Oil-water Composite Cooling Method of Hub Motor for Electric Vehicles

Cheng-ning ZHANG, Fu-lai GUO and Yu-gang DONG
School of Mechanical Engineering, Beijing Institute Technology, Beijing 100081, China

Keywords: Wheel hub motor, Oil water combined cooling, ANSYS, Power density, Temperature field.

Abstract. Hub motor has poor heat dissipation conditions limited by the installation space and working environment, high temperature rise in the process of operation has been a bottleneck to further improve the power density and torque density. The increase of power density means the increase of motor loss density and the acceleration of motor temperature rise, which will accelerate the aging of internal insulation materials and reduce the reliability of the motor to a certain extent. The cooling effect of traditional water jacket cooling is limited, and it cannot meet the cooling requirements of hub motor more and more. Taking hub motor for special vehicle as the research object, the cooling structure of rotor oil cooling and compound water jacket cooling are designed. The heat inside the motor is mainly carried away by the lubricating oil and water in the form of heat conduction and convection heat transfer. ANSYS software was used to build a 3d model of the motor, to simulate the temperature field of the motor, and to analyze the temperature distribution inside the motor under different working conditions. The low-speed high-torque, one-hour temperature rise test of the motor prototype was carried out on a bench built in the laboratory, and the test results were compared with the simulation results of the temperature field, showing a good consistency, which verified the rationality of the model.

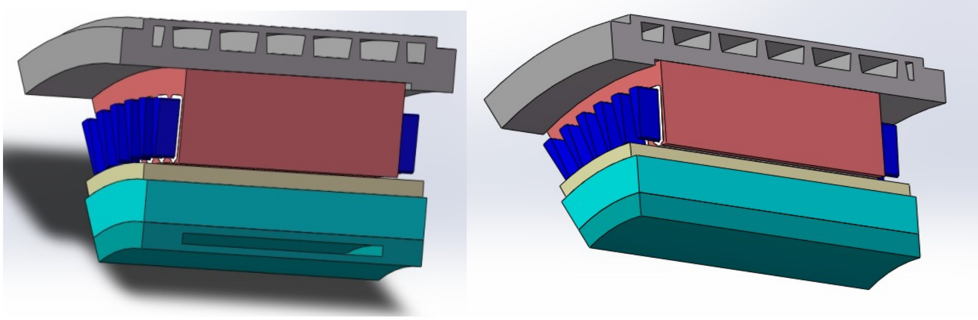
Introduction

In the traditional oil cooling method, the stator and rotor of the motor are immersed in the cooling oil, and the cooling effect is good[1]. However, the cooling oil has to pass through the blade agitation, resulting in a large energy loss at high speed. With the in-depth research of oil-cooling mode, there are more and more new oil-cooling structures in the motor[2]. Li ye[3] separated the stator and rotor of the motor with the ultra-thin casing made of glass fiber, and cooled the end winding directly by the cooling oil in the sleeve, which reduced the average temperature of the motor by 40%.Robert Camilleric Presents a thermal fluid flow model is used to predict temperature and flow distribution of the oil cooled motor directly[4], establishes the numerical model to predict the motor section stator temperature distribution, identify hotspots and its location, and makes the hot spot temperature reduces the 13 °through improving the motor stator flow geometry. The error was within 6% compared with the experimental results through measuring the 1/4 model of the stator. Pia M. Lindh[5] took the double stator permanent magnet synchronous motor with 100 kw as the research object, setting up a stainless steel coolant pipes for cooling. Through the research found that direct cooling reduced the temperature about 50°C than indirect cooling method.

Motor losses are mainly concentrated in the windings and core, so it is necessary to design the cooling structure to make the oil as close as possible to the heat source to achieve better cooling effect[6]. The above cooling forms are mainly only cooling for end winding or stator core. They are not cooling multiple heat sources from inside the motor at the same time, so, the cooling structure is designed by using the methods of the oil passing through the end oil cover[7], the groove wedge and the stator core holes, which is mainly aimed at the end winding, the slot winding and the stator core. In order to achieve better cooling effect, and improve the hub motor power density and torque density[8].

