Engine Cooling Device of New Energy Vehicle

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Abstract. With the environmental pollution and the shortage of oil resources becoming more and more serious, the development and application of new energy vehicles have attracted more and more attention. Engine is an important part of new energy vehicles, and its performance has a great impact on the vehicle. Compared with traditional industrial motors, new energy vehicle engines have higher requirements on power density, and the improvement of power density poses new challenges to the design of motor cooling system. The purpose of this paper is to study the engine cooling device of new energy vehicles and improve the overall performance of the vehicle. The main research content of this paper is to lay a foundation for the theoretical basis of the engine cooling device, elaborate the working principle of the motor cooling system and the loss of the motor in operation. Then, the heat dissipation system of permanent magnet synchronous motor based on heat pipe is studied experimentally. Aiming at the problem of only considering the temperature rise and ignoring the pressure loss in the flow channel design, a flow channel design method considering the motor temperature rise and the flow channel pressure loss is proposed, and the motor flow channel is optimized. The test results show that the maximum temperature rise at the end is close to 16.56 ℃, which is in good agreement with the simulation results. It shows that the heat pipe based heat dissipation system can effectively reduce the temperature rise of motor winding, which provides a new idea for the heat dissipation design of permanent magnet synchronous motor

Keywords: New Energy Vehicle, Engine Cooling Device, Motor Temperature Rise, Permanent Magnet Synchronous Motor

1. Introduction
The automobile industry is the pillar industry of China's national economy. At present, China's automobile production and marketing scale has ranked first in the world. In the future, the automobile industry will still maintain a large growth momentum for a long time, and the resulting problems such as the shortage of oil resources and environmental pollution can not be completely solved for a long time [1-2]. Under such circumstances, new energy vehicles have attracted extensive attention of various automobile manufacturers [3-4]. The motor, that is, the engine is the central part of the car, and its quality directly affects the performance of the car [5-6].
Many scholars at home and abroad have their own research on the heat dissipation device of automobile engine [7-8]. For example, Yan J established the 3D CFD simulation model of Li ion battery pack and permanent magnet synchronous motor of solar car by using computational fluid dynamics method and software, and analyzed the temperature field change of Li ion battery pack and permanent magnet synchronous motor by flow and heat transfer coupling simulation [9]; in 2015, Jiang, Zhang, Zhao, Et al and other scholars conducted three-dimensional simulation research on the gas in the engine compartment of a car, and concluded that adding a wind shield around the cooling module can effectively improve the heat dissipation of the engine [10].

Aiming at the problem of high temperature rise of permanent magnet synchronous motor, this paper analyzes the characteristics of internal heat transfer of traditional motor, innovatively combines heat pipe technology with motor, and puts forward the design scheme of motor cooling system of new energy vehicle based on heat pipe. The key parts of the new scheme, such as the arrangement of heat pipe, the connection between heat pipe and motor, and the parameters of water cooling channel, are designed and optimized. The main work includes the analysis of various losses existing in the operation process of the motor, the study of the influence of different heat pipe layout on the performance of the cooling system, the verification of the feasibility of the motor cooling system scheme based on heat pipe, and the new ideas for the motor cooling design [11-12].

2. Theoretical Basis of Engine Radiator

2.1 Overview of Motor Cooling System

The cooling principle of the engine is that the cooling water is pressurized in the water pump and enters the water-cooled shell of the generator. The cooling water flows through and absorbs the heat generated by the motor, and then enters the thermostat. The thermostat can adjust the heat dissipation capacity of the cooling system by controlling the flow rate to ensure that the drive motor works normally at the appropriate temperature. Finally, the cooling water flowing through the radiator will cool the air to the surrounding air, and the cooled water will return to the water pump, so a cycle.

2.2 Motor Loss Calculation

2.2.1 Copper Consumption of Winding.

The copper consumption of winding is calculated according to Joule Law: the copper consumption of winding is equal to the square of the current in the winding multiplied by the resistance value of the current, and can be expressed as follows:

\[ P_{Cu} = m l^2 R_l \]  

(1)

In (1), M is the number of phases of winding, h is the effective value of winding phase current, R_L is the effective value of the phase resistance.

