within the wick structure construction, sintered metal powder can exhibit exceptionally high thermal performance (Pounds et al, 2014)[7].

Vortex generators such as fins, ribs, wings have been used for heat transfer enhancement of the modern thermal systems. Vortex generators form secondary flow by swirl and destabilize the flow (Mirzaei et al, 2012)[4]. The generation of longitudinal vortices and creating rotating and secondary flow in the main flow which can raise turbulent intensity, mixes the warm and cold fluid near and in the center of channel and increase the heat transfer in the heat exchangers.

A phase change recirculating system includes two phase system consisting of a set of evaporating and condensing area with self driven mechanism. Heatpipe systems consist of wicks that do not require gravity feed. This system can be used for a load limit of 100W -150W (Seri et al, 1995)[1].

II. EXPERIMENTAL SETUP

The test rig consists of a Aluminium spiral radial fin with a sintered copper heat pipe and a 12W fan of dimension 100×100mm is mounted on the assembly to force the air on spiral radial fins for enhancement of heat transfer. The water is circulated from a concentric tray with the ribs placed in the concentric tray (Ting et al, 2015)[10]. The serpentine in the tray for the coolant flow enhances heat transfer rate (Ting et al, 2015)[10]The water is circulated from the tray which is in direct contact to the heat source. This system is fitted in the metal box of size 100×100×150mm. The project work was motivated to reduce the size of the available cooling devices which are 300×300×250mm in dimensions. The cost of the cooling system is also, as there is negligible operating cost to the present cooling devices. The rotary fans have wide used but it is not ideal for small electronics because of producing components such as rotor, bearings,motor and shaft smaller than a critical size (Sheng et al, 2015)[9].

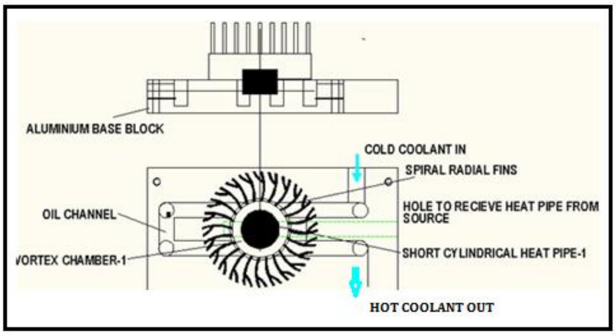

Fig. no. 1 Experimental setup

The working of the test rig consists of different concepts which together coordinate to the heat removal at higher rate than the available cooling devices. The tray is in direct contact with the heat source consists of a water flow rate from the head of 500mm. The ribs in the tray are used to generate the swirls around the ribs which create vortices and it enhances the heat dissipation (Mirzaei et al, 2012)[4]. The tray is made to occupy the heat source and water is used to collect the heat from the surface of the heat source and it is directly transferred to the evaporative region of heat pipe. Water is basically used to transfer the heat from surface of the source to the heat pipe and water is most generally used, as liquid prevents contamination (Darren et al, 2014)[6]. Heat pipe can works in anti-gravity feed so it is mounted horizontally and fitted with the radial fin on the condensing region of heat pipe. The radial fin is supported to dissipate more amount of heat to atmosphere by a fan, which blows atmosphere air on the assembly (Sukhvinder et al, 2012)[3]. The heat pipe working is based on the temperature gradient so to prevent the system inefficiency during low temperature gradient the heat pipe is incorporated with radial fin and fan (Zhe-Shu et al, 2009)[2]. Thus the system is called as HYBRID VORTEX COOLING SYSTEM.

III. RESULTS AND DISCUSSION

1. Temperature gradient – time relation

The relationship between the temperature gradient and time represents the time required to attain the temperature gradients. This relation is obtained for various set-ups to know the efficient set-up for better and quick cooling. The quicker the cooling the better the performance.