Hub Motor Oil-water Composite Cooling Structure Model

The oil-water compound cooling motor is composed of housing, front end cover, rear end cover, rotor, stator, shaft, etc. Its characteristic is that the rotor shaft of hub motor is hollow shaft with lubricating oil inside. The lubricating oil cools the permanent magnet and rotor core through the hole on the rotor, and the stator core and windings are cooled through the water jacket. The external surface of the stator is water-cooled, and the internal surface of the rotor is oil-cooled to strengthen the heat dissipation of the motor, so as to solve the problem of overheating of the rotor surface and enable the motor to work for a long time with a mass power density up to 1.3kw /Kg. The specific structure is shown in Figure 1 (a). Main design parameters of the motor are shown in Table1.



(a) (b)

Figure 1. Structure drawing of oil-water compound cooling and water-cooling mode of motor

Table 1. Main design parameters of the motor

pole logarithm	6
slot number	72
Rated power (kw)	450
Rated speed (rpm)	3232
Rated line voltage (V)	500
maximum torque (Nm)	2000
air gap length (mm)	10
armature length (mm)	236
Permanent magnet material	YXG30
winding parallel branches number	3
conductor number per slot	6
full slot rate	71%

Motor Simulation Analysis

First, the following assumptions are made before establishing the motor simulation model[9-10]:

1) Due to the superposition of the axial silicon steel sheet of the motor, the thermal conductivity is small, so the axial thermal conductivity of the motor is ignored;

2) Do not consider the heat dissipation of the end winding of the motor;

3) The assembly clearance between the outer surface of the stator and the housing and the clearance between the inner surface of the rotor and the shaft are ignored.

Based on the above assumptions, the complex three-dimensional model inside the motor is simplified into a two-dimensional model for temperature field analysis. In order to ensure the calculation speed of the model, the 1/12 model of the motor is selected for analysis considering the symmetry of the motor, and the model is established as shown in the Figure 2.

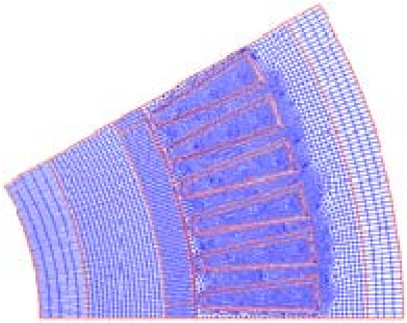
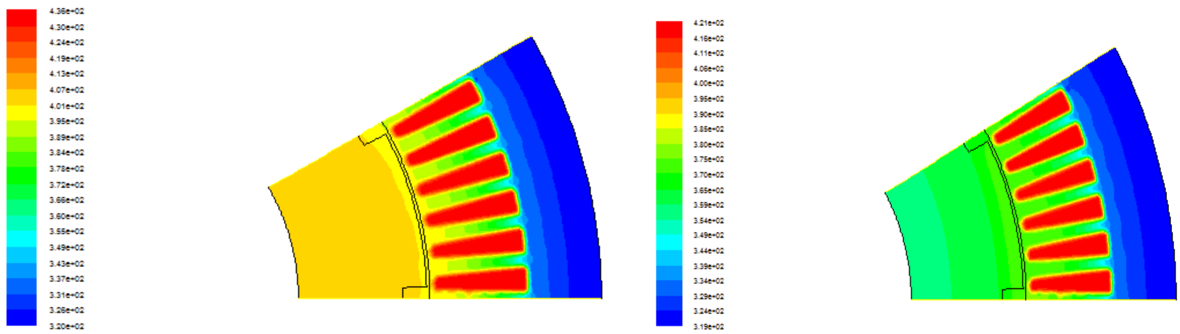


Figure 2. Grid subdivision of the motor

The selection of loss data is based on the empirical data of the motor loss power experiment on the test bench. 25KW and 31KW are selected as the total loss of the motor in two working conditions of rated and peak respectively. At the same time, the condition of oil cooling and water cooling is simulated by setting the boundary condition of the rotor side.

