Battery Pack’s Structure Design Based on the Heat Flow Field Simulation

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ABSTRACT

The heat generation mechanism and heat transfer mode of lithium-ion battery were studied. The internal heat of the battery was transferred to the surface of the cell by heat conduction. A small part of the heat was transmitted through thermal radiation. The heat of the lithium ion battery pack was air and module. And then the ANSYS fluent was used to simulate the single module and the battery pack. The distribution of the heat flux of the single battery module and the distribution of the heat flow of the battery pack were obtained. The results showed that the heat accumulated in the single module and the battery pack center was serious. And the module center, the middle part of the module temperature is higher, the temperature distribution is not balanced. Finally, to improve the existing structure, in each module 10mm height between the one-way airway, the maximum temperature drop 0.9 ℃, the result of the improvement is good.

1. INSTRUCTIONS

The internal lithium battery pack will get hot during the process of electric car running. And the generation of heat accumulates inside the module if the cooling structure is not good. It leads to local temperature rise and temperature is not balanced. When heat gathered more than the normal work of the lithium ion battery temperature range, the battery cycle life and safety use would be affected, and even lead to the occurrence of safety accidents. At home and abroad in view of the lithium
ion battery pack heat treatment measures are mainly from two aspects now. On the
one hand is the battery itself material, is looking for high temperature resistance of
new materials of high thermal conductivity. On the other hand is, from the external
battery, strengthen the battery heat conduction. At present, exploration of battery
materials has been tended to enter the stage of bottleneck. External battery cooling
method including air cooling, liquid cooling and phase change materials thermal, air
as cooling medium. Because of its ubiquitous and it can save the cost of battery pack
production without increasing the complexity and air tightness requirements of the
battery pack structure, it become a research hotspot for scholars at home and abroad.

The research object is the lithium ion battery pack produced by a domestic
company. Based on the actual sizes of battery and battery pack, with the aid of UG
lithium battery pack 3D simulation model and using Computational Fluid Dynamics
(CFD) technology and the simulation method, the internal battery pack in the cooling
temperature field distribution and mutual influence of each battery module
are researched and its thermal field distribution of heat dissipation structure
improvement measures are put forward.

2. MECHANISM OF HEAT GENERATION OF LITHIUM-ION
BATTERIES

Currently on the market power lithium ion battery can be point cylinder type and
square type two kinds according to the structure. The type 18650 winding battery
power lithium ion battery studied in this paper is cylindrical type, namely to 18 mm
in diameter, height is 65 mm cylindrical batteries, nominal voltage of 3.6 V, standard
discharge current of 1.25 A (0.5 C). When the lithium ion battery is charged and
discharged, the inside of the battery will generate heat first, then the heat will be
transferred and the internal temperature of the battery will change accordingly.

2.1 The Calculation of the Internal Heat of the Battery

Battery produces heat $Q_t$ consists of chemical reaction heat $Q_r$, deputy reaction
heat $Q_s$, heat polarization $Q_p$, and joule heat $Q_j$. The joule heat is from the battery
intrinsic resistance and contact resistance of various materials. The polarization heat
is the battery internal electrochemical polarization and ohm polarization and other
heat generated in the condition of charging and discharging.

Assuming the internal heat of the battery is uniform and the calculation model of
the heating power is established, the battery heat production in the model is mainly
the chemical reaction heat and the ohms heat. It can be described as follows:

$$
\begin{align*}
Q &= \frac{I}{V} (E_{oc} - E - T \frac{dE_{oc}}{dT}) \\
IR &= E_{oc} - E
\end{align*}
$$

(1)
In the formula, \( Q \) is the heat generation rate of internal unit volume of lithium ion battery; \( I \) is the discharge current of lithium ion battery; \( V \) is the total volume of lithium ion battery; \( T \) is temperature of lithium ion battery; \( E_{OC} \) is the open circuit voltage of the lithium ion battery—that is the nominal voltage of the battery; \( E \) is lithium ion battery working voltage; \( R \) is lithium ion battery internal resistance; \( dE_{OC}/dT \) is lithium ion battery voltage change rate with temperature.

