Dynamic and static analysis of the battery box structure of an electric vehicle

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Abstract. As an important device to protect batteries in electