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Temperature field simulation and optimization of multifunctional distribution box

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Abstract. With rapid development of electric vehicles, the multifunctional distribution boxes were constantly updated. In order to overcome excessive volume and confused layout of rectifier and inverter modular, a new multifunctional vehicle distribution box was design. The rectifier, dc conversion and high voltage distribution modular integrated in the smaller box. The internal modules of the distribution box would affect each other and the temperature field. A few of design and improve rules were presented after temperature field simulation by ANSYS. The simulation result shows the improved rules would reduce the temperature and volume of the box.

Key words. Vehicle distribution box, temperature field, natural Cool, heat dissipation optimization.

1. Introduction

The distribution box was the core part of electric vehicle, which played an important role in the power reception and distribution of on-board power. The design of the on-board distribution box was of great significance to the distribution and safety of the electric power.

The research of the distribution box was about distribution ability, fast filling technology and cabinet volume. Paper [1] presented a vehicle charging model, and through the power device, changed the output of the charging voltage and current waveform. In Paper [2], a new prioritize rule was designed to solve the problem of the existing power supply in power distribution system according the input conditions of vehicle-mounted equipment. But there was still some deficiency in the study of the modular design and the temperature distribution of the box.

Based on the existed vehicle distribution box, the research was focus on the

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reduction designed of the box volume by integrating the rectifier, DC conversion and high voltage distribution box together. And the temperature field simulation and improve design to optimize layout and the heat dissipation structure was presented. The simulation result showed the design rule was effective and system performance was improved.

2. Distribution Box structure design

The multifunctional distribution box was a fully enclosed box with an external structure size of 480mm *350mm *230mm. The side of the box has various types of wire holes for the energy transmission between internal and external terminal. Cooling fin was added in the bottom and other side to achieve better heat dissipation. As shown in in Fig.1.

Fig. 1. External structure of the distribution box

There were two layer in the box and a high temperature mica board between the two layers. The upper non-heat-resistant layer module mainly involved shunt, fuse, starting resistance used for high-voltage power distribution, fast charge control and communication control. There were conversion modules in the bottom layer. As the conversion modules was in the bottom layer, the design can isolate non-heat-resistant devices from the main heat source of converter and effectively reduce the overall size of the distribution box. As showed in Fig.2.

3. Simulation of Box Temperature Distribution

3.1. Analysis of Heat source

The heat of electrical components was usually generated by the various losses of electrical components, which include the resistance loss, ferromagnetic loss and dielectric loss. As taking DC to distribute power in the box, the ferromagnetic loss, dielectric loss and resistance loss can be neglected. Resistance loss power can be

Fig. 2. Internal structure of distribution box

reflected by its power loss, the equation is:

$$P_R = K_f I^2 \rho_0 \left(1 + \alpha\theta + \beta\theta^2 + \cdots\right) \frac{l}{A} \tag{1}$$

P_R was the heating power of the corresponding resistance; K_f was the additional loss coefficient (in the distribution box additional loss coefficient was similar to 1); α, β was the temperature coefficient of resistance; l, Arespectively, the conductor length, cross-sectional area The As shown in Fig.1, due to the non-heat-resistant components of the overall heat module was small which can be ignored; so hot spots of the whole box were mainly concentrated in the rectifier module.

3.2. Analysis of Heat Transfer Theory

In the energy balance and exchange principle, the heat would transmit to other medium, and heat transfer can be transmitted by three kinds: heat conduction, thermal convection and thermal radiation.