2.2 Analysis of Internal Heat Transfer in Battery Pack

There are three heat transfer modes within the battery pack: heat conduction, convection and radiation.

(1) Heat conduction
Heat conduction phenomenon is a phenomenon of heat transfer occurred between the two objects (or parts) touch each other. The necessary condition of heat transfer is a temperature difference between the two things, which make the material in the object molecules through strong molecular thermal motion will be heat transfer.

(2) Heat convection
Heat convection is a kind of heat transfer in gas and liquid. It also is a heat transfer process combining complex convection and heat conduction. The heat convection heat transfer rate equation is:

\[
\frac{q}{A} = h \Delta T
\]  

(2)

In the formula, \( q \) is convection heat transfer rate in the process of convection type; \( h \) is convection heat transfer coefficient; \( A \) is area of perpendicular to the direction of heat flow; \( \Delta T \) is difference value between the fluid and surface temperature.

(3) Heat radiation
Heat radiation does not require a medium. It is a heat exchange form that is absorbed by other objects and is absorbed by other objects because of the electromagnetic energy of the atomic motion in the object.

The heat transfer rule in the power lithium ion battery pack is based on the formula of heat conduction, heat convection and heat radiation. And it is also based on the mass conservation control equation:

\[
Q_w = Q_e + Q_a
\]  

(3)

In the formula, \( Q_w \) is total heat production in power lithium ion battery; \( Q_e \) is heat exchange heat in power lithium ion battery; \( Q_a \) is absorption heat itself in power lithium ion battery. It also is the heat to make the power battery temperature rises \( \Delta T \).

The material of power lithium ion battery has the function of the energy absorption. Therefore, after the battery temperature rises \( \Delta T \), lithium ion absorption heat equation expressed as follows:
\[
\sum_{i=1}^{n} m_i \Delta c_{pi} \Delta T = Q_s = Q_s - Q_c
\] (4)

In the formula, \(m_i\) is the quality of each component in lithium ion power battery; \(\Delta c_{pi}\) is the specific heat capacity of each component in lithium ion power battery.

Based on the lithium ion battery pack bulk heat flow field are studied, this paper mainly studies the thermal field distribution in the air around the module, as well as the thermal field of the interaction between modules, namely the main thermal convection of air and module.

3. HEAT FLOW SIMULATION AND STRUCTURE DESIGN

3.1 Determination of Simulation Parameters

In this paper, a 3D cooling battery model is established and the equation of heat dissipation of the battery is further derived from the equation of energy conservation of fluid dynamics:

\[
\rho c_p \frac{\partial T}{\partial t} = \text{div}(k \text{ grad } T) + S_t
\] (5)

The battery core material is treated equally. According to the principle of mass balance, the density is \(2727 \text{ kg/m}^3\). Comparison of heat capacity and heat conductivity coefficient is: \(c_p = 1000 \text{ J/(kg} \cdot \text{°C)}\) and \(k = 3.00 \text{ W/(m} \cdot \text{°C)}\). According to the calculation model of Bernardi's thermogenic rate and the thermogenic rate, the calculated heat rate of the monomer core is \(10815.4 \text{ (W/m}^3\)\).

In conclusion, the thermal property parameters of the battery can be seen and the physical parameters of the conductive silica gel are provided by the manufacturer. Table I is available.

### TABLE I. 18650 DYNAMIC LITHIUM ION BATTERY AND THERMAL PROPERTIES OF THERMAL CONDUCTIVITY.

| materials                  | consistency (kg/m³) | specific heat (J/(kg·°C)) | heat conductivity coefficient (W/(m·K)) | Heat production rate (W/m³) |
|----------------------------|---------------------|---------------------------|----------------------------------------|----------------------------|
| Battery core material      | 2727                | 1000                      | 3                                      | 10815.4                    |
| thermal conductive silicone| 1079                | 1450                      | 0.45                                   | /                          |
3.2 Setting of Simulation Conditions

The former can be seen that the heat dissipation of the battery module belongs to the natural convection situation, and the heat dissipation fluid is the air. Thus the following assumption is made to the air: (1) ignoring the inertia of the air; (2) air is an uncompressed ideal medium.

