Structural Type Selection of Water-cooled Motor Controller Based on ICEPAK

Weijian Zhao¹, ², *, Huizhi Sun¹, Weiping Fang¹ and Benchao Liu¹

¹School of vehicle engineering, Shandong transport vocational college, Weifang, China
²College of transportation, Shandong university of science and technology, Qingdao, China

*Corresponding author: weijianzhao@sdjtzyxy.com

Abstract. Three kinds of water-cooled radiator structures of the motor controller are designed in the process of developing the motor controller of the electric vehicle. Based on ICEPAK, the detailed distribution of the temperature field is obtained by simulation analysis of thermal analysis. The temperature situation of the IGBT, the thermal resistance of the radiator and the pressure drop of the radiator are analysed. The results show that the cooling effect of the cross shaped needle shaped radiator is the best, so it is selected as the radiator of the water-cooled motor controller.

Keywords: ICEPAK, motor controller, IGBT, heat radiator structure, thermal analysis.

1. Introduction
In the development process of pure electric vehicle motor controller, the heat dissipation problem of key module IGBT (insulated gate bipolar transistor) often causes the motor controller to fail to reach the specified power, and even causes the motor controller to overheat and burn out, which has seriously affected the stability of the vehicle [1, 2]. Therefore, it is urgent to solve the heat dissipation problem of motor controller.

Because the traditional theoretical analysis and experimental verification methods are time-consuming and laborious, the actual effect of the cooling system of the controller can be simulated through CFD (Computational Fluid Dynamics) software, and the errors of simulation results are within the allowable range of engineering calculation [3, 4, 5].

In this paper, based on ICEPAK software, three kinds of radiator structure are selected to verify the feasibility of the scheme and save material and financial resources. Besides, the method of selecting motor controller structure by using simulation software is proposed, which can not only improve the heat dissipation performance of existing motor controller, but also reduce the pre-research time of developing new motor controller R & D progress.

2. Research object
Based on a pure electric vehicle electric drive system development project, permanent magnet synchronous motor with rated power of 25kW and motor controller with capacity of 90KVA are adopted.
The main heat source of the motor controller is IGBT module, and the estimated total heating power is 1.0kw. Traditional air cooling has been difficult to meet the cooling requirements of motor controller. From the perspective of technical development, a new water-cooling method is adopted [6].

The cooling system of the motor controller is shown in Figure 1. The top part is IGBT power module, and the lower part is connected with the heat dissipation bottom plate for heat dissipation. Under the heat dissipation bottom plate, needle shaped, fin or S-shaped water channel is designed for better heat exchange. The bottom of the cooling channel, cooling water from the water inlet into, the water outlet, will take away the heat.

![Figure 1. Cooling system of motor controller.](image)

The cross arrangement of needle shaped radiator can increase the turbulence intensity of water in the channel, increase the heat transfer area, reduce the thermal resistance and improve the heat dissipation effect. It is found that cross arrangement is better than sequential arrangement in heat dissipation [7]. Fin type radiator is widely used in air-cooled and water-cooled cooling devices for electronic components due to its convenient processing and low cost. The S-shaped channel can increase the turbulent flow of the coolant, increase the heat exchange area and improve the heat dissipation capacity. Therefore, three kinds of radiators are designed respectively, and the geometric model is constructed by using 3D modeling software, as shown in Fig. 2.

![Figure 2. Schematic diagram of three kinds of radiators.](image)
3. Numerical parameter setting of water-cooling simulation
In order to effectively analyze the change of flow field and temperature field in the channel, it is necessary to make some basic assumptions to simplify the problem [8]. The basic assumptions are as follows:

1) the flow field is a three-dimensional steady turbulent flow field with uniform flow velocity at the inlet;
2) incompressible Newtonian fluid;
3) the influence of gravity field and thermal radiation is ignored;
4) the convection coefficient with the outside air is ignored.
5) The contact thermal resistance between water cooling radiator and IGBT is ignored.

It was found that there were 12 points with obvious fever in IGBT. Under rated condition, the heating power of IGBT is about 1000W; under peak condition, the heating power of IGBT is about 2500W. In order to simulate the actual situation better, the heating of IGBT is simplified to 12 small heat sources. The 12 heat sources are asymmetric, and the distribution of heat sources is shown in Fig. 3.

![Figure 3. Distribution of heat sources.](image)

In addition, in order to make the simulation results as reliable as possible, the module components should be consistent with the actual object as far as possible when setting the parameters such as material properties and boundary conditions.

4. Thermal simulation analysis
4.1. Establishment of geometric model
In ICEPAK, the model is modified appropriately, the priority of the model is adjusted, and various boundary conditions are applied. The model of heat source surface is shown in Fig. 4.
4.2. Meshing
For the cross arranged pin radiator, because the size of the cooling column is small and dense, the grid size of the cooling column should be set separately, and the maximum grid size of the cooling column should be set to 1/4 of the global maximum grid size to ensure the grid generation accuracy.