For permanent magnet synchronous motor, in the process of operation, due to the generation of various losses, the motor temperature will inevitably rise. For high-power motors, the copper consumption is often large, the temperature of the winding is high, and the resistance of the stator winding changes greatly with the temperature. The variation of winding resistance with temperature can be expressed as follows:

\[ R = R_0 [1 + \alpha_0 (\theta - \theta_0)] \]  

(2)

Where, \( \theta_0 \) is the starting temperature, 25 °C in this paper, \( \theta \) is the temperature coefficient of resistance, R is the resistance value of winding at \( \theta \) temperature. And \( R_0 \) is calculated as follows:

\[ R_0 = \rho \frac{2LN}{\pi a [N \sqrt{(2j)}]^2} \]  

(3)

During the operation of the motor, the copper consumption will increase with the increase of the motor temperature, but it will gradually become stable. In this paper, the finite element method is used
to calculate the temperature field of the motor, so UDF is compiled to update the value of copper consumption when the winding is loaded with copper consumption heat source, so as to compensate the increase of copper consumption with the increase of temperature and achieve a better calculation effect. The code written in this paper can read the results of the previous iteration in each iteration, extract the temperature value calculated in the previous iteration, and recalculate the heating power into the next iteration, and this process is independent for each grid of the winding, which can restore the copper consumption value of the winding to the greatest extent.

2.2.2 Basic Iron Consumption. Iron loss refers to the power loss on the core. The basic iron loss of permanent magnet synchronous motor usually consists of two parts, one is the hysteresis loss of magnetic materials, the other is the eddy current loss in the core.

2.2.3 Mechanical Loss. The mechanical loss is related to the friction loss of the bearing and the wind friction loss of the rotor surface. Among them, the brush friction loss only appears in the brush permanent magnet synchronous DC motor, while the research object of this paper is water-cooled brushless permanent magnet synchronous motor, there is no such loss. Therefore, the mechanical loss part mainly investigates the wind friction loss on the rotor surface and the friction loss of the bearing.

1) Friction Loss of Bearings
   The bearings used in this motor are deep groove ball bearings 6313 and 6312. For the friction loss of rolling bearing (unit: W), the following formula is used for approximate calculation:
   \[ p_f = 0.15 \frac{F}{d} v \times 10^{-5} \]  
   \( (4) \)

2) Wind friction loss on rotor surface
   When the motor is running at high speed, the roughness of the rotor surface will cause wind friction loss.

2.2.4 Stray Loss. The loss of the high harmonic in the core caused by the high harmonic and the slotting of the core is called stray loss. Generally, it is selected according to its specific situation and practical experience, and there is no accurate calculation formula. With the increase of motor load, the output current of motor also increases, and the stray loss is approximately proportional to the square of output current.

2.2.5 Determination of Heat Source in Motor. The rated speed of PMSM is 955r/min and the speed is low. Therefore, the friction loss of bearing and the wind friction loss on the rotor surface are very small, so it can be ignored in the subsequent finite element analysis and calculation. Because stray loss is the loss in the core, it is loaded into the stator core as a part of the iron consumption in the finite element calculation. In this paper, the loss of rotor core and magnetic steel is not involved in the discussion of loss, which is because in PMSM, this part of loss is very small and can be ignored.

3. Design and Experiment of PMSM Heat Dissipation System Based on Heat Pipe
Through the simulation of ANSYS software, it is found that the heat dissipation effect of the heat pipe cooling system based on the tail bending heat pipe is better, the maximum temperature rise of the winding is reduced by 15.8 °C, and the heat dissipation effect of the straight heat pipe cooling system based on the tail is slightly worse, only the temperature rise of the winding is reduced by 13.2 °C. Therefore, this section is based on the heat pipe heat dissipation of permanent magnet synchronous motor temperature rise experiment.

3.1 Thermal Conductivity Measurement Test
The formula of steady-state method is simple and the measurement time is long, so it is necessary to measure the heat conductivity and the temperature of some points on the sample to be tested. The research object of this paper is the temperature rise of the motor under rated working conditions. It
does not need to measure the volume heat capacity and thermal diffusivity of the iron core and winding, so the steady-state method is used to measure, and the protective hot plate method is used to measure the thermal conductivity of the iron core and winding.

3.1.1 Measurement of Axial Thermal Conductivity of Motor Stator and Rotor Core

1) Construction of measurement platform
   A water cooling plate is placed on the upper side of the sample to be tested, and a main heating plate and a protective heating plate are arranged below the sample to be tested. As an auxiliary heat source, the protective heating plate provides temperature compensation to make the temperature of the upper and lower surfaces of the main heat source consistent, so that the heat flow in the whole device is one-way heat flow and the measurement accuracy is improved. The insulation layer of the whole base is made of bakelite, and an aluminum hollow bracket is made on the outside to support the base and leave the lower part empty. The inner and outer surfaces of the samples are covered with multi-layer insulation cotton.

