Thermal Modeling and Analysis of Liquid Cold Plate

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Abstract - Electronics cooling research has been largely concentrated on high heat flux removal from major industrial and military equipment in the recent years. Some of these are power drives, insulated-gate bipolar transistor (IGBT) controllers, radio-frequency (RF) generators, magnetic resonance imaging (MRI) machines, traction devices for locomotives, battery chargers, UPS (uninterrupted power systems), DC-AC converters ,AC-DC inverters, and army tanks (using transmission fluid already at a high temperature). The high-power, high-heat-flux demands have been experiencing a major paradigm move from air cooling to liquid cooling over the last decade, as air cooling has sufficed only for lower power electronic devices. Beyond a range of about 1500Wdissipation, there are many physical and design constraints that may dictate a shift toward liquid cooling as the preferred medium. This project deals with the Design and optimization of the cold plates of IGBT used in defense power electronics. 800-W insulated-gate bipolar transistors, 8 in number (each 8100 mm^2) are used in defense electronics (power amplifier) which were sufficiently cool with liquid cooling. The objective of the present work is to reduce thermal resistance, increase heat transfer rates from IGBT's by using DI water as coolant which flows through channels through formed tube.

Computational fluid dynamics (CFD) software was used to estimate the thermal performance of the cooling system based on steady-state loading conditions. Conjugate Heat Transfer analysis of the IGBT cooling plate is carried using the CFD software to document the temperature distribution, velocity of flow and the pressure drop. The cooling plate is designed in solid works software and the flow analysis is carried out using the solid works flow simulation software. Temperature optimization of the cold plate was done to achieve 358 K which is a design constraint and optimization of cold plate is done by changing the profile of flow channels, keeping inlet and outlet diameters constant. Three models namely Existing model, Proposed Model-1, Proposed Model-2 was designed and CFD analysis was performed on each model and results were compared.

Key Words: Liquid cold plate, IGBT, Conjugate Heat Transfer

1. INTRODUCTION

Electronics cooling research has been largely focused on high heat flux removal from computer chips in the recent years. However, the equally important field of high-power electronic devices has been experiencing a major paradigm shift from air cooling to liquid cooling over the last decade. Integrated power electronics such as IGBT's (Insulated Gate Bipolar Transistors (IGBTs), are widely used to efficiently deliver electrical power in electrical drive systems in transportation, home electronics, and electrical grid applications. It is required to improve volumetric requirements, weight, ruggedness, thermal heat dissipation, noise levels, and reliability while applying integrated power electronics to electric drive systems. Modern integrated power electronics have higher power density compared to past technologies. Heat removal is the major limiting factor in these electronic components. In order to achieve adequate cooling at high power densities, design engineers are forced to look beyond standard air cooling method. For integrated power electronic modules liquid cooling has become an accepted and necessary form of heat dissipation. To get effective heat dissipation, cold plates and heat pipe technologies were evolved in efficiency and reliability.

1.1 Classification of Cold Plates

The cold plates are classified as follows:

1. Formed Tube Cold Plate (FTCP)
2. Deep Drilled Cold Plate (DDCP)
3. Machined channel Cold Plate (MCCP)

Form tube liquid cold plates ensure minimum thermal resistance between the device and the cold plate by placing the coolant tube in direct contact with the device base plate. In this design, copper plate is generally used, although aluminum is sometimes employed in low power applications. In Deep drilled cold plate the heat flux and power dissipation increases, the contact resistance of the plate and the tube wall become unacceptably high. In this design deep holes are drilled in the plane of the substrate plate. In Machined channel cooling plate, the heat flux increase; it becomes necessary to performance of the channels. In this design, channels are machine-cut into the base plate and a cover is soldered in place to form the flow passages. In the literature thermal analysis of form tube, machined channel and Deep drill cold plates at different working environment has been done. This shows there is a lack of study in the behavior of three different Cold plates at same working environment.

