Design and Simulated Analysis of Low Heat Flux Cold Plate for High-power Power Electronics Equipment

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Abstract. The thesis has carried out design and simulated analysis of low flux cold plate for high-power power electronics equipment. First, according to heat distribution and design requirements, two kinds of flow passage for low flux cold plate is designed. Then performance characteristics simulation of different flow passage for cold plate is performed. And the heat dissipation characteristics of two kinds of flow passage can both meet the design requirements. Finally, from the perspective of high temperature, temperature difference, pressure drop and so on, the simulated results are comparative analysis. And it is helpful to the design and optimizing of cold plate for high-power power electronics equipment.

Keyword: High-power power electronics equipment, low heat flux cold plate, low heat flux cold plate.

1. Introduction
With the development of more electric technology, there are more and more electrical equipment on civil aircraft, and electric power is also increasing. At the same time, its heat productivity is getting bigger and bigger, especially the calorific value of high-power power electronics equipment is also more and more\(^ {1,2}\). And natural cooling or forced air cooling can’t meet cooling demand, or it will affect the equipment’s reliability and life. However, liquid cooling can effectively bring the heat produced by high-power power electronics equipment. And it can be achieved by cold plate. For civil aircraft, Boeing B787 adopts liquid cooling to cool the high-power power electronics equipment such as ATRU and CMSC. Therefore, the design of cold plate is the key to the heat dissipation of power electronics equipment. And it is very necessary to conduct performance characteristics simulation of cold plate during the phase of preliminary design. Meanwhile, it is also important to the optimization design of cold plate.

2. Cold plate for High-power Power Electronics Equipment Overview
Cold plate is a kind of heat exchanger that uses single cooling fluid. And it is a key cooling component for high-power power electronics equipment. The heat produced by power electronics equipment is brought by cooling fluid which flow through cold plate. The heat dissipation performance determines the power electronics equipment’s working temperature, it directly affect the reliability and stability of power electronics equipment. And the design of flow passage for cold plate can also directly affect the heat dissipation performance.
3. Design of Cold Plate for High-power Power Electronics Equipment

3.1. Design Requirement

The heat distribution of high-power power electronics equipment is shown as figure 1.

![Figure 1. Heat distribution of high-power power electronics equipment.](image1)

The design requirements of low flux cold plate for high-power power electronics equipment are as follows:

- The heat loss for high-power power electronics equipment is about 3.3Kw. Among then, the heat loss of rectifying diode is about 1.8kW, the heat loss of transformer is about 1.4kW, the heat loss of resistance is about 800W, the heat loss of inductance is about 200W.
- The temperature of cooling fluid is from 9°C to 30°C.
- The temperature should not more than 70°C in a single cooling fluid cycle.
- The pressure drop of cooling fluid should not more than 10psi at rated flow.
- The highest temperature at normal working condition should not higher than 300°C.

3.2. Design of Flow Passage

According to the heat distribution and the design requirements of high-power power electronics equipment, A kind of serpentine flow passage and a kind of flow passage with tiny embedded fins are designed for the cold plate. The structures of flow passage are shown in figure 2 and figure 3. As is shown in figure 2, it is relatively sparse for ribs in the flow passage. In the right area of flow passage, the thickness is about 6mm, and the central distance for adjacent rib is about 12mm. In the left area of flow passage, the thickness is about 5mm, and the central distance for adjacent rib is about 15mm. The distribution of flow passage can cover all the heating components, and the height of the flow passage is about 14mm. As is shown in figure 2, the thickness of all fins is about 2mm, the central distance of adjacent fin is about 5mm, the height of fin is about 14mm. The arrangement of fin can form certain inclination, which can make the fluid velocity uniformly in the tiny flow passage. And the kind of flow passage have the outstanding superiority in heat dissipation. However, as the cooling fluid flow longer, the flow resistance is bigger and the pressure drop of import and export for cold plate is also bigger.

Expendable material (such as water for use in water boilers) may be carried aboard the aircraft. And it is assumed that the rate of consumption of the expendable material is constant. There are two cases in the following:

![Figure 2. Flow passage 1.](image2)

![Figure 3. Flow passage 2.](image3)
4. Simulated Analysis

4.1. Simulated of Flow Passage 1 for Cold Plate

The heat dissipation characteristics have been simulated by the software Flow EFD. And the simulation conditions are as follow: the temperature of feed liquid is 9°C and 30°C, and the flow of cooling fluid is 0.0004 m³/s. when the temperature of feed liquid is 9°C, the simulated results are shown in figure 4 to figure 7. It can be obtained as follow:

- The highest temperature area of power electronics equipment is at rectifying diode, and the value is about 62.75°C.
- The highest temperature of cooling fluid is about 34.9°C, the temperature difference of import and export for cold plate is about 2.44°C.
- The highest velocity of cooling fluid is about 3.848m/s.
- The pressure drop of import and export for cold plate is about 3.12psi, which is less than 10psi.
- The total heat exchange amount is about 3.299kW, which is meet the heat dissipation requirement of 3.3kW.

when the temperature of feed liquid is 30°C, the simulated results are shown in figure 8 to figure 11. It can be obtained as follow:

- The highest temperature area of power electronics equipment is at rectifying diode, and the value is about 83.73°C.
- The highest temperature of cooling fluid is about 55.71°C, the temperature difference of import and export for cold plate is about 2.41°C.
- The highest velocity of cooling fluid is about 3.388m/s.
- The pressure drop of import and export for cold plate is about 2.19psi, which is less than 10psi.
- The total heat exchange amount is about 3.3kW, which is meet the heat dissipation requirement of 3.3kW.
The flow passage 1 can meet the design requirements, and when the temperature of cooling fluid at the import for cold plate increase from 9°C to 30°C, the highest temperature area of power electronics equipment also increased from 62.75°C to 83.73°C, which increased by 20.62°C, and the highest temperature of cooling fluid increased from 34.9°C to 55.71°C, which increased by 20.81°C. Due to temperature increased and viscosity of cooling fluid decreased, the flow resistance also reduced from 3.12psi to 2.19psi, which decreased by 0.93psi.