3.2.1 MODEL SELECTION

The natural convection air in the battery pack of this paper belongs to turbulence so it can select turbulence model. Since the standard k-epsilon (2 eqn) is a uniform turbulent flow for isotropic isotropy and it is a typical two equation model, the performance is stable and the most widely used. So this paper also selects the standard k-epsilon model. Turbulence energy $k$ and turbulent dissipation rate $\varepsilon$ maintain the default values provided by the system.

3.2.2 SETTING OF BOUNDARY CONDITIONS

This paper assumes that the battery working environment temperature is room temperature 25 ℃, i.e., set the software to simulate the temperature of 298 K. Under the condition of natural air cooling, surface convective heat transfer coefficient is 5W/m²·k. This paper operating pressure is the default value of 101315 Pa and when the heat production rate in 80%SOC, 0.5 C discharge rates in numerical value has been calculated before, that is $\frac{3}{4} \times 1.0815 \times 10^8$ mW. The selection of solver is based on the pressure method and the solution control algorithm is used to solve the SIMPACK numerical method of the incompressible flow field, with all parameters are kept by default.

3.3 Thermal Simulation Analysis

This paper studies the distribution of heat in the battery pack under the condition of 0.5 C, which lays the foundation for the design of the rear battery pack structure. In real life, the internal heat of lithium ion battery is complex. In order to reduce the difficulty of simulation analysis and reduce the time of fluent calculation, this paper assumes that:

(1) The internal materials of the lithium ion battery are homogeneous and the heat is uniform;
(2) In continuous working condition, the working current density of the battery is not changed due to different position and time;
(3) The internal heat exchange of the power lithium ion battery is not considered;
(4) The temperature change of the flow field system is only related to the specific heat capacity (constant) of the material;
Based on the above four assumptions, the geometric model of the core-core is simplified as \( D = 18\text{mm}, H = 65\text{mm} \) column, which means that the core of the battery module is treated as a homogeneous and stable heat source.

### 3.3.1 POWER LITHIUM BATTERY PACK MODEL

**1) The original geometric model**

The 3D actual model of lithium ion battery pack is shown in figure 1. Battery pack with two 10 modules along the Z axis of tandem module arranged in parallel, 40 mm spacing and along the Y-axis 40 mm from two battery pack enclosure wall. The Z-axis direction two battery modules from the wall of 70 mm, the X-axis distance two wall 10 mm. Overall battery pack size is \( 830\text{mm}(Z) \times 560\text{mm}(Y) \times 250\text{mm}(X) \). Battery module size is \( 230\text{mm}(Z) \times 220\text{mm}(Y) \times 69\text{mm}(X) \) and casing thickness is 2mm. The 131 cores of 18650 battery are arranged in order and the cores of the battery are 34mm along the center of the X-axis and 19mm along the center of the Y-axis. Due to the symmetry of the left and right sides of the battery pack, the flow field simulation is calculated for the convenience of simulation.

![A geometric model of the battery pack](image1)

![A single module profile of the battery](image2)

**Figure 1.** The three-dimensional actual model of lithium ion battery pack provided by the manufacturer.

**2) Structural improved mode**

In natural condition at present, the improvement measures mainly from the battery pack bulk heat flow field to find the optimal outlet position, increase the cooling air circulation area and according to the laws of the radiator to adjust the combination between the module, the module internal batteries configuration method to obtain. To sum up, in this paper, according to the result of battery pack cooling simulation analysis, improvement measures for while maintaining module arranged on the basis of the up and down at the end of each module and module increased contact between two height is 10 mm rectangle block. As shown in figure 2. The equivalent of the battery module between the box body along the Y-axis direction an extra 10 mm high, 220 mm long unidirectional air flow to increase the cooling air circulation area.
3.3.2 SIMULATION RESULTS ANALYSIS

The simulation ends after the calculation of 7200s. At this time, the model converges. After the relevant results and data are processed in CFD-post, the distribution of heat flow field in 1/4 battery packs before and after the model improvement can be obtained. As shown in figure 3 – figure 5.