1.2 Liquid Types—Coolant Issues

The type of liquid, fluid and system pressure, fluid flow, inlet temperature, cold plate weight, type of material, and the allowable or desired pressure drop are major factors in the cooling system design. Plain water is the optimum cooling choice and will be used only in controlled environments, laboratory conditions, or requested solutions. Tap water may contain active ions or other impurities, which will attack the inside of aluminum flow channels. Given time, those aluminum channels will corrode, causing a leak path and ultimately equipment failure. That is why copper in tube or channel form is the preferred solution with water and other liquids.

Distilled water or DI water is a challenge to cool with. A suitable corrosion inhibitor must be incorporated into the system so as not to dissolve metal from the cold plate or soldered connections. DI water without an inhibitor will attack any stress points (such as tube bends) and cause a leakage path with dire results.

The use of a vaporizable dielectric fluid, R134a indirectly contacting the chips, operating at its saturation temperature, allows the use of a smaller quantity of liquid, a smaller pump for low flow operation, and smaller tubing diameters, when compared to a comparable single-phase water cooling system , and to dissipate the same module heat loads. The use of a vaporizable dielectric fluid in a copper cold plate with convoluted fin internal structure is demonstrated to yield around 100% additional capacity to dissipate heat generated at the IGBT module. In the present work DI water and R134A were used as coolants for liquid cooled plate at the same design and operation conditions.

2. PROBLEM DEFINITION

This project deals with the evaluation of the best design with the different inlet and outlet diameters of the cooling plates by performing CFD analysis. The cooling plate is used in defence power electronics. CFD analysis is performed to characterize thermal performance based on steady-state loading conditions. Conjugate Heat Transfer Analysis of the IGBT cooling plate is carried using the CFD software to document the temperature distribution and the pressure distribution. Design evaluation of the cooling plate was done for better temperature distribution.

The cold plates are designed in solid works software and the flow analysis is carried out using the solid works flow simulation software. The cooling plate is made up of two copper plates sandwiched together by soldering. The inside of cooling plates contains flow channels. The coolant considered in this analysis is de-ionized water. CFD analysis was carried out using Solid works flow simulation. The temperature distribution and pressure plots are observed and documented. Design evaluation of the cooling plate was carried out based on the better heat transfer rate and less temperature distribution.

2.1 Methodology

The objective is to evaluate a cooling plate which has a comparable ability to cool the integrated power electronics module.

- 3D model of the cooling plates with different flow channel profiles by keeping inlet and outlet diameters constant was developed from the 2D drawings using Solid works software.
- The 3D model is imported into Solid works flow environment to perform the CFD analysis.
- Temperature, Velocity and Pressure distribution are observed and documented.
- Results, discussions, comparison and conclusions of the results of different cooling plates shall be made.

3. MODELING OF COLD PLATE

3D model of the cooling plates with different flow channel profiles by keeping inlet and outlet diameters constant was developed from the 2D drawings using Solid works software. The 3D model is imported into Solid works flow environment to perform the CFD analysis

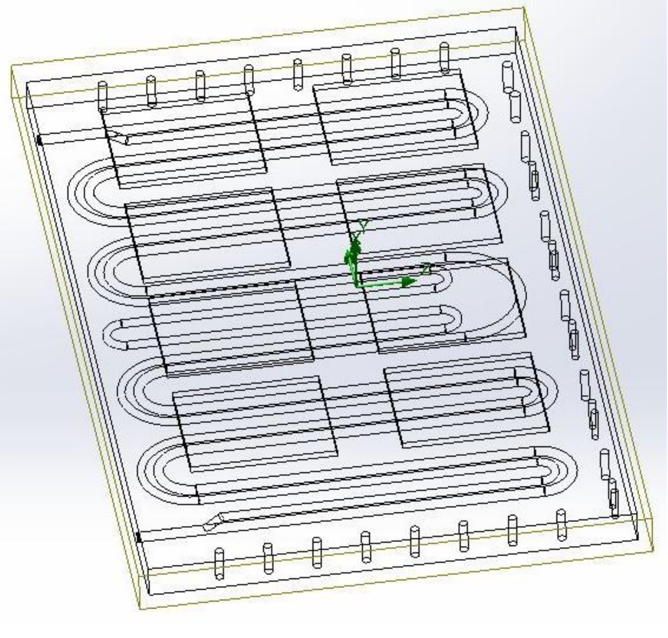

Fig-1:3d Existing Model of Cold Plate (FTCP)

3.1 Proposed Models

In proposed models the plate dimensions are kept constant. To increase the amount of heat transfer here the flow path was changed and it was shown in the following figures.