According to Fourier's law, the formula for constructing the heat conduction mathematical model was as follows:

$$q* = -\lambda \frac{\partial T}{\partial n} \tag{2}$$

In operation process of the distribution box, the converters would be heated slowly due to the role of power electronic devices. When the process was not finished, the temperature of the whole module changes with time and space, and the temperature field can be defined as the temperature field of non-transient conduction problem. In combination with (2), there were three dimensional control equations:

$$\rho c \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial y}\right) + Q \tag{3}$$

Thermal convection can be divided into natural convection and forced convection, because the distribution box was not forced cooling measures, and then forced convection was zero. Newton cooling formula:

$$q' = h_f\left(T_S - T_B\right) \tag{4}$$

The net heat generated by heat radiation between two objects follows the Steven-Boltzmann equation:

$$q'' = \varepsilon\sigma A_1 F_{12}\left(T_1^4 - T_2^4\right) \tag{5}$$

3.3. Simulation results analysis

In order to realize the simulation environment, the corresponding model was imported into ANSYS Workbench, and the following parameters were set: the direction of the fluid simulation was Z direction and the initial value of 0.15m/s; the gravity was the opposite direction of Z axis, The size of the box was 9.8m/s^2; the lower heat source of the box was about 4.25*10^5 W, the volume of the box was 0.027m^3, and the heat volume of each box should be set as 15740740 W/m^3; the contact material was ideal air; Compensation set as 350 steps; shell material was set as the traditional profile — steel, and temporarily on the box shell for any heat treatment. In the case where the confirmation curve converges within the number of steps, the following simulation was performed. As shown in Fig.3, the temperature of heat source in the bottom was the highest, reaching 542K (269). Due to the direct heat conduction of the heat source, the temperature of the middle partition was 353K (80??), the top of the distribution box shell temperature was relatively low, 325K (52). As shown in Fig.3, the red wire frame area was the battery management system (BMS), because the battery management system material insulation and the system has were own cooling device[3].

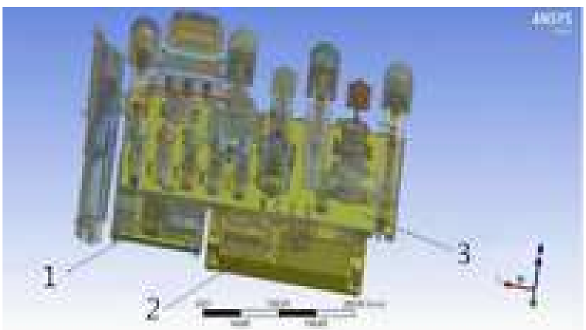

Fig. 3. Initial model temperature field distribution

4. Parameter optimization settings

Currently on the market power rectifier device involved in the composition of materials were generally SiC, and the material of the power rectifier device operat-

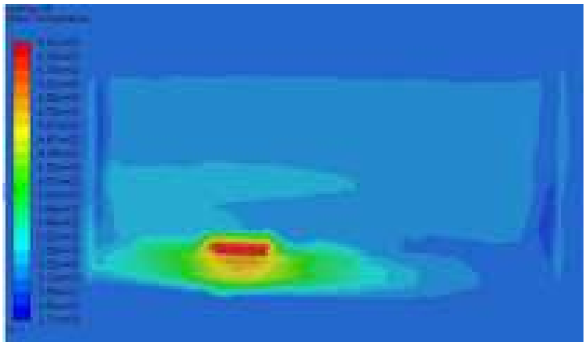

Fig. 4. Simulation of temperature field optimization in distribution box

ing temperature does not exceed 0-110[4]. If the box heat source module exceeds the temperature range, the distribution box would automatically power off through the protection, even more may cause the box burned. In order to ensure the reliable operation of the vehicle distribution box over a long period of time in the reasonable temperature range, this paper tried to make the heat of the distribution box (rectifier module) temperature 373K (100) through the non-forced cooling of the overall improvement and optimization of the distribution box, the temperature of the middle separator dropped to 338K (65), the shell temperature dropped to 333K (60); to ensure the safety of non-heat-resistant materials. According to the proposed structure and characteristics of the vehicle distribution box, the temperature field of the distribution box was optimized according to the simulation flow chart in Fig. 4.