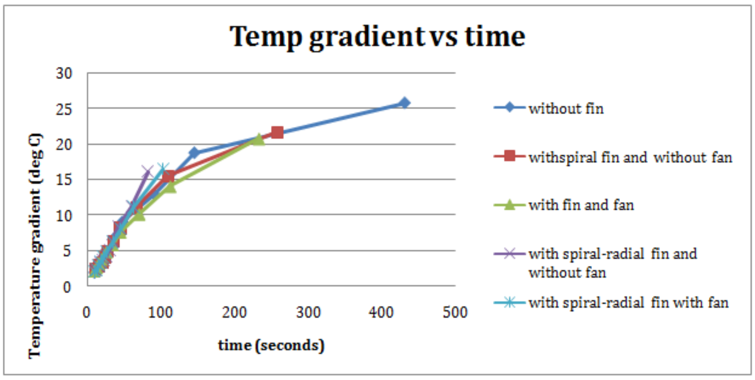

Fig.no.2 Graph of temperature gradient vs time

A graph is plotted as in fig. 1, it consists of the set- up readings from that we can observe that without fin set up requires 431 seconds to attain a temperature gradient of 25.8 deg C whereas a set-up which consists of fin and fan both requires only 233 seconds to attain temperature gradient of 21 deg C. The other set-up which is with spiral and radial fin with fan and with spiral and radial fin without fan can attain similar temperature at the expense of 83 and 103 seconds. The spiral radial fin attains the temperature gradient at a higher rate comparatively to other assemblies.

From fig 2 the temperature gradient attain by the spiral radial fin and fan assembly has the maximum efficiency than any other assembly and selection of this assembly for any stationary control panel can give the maximum efficiency at the expense of only power input to fan. The difference between the assembly with and without fan is 15%. Thus if the fan is not to be used the performance will be reduced by the difference i.e 15%. The heat dissipation rate increases as the assembly changes as shown in fig. 2. The forced convection can only give the 25% of performance whereas the radial fins can give 70% efficiency in compare to the spiral radial fin with fan assembly. The maximum efficiency attained is only by spiral radial fin.

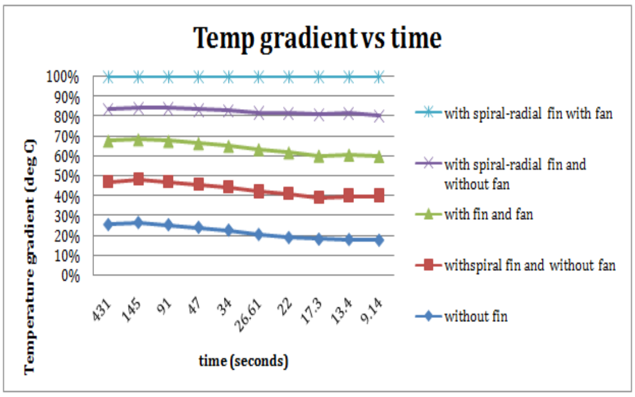

Fig.no.3 Graph of temperature gradient vs time

2. Temperature gradient – mass flow rate

The graph is plotted of temperature gradient against mass flow rate of water in kg/s. This graph gives the comparison in the consumption of mass flow rate to attain the temperature gradient by system. The higher the temperature gradient with low mass flow rate is called as most economical and high effective system. These readings are obtained by regulating the flow of 200ml by flow regulator at different speed.

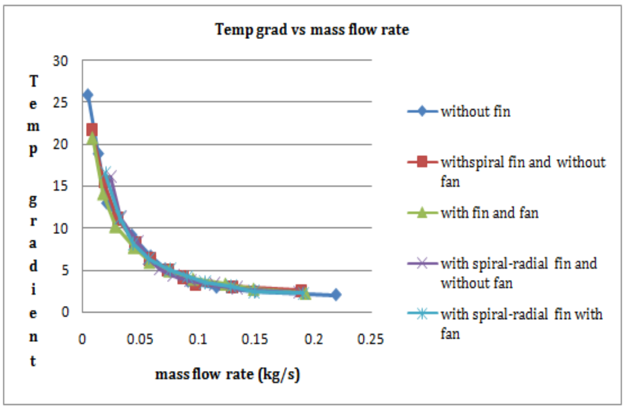

Fig.no.4 Graph of temperature gradient vs mass flow rate(kg/s)

The graph represents the negligible change in readings after the sweet spot. The observations from the graph can be made as same as with temperature gradient vs time graph.