4.3. Solution results
This solution algorithm adopts coupling algorithm (advantages are small error and easy convergence); set 200 iteration steps to solve, and the result is shown in Fig. 5.

Figure 4. Schematic diagram of three kinds of radiators in ICEPAK.
(a) Pin radiator under rated condition

(b) Finned radiator under rated condition

(c) S-channel radiator under rated condition

(d) Pin radiator under peak condition
5. Result analysis

5.1. The temperature of IGBT

The data obtained from the simulation calculation (the maximum temperature of the IGBT under the rated operating conditions and the peak operating conditions) are preliminarily sorted out, as shown in Figure 6 and Figures 7.

![Temperature field distribution diagrams](image)

**Figure 5.** Temperature field distribution diagrams.

![Temperature of IGBT under rated conditions](image)

**Figure 6.** Temperature of IGBT under rated conditions.
Figure 7. Temperature of IGBT under peak conditions.

The comparison shows that under rated conditions, the temperature near the IGBT heat source of the cross-arranged nail-shaped radiator is about 2°C and 3.5°C lower than that of the finned and S-shaped runner radiators, respectively; under peak conditions, the cross-arranged nail-shaped heat dissipation effect is significant.

5.2. Radiator thermal resistance and pressure drop analysis

The thermal resistance is usually used to determine the cooling effect of the radiator. If the thermal resistance of the radiator is small, it means that the heat dissipation effect is good. After calculation, it is found that under the rated working condition and peak working condition, ignoring the error factor, the thermal resistance of the radiator is unchanged, and the pressure drop is also kept constant. The thermal resistance and pressure drop of the heat sink are summarized, as shown in Figure 8.

Figure 8. Comparison of thermal resistance and pressure drop of different structures.

The analysis found that the thermal resistance of the cross-arranged needle-shaped radiator < the thermal resistance of the finned radiator < the thermal resistance of the S-type water channel radiator.
terms of pressure drop, the pressure drops of the finned radiator<the pressure drops of the cross-arranged needle-shaped radiator<the pressure drops of the S-channel radiator.

After comprehensive comparison, the order of heat dissipation effect should be: cross-arranged nails>finned>S-shaped channels. This is because the cross-arranged nail-shaped runner radiator does not change the overall external shape of the radiator, and a spoiler cylinder is placed in the inner runner of the radiator. When the cooling fluid rushes toward the spoiler cylinder, a turbulent flow field is generated inside, resulting in the phenomenon of flow around the cylinder. The separation of the boundary layer is suppressed, the turbulence intensity is significantly improved, and a better heat dissipation effect is obtained. In the case of ignoring processing and operating costs, the cross-arrangement of nail-shaped runner radiators should be given priority. In this pure electric vehicle electric drive system development project, the radiator structure of the motor controller is selected as a cross-arranged nail-shaped flow channel type.

6. Conclusion
Based on ICEPAK software, this paper conducts thermal simulation and thermal analysis on the three water-cooled radiator structures designed, and draws the following conclusions:

1) Use ICEPAK software to analyse and compare the heat dissipation effects of the three radiators. The heat dissipation effect of the shaped radiator is the best;
2) Use ICEPAK software to select a cross-arranged nail-shaped radiator as the heat sink of the water-cooled motor controller;
3) A method to simplify the design process using ICEPAK software is proposed for future design Application of this method in the process can significantly improve development efficiency.

Acknowledgments
This work was financially supported by the plan of introducing and educating young innovative talents in colleges and universities of Shandong Province, China.

References
[1] M. Janicki, A. Napieralski, Modelling electronic circuit radiation cooling using analytical thermal model, Microelectronics Journal. 31 (2000) 781 - 785.
[2] C. Wang, H. Y. Zhou, H. H. Wang, Design and analysis of the heat dissipation of the power board of the high-power series-excited DC motor controller, Micro Motor, 12 (2008) 11 - 12.
[3] S. W. Wang, W. J. Zhao, Z. G. Tang, Thermal simulation and thermal analysis of pure electric vehicle water-cooled motor controller, Micro Motor, 41 (2013) 11 - 13.
[4] W. J. Zhao, Thermal simulation and thermal analysis of pure electric vehicle motor controller, Hefei University of Technology. (2013).
[5] Y. F. Xu, Numerical simulation and experimental research on ventilation and heat dissipation of components in electrical equipment, Northwestern Polytechnical University. (2006).
[6] H. Y. Zhang, D. Pinjala, P. S. Teo, “Thermal management of high power dissipation electronic packages: from air cooling to liquid cooling”, in Proceedings of the 5th Electronics Packaging Technology Conference, EPTC 2003. IEEE, 2003, pp. 620 - 625.
[7] X. X. Gao, Research on thermal design of high-power electronic components and equipment structure, North China Electric Power University. (2006).
[8] F. J. Wang, Computational fluid dynamics analysis, Tsinghua University Press, Beijing, 2004.