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Design of the cell spacings of battery pack in parallel air-cooled battery thermal management system

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ABSTRACT

In this paper, the cooling performance of the parallel air-cooled Battery Thermal Management System (BTMS) is improved through designing the spacing distribution among the battery cells. Computational Fluid Dynamics (CFD) method is employed to calculate the flow field and the temperature field of the BTMS. Then an optimization strategy combined with the CFD method is used to adjust the cell spacings, with the target of minimizing the maximum cell temperature difference. Typical cases are used to test the effectiveness of the proposed optimization process for cell spacing optimization. The results indicate that the maximum temperature of the battery pack is reduced by approximately 3.0 K and the maximum cell temperature difference is reduced by more than 60% after optimizing the cell spacing distribution. By choosing appropriate initial cell spacing distribution and step length of the cell spacing adjustments, optimized results can be obtained in short time without sacrificing the performance of the solution. Furthermore, the cell spacing optimization does not increase the total power consumption, and the optimized BTMS achieves good cooling performance for various inlet airflow rates. It is suggested that the presented optimization process is an effective method to design the cell spacing distribution and to improve the cooling performance of the BTMS.

1. Introduction

In recent years, electric vehicle (EVs) and hybrid electric vehicles (HEVs) have attracted worldwide attention due to their potential to relieve the energy shortage and environmental pollution problem. In EVs and HEVs, lithium battery pack is one of the most important components, which applies power to the vehicles and determines the performance of the vehicles. The performance of the lithium battery pack depends on the cell temperature. The appropriate operating temperature for the lithium battery cell is between 20 °C and 40 °C. Thus, battery thermal management system (BTMS) is essential to dissipate the heat generated by the battery cells and guarantee the proper cell temperature when the lithium battery pack is operating.

Many thermal management technologies have been developed for heat dissipation of the battery pack, including air cooling [1–3], liquid cooling [4–6], phase change material cooling [7–10] and heat pipe cooling [11,12]. Among these technologies, air cooling is one of the most commonly used solutions due to the low cost and simple structure of the system. Scholars have made great efforts to investigate the air-cooled BTMS, finding that structure of the system strongly influences the performance of the BTMS. Pesaran et al. [13] studied the cooling performances of the BTMSs with serial ventilation cooling and parallel ventilation cooling, respectively. The results indicated that the system with parallel air cooling can achieve lower maximum temperature and maximum temperature difference of the battery pack than the one with serial air cooling. Mahamud et al. [14] used the reciprocating airflow to reduce the temperature difference of the battery pack. Yu et al. [15] combined the serial ventilation cooling with the parallel ventilation cooling to reduce the temperature and the temperature difference of the system. Wang et al. [16] compared the performances of various battery cell arrangement structures, finding that the forced air cooling performed well with axisymmetric module structure. Sun et al. [17] introduced a tapered upper cooling duct to improve the performance of the parallel air-cooled BTMS with U-type flow. The numerical results showed that the maximum temperature variation of battery pack was reduced by 70%. Subsequently, Sun et al. [18] improved the parallel air-cooled BTMS with Z-type flow through using the

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tapered inlet and outlet ducts. The results indicated that the maximum lumped cell temperature difference and the maximum lumped peak cell temperature were respectively reduced by 7.2 °C and 6.3 °C. Park [19] compared the performances of the BTMSs with U-type flow and Z-type flow. The tapered manifold and pressure relief ventilation were introduce to improve the performance of the system. Chen et al. [20] combined Newton method with the flow resistance network model to optimize the angles of the divergence and convergence plenums. The results indicated that the maximum temperature difference of the battery pack was reduced by more than 30%.

Among the various structure parameters that affect the cooling performance of the system, the spacing distribution among the battery cells is one of the most important ones. Zhu et al. [21] adopted the cell spacing distribution with 2 mm decreasing and 4° plenum angles to improve the performance of the BTMS. The results showed that the maximum temperature difference of the battery pack can be controlled within 3 °C. Fan et al. [22] found that uneven gap spacings among the cells can help to reduce the cell temperature difference compared the uniform gap spacings. Yang et al. [23] explored the effects of longitudinal and transverse spacings on the cooling performance for the battery pack with the aligned and the staggered arrays. Then an appropriate solution for the aligned arrangement of battery pack was obtained by trade-off the maximum temperature rise, the temperature difference, the power requirement and the cooling index. Zhao et al. [24] studied the influence of the ratio of spacing distance between neighbor cells and the cell diameter on the cooling performance of the BTMS. Severino et al. [25] combined Multi-Objective Particle Swarm Optimization with numerical method to arrange the cell spacings of battery pack and the position of the inlet airflow. The optimized system reduced the maximum temperature and the maximum temperature difference of the battery pack by 2 °C. Based on the flow resistance network model and the heat transfer model, Chen et al. [26] developed an effective optimization strategy to design the spacing distribution among the battery cells. The results indicated that the maximum temperature of the battery pack was reduced by 42% after the optimization of the cell spacing distribution.