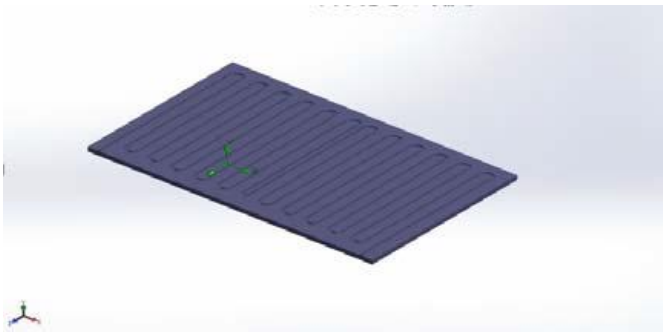

Fig-2: 3d model of proposed model – 1

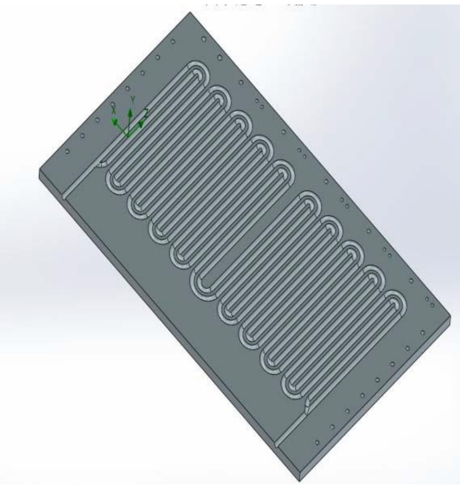

Fig-3: 3d model of proposed model – 2

4. CFD ANALYSIS OF LIQUID COLD PLATES

The flow analysis of liquid cold plates was carried out by considering the inlet mass flow rate of fluid as 1.86 kg/sec and a static pressure of 101325pa. The liquid plate is analysed with two different fluids DI water and R134a.

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Table -1: properties of water and R134a

	Thermal conductivity (w/mK)	Heat capacity (J/Kg K)	Boiling point (^{0}C)	Freezing point (^{0}C)
Water	0.56	4219.3	100	0
R134A	0.092	1346	-26.1	-101