From fig 2 and fig 4, the spiral radial fin setup gives better performance than any other set up as the logarithmic graph shows following result for spiral radial fin with fan setup
The flow rate requirement by the forced convection is much higher where as it gives only 50% of the spiral radial fin with fan temperature gradient from fig. 5. The forced convection offers only 50% cooling than spiral radial fin assembly with 10% high flow rate which is uneconomical and bulky unit also with an increase in size. From the experiments the spiral radial fin with fan gives the maximum efficiency with minimum flow rate and at high rate.

The readings vary on the basis of types of fins, the numerical analysis of fin is done by using the classical formulae.

$m = \sqrt[2]{\frac{hp}{kA}}$ and q= kAm(ΔT) and assuming fin efficiency to be 50%.

The fin dissipates 83W whereas by the designed system is 42W. Thus the selection of fin is valid.

3. Computational analysis of spiral radial fins

The computational analysis is done to validate the selection of fins and its heat flux. The validation of fins is done by using ANSYS 16.0. The temperature distribution and heat flux distribution is analysed.

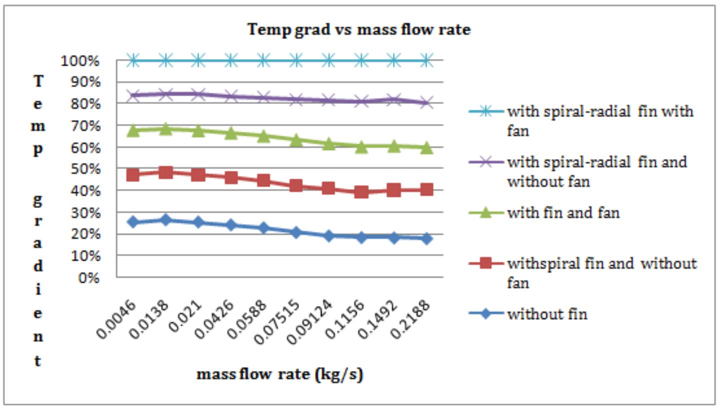

Fig. no.5 Graph of temperature gradient vs mass flow rate(kg/s)

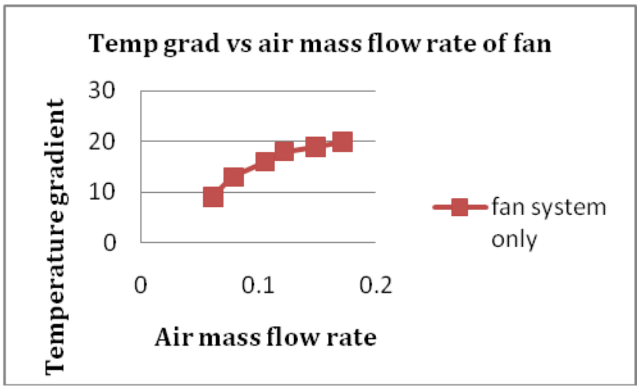

Fig no. 6 Graph of fan system temp grad vs mass flow rate

The model was developed using UG NX and data was transferred using step 023. The meshing of the geometry was done by using nodes 48841 and 6920 of elements as shown in fig.6