Figure 2. Improved model of module layout in battery pack.

(a) Before improvement                                               (b) After improvement

Figure 3. Thermal field distribution on the flow solid coupling surface of the battery pack (z).

(a) Before improvement                                               (b) After improvement

Figure 4. The temperature distribution in the axial (x) section of the battery pack model.
According to Figure 3(a), Figure 4(a) and Figure 5(a), the highest temperature in the battery pack is 319.8 K, and the lowest temperature is 298.1 K. Temperature difference within the battery pack is 21.7 °C. It increased 1.2 °C compared with a single module work. This is due to heat accumulation in the center of the battery pack each module. As the superposition of battery module, the module of heat influence each other and cause the battery pack temperature rise than the battery module temperature rise is increased. And that the closer the air is to the outside air, it will be lower than the center of the module and it will be lower than the heat of the module at the center of the battery pack. Within the battery pack, close to the symmetrical module overall the fluid-structure coupling surface temperature is close to the battery pack shell the fluid-structure coupling surface temperature is high. This is because the two modules are symmetrical. In the central battery pack while there are air natural convection, but they still have influence each other and you will be presented with the phenomenon of heat overlay.

Battery pack, according to the improvement of heat flow field simulation, is near the body boundary due to air circulation, to take away a lot of heat. So the heat accumulation in the border than the center of the poor liquidity is much lower, and part of the heat accumulation in the center of the module is higher than the edge. In the battery module, the central heat accumulation is also serious because temperature gathered together and influenced each other. In the middle of the four modules, the temperature is particularly high. There is also a larger temperature difference between modules. If sustained severe temperature rise trend, it will play a battery pack for the best performance and still exist in the use of safety for the battery pack for the structure improvement of existing design, improve heat dissipation.

According to Figure 3(b), Figure 4(b) and Figure 5(b), after add a one-way flow of air, the highest temperature inside the battery pack is 318.9 k. And the high temperature is 319.8 k which did not improve before, 0.9 °C reduced. By temperature cloud image contrast, the scope of each section after the structure is improved high temperature gather less, on the surface of the fluid-structure coupling temperature
distribution more uniform distribution of some previous also, and thus the structure improvement is effective.

CONCLUSION

Aim at the lithium ion battery module and battery pack, this paper established the corresponding 3D heat transfer model. By means of CFD method with fluent software, the battery module and a battery pack for the transient heat flow field simulation. It found that the heat gathered in the center of the battery pack is serious with higher temperature and the heat distribution is not balanced and the temperature distribution uniformity is poor. Therefore, we improve the structure of battery pack and add the unidirectional air flow between each module for heat dissipation. And we compare the simulation results with the battery pack which did not improve. The result points out that the improved scheme can make the highest temperature inside the battery pack. In the future, we can further study the following aspects:

(1) Battery pack heat dissipation structure design at present is mainly change the heat transfer medium, this paper too. In the future, according to the module internal distance - heat transfer equation, we can design a battery internal batteries arrangement way to reduce the average temperature and balance the internal thermal field;

(2) Due to the differences in the heat transfer of battery cells and it is not identical, it can be used to study how the monomer is arranged in the module in the future.

(3) Due to the filling of the conductive silica gel between the core of the battery module, the thermal conductivity of the heat-conducting silica gel can be studied in the future;

(4) In order to simplify the calculation and simulation, this article will be treated as lithium ion batteries for all round heat source. And the actual battery is cascading winding type structure. In the future it can be layered structure of monomer battery model according to the actual processing and improve the accuracy of the model and simulation.

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