Algorithmic and Simulated Based Structural Optimization of Air-Cooling Heat Dissipation Structure for EV Battery Pack

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Abstract. This paper proposes an approach to optimize the effect of air-cooling heat dissipation structure for electric vehicle lithium-ion battery pack through CFD simulation and Genetic Algorithm. A 3D model of air-cooling heat system of battery pack is calculated and built through CFD, and the proxy model of battery pack structure parameters and function is established by BP neural network. Then based on this proxy model and genetic algorithm, the three structural parameters with lower maximum temperatures and temperature differences are calculated.

1. Introduction
With the promotion of clean energy, EV began to popularize in the world. The lithium-ion battery releases heat during the discharge process, causing the temperature of the battery to change. If the heat in the battery does not emitted well into the surrounding environment, the temperature inside the battery pack may exceed the safe operating temperature range of the battery, which may be dangerous [1].

In addition, the temperature of each module in battery pack must also be controlled within a certain range for best performance [2]. Therefore, an efficient cooling system is very necessary.

For the EV lithium-ion battery packs are usually fixed in overall size, this paper focus on the optimization of internal structural parameters, and the main goal is to obtain structural parameters with the lowest maximum temperature and temperature difference

2. CFD Modelling
Computational Fluid Dynamics (CFD) is a branch of fluid mechanics combining numerical computation and data visualization techniques to simulate and analyze issues involving fluid flow and heat transfer. Its main method is to replace the original continuous physical quantity field with a discrete numerical point, these discrete points through various mathematical derivation and calculation to establish algebraic equations, and then these established equations to solve. Then we can an approximate solution.

The CFD numerical calculation process is mainly shown in Figure 1.

**Figure 1.** Main process of CFD numerical calculation.
In addition to the governing equations, CFD modelling also includes the following work.

2.1. 3D thermal model of lithium-ion battery

Based on the research results of K Onda [3] and others, the following mathematical models are established:

$$\rho c_p \frac{\partial T}{\partial t} = \lambda_x \frac{\partial^2 T}{\partial x^2} + \lambda_y \frac{\partial^2 T}{\partial y^2} + \lambda_z \frac{\partial^2 T}{\partial z^2} + Q$$  (1)

The thermophysical parameters ($\rho$, $c_p$, $\lambda$) of battery can be obtained by weighted average mass [4].

2.2. The establishment of geometric model and fluid-solid coupling model of battery package

Through desk research, it is assumed that the size of battery is 445mm$x$72mm$x$172mm, the radius of the pole column is 18mm, and the height is 20mm. The distance between the batteries is 4mm. The 5 battery are arranged in order to form the battery pack, and the simplified flow-solid coupling model of the battery pack is shown in Figure 2.

![Figure 2. Simplified flow-solid coupling model of battery pack.](image)

2.3. Grid division and independence verification

The accuracy of numerical simulation results is related to the grid division. Therefore, using a reasonable method to divide the grids can effectively improve the accuracy of calculation, but also can improve calculation efficiency for the reduced grids [5].

Structured grid and unstructured grid are two main ways of grid division. This paper adopts the hexahedron structured grid division by importing geometric models into ICEM software of ANSYS.

After independent verification, considering the calculation time and accuracy [6], the total grid number is determined to be 931569 as shown in Figure 3.

![Figure 3. Grid independence analysis curve.](image)
2.4. CFD simulation model settings

2.4.1. Definition of physical parameters. The definition of parameters (ρ, cp, λ, μ) is shown in table 1

|                | ρ (kg·m⁻³) | cp (J·Kg⁻¹·K⁻¹) | λ(W·m⁻¹·K⁻¹) | μ (kg·m⁻¹·s⁻¹) |
|----------------|------------|-----------------|--------------|----------------|
| Battery        | 1958.7     | 733             | 0.913/2.732/2.732 | -              |
| Box            | 8030       | 502.48          | 16.27        | -              |
| Air            | 1.23       | 1006.43         | 0.024        | 1.79e-5        |

2.4.2. Definition of heat source. In the process of battery pack work, mainly involves three types of heat transfer: heat conduction, heat convection and heat radiation. With a discharge multiple of 2C, the battery's heat generation rate can be calculated to be 23948.2 W/m³.

2.4.3. Settings for boundary conditions. The heat transfer between the surface of battery and the air flowing is in the form of a fluid-solid coupling heat exchange. In Boundary Conditions, Thermal Conditions chose Coupled. Convection transfer rate is set to 5 W/m²·K, import wind speed is set to 5 m/s. The wall boundary is set to 25°C.

2.4.4. Settings for the parameters of solution control. Simple discrete algorithm is adopted. The Momentum and Energy options under the Spatial Discretization option is selected to Second Order Upwind, and the other options are the default settings. The Under-Relaxation Factors is set to the default setting.