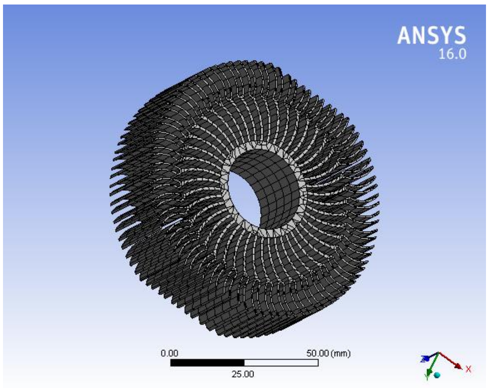

Fig no. 7 Meshing of spiral radial fin

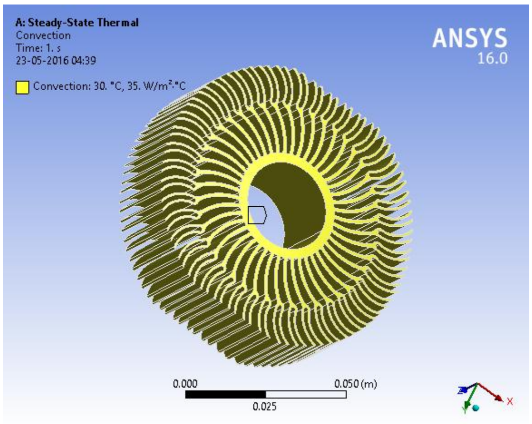

Fig no.8 Fins under steady state thermal convection analysis

The fin is analysed under steady state thermal condition for convection mode of heat transfer for 1sec time of period at 30 deg C and 35W/m^2 deg C.

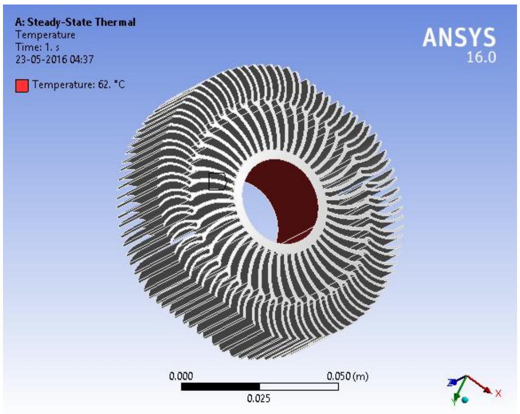

Fig no. 10 Thermal analysis at 62 deg C

The fig 9 shows that the area in contact with the heat pipe is under high temperature than other area of the fins.

The fig 10 shows the maximum temperature is concentrated at the centre of the fin whereas the concentration of temperature reduces away from the centre and it is minimum at the tips of the fin where it is in contact with the atmospheric air forced by the fan on it.

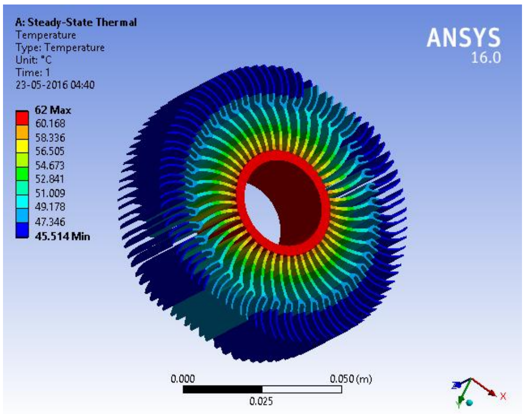

Fig no.11 Steady state thermal temperature analysis

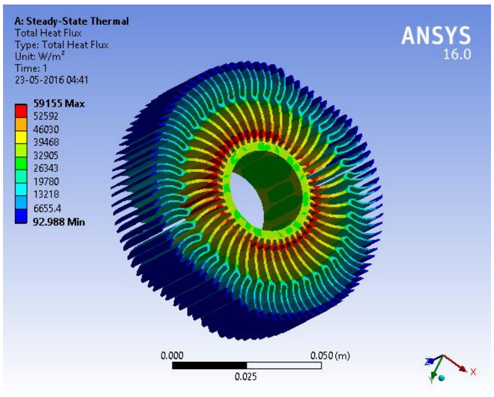

Fig no.12 Total heat flux analysis

The total heat flux analysis is shown in fig.11, maximum heat flux is concentrated at the base of the fins which reduces to minimum towards the tip of the fin in contact with the fan blown atmospheric air.

