Design of thermal management system for lithium battery at low temperature

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Abstract. The battery capacity of lithium battery will decay at low temperature, and the battery performance will seriously decline at extremely low temperature, and the electrolyte will also freeze. Therefore, lithium batteries need to be preheated at low temperature. This paper selects 22 Ah lithium iron phosphate battery as the research object. The preheating scheme of PTC aluminum plate heating plate for lithium battery was designed by thermal parameter calculation and simulation method. The preheating scheme was optimized by changing the number (2, 3 and 4 pieces) and size (120%, 80% and 60% lithium battery size) of PTC heating plate. The results show that when heating 6 pieces of 22 Ah lithium iron phosphate battery, the preheating effect of 3 pieces of PTC heating plate close to the size of lithium battery is the best.

Keywords: Lithium battery, Thermal management, Low temperature, PTC heating.

1 Introduction

A large number of exhaust gases emitted by motor vehicles have caused serious pollution to the environment, and oil is a non-renewable resource. The driving energy of electric vehicles is the energy that can be generated continuously, and electric vehicles are basically non-polluting[1]. The motor structure is also simpler than the internal combustion engine, so the development of electric vehicles has become an inevitable trend[2, 3]. In this context, the research on electric vehicles is of great significance.

The stable discharge of lithium battery has become the top priority of research, and it can be realized by controlling the thermal characteristics of lithium battery (ohmic resistance, open circuit voltage, etc.) reasonably. In addition to battery resistance, open circuit voltage and other characteristic parameters, the ambient temperature also affects the thermal characteristics of lithium batteries[4, 5]. When the ambient temperature decreases, the electrolyte of the battery will be affected first, which will reduce the flow rate of ions, increase the polarization resistance and ohmic resistance, and reduce the battery capacity and peak power. It can even freeze the electrolyte, rendering the battery useless and

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limiting the use of electric vehicles in regions with low temperatures. Designing preheating scheme is an important task to ensure normal discharge, capacity and safety of lithium battery at low temperature[6, 7].

At present, the battery preheating methods are mainly divided into two aspects: one is internal heating, that is, using the internal impedance of the battery, by applying different frequencies of alternating current to make the battery internal heating, so as to achieve the purpose of preheating; the other is external heating, that is, using the heating medium to directly or indirectly heat the battery[8, 9]. An external heating PTC preheating scheme is proposed. PTC heating plate has reliable performance, and long service life. Compared with other thermal management schemes, it also has many unique advantages, and is becoming an important choice for lithium battery thermal management heating module

2 Simulation analysis of preheating scheme

22 Ah lithium iron phosphate battery was selected as the research object, and the size was determined to be 200 mm×180 mm×7.7 mm. Through the analysis of the related experiments on the static capacity test of lithium iron phosphate battery[10], when the lithium iron phosphate battery is above 10 °C, the decrease of battery capacity against temperature is relatively small. When the temperature is below 10 °C, the battery capacity decreases significantly with the decrease of temperature. Therefore, it can be considered that when the temperature of lithium iron phosphate battery is above 10 °C, the battery performance is basically restored.

In the structural design, thermal conductive silicon film was added between PTC aluminum plate and lithium battery to improve the surface smoothness and heat conduction efficiency of PTC aluminum plate. NF1000 thermally conductive silicon film was selected with the size of 200 mm×180 mm×1 mm and the thermal conductivity of 10 $W/m^{-1}K^{-1}$. The temperature range was suitable for ultra-low temperature environment.

The modeling of lithium battery group and PTC aluminum plate was carried out. According to the study of Liu et al[11], the physical parameters of each component of 22 Ah lithium iron phosphate battery were shown in table 1. The internal material of PTC aluminum plate is ignored[12], and the filling material is aluminum. The modeling of thermally conductive silicon film is omitted to make the model more intuitive. The modeling structure is shown in figure 1.

Table 1. Physical parameters of each component medium of monomer 22 Ah LiFePO4 lithium battery.

	Mean specific heat ($Jkg^{-1}K^{-1}$)	Thermal conductivity ($Wm^{-1}K^{-1}$)	Density (kgm^{-3})
Cathode (aluminum)	880	237	2700
Negative electrode (copper)	390	386	8960
Lithium battery	1083.75	0.905/2.687	2194

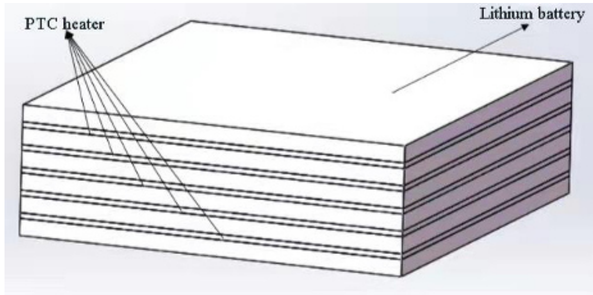

Fig. 1. Structure diagram of PTC and lithium battery pack.

The calculation domain is constructed as 360 mm×400 mm×360 mm cuboid, and the additive material is air. The parameters of lithium battery are set according to the above, and the parameters of PTC aluminum plate heating plate follow the material. Set the transient research time step to 10 s and the end time to 1800 s.

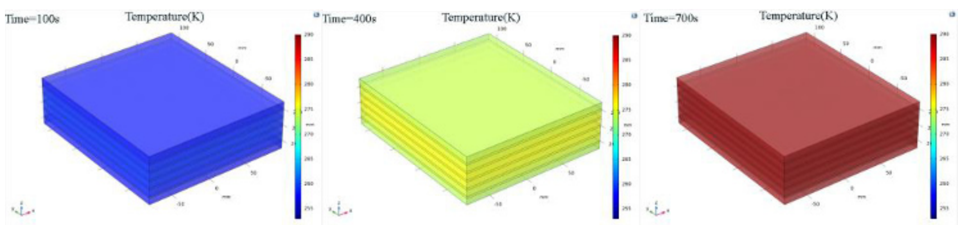

Fig. 2. Temperature distribution of PTC preheating scheme at 100 s, 400 s and 700s.

In figure 2, the PTC heating plate and lithium battery were at 255 K at 100 s. At 400 s, the temperature of PTC heating plate rises to 276 K, the maximum temperature of lithium battery reaches 275 K, the minimum temperature is 273 K, and the temperature difference is 2 °C. The temperature after 700 s has reached above 290 K; from the overall analysis, PTC aluminum plate heating plate in the heating process temperature rise is relatively stable; the temperature distribution of lithium battery is very uniform, and the temperature difference is kept within 2 °C with a quick heating process.

3 Simulation optimization of preheating scheme

3.1 Optimize the number of PTC aluminum plate heating plate

In order to simplify the installation, reduce the load and save the cost, the number of PTC heating plates was used for the simulation analysis of the three comparison groups of 2, 3 and 4 plates. Different combination methods of PTC heating plates and lithium battery are shown in figure 3

The three arrangements are simulated and analyzed, and the total input power is set to 120 W. Transient research is used. The preheating time is 900 s, and the parameters are consistent. The temperature distribution at 900 s, as shown in figure 4, is compared to obtain the temperature distribution map.

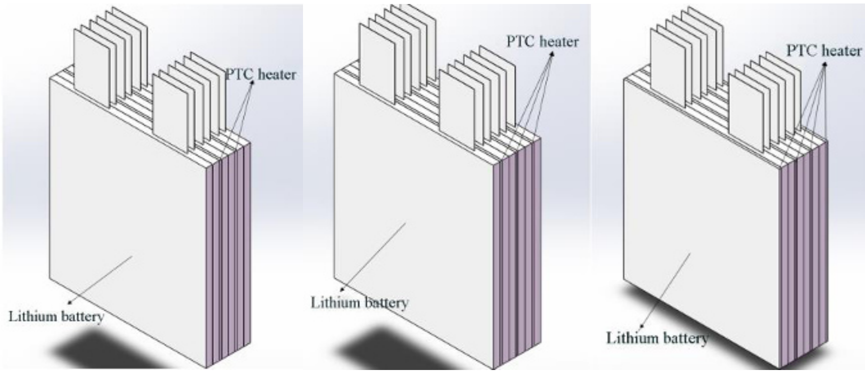

Fig. 3. Different combination methods of PTC heating plates and lithium battery.

The combination of lithium battery and less pieces of PTC heating plates reduces the cost of PTC heating plates. As for two PTC heating plates, when the two lithium batteries in the middle reach the preheating target temperature, the outer lithium battery has not yet reached; when the temperature rise of the outer lithium battery is enough, the temperature of the inner lithium battery is always higher than that of the outer lithium battery due to continuous heating. The combination of three PTC heating plates and lithium battery pack can be clearly seen in the same output power and heating time conditions, the preheating effect is better than that of two PTC heating plates. However, the 120 W output power was distributed in three PTC heating plates, making the overall temperature rise to 25 °C, slightly insufficient. As for four PTC heating plates, from the point of view of temperature distribution, good consistency, it's preheating is more uniform; 120 W input power is dispersed on four PTC heating plates to make the overall temperature rise 20 °C. At the same time, the outermost PTC heating transmits part of the heat to the air, resulting in low utilization rate of heat in this way.

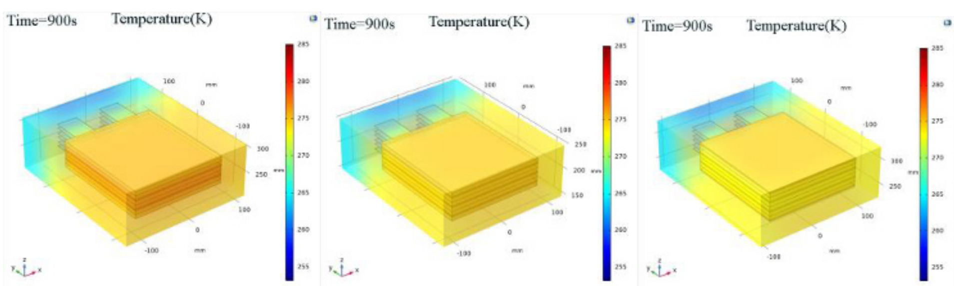

Fig. 4. Temperature distribution of lithium battery group combined with two, three, and four PTCs at 900 s.

3.2 Optimization of PTC aluminum plate heating plate size

The optimal preheating method of PTC heating plate number, that is three PTC heating plates, is adopted, and the size of each PTC heating plate is taken as the variable for analysis. In order to facilitate the setting of variable comparison group, the PTC heating plates of different sizes are set to maintain the same length-width ratio, and the length difference is 20 %. Three comparison groups of 120%, 80% and 60% of the lithium battery size are set respectively. The structure is shown in figure 2.

It is assumed that except for the different sizes of PTC heating plates, the parameters are the same. The simulation comparison of these three comparison groups is carried out to obtain the simulation results.

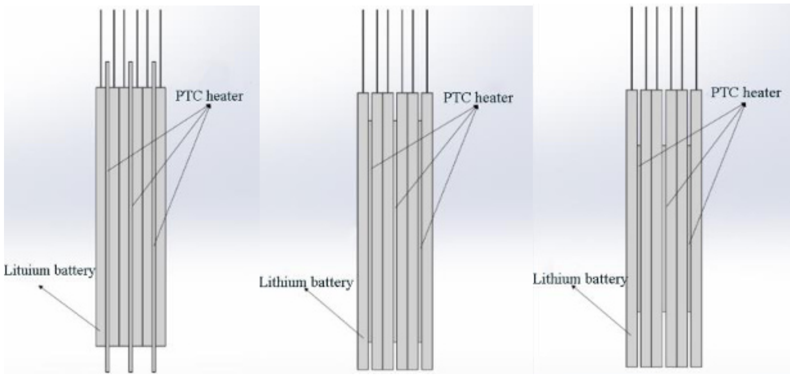

Fig. 5 120% size (left), 80% size (middle) and 60% size (right).

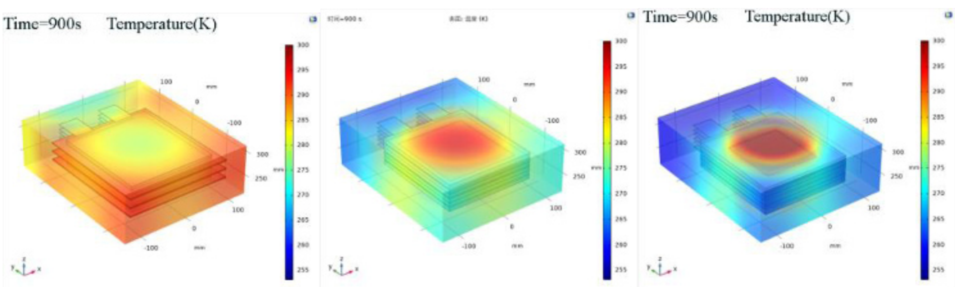

Fig. 6. Temperature distribution with different sizes of PTC heating plate at 900 s.

As shown in figure 6, when the size of the PTC heating plate is larger than that of the lithium battery, the air will be heated by the prominent edge of the PTC heating plate, so that the temperature of the surrounding air will increase, and the edge of the lithium battery will be double heated by the hot air and the PTC heating plate, so that the edge temperature is higher than the middle temperature. At 900 s, the maximum temperature at the edge of the lithium battery is 290 K, and the minimum temperature at the middle position is 280 K, with large temperature difference. When the PTC heating plate is 80% of the lithium battery size, it is found that the temperature is accumulated in the middle of the battery, and the middle temperature is higher than the surrounding temperature. At 900 s, the highest temperature in the middle is 295 K, the lowest temperature around the lithium battery is 275 K, the temperature difference is 20 °C, and the heating uniformity is poor. When the PTC heating plate is 60% of the lithium battery size, it can be seen that the heating effect will become extremely poor, and the temperature distribution of the lithium battery is extremely uneven. At 900 s, the temperature difference of lithium battery reached 35 °C.

4 Conclusion

In this paper, the preheating effect of PTC heating plate on lithium battery is analyzed by simulation. The combination of six lithium iron phosphate batteries with different number of PTC heating plates (2, 3, 4) and different sizes (120%, 80%, 60%) was simulated and analyzed.

The simulation results show that the preheating effect of six lithium iron phosphate batteries is the best by using three PTC heating plates closest to the size of lithium battery, which can ensure the uniformity and efficiency of lithium battery preheating. At the same time, the preheating cost is reduced by using fewer PTC heating plates, which is conducive to the promotion and utilization of technology.

The PTC aluminum plate heating plate is used to preheat the lithium battery. The PTC aluminum plate heating plate can be used as the heating element and the bearing structure of the lithium battery, which can save part of the fixed aluminum plate and facilitate the assembly. At the same time, the PTC heating plate has the characteristics of long service life. It can be used for more than 10 years in the thermal management of power batteries, which greatly saves the cost.

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