DESIGN AND ELECTROMAGNETIC THERMAL ANALYSIS OF ELECTRIC VEHICLE HUB MOTOR BASED ON FINITE ELEMENT SIMULATION MODEL

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Abstract - In order to study the design and electromagnetic heat of electric vehicle hub motor based on finite element simulation model, the electric vehicle hub motor is designed by using finite element method, and the simulation model based on finite element method is established. The maximum speed of electric vehicle, the number of poles and the temperature field are collected and analyzed to verify the operation effect of the simulation model. The results show that from the data of the start-up process, about 40ms, the speed is accelerated rapidly and it is in the exponential rising stage. Until 150ms, the speed starts to reach a stable state, and its speed reaches about 189rmp. From the point of view of the pair pole number, the power factor of the motor decreases linearly with the increase of the pair pole number; from the point of view of the temperature field, when the height of the stator yoke remains unchanged, the temperature at the highest temperature reaches stability between 25 and 30 minutes, and its stable temperature reaches 156°C. When the height of the stator yoke increases by 20mm and 30mm, the temperature curve at the highest temperature almost coincides and the stable temperature of them is 123°C. Based on the finite element simulation model, the simulation model of electric vehicle hub motor is designed. Through the verification, it basically meets the expectation, and its optimization effect runs well and meets the expectation. Although there are still some shortcomings in the research process, it can also contribute to the development of the automotive industry, and has a certain reference and guidance role for future research, which is a research subject closely following the direction of development.

Keywords: Finite Element Method, Stator Yoke Height, Hub, Pair Pole Number.

1. Introduction

Along with the rapid development of science and technology, people's living standards are constantly improving, and there are more choices for travel modes. However, with the continuous development of industrial science and technology, the use of energy is attracting more and more attention, and various new energy sources are constantly being explored. The rapid development of modern industrial technology has brought people rich material resources and fast and convenient transportation. At the same time, a series of environmental and livelihood problems have been found, including air pollution, three-waste emissions, rising oil prices and traffic congestion, etc., which are all threatening people's health.

With people's increasing awareness of health requirements, based on people's travel needs, new energy vehicles have become the trend of development in the future under the increasingly prominent environmental conditions such as the earth's energy crisis [1] (as shown in Figure 1) and haze.

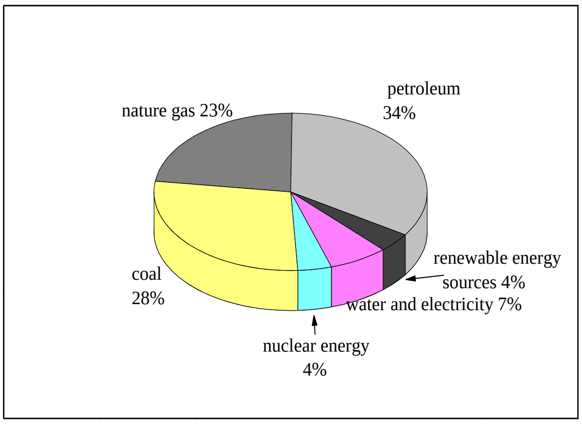

Figure 1: World primary energy consumption map in 2017

In recent years, although the use of non-renewable energy such as oil, coal and natural gas has met people's living needs, it will not be able to solve the problems of low energy utilization, serious air pollution (such as haze) and excessive emission of three wastes in the next few years [2].

Therefore, in order to cope with the energy crisis and environmental pollution, the development speed of traditional automobile industry will be constrained by the shortage of energy, and the use of new energy cannot be achieved. Therefore, the development of electric vehicles will have a better future than the traditional automobile industry, and it is also an effective measure to solve the impact of the energy crisis on it, and fully meet the slogan of "low carbon, green and environmental protection" advocated by people. In the 13th Five-Year Plan of China, it has been listed as one of the key areas of concern of "Made in China 2025" because of its advantages, and has great potential for development [3].

The drive of electric vehicle is divided into centralized motor drive and distributed multi-motor drive. But in order to make the drive have the characteristics of large starting torque, wide speed range, small size, light weight, high efficiency, convenient maintenance, low price, dynamic braking and energy feedback, distributed drive has more advantages, and can also realize the independent control of single wheel of the vehicle and finally achieve ESP, ABS, EBD and other vehicle dynamics control technology [4].

As one of the most critical parts of electric vehicle, the quality of hub motor directly determines the safety performance of electric vehicle, but in order to make it have more advantages, it is supposed to start from the actual situation and consider the different driving conditions such as start-up, up-and-down, acceleration and deceleration in actual driving, so as to achieve a significant increase in energy utilization.