3. Structural Parameters and Effects on Heat Dissipation

Based on the model established above, it can be found that without changing the overall size and structure distribution, there are three structural parameters that may affect the cooling effect: air inlet angle (α), air outlet angle (β), tolerances of distance between batteries (d).

![Figure 4. Structural schematics for battery pack cooling system.](image)

Based on the size of battery pack and experimental results available, the values of α, β, d are initially selected: α=0°~4°, β=0°, d=0mm; β=0°~4°, α=0°, d=0mm; d=0~0.6mm, α=0°, β=0° (average distance between batteries is 4mm). The Figure 5 shows the effect of each parameter on the maximum temperature and temperature difference of the battery pack.
4. Optimization of Battery Pack Structural Parameters
To systematically optimize the structural parameters of system, three parameters need to be considered at the same time. The first step is to use orthogonal test, select sets of data and simulate. After that, the BP neural network is used to establish the proxy model of battery pack structure. Finally, genetic algorithm is used to carry out multi-objective optimization to obtain the structure with the best effect.

4.1. Orthogonal test
Based on previous research results and practical experience, four reasonable levels are set for the three parameters [7]. And 16 sets of data were obtained through orthogonal testing, as shown in the Table 2

|   | α(°) | β(°) | d(mm) | Tmax(K) | ∆T(K) |
|---|------|------|-------|--------|-------|
| 1 | 2    | 2    | 0     | 309.72 | 6.40  |
| 2 | 2    | 2.5  | 0.2   | 308.23 | 4.93  |
| 3 | 2    | 3    | 0.4   | 307.70 | 4.58  |
| 4 | 2.5  | 4    | 0.6   | 309.92 | 6.52  |
| 5 | 2.5  | 2    | 0.2   | 308.36 | 5.09  |
| 6 | 2.5  | 2.5  | 0     | 309.06 | 5.69  |
| 7 | 2.5  | 3    | 0.6   | 309.26 | 5.77  |
| 8 | 2.5  | 4    | 0.4   | 308.31 | 5.03  |
| 9 | 3    | 2    | 0.4   | 307.74 | 4.72  |
| 10| 3    | 2.5  | 0.6   | 308.55 | 5.30  |
| 11| 3    | 3    | 0     | 309.05 | 5.67  |
| 12| 3    | 4    | 0.2   | 309.96 | 6.50  |
| 13| 4    | 2    | 0.6   | 309.95 | 6.32  |
| 14| 4    | 2.5  | 0.4   | 307.81 | 4.65  |
| 15| 4    | 3    | 0.2   | 308.06 | 4.93  |
| 16| 4    | 4    | 0     | 310.07 | 6.84  |

4.2. Proxy model of battery pack structure based on BP neural network
The experimental model is simulated instead by BP neural network, and the proxy model of the maximum temperature and the temperature difference are established [8].

This paper adopts MATLAB for programming. Because the length of the article is limited, the program is not written in the article.
4.3. Optimization of battery pack structure parameters based on genetic algorithm

In this paper, the genetic algorithm is selected for the optimal design of the output parameters, and the optimization program is written by using MATLAB. The main work is as follows [9].

1. Determine the number of variables: 3 (α, β, d);
2. Select the initial value of the variable: lower limit= [2, 2, 1], upper limit= [4, 4, 2.5];
3. Introduce proxy model based on BP neural network;
4. Determine the fitness function: fitness function in MATLAB;
5. Introduce nonlinear inequality and nonlinear equations;
6. Configure the basic parameters of genetic algorithm: 'ParetoFraction' 0.3, 'PopulationSize' 300, 'Generations' 50, 'StallGenLimit' 50, 'TolFun' 1e-6, 'PlotFcns' @gaplotpareto;

Through the above works, the genetic algorithm is configured. Pareto front figure (Figure 6) can be obtain by running the MATLAB program.

![Figure 6. Pareto front figure.](image)

After optimization we can get the Pareto optimal solution: air inlet angle (α) is 2.13°, air outlet angle (β) is 2.78°, tolerances for distance between batteries (d) is 0.33mm. At this time, the maximum temperature of battery pack is 34.05℃, the temperature difference is 3.53℃.

5. Conclusion

In this paper, an approach for improving heat dissipation of EV battery pack by optimizing three structural parameters is presented. Through obtained results, conclusions are drawn as follows:

1. Reasonable design of air inlet/outlet angle and tolerances of distance between batteries can significantly reduce maximum temperature and temperature difference in the battery pack;
2. With the optimized structural parameters, the maximum temperature of battery pack is 34.05℃, reduced by 2.79℃ (initial structure 36.84℃). The temperature difference is 3.53℃, reduced by 2.9℃ (initial structure 6.43℃).

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