4.1. Improvement of distribution box material

In [5], the heat dissipation method of the closed cabinet was mainly heat conduction in the case of the total heat generation. By the formula (2), (3) the temperature in the transmission direction when the transmission medium properties (such as specific heat capacity, density, etc.) must be linked to the transmission medium properties can be reflected in the thermal conductivity 373K (100), for example, for several common materials, thermal conductivity and its market price as shown in Table 1 below:

Table 1. Common material thermal conductivity and current market price

Material name	**silver**	**copper**	**aluminum**	**steel**	**cast aluminum**	**cast iron**
Coefficient of thermal conductivity(w/mK)	412	377	237	17	165	66
price (RMB/kg)	3800	45.4	13.5	4.5	6	3

Traditional distribution box materials commonly used steel. When the use of copper in the distribution box cooling requirements, the price of copper was more than ten times the price of steel, obviously does not meet the requirements of economic costs. Iron materials were good in the thermal conductivity, the price was in a more reasonable position, and the material itself was high hardness and suitable for distribution box shell material. At the same time, the cast aluminum material as the middle partition material, which would help reducing heat transmission to the shell through the convection. It would further improve the cooling efficiency. The simulation results were shown in Fig.5, the heat conduction in the box, the heat convection was obviously enhanced, and the temperature of the bottom heat source was obviously diffused to other parts in the box. The bottom heat source temperature up to 406K (133), although it had a significant drop of 136K (136??) compared with Fig.1. But the box within the power rectifier device failed to achieve reliable operation. So the other structures need optimize with improving the material together.

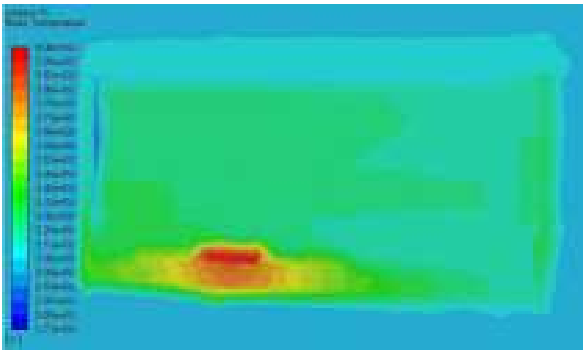

Fig. 5. Material improved model temperature field distribution

4.2. Add the shell cooling structure

On the basis of improved material on the box, the bottom heat source had a relatively good heat diffusion channel. But in the case of long-term operation, the heat concentrated in the box as shown in Fig.5, even if the box material has been improved. The traditional distribution box with air-cooled heat sink on the distribution box inside the forced cooling, the effect was obvious, low manufacturing costs, but not conducive to the distribution box of the seal. In this paper, the distribution box was designed to ensure the cooling efficiency and manufacturing costs on the basis of the used of closed heat sink. The three sides of the distribution box (excluding the port surface) used vertical bar non-hollow heat sink. The different heat dissipation shape and structure of the heat capacity was shown in [6-7], heat transfer factor j can be used to reflect a heat dissipation Capacity; heat transfer factor j the greater the greater the heat capacity. The shape and structure of the non-hollow fins referred to in this paper can be approximated as wave-shaped heats and as formula (6): a was the air flow rate, take 300mm/s; σ was the aerodynamic viscosity, taken $1.48*10^{-5}\mathrm{m}^2/\mathrm{s}$; l was the equivalent diameter; F_H was the heat collection height, taken 10mm; L_D was the cooling width, take 6mm; F_P was the heat gap, taken 15mm.

It can be seen that the heat transfer coefficient of the heat sink was linearly increased with the length of the heat sink. When the heat sink structure was known, the heat transfer factor can be increased by increasing the heat sink length (equivalent diameter) to speed up the heat dissipation. Combined with the box structure of the distribution box, the length of the heat sink in the surrounding case of the box body can be designed 200mm, At this time the heat transfer factor size was 148W/m^2?K. So the distribution box around the shell used vertical flying hollow heat sink. The length was 200mm, the width was 6mm, the height was 10mm, the interval was 15mm. There are two heat sink in the bottom, the horizontal and the vertical heat sink. The horizontal length was 450mm, vertical length was 300mm, width was 6mm, height was 10mm, interval was 15mm.The simulation results were shown in Fig.6. Compared with Fig.5, the material of the distribution box was improved, and the non-hollow heat sink was added to the shell. The heat source temperature was reduced by nearly 30K (30), and the heat dissipation of the inside heat of the box was promoted.