In summary, the application of improved motor drive technology in electric vehicles not only meets the call of global energy saving and emission reduction and resolves the constraints of energy crisis on its development, but also makes greater contributions to environmental protection, breaks the traditional thinking of vehicle drive, and promotes further improvement of vehicle performance.

By using the finite element simulation model, the simulation model of electric vehicle hub motor drive is designed, and data are collected from three aspects of motor speed, pole number and temperature field to validate the system model.

2. Literature Review

With the increasing urgency of energy crisis and various advantages of motor drive, the electric drive mode of wheel hub is called the ultimate drive mode in the industry. In recent years, a series of related studies have been carried out at home and abroad. Conggan Ma et al. proposed a new black-and-white box detection method for the abnormal noise of wheel hub permanent magnet synchronous motors (HPMSMs) in 2016. The white-box method is used to validate the electromagnetic field model, structural vibration model and acoustic calculation model of HPMSM, and a noise reduction method is proposed. The results show that the proposed method significantly improves the efficiency of diagnosis and optimization of abnormal noise of high-speed permanent magnet synchronous motor [5]. In 2017, Qiping Chen et al. studied the theory of electromagnetic field and the working principle of motor, designed the internal and external rotor motor of mini electric vehicle, and analyzed the model.

Using Ansoft Maxwell software, they also established the finite element model of the external rotor of the wheel motor, and subdivided the finite element mesh. They analyzed magnetic flux density, magnetic field intensity and magnetic line by dynamic simulation and studied and analyzed the starting characteristics and the variation of the torque curve of the motor. The results showed that the simulation results were in good agreement with the design results, which showed that the design scheme of the outer rotor in-wheel motor was effective and could meet the performance requirements of the outer rotor in-wheel motor of mini electric vehicle [6]; J. Jency Joseph et al. proposed a compact flat permanent magnet brushless DC motor in 2018, established the finite element method and Matlab/Simulink model, and analysed their performances. A 2.75kW motor was designed by using Ansys Maxwell software.

The parameters such as armature resistance, armature inductance, stator weight, rotor weight and motor density were extracted. By changing the motor parameters, damping parameters and load, the torque and speed characteristics of the motor were analyzed.

The results showed that the design results were in good agreement with the analysis results [7]. Zhe Li and Ling Zhengz proposed a multi-objective optimization method for active suspension system in

2019 to solve these problems by developing an integrated wheeled electric vehicle model.

The unbalanced electromagnetic excitation of in-wheel drive motor was studied by analytic method and finite element method. The Pareto solution set of the optimal parameters was generated by multi-objective particle swarm optimization method, and the effectiveness of the method was verified by comparing the dynamic performance of vehicles.

The results showed that the optimized active suspension system reduced the sensitivity of vehicle system to electromagnetic excitation, and achieved a good balance between ride comfort and stability of vehicle and the utilization of active suspension [8].

From the above research, it is seen that scholars are constantly exploring the hub drive of electric vehicle to make its performance more optimized. Based on this purpose, the motor is designed here in order to achieve better safety performance and provide some guidance for the future development of hub drive.

3. Method

3.1. Finite element method

The finite element method is a numerical method based on variational principle or weighted residual method, which discretizes the whole solution domain into a series of small elements (triangle, quadrilateral, etc.) and then establishes interpolation functions in each cell as approximate trial functions to solve the boundary value problems of differential equations [9]. Based on Maxwell's equations, the finite element method is used to calculate the electromagnetic field. Firstly, the treated objects are divided into finite elements (including nodes). Then, according to the vector magnetic potential or scalar potential, the electromagnetic potential or potential at each node under certain boundary conditions and initial conditions are solved, and then other related quantities, such as current density, flux density and energy, can be derived from these degrees of freedom [10]. In Maxwell's equations, the relationship between the field is as follows [11]:

$$D = \varepsilon E \tag{1}$$

$$B_r = \mu H \tag{2}$$

$$J = \sigma E \tag{3}$$

D is the displacement vector (C/m^2), E is the electric field intensity (V/m), B_r is the magnetic induction intensity (T), H is the magnetic field intensity (A/m), J is the current density (A/m^2), ε is dielectric coefficient (capacitance), μ is permeability and σ is conductivity.

3.2. Structural design of electric vehicle hub motor

The main dimensions of permanent magnet brushless direct current (DC) motor are the diameter of stator core (air gap) and the length of stator core.

There are three main methods to determine the main dimensions: stator split ratio method, electromagnetic load determination method and viscous damping coefficient method [12].

The stator split ratio method can also determine the yoke height and groove height of stator core, but the length of stator core cannot be determined.

When the stator slot area decreases, the stator inner diameter must be reduced in order to keep the copper loss unchanged. By reducing the optimal stator split ratio, the copper loss index corresponding to the slot area can be achieved. The diameter of stator core (air gap) and the length of stator core are the main factors affecting the electromagnetic torque and the main size of the motor. The performance of the motor can be improved by using better magnetic material and designing reasonable magnetic circuit to increase air gap flux density, and increasing the use of core material and copper material (slot area) as much as possible. The thermal parameters of hub motor materials are shown in Table 1.

Table 1: Thermal parameter table of hub motor material

Material	Thermal conductivity (W/(m*°C)	Density (Kg/m^3)	Specific heat capacity (J/(Kg*°C)
Copper conductor	383	8958	383.5
Silicon steel sheets	40	7710	425
Permanent magnet	9	7511	419

According to the performance indicators of hub motor, the overall size of the motor is smaller, the quality is lighter, it needs to provide high torque and low speed, and the torque fluctuation is smaller.

Therefore, the multi-stage external rotor surface mounted magnetic circuit structure is the most suitable. The material of permanent magnet is NdFeB.

3.3. Construction of simulation model based on finite element method

In the finite element analysis of hub motor, according to the key parameters of hub motor, reasonable size is designed for analysis, and the heat loss in the motor needs to be analyzed and studied first. The design model is shown in Figure 2.

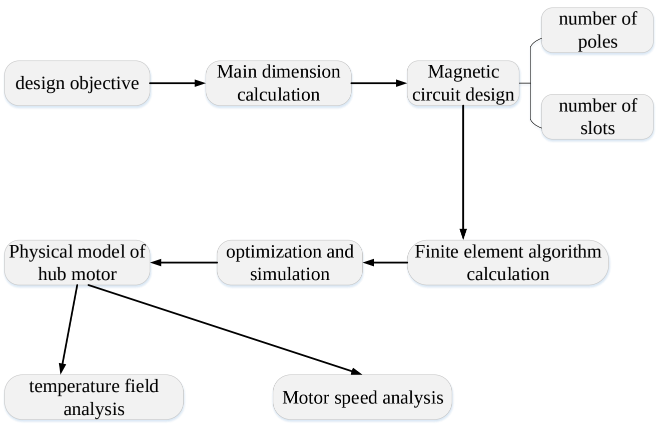

Figure 2: Hub motor and electromagnetic design process

The operating condition of electric vehicle drive motor is more complex. The simulation model based on finite element method is designed, and data are collected from three aspects of motor speed, pole number and temperature field to validate the system model.

4. Results and discussion

As shown in Figure 3, the speed curve of hub motor during starting process is considered. From the figure, it is seen that in the simulation model designed, the speed of hub motor is relatively slow at the beginning of 0-38ms operation, which belongs to the start-up stage, and the speed fluctuation is relatively large. Until about 40ms, the speed of hub motor speeds up rapidly and is in the exponential rising stage. This time has not lasted for a long time.

At about 48ms, the speed increase rate begins to slow down gradually until 150ms. The rotational speed starts to reach a steady state with the speed of about 189rmp. Therefore, in the stable operation process of hub motor, the electromagnetic torque is large at the initial starting time and has a small fluctuation range, then gradually reduces and finally reaches a stable fluctuation range, which meets the requirements of large starting torque.

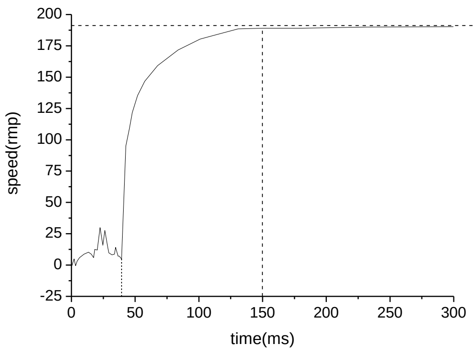

Figure 3: Speed curve during motor start-up

As shown in Figure 4, the power factor of the motor varies with the series logarithm. It can be seen from the figure that the maximum power factor of the motor with different pole logarithms is different when it achieves a stable speed of 189rmp. With the increase of the pair pole number, the power factor of the motor decreases linearly. Therefore, in order to ensure that the motor has better efficiency characteristics, the power factor of the motor cannot be chosen too low. Considering the error of equivalent calculation of magnetic circuit, the power factor of the rated point of peak torque should be above 0.85.

Therefore, 9 pairs of poles are selected for motor simulation model design and operation, and the effect is good.

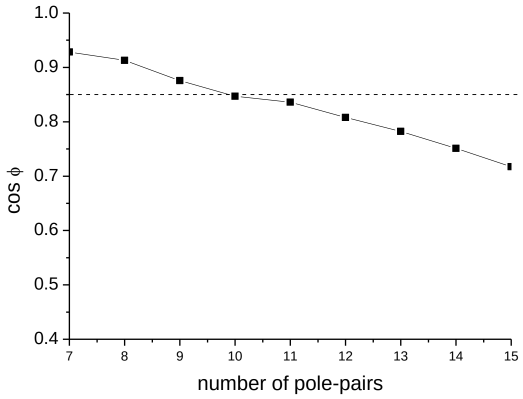

Figure 4: Curve of power factor varying with pole logarithm

Figure 5 shows the temperature rise at the highest temperature of high hub motors with different stator yokes. It can be seen from the figure that when the height of the stator yoke remains unchanged, the temperature at the highest temperature reaches stability between 25 and 30 minutes, and its stable temperature reaches 156°C.

Before 25 minutes, its temperature is in the exponential rising stage, and its temperature change law is first rapid and then slow, showing a parabolic trend. The temperature curves at the highest temperature of 20mm and 30mm increase of stator yoke height almost coincide.

The time of reaching stable temperature is between 20 and 25 minutes, which is slightly ahead of the time of reaching stable temperature before the increase of stator yoke height. The stable temperature of both are about 123°C, which is lower than that before the increase of stator yoke height, and the temperature change rule before reaching stable temperature is first urgent and then slow, showing a parabolic trend of change.

When the height of stator yoke increases to a certain value, it will reach a saturation of heat dissipation. Before the saturation of heat dissipation is reached, increasing the height of stator yoke appropriately will have obvious cooling effect.

But when the height of stator yoke increases to a certain extent, it will not further improve the cooling effect, but will increase the cost of motor manufacture and affect the performance-price ratio of motor.

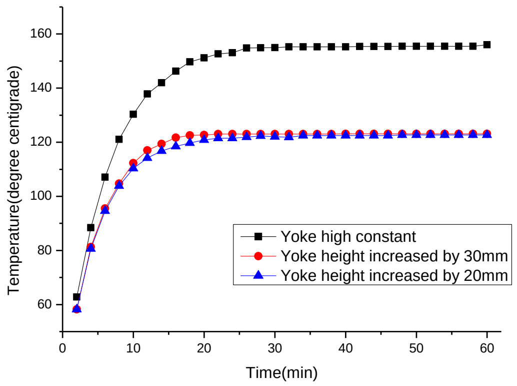

Figure 5: Temperature rise variation at the maximum temperature of high hub motor with different stator yokes

5. Conclusion

Based on the finite element simulation model, the electric vehicle hub motor is designed, and the simulation model based on the finite element method is established. By analyzing the structure and driving principle of electric vehicle, the mechanical drive layout and the transmission-less drive layout are compared.

The maximum speed, pole number and temperature field of the electric vehicle are analyzed to verify the operation effect of the simulation model.

Through the statistical analysis of the data obtained, it can be concluded that the fluctuation of speed gradually decreases during the start-up process and finally reaches a stable fluctuation range, which meets the requirement of large start-up torque. From the point of view of pair pole number, the power factor of the motor decreases linearly with the increase of pair pole number. Therefore, in order to ensure that the motor has better efficiency characteristics, the power factor of the motor cannot be chosen too low, so the design and operation effect of the motor simulation model based on the selected poles is in line with expectations; from the point of view of temperature field, when the height of the stator yoke is unchanged, its stable temperature reaches 156°C, the law of temperature change is first rapid and then slow, showing a parabolic trend; when the stator yoke height increases by 20mm and the maximum temperature increases by 30mm, the temperature curves almost coincide, and the stable temperatures of both are about 123°C.

In summary, the simulation model of electric vehicle hub motor based on finite element simulation model is designed, and it is basically in line with expectations after validation, and its optimization effect is good. It is hoped that this study can provide reference and guidance for the development of automotive industry, but there are still some shortcomings. For example, the temperature field of hub motors with different stator yoke heights is simulated and analyzed, but the sample data with high stator yoke are less, so it is impossible to accurately calculate the stator yoke heights when the heat dissipation saturation is reached. Therefore, it is necessary to add high sample data of stator yoke for further analysis and research.

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