2) Measurement steps
   a. Install the sample to be tested on the test bench and install the insulation layer; B. adjust the input voltage through the resolver to control the heating power P of heating rod 1 on the main heating plate; C. After the temperature collected by each thermocouple is stable, calculate the average temperature T1 and T2 collected by thermocouple A and thermocouple B respectively; if T1 < T2, increase the input voltage of heating rod 2; if T1 < T2, increase the input voltage of heating rod 2; if T1 < T2, increase the input voltage of heating rod 2 if T1 > T2, reduce the input voltage of heating rod 2 until T1 and T2 are less than 1%; D. calculate and record the average temperature value T2 collected by thermocouple B and the average temperature value T3 collected by thermocouple C; e. calculate the axial thermal resistance R1 and contact thermal resistance R of silicon steel sheet_ The axial thermal resistance R of silicon steel sheet is obtained by changing the sample and repeating the operation of A-D_ 2 and contact thermal resistance R_ Replace the sample again and repeat the operation of A-D to obtain the axial thermal resistance R of silicon steel sheet_ 2 and contact thermal resistance R_ The axial thermal resistances R1, R2, R3 and contact thermal resistances r of each silicon steel sheet obtained by E-G were compared_ 01, R_02, R_ The final silicon steel sheet axial thermal resistance R and contact thermal resistance R are obtained by calculating the average value_ 0; I. using the single-chip axial thermal resistance R and contact thermal resistance R of silicon steel sheet_ The axial thermal conductivity λ of the stator core is calculated according to the number of laminations and the total thickness l of the stator core.

3) Measurement data processing
   Both stator core and rotor core are made of laminated silicon steel sheet. If the silicon steel sheet and its surface insulation coating are regarded as a whole, the axial thermal resistance of the iron core made of laminated silicon steel sheet is mainly composed of two parts, one is the axial thermal resistance R of the silicon steel sheet itself, and the other is the contact thermal resistance produced when the silicon steel sheet is laminated the measured thermal resistance is also the result of the combined effect of these two parts. Due to the large axial thermal resistance of the iron core, if the thickness of the iron core is too large, the temperature difference between the cold end and the hot end will be too large, and the temperature of the hot end will be too high, which requires high temperature resistance of the thermal insulation material, which is not conducive to the construction of the measurement platform. Therefore, the sample to be tested is made of a small number of silicon steel sheets.

   The silicon steel sheet material used in this paper is 50sw470 with a thickness of 0.5mm. From the point of view of test cost control, in order to avoid reopening the laminating die, the sample is directly made of md15 stator lamination. The relevant parameters of the sample are shown in Table 1
Table 1. Core sample parameter table

| Sample number | Total thickness of sample /mm | Quantity of silicon steel sheet | Coefficient of overpressure |
|---------------|-----------------------------|---------------------------------|-----------------------------|
| 1             | 11.198                      | 10                              | 0.98                        |
| 2             | 18.924                      | 30                              | 0.98                        |
| 3             | 31.078                      | 50                              | 0.98                        |

The thermal conductivity of each sample under different test power is shown in Table 2.

Table 2. Thermal conductivity of samples under different test power

| Sample number | Measuring power (w) | Thermal conductivity (W·m⁻¹) |
|---------------|---------------------|-------------------------------|
| 1             | 50                  | 4.587                         |
|               | 80                  | 4.556                         |
|               | 100                 | 4.538                         |
| 2             | 50                  | 4.527                         |
|               | 80                  | 4.498                         |
|               | 100                 | 4.452                         |
| 3             | 50                  | 4.495                         |
|               | 80                  | 4.458                         |
|               | 100                 | 4.437                         |

3.1.2 Measurement of Thermal Conductivity of Motor Stator Winding

1) Measuring platform and method

The basic structure of the platform for measuring the radial thermal conductivity of stator winding and the arrangement of its thermocouples are similar to the platform for measuring the axial thermal conductivity of stator core mentioned above. Three K-type thermocouples are respectively distributed on the upper surface of the sample, the lower surface of the sample and the lower surface of the main heating plate. The measurement method of thermal conductivity is basically the same, but it should be noted that when measuring the thermal conductivity of the winding, the actual heating power is 10W, 20W, 30W, which is the poor thermal conductivity of the coil radial. Too high power will cause too high temperature at the heating end and damage the external bakelite insulation.

2) Treatment of winding samples

No matter it is between slot winding or end winding, the distribution of conductor in its main direction is random and disordered, so it is impossible to establish an accurate model to describe the winding, and the radial thermal conductivity of winding can only be measured approximately by test.

3) Processing of measurement results

Because there is no regular distribution of the conductors along the radial direction in the windings between slots, the average thermal conductivity of the windings along the radial direction is measured under the condition of a certain slot full rate. In order to prevent the inaccurate measurement results caused by uneven distribution of wires, internal bending, wire dropping and leakage in the process of painting, three samples with the same size and 75% tank full rate were made.