In order to analyze the feasibility of oil-water composite cooling mode of high power density motor, the cooling situation of oil-water composite cooling mode and water-cooling mode was compared and analyzed respectively. ANSYS simulation software is used to analyze and calculate the temperature field distribution of two kinds of motors[11].

Analysis of Rated Operating Conditions Simulation Results

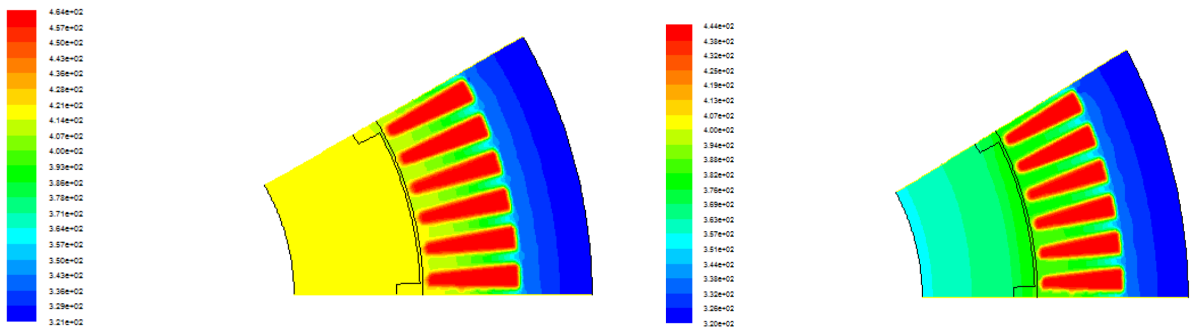


(a) (b)

Figure 3. Simulation results of oil-water combined cooling and water cooling under rated working conditions

Figure 3. (a) is the simulation result of oil-free cooling under rated working conditions, and fig2.2 (b) is the simulation result of oil-water combined cooling under rated working conditions. By comparing the temperature distributions of the two cooling modes in figure 2.2, the following conclusions can be drawn: The highest temperature is in the winding, and the stator yoke has best cooling effect. The rotor temperature can reach 133℃with water cold, and the permanent magnet temperature can reach 127℃. After oil cooling is added to the inner surface of the rotor, most heat of the rotor and permanent magnet is taken away by the oil. The temperature of the rotor and permanent magnet drop to 100℃, which is about 15% lower than only water cooling.

Analysis of Peak Operating Conditions Simulation Results



(a) (b)

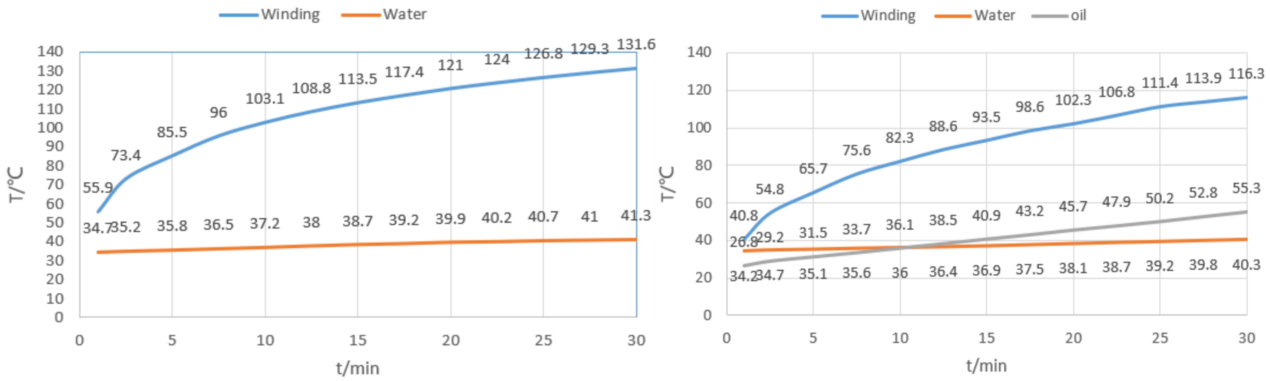
Figure 4. Simulation results of oil-water combined cooling and water cooling under peak working conditions

Figure 4. shows the simulation results of oil-water combined cooling and water cooling under peak conditions, and (a) shows the temperature variation under water cooling, (b) is the temperature variation diagram of oil-water combined cooling mode. Winding and rotor temperature change under peak condition trend the same measurement with the rated conditions., stator and permanent magnet temperature obviously drops when increase oil cooling, but becaus the winding temperature rises to 160℃, so the peak condition motor cannot work for a long time.