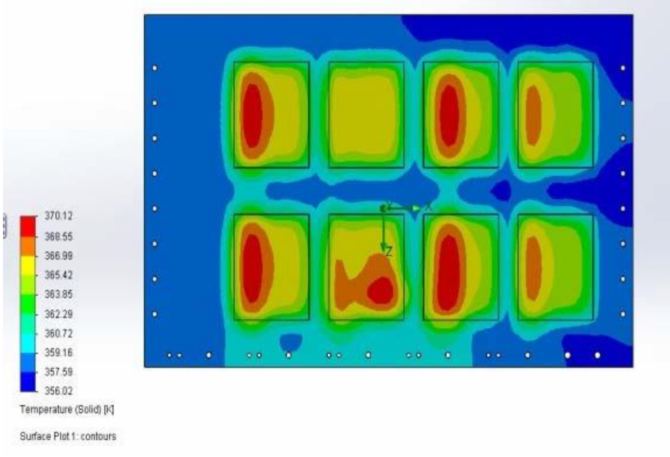

Fig-4: Temperature distribution in existing model

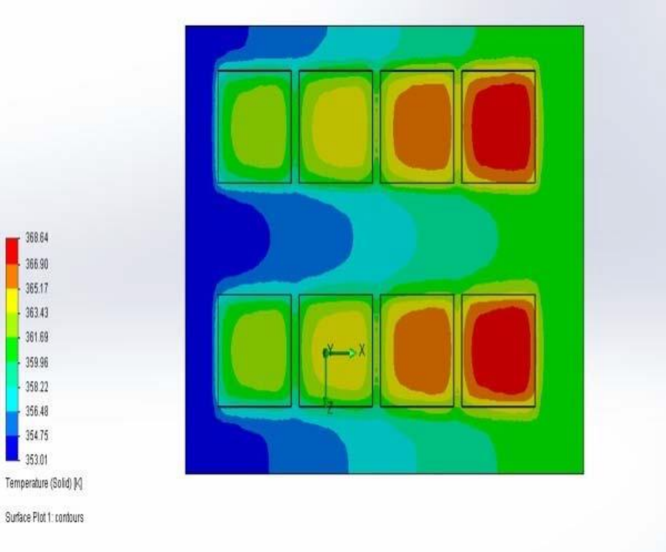

Fig-5: Temperature Distribution in Proposed Model-1

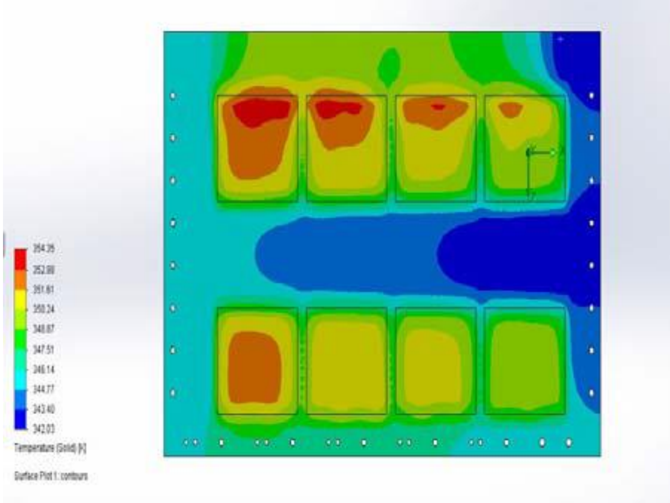

Fig-6: Temperature Distribution in Proposed Model-2

5. RESULTS AND DISCUSSION

Liquid cold plate has been designed and been analyzed for temperature distribution. Initially CFD Analysis is done for liquid cold plate. From the existing model results have been plotted i.e. Temperature distribution, Pressure and Velocity. From the results it is observed that maximum temperature on the cold plate is 370 K .The temperature is out of the design limits, for decreasing the temperature design changes are done on the model by increasing number of flow channels. In the proposed model the numbers of channels are increased and also CFD Analysis was done on the modified model and temperature, pressure and velocity are plotted. From the results it is observed that maximum temperature on the cold plate is 368 K. Further modifications are carried out on the cooling plate to reduce the temperature distribution. In proposed model -2 number of flow channels are further increased keeping length, width and thickness constant. From the CFD results it is observed that maximum temperature on the cold plate is 354 K. In proposed model -2 temperature is within the design limits. The comparison of the results for all the cases were tabulated in Table 2.

Table - 2: comparison of case results

	Existing model	Proposed model-1	Proposed model-2
Temperature (k)	370	368	354
Pressure (pa)	9286508	3.88E+07	1.33E+07
Velocity (m/sec)	77.529	94	77.503

6. CONCLUSION

In this project design optimization of the cold plates used in defence power electronics was done. Conjugate Heat Transfer Analysis of the IGBT cooling plate is carried out using the CFD software to document the temperature distribution, velocity of flow and the pressure drop. Design optimization of the cold plate was done to achieve the temperature of less than 85 degrees, which is a design constraint. Optimization is done by changing the profile of flow channels, keeping inlet and outlet diameters constant. Three such iterations have been performed and the results are compared. From the results that the maximum temperature of 370 K (97 0C),368 (95 0C) and 354 (81 0C) is observed for original, modified model-1 and modified model- 2 respectively. Hence it is concluded that the modified model-2 is the best design of cold plate to maintain the temperature within the design limits.

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