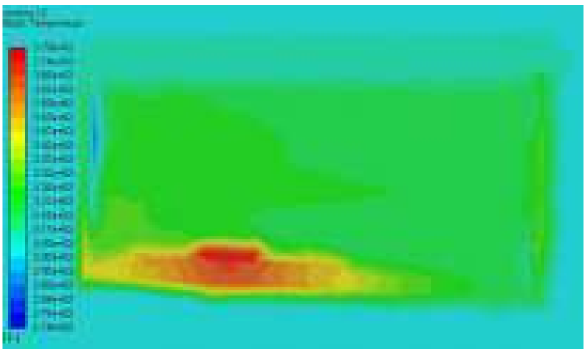

Fig. 6. Bottom for the horizontal, vertical heat sink simulation map (a) Horizontal type (b) vertical type

4.3. Optimization of Heat Dissipation Structure

Through the improvement of the front box material, adding the shell heat dissipation structure, the cooling efficiency was improved. But even so, the maximum heat source temperature up to 378K (105), which was still not conducive to the reliability of distribution box operation. In view of these defects, we optimized the structure of the bottom heat sink. Relative to the addition of horizontal or vertical heat sink, the inclined heat sink was used, which was the red wire frame shown in Fig.7. The heat sink specifications was 28mm in length, 6mm in width, 10mm in height, 9mm in vertical spacing, 8mm in transverse direction spacing. Simulation result was showed in Fig.8, the body heat source temperature was 365 K(92), which decreased 15K(15) compared with the results showed in fig.7. It can be seen that the optimization of the heat dissipation structure further promoted the heat dissipation function of the distribution box, and the empirical formula showed that the heat dissipation coefficient of the type heat dissipation box was $0.04\mathrm{W/cm}^2$.

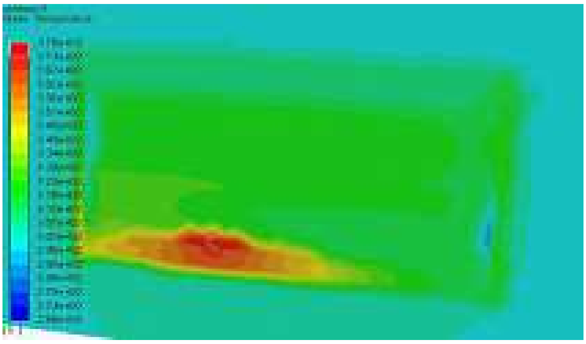

Fig. 7. Bottom oblique heat sink structure

Fig. 8. Simulation diagram of the bottom was the inclined heat sink

Table 2 was taken from the Fig.3, Fig.5, Fig.7 and Fig.8, which was the different temperatures of the various models. Obviously, in the process of model improvement, only the final thermal structure optimization model meets the requirements of this paper.

Table 2. Temperature values of various models in different location of distribution boxe

	Heat source	**Middle partition**	**shell**
I target model	373K(100°C)	338K(65°C)	333K(60°C)
II initial model	542K(269°C)	353K(80°C)	325K(52°C)
III material improvement model	406K(133°C)	346K(73°C)	320K(47°C)
IV additional heat dissipation structure model	378K(105°C)	329K(56°C)	318K(44°C)
V heat dissipation structure optimization model	365K(92°C)	325K(52°C)	331K(39°C)

5. Conclusion

A new multifunctional vehicle distribution box was designed in the paper. The improve design would reduce the volume and the temperature of box when the performance was ensured. The simulation results of the temperature field showed that the change of the box material, adding and improve of the external heat dissipation mechanism and its structure would accelerate heat dissipation and ensure the stable operation of the distribution box, which had strong practical reference significance in designing vehicle power box.

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