3.2 Motor Temperature Rise Test

3.2.1 Temperature Rise Test Platform. The measurement platform consists of motor characteristic test bed, motor to be tested, USB temperature acquisition card, K-type thermocouple and notebook computer. In this paper, the motor characteristic test bench is used to provide rated load for the motor to be tested, so that the motor can work under rated conditions after being powered on. The temperature of the motor winding is collected by K-type thermocouple. Two temperature measuring points are set on the outermost side of the front end winding and the rear end winding respectively.
The two temperature measuring points of the front end winding are named as temperature measuring point 1 and temperature measuring point 2, and the temperature measuring points of the rear end winding are named as temperature measuring point 3 and temperature measuring point 4. The signal collected by the thermocouple is input into the computer through the USB temperature acquisition card, and the real-time measured temperature is displayed through the software and the test data is recorded.

4. Analysis of Experimental Results

4.1 Measurement Results of Axial Thermal Conductivity of Motor Stator and Rotor Cores

According to every two groups of measurement results, a group of calculated axial thermal resistance $R$ and contact thermal resistance $R_0$ of silicon steel sheet can be obtained. Three groups of different thermal resistance values can be obtained by combining three groups of test data in pairs. The final thermal resistance results are their average values: the calculation results are shown in Table 3.

Table 3. Calculated value of thermal resistance

| Sample number | Material axial thermal resistance R (K/W) | Contact thermal resistance $R_0$ (K/W) |
|---------------|-----------------------------------------|---------------------------------------|
| 1             | 0.002548096                             | 0.007856432                           |
| 2             | 0.002896753                             | 0.007387667                           |
| 3             | 0.003809786                             | 0.005783789                           |
| average value | 0.003247854                             | 0.006387893                           |

The axial average thermal resistance $R$ and contact thermal resistance $R_0$ of the material in Figure 1 are compared into the formula, the axial thermal conductivity of iron core is calculated to be $\lambda = 4.430$ W/(m·K).

![Figure 1. Calculated value of thermal resistance](image)
4.2 Measurement Results of Thermal Conductivity of Motor Stator Winding

According to the thermal conductivity calculation formula of the sample, the measurement results are shown in Table 4.

Table 4. Measurement table of thermal conductivity of winding

| Serial number | Power (W) | Thermal conductivity of winding (W··) |
|---------------|-----------|-------------------------------------|
| 1             | 10        | 1.6578                              |
|               | 20        | 1.5956                              |
|               | 30        | 1.5462                              |
| 2             | 10        | 1.6023                              |
|               | 20        | 1.5765                              |
|               | 30        | 1.5298                              |
| 3             | 10        | 1.6276                              |
|               | 20        | 1.5894                              |
|               | 30        | 1.5267                              |

Figure 2. Measurement diagram of thermal conductivity of winding

As shown in Figure 2, the thermal conductivity of the three samples is calculated. After taking the average value, the average value of the radial thermal conductivity of the winding sample is 1.5835.

4.3 Analysis of Temperature Rise Test Results

After finishing, the test results and simulation results of the original motor and the motor based on the tail bending heat pipe heat pipe cooling system are summarized respectively. Although the temperature measurement point 1 and the temperature measurement point 2 are located at the front end winding at the same time, the temperature measurement point 3 and the temperature measuring point 4 are located at the end winding at the back end, but their measurement values are different. Especially, the difference between the temperature measurement point 3 and the temperature measuring point 4 of the end winding at the back end is about 6.5 °C. According to the measurement results, the temperature rise of the front end winding has reached nearly 16.56 °C, and the temperature rise of the end winding at the back end is also reduced by 8-9 °C. That is, the heat of the end winding is successfully derived through the heat pipe or sealing glue by the design of the heat dissipation system based on the heat pipe, which effectively reduces the temperature rise of the end winding and improves the insulation life of the winding.
5. Conclusion
This paper has made some achievements in the analysis of temperature field and heat dissipation transformation of PMSM, but due to the limited time and energy, there are still some shortcomings. The following aspects are expected for the follow-up work. Aiming at the characteristics of heat dissipation from the end cover of the heat pipe based heat dissipation system, the water cooling channel is optimized and designed more appropriately. The integral scheme of the end winding is reformulated to make the angle between the outer surface and the end face of the core closer to 90°, so that the heat pipe and the end winding are more closely connected. Furthermore, the angle between the outer surface of the winding and the end face of the core is further explored to disperse the motor influence of heat; fill as many independent heat pipes as possible in the cavities formed by the end winding, the casing and stator. These heat pipes only exist in the cavity, which is equal to the phase change to improve the heat conduction capacity of the sealing adhesive, and study the influence of the heat pipe arrangement on the heat dissipation of the motor.

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