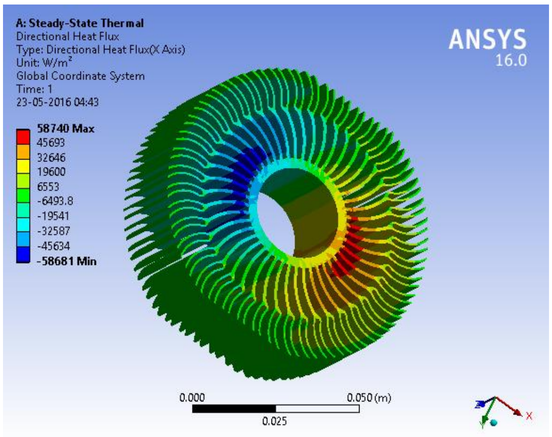

Fig no.13 X-Directional heat flux

The heat flux is analysed in only X-direction which is maximum at a side at minimum in reverse direction as shown in fig. 12

IV. CONCLUSION

1. The hybrid vortex cooling system is 50% more efficient than forced convection units used generally.
2. The system gives higher rate of cooling at low flow rate than any other fin using system.
3. The system consumes minimum power to dissipate significant amount of heat at higher rate.
4. This system can be used without fan i.e with no power consumption at the expense of 15% low efficiency.
5. The experimental results are compared with the empirical formulae and confirmed with the error of 5.67%.
6. The computational analysis defines the heat concentration in the centre and minimum at the ends which verifies the system is performing thermally as per the requirements.
7. The total heat flux is distributed maximum at the centre and minimum at the tips which shows the heat dissipation is achieved by contact of air at tip.

REFERENCES

1. Seri Lee (1995), Optimum design and selection of heat sinks, *IEEE Semi-Therm Symposium*, Vol.11
2. Zhe-Shu Ma and Shou-Guang Yao (2009), Experimental investigation of a novel heat pipe cold plate for electronics cooling, *Journal of Scientific and Industrial Research*, Vol. no. 68 page no. 861-865.
3. Sukhvinder S. Kang (2012), Advanced cooling for power electronics, *International Conference on Integrated Power Electronics Systems,*
4. M. Mirazei and A. Sohankar (2012), Heat transfer augmentation in plate finned tube heat exchangers with vortex generators: A comparison of round and flat tubes, *IJST*, Vol.no. 37, page no. 39-51
5. Angie Fan, Richard Bonner, Stephen Sharratt and Y. Sungtack Ju (2012), An innovative passive cooling method for high performance light-emitting diodes, *28th IEEE Semi-Therm Symposium*
6. Darren Campo, Jens Weyant, Bryan Muzyka (2014), Enhancing thermal performance in embedded computing for ruggedized military and avionics, *14th IEEE ITHERM Conference,*
7. Dan Pounds and Richard W. BonnerIII (2014), High heat flux heat pipes embedded in metal core printed circuit boards for LED thermal management, *14th IEEE ITHERM Conference*

8. Dong Ho Shin, Joon Shilh Yoon, Han Seo Ko (2015), Experimental optimization of ion wind generator with needle to parallel plates for cooling device, *International journal of heat and mass transfer,* Vol.no.84 page no. 35-45

9. Sheng-Lun Ma, Jing-Wei Chen, Hung-Yi Li, Jing-Tang Yang (2015), Mechanism of enhancement of heat transfer for plate –fin heat sinks with dual piezoelectric fans, *International journal of heat and mass transfer,* Vol.no. 90, page no. 454-465

10. Ting Wang, Bo Gu, Pengcheng Zhao, Cheng Qjan (2015), Numerical investigation of liquid cooling cold plate for power control unit in fuel cell vehicle, *Microelectronics Reliability,* Vol.no. 55 page no. 1077-1088