Analysis of Motor Test Results

Figure 5. Bench test of motor prototype

32 Great Wall lubricating oil can meet the insulation requirement. Pump flow is $3m^3/h$. The oil outlet temperature sensor is stuck on the oil outlet wall, the oil inlet temperature sensor is on the side of the oil pump, and one temperature sensor is buried in the motor. Bench test is shown in Figure 5.



(a) (b)

Figure 6. Motor temperature curve with 30 minutes

It can be seen from the Figure 6. That: in the case of only water cooling, motor winding temperature can reach to 131.6℃ after working 30 min, and in the case of Oil-water composite cooling, motor winding temperature can reach to 116℃, the winding temperature is dropped by 12%. The rapid rise of oil temperature indicates that the rotor core has a good cooling effect.

Conclusion

The oil-water compound cooling motor structure is proposed and the simulation model is established. The simulation results of two cooling structures under different working conditions are obtained. By comparing the simulation results of motor internal temperature under rated working condition and peak working condition, it is concluded that the temperature of rotor and permanent magnet can be effectively controlled after adding oil cooling, which can solve the problem of too high rotor temperature and rotor demagnetization and improve the power density of motor. This lays a foundation for further eliminating the water cooling device in the transmission system.

References

[1] David A. Staton and Andrea Cavagnino, “Convection Heat Transfer and Flow Calculations Suitable for Electric Machines Thermal Models”, 2008.

[2] F. Márquez-Fernández, A. Reinap, Zhe Huang, M.Alaküla,” Design, optimization and construction of an electric motor for an Electric Rear Wheel Drive Unit application for a Hybrid

Passenger Car", 2010.

[3] Li, Ye, Fan, Tao, Wen, Xuhui, Li, Yong, "Numerical research on hydraulic and thermal performance of the motor water jackets based on the orthogonal experiment" ICEMS 2013, p 860-863, 2013.

[4] Robert Camilleri, "Predicting the Temperature and Flow Distribution in a Direct Oil-Cooled Electrical Machine With Segmented Stator," IES 2016, p82-87.

[5] Pia M. Lindh, Direct Liquid Cooling in Low-Power Electrical Machines: Proof-of-Concept. Hoboken, IEEE transactions on energy conversion, vol. 31, no. 4, 2016.

[6] Wei Wu, Chenhui Hu, Jibin Hu1, Shihua YuanJet, "Cooling for rolling Bearings: Flow visualization and temperature distribution" Applied Thermal Engineering 105 (2016) 217–224.

[7] Ranran Liu, Ping Zheng, Dagang Xie, and Lixin Wang, "Research on the High Power Density Electromagnetic Propeller" IEEE Transactions on Magnetics, 2007.1,Vol. 43, NO. 1, pp355-358.

[8] Q. Li, T. Fan, X. Wen, and P. Ning, "An Analytical Approach to Magnet Eddy-Current Losses for Interior Permanent-Magnet Synchronous Machines During Flux Weakening," IEEE Transactions on Magnetics, vol. 51, no. 8, 2015 , Art. ID 8107109.

[9] C Y Liu, K J Jiang, Y Zhang. Study on temperature rise performance of eddy current retarder in automobile. 2010 International Conference on Future Information Technology and Management Engineering (FITME), 2010(1): 550-553.

[10] C. Jungreuthmayer et al., "A detailed heat and fluid flow analysis of an internal permanent magnet synchronous machine by means of computational fluid dynamics," IEEE Trans. Ind. Electron., vol. 59, no. 12, pp. 4568–4578, Dec. 2012.

[11] "JMAG version 10 -user's manual solver," JSOL Corporation, Tokyo/25-24, Harumi, Chuo-ku, Tokyo, 104-0053, Japan, 2010.