Research on Heat Dissipation of Electric Vehicle Based on Safety Architecture Optimization

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Abstract. In order to solve the problem of excessive temperature in the discharge process of lithium-ion battery and the temperature difference between batteries, a heat dissipation of electric vehicle based on safety architecture optimization is designed. The simulation is used to optimize the temperature field of the heat dissipation of the battery. A reasonable heat dissipation control scheme is formulated to achieve heat dissipation requirements. The results show that the ideal working temperature range of the lithium ion battery is 20°C~45°C, and the temperature difference between the batteries should be controlled within 5°C. A cooling fan is arranged at the original air outlet of the battery model, and the two cooling fans work in turn to realize the reciprocating flow. The temperature difference is controlled within 5°C to ensure the good temperature uniformity between the batteries of the electric vehicle. Based on the above finding, it is concluded that the heat dissipation design for electric vehicle batteries is safe and effective, which is the most effective methods to ensure battery life and vehicle safety.

1. Introduction
The electric vehicle powered by lithium-ion battery has become a hot spot in the international competition. The research and development of the heat dissipation scheme of the battery is very important for the safe and reliable operation of the electric vehicle. Compared with traditional fuel vehicles, lithium-ion battery electric vehicles have the advantages of no vibration, no noise and no pollution. Its development prospect is broad, and has become one of the important development directions of automobile industry in the future. However, lithium ion batteries generate a large amount of heat when they are used, resulting in an increase in the temperature of the battery and an uneven temperature inside the battery. This will affect not only the performance of the battery, but also the life of the battery and the safety of the battery [1]. Therefore, the thermal performance analysis and scientific heat dissipation management of lithium-ion batteries are the most effective methods to ensure battery life and vehicle safety. It can not only ensure the whole temperature of the battery in the ideal temperature range, but also ensure the temperature difference between each battery monomer is within the acceptable range. At the same time, the new technology can keep the performance of the power battery in the optimum state [2].
2. Literature review
In order to make the battery work within the optimum temperature range, scholars at home and abroad have carried out related research work. Yang Naixing and others designed the cylindrical structure lithium battery to improve the heat radiation performance. YAMADA uses paraffin as a phase change material and develops a hybrid cooling system for pipe thermal anomalies and thermal runaway. Firstly, ANSYS thermal analysis software is used to simulate the heat generating temperature field of the cell under natural convection. The accuracy of the model is verified by single charge discharge experiments, and the whole model of the battery pack is built [3]. The CFD simulation software is used to simulate the temperature field of the battery under forced air cooling condition, and the temperature distribution of the battery is observed and measured. The heat dissipation effect is analyzed, thus changing the heat dissipation mode and optimizing the temperature field of the battery [4]. Realizing the effective heat dissipation of the battery can ensure the good performance and sufficient service life of the power battery, and has a milestone significance for the safe driving of the electric vehicle.

3. Methods

3.1. Structure and working principle of lithium-ion battery
The internal structure of the lithium ion battery is shown in figure 1. When the battery is charged, the lithium in the cathode material falls off and passes through the membrane into the negative graphite. When the battery is discharged, the lithium ion is removed from the negative graphite and passed through the diaphragm back into the positive material. The charged lithium ions are constantly inserted and removed from the anode and cathode. This phenomenon is called "rocking chair battery" [5].

3.2. Analysis of batteries temperature characteristics
According to the principle of battery reaction, from the electrochemical point of view, it can be seen that the heat of the battery comes from four parts, respectively: electrochemical reaction heat $Q_r$, Joule heat $Q_j$, polarization reaction heat $Q_p$ and deputy reaction heat $Q_s$. According to the basic principle of internal structure and heat transfer of lithium ion battery, it is known that the heat produced by the reaction of the battery in the battery is heat transfer. And the heat eventually reaches the surface of the battery. There is a temperature difference between the surface temperature of the battery and the ambient temperature. A high temperature object transfers heat to a lower temperature object, so that the surface of the cell is convection heated with the outside. Objects with high temperature can generate electromagnetic waves around them, so the radiation heat transfer is also carried out on the surface of the battery [6].

![Internal structure of battery](image-url)
The temperature has a great influence on the performance of the battery. Analysis of the temperature characteristics of the battery is mainly to study the effect of temperature on the battery capacity, internal resistance, life, as well as charging and discharging performance [7]. The thermal effect of lithium ion monomer is experimentally investigated, and the thermal characteristics of the battery are further understood, which provides a specific experimental verification process for the subsequent battery simulation.