4.2. Simulated of Flow Passage 2 for Cold Plate

The heat dissipation characteristics have been simulated by the software Flow EFD. And the simulation conditions are as follow: the temperature of feed liquid is 9°C and 30°C, and the flow of cooling fluid is 0.0004 m³/s. when the temperature of feed liquid is 9°C, the simulated results are shown in figure 12 to figure 15. It can be obtained as follow:

- The highest temperature area of power electronics equipment is at rectifying diode, and the value is about 55.62°C.
- The highest temperature of cooling fluid is about 28.27°C, the temperature difference of import and export for cold plate is about 2.41°C.
- The highest velocity of cooling fluid is about 3.934m/s.
- The pressure drop of import and export for cold plate is about 5.59psi, which is less than 10psi.
- The total heat exchange amount is about 3.29kW, which is meet the heat dissipation requirement of 3.3kW.

Figure 8. Temperature of cold plate. Figure 9. Temperature of cooling fluid.

Figure 10. Velocity of cooling fluid. Figure 11. Pressure of cooling fluid.

Figure 12. Temperature of cold plate. Figure 13. Temperature of cooling fluid.
Figure 14. Velocity of cooling fluid. Figure 15. Pressure of cooling fluid.

when the temperature of feed liquid is 30℃, the simulated results are shown in figure 16 to figure 19. It can be obtained as follow:

- The highest temperature area of power electronics equipment is at rectifying diode, and the value is about 78.01℃.
- The highest temperature of cooling fluid is about 50.46℃, the temperature difference of import and export for cold plate is about 2.31℃.
- The highest velocity of cooling fluid is about 3.741m/s.
- The pressure drop of import and export for cold plate is about 4.01psi, which is less than 10psi.
- The total heat exchange amount is about 3.299kW, which is meet the heat dissipation requirement of 3.3kW.

Figure 16. Temperature of cold plate. Figure 17. Temperature of cooling fluid.

Figure 18. Velocity of cooling fluid. Figure 19. Pressure of cooling fluid.

The flow passage 2 can meet the design requirements, and when the temperature of cooling fluid at the import for cold plate increase from 9℃ to 30℃, the highest temperature area of power electronics equipment also increased from 55.62℃ to 78.01℃, which increased by 22.39℃, and the highest temperature of cooling fluid increased from 28.27℃ to 50.46℃, which increased by 22.19℃. Due to temperature increased and viscosity of cooling fluid decreased, the flow resistance also reduced from 5.59psi to 4.01psi, which decreased by 1.58psi.

5. Comparative Analysis

When the flow of cooling fluid is about 0.0004m³/s, and the temperature of cooling fluid at the import for cold plate is about 9℃ and 30℃ respectively, the simulated performance characteristics of two
kinds of flow passage for cold plate are shown in table 1 and table 2. It can be seen from Table 1 and Table 2, the heat dissipation capacity of flow passage 2 is stronger than flow passage 1. And the highest temperature of flow passage 2 is lower than flow passage 1. Although the pressure drop of import and export for flow passage 2 is higher than flow passage 1, the pressure drop of import and export for flow passage 2 can meet the design requirement of 10 psi. Therefore, considering of high temperature, temperature difference, pressure drop, the flow passage 2 is better than flow passage 1.

Table 1. Comparative analysis of simulated performance for different flow passage.

|                | highest temperature of cold plate | highest temperature of cooling fluid | temperature difference of import and export for cold plate | highest velocity of cooling fluid m/s | pressure drop of import and export for cold plate psi |
|----------------|----------------------------------|-------------------------------------|----------------------------------------------------------|-------------------------------------|-----------------------------------------------------|
| Flow passage 1 | 62.75                            | 34.9                                | 2.44                                                     | 2.50                                | 3.12                                                |
| Flow passage 2 | 55.62                            | 28.27                               | 2.41                                                     | 2.50                                | 5.59                                                |

Table 2. Comparative analysis of simulated performance for different flow passage.

|                | highest temperature of cold plate | highest temperature of cooling fluid | temperature difference of import and export for cold plate | highest velocity of cooling fluid m/s | pressure drop of import and export for cold plate psi |
|----------------|----------------------------------|-------------------------------------|----------------------------------------------------------|-------------------------------------|-----------------------------------------------------|
| Flow passage 1 | 83.73                            | 55.71                               | 2.41                                                     | 2.5                                 | 2.19                                                |
| Flow passage 2 | 78.01                            | 50.46                               | 2.31                                                     | 2.5                                 | 4.01                                                |

6. Conclusion
The thesis has carried out design and simulated analysis of low flux cold plate for high-power power electronics equipment. The simulated performance results show that the serpentine flow passage and tiny embedded flow passage can both meet the heat dissipation requirement of cold plate for high-power power electronics equipment, but the heat dissipation performance of the tiny embedded flow passage is better than the serpentine flow passage. However, the simulated results also have its limitation, it can only be suitable for the preliminary and can not represent the actual heat dissipation capacity. In other words, the actual heat dissipation capacity can be obtained by performance test.

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