Previous studies have shown that the cooling performance of the BTMS can be remarkably improved through designing the cell spacing distribution. Though some optimization methods have been introduced to optimize the cell spacing distribution, there exists a certain temperature difference among the battery cells due to the errors of the models. In this paper, the optimization of the cell spacing distribution is conducted. The Computational Fluid Dynamics (CFD) method is used to calculate the flow field and the temperature field of the BTMS. Based on the CFD method, an optimization strategy is introduced to design the cell spacings, for the target of minimizing the cell temperature difference. Typical cases are introduced to test the performances of the optimized system. The influences of the initial cell spacing distribution and the step length of the spacing adjustments on the performance of the optimized BTMS are also discussed.

The remainder of the paper is organized as follows. Section 2 introduces the calculation models to evaluate the performance of the BTMS. Section 3 presents the cell spacing optimization problem and the optimization process to solve the problem. Section 4 introduces the numerical cases and validate the numerical method. Section 5 discusses the optimized results. Section 6 presents the conclusions.

2. Calculation models

2.1. Illustration of the parallel air-cooled BTMS

Parallel air-cooled system is one of the most commonly used air-cooled systems for battery thermal management. Fig. 1 shows the schematic of the parallel air-cooled BTMS. In the system, a battery pack with $N \times M$ prismatic battery cells is included. The cooling air is pumped into the system from the inlet. The air is distributed into the cooling channels by the divergence plenum. The air then removes the heat generated by the battery cells. Leaving the cooling channels, the air is converged into the outlet duct by the convergence plenum and is ejected through the outlet. The temperature distribution of the battery pack depends on the airflow rate distribution among the cooling channels, which strongly depends on the spacing distribution among the battery cells. Thus,

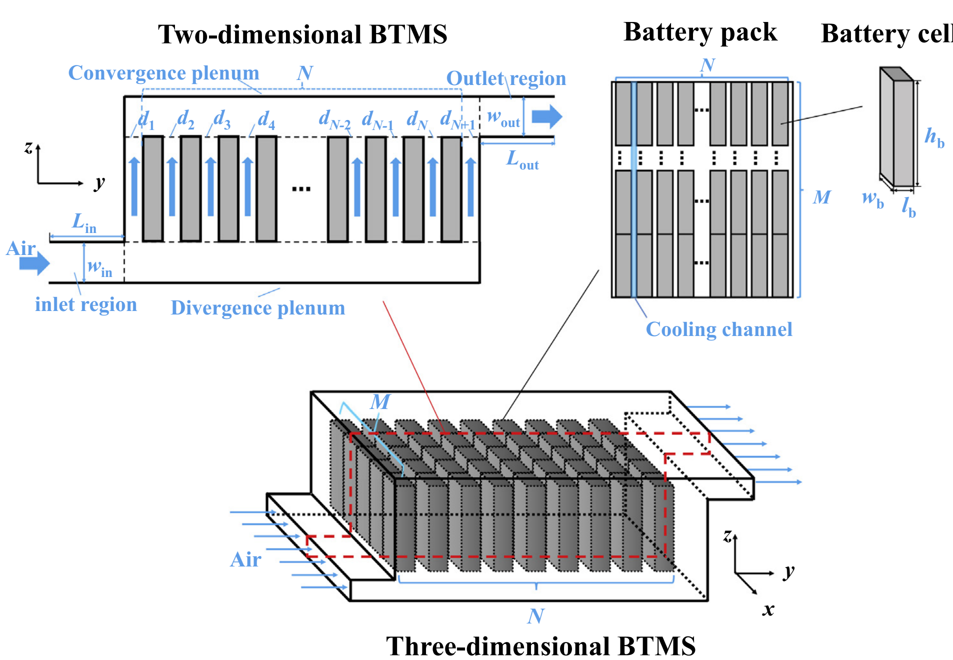

Fig. 1. Schematic of the parallel air-cooled BTMS.