3.3. Three-dimensional thermal model of lithium-ion battery
IFR26650 cylindrical lithium iron phosphate battery is selected. Its size is: 26 mm diameter, 65 mm high, 0.25 mm battery shell thickness. The thermal physical parameters such as specific heat, thermal conductivity and density of the battery are calculated according to the parameters of each material in the battery. A three-dimensional thermal model of lithium-ion battery was established by using ANSYS thermal analysis software. When the model is heated, the loads, the natural convection boundary condition and the initial temperature $25^\circ C$ are generated. The natural convection heat transfer coefficient is 5W/m2K. The solution method is set to transient analysis, and the simulation time and time step are defined. Under the natural convection environment, the temperature rise of the battery is obtained by the discharge of 1C, 2C, 3C and 4C, and the simulation is carried out at last.

3.4. Simulation and analysis of temperature field of battery pack CFD
The basic definition of computational fluid dynamics (CFD) is: Based on fluid dynamics, it uses the three conservation laws of mass, energy and momentum as the basic governing equations to simulate the flow state of fluid, and finally obtains the physical quantities of complex fluid in each position [8]. Fluent is the CFD software package which is widely used in the world, highly commercialized and highly specialized. It can simulate complex flow phenomena, heat conduction problems and fluid structure coupling problems. At the same time, it can calculate the flow of fluid using various structured and unstructured grids. According to the physical characteristics of each flow phenomenon, the calculation method suitable for it is chosen. Fluent can also control the speed of calculation, and make the precision and stability of the result reach the optimum value [9]. The whole calculation process is shown in figure 2.

![Figure 2. Basic program diagram of Fluent simulation](image)

A power cell grouping module with upper and lower layers is designed, and a parallel unidirectional flow ventilation scheme is selected. In the pre-processing software gambit, the grid is
divided, and the material, physical attributes and boundary conditions of the model are set up. After the solution model is established, the flow field is initialized and the residual in the calculation is set up. The Fluent software is used to simulate the flow field.

3.5. Heat dissipation control strategy for lithium-ion batteries
The temperature field of the reciprocating flow cooling of the battery model is analyzed when the ambient temperature is 32 and 40℃. The reciprocating cycle is 300 s. Through the simulation analysis of the battery temperature field under different environmental temperature, a reasonable heat dissipation control scheme is set up and verified by experiments.

4. Results and discussion

4.1. Analysis of temperature characteristics of lithium-ion batteries
At different temperatures, the relationship between the battery capacity and temperature is shown in figure 3. When the temperature is low, the battery capacity is also low. In addition, as the temperature drops, the battery capacity also drops. When the battery temperature is below 5℃, the capacity of the battery is rapidly attenuated. On the contrary, when the temperature is over 20℃, the discharge capacity of the battery changes slowly and basically reaches the rated capacity of the battery. When the temperature is between RT~45℃, the capacity of the battery is always maintained at 100%.

Figure 3. Change curve of battery capacity and temperature

The temperature difference causes the internal resistance of the battery to change (shown in figure 4), and the test result shows that the temperature is constant. When the SOC is between 0.2~1.0, the battery internal resistance is almost constant, and its value is smaller. When the temperature is between 25 and ~ 40℃, the temperature has little influence on the internal resistance of the battery. The experiment shows that the lithium-ion battery is within its ideal operating temperature range, and there is little difference in the internal resistance of the battery under the condition of no excessive discharge.
4.2. Establishment and verification of thermal effect model

Adjusting the experimental environment at room temperature, the temperature rise test of lithium-ion battery under different rate discharge was carried out. The discharge rates are 1C, 2C, 3C, 4C. The average temperature of four channels of each cell is averaged, and the experimental data are processed. As shown in figure 5, the temperature rise curve of the battery discharging at different rates is obtained.

As the battery is discharged, the temperature of the battery rises gradually. The greater the discharge rate of the battery is, the greater its heat output is. The more heat gathered inside the battery is, the greater its temperature rise rate is. After the battery was discharged at 1C, 2C, 3C and 4C, the surface temperature of the battery reached 31.4°C, 39.30°C, 48.05°C and 56.2°C, respectively. The
higher the battery temperature is, the greater the impact on its performance is. Therefore, the effective heat dissipation of the battery will greatly improve the performance of the battery.

Table 1 is the thermal physical parameters of the battery obtained by calculation. The experimental results of the same discharge rate and the same ambient temperature are compared with the simulation results. The error analysis is shown in figure 6. When the batteries are discharged at different discharge rates 1C, 2C, 3C and 4C, the average temperature of the surface of the battery is compared. The difference between the experimental results and the simulation results is 0.12℃, 0.72℃, 0.85℃, 1.41℃, respectively. Although there are some errors in the results, the errors are small and within the range of 1.5℃. This shows that the thermal model is accurate, and the calculation of thermal physical parameters and the setting of parameters in simulation are correct. It is feasible to study the thermal characteristics of the battery with this thermal model.

Table 1. Thermophysical properties of lithium-ion batteries

| Battery component | Materials                  | Density Kg/m³ | Specific heat KJ/(Kg·K) | Thermal conductivity W/(m·K) |
|-------------------|----------------------------|---------------|-------------------------|-----------------------------|
| Battery core      | Mixing of various materials| 2066          | 1167.24                 | λr,θ=0.95                   |
| Battery case      | Stainless steel material   | 8030          | 502.48                  | λz=25.86,16.27              |

Figure 6. Error comparison between experimental and simulated values

4.3. Simulation analysis of temperature field CFD of lithium-ion battery

The temperature difference between the battery model and the discharge rate at different discharge magnifications is shown in figure 7. When the battery discharge at a small rate of 1C, because the heating rate is small and the surface temperature of the battery is not high, its heat is only several degrees higher than the ambient temperature and the temperature difference is not large. The heat dissipation air with a speed of 0.3m/s can give a good heat dissipation effect on the battery model. The temperature difference of the 2C rate discharge cell increased much, and the inlet wind speed of 0.5m/s can reduce the maximum temperature of the battery to an ideal value. However, the temperature difference between the batteries reaches 4.31℃, and the temperature uniformity between the batteries is not ideal. The temperature difference between the same batteries is within 2℃, and it is within the acceptable range. The temperature difference between the upper and lower batteries of 3C rate discharge is great, and the maximum temperature of the 1m/s can be controlled at the ideal
temperature range by the heat radiation wind speed of the battery. But the temperature difference between the batteries exceeds the ideal value, reaching 7.10°C, which will seriously affect the performance of the battery.

![Figure 7. Surface temperature difference at different rate discharge cells](image)

4.4. Verification of heat dissipation control scheme

Figure 8 shows the cooling effect of reciprocating flow cooling at 32°C and 40°C. When the ambient temperature is 32°C, the battery will discharge at 1C, 2C and 3C rate, and the reciprocating flow with different wind speed can control the temperature of the battery model within 45°C. The temperature difference is less than 4°C, which achieves the temperature control target of the battery, and ensures the temperature uniformity of the battery. When the ambient temperature reaches 40°C, the temperature of the battery is difficult to decrease. When the battery is discharged at 1C and 2C rate, the maximum temperature of the battery can be reduced to the ideal temperature by using the reciprocating environment wind with larger speed. When the discharge rate of the battery is 3C, it is difficult to keep the temperature of the battery down by ambient air cooling.
In order to verify the above scheme, when the external temperature is 28°C and 32°C, respectively, the maximum temperature of the battery reaches 38.30 and 41.91°C after the reciprocating flow heat is over. This is 10 and 13.07°C lower than that without heat dissipation, respectively. The temperature difference of the battery is controlled within 3°C in the whole discharge process, and the maximum temperature of the battery and the temperature difference between the batteries are all in the ideal temperature range, which shows that the heat dissipation control scheme is feasible.

**Figure 8.** Comparison of heat dissipation effects of reciprocating flow under different temperature conditions

5. **Conclusion**

IFR26650 lithium-ion battery is selected as the object of study. In order to solve the battery heat problem, the influence of temperature on the battery capacity and internal resistance is analyzed. In order to get good battery performance, the ideal operating temperature range of the lithium ion battery is 20–45°C, and the temperature difference between the batteries should be controlled within 5°C. The three-dimensional thermal model of lithium-ion battery is established by theoretical calculation of thermal physical parameters needed for the simulation of lithium-ion battery. The discharge experiment of single cell is carried out, and the simulation results show that the model has practical value. A power cell grouping module with an upper and lower layered structure is designed, and the optimized reciprocating flow heat dissipation scheme is selected. The maximum temperature and the temperature difference of the battery can be well controlled so as to meet the requirement of heat radiation management.

This research has only analyzed the heat dissipation of the battery in the high temperature environment, and the low temperature has great influence on the performance of the battery. Throughout the study, the inside of the battery is treated as a homogeneous heater, and each component is an independent heat source. Therefore, the next step should establish a fine thermal model to analyze the impact of low temperature on the performance of the battery. Based on this, the thermal management of the power battery in the full temperature range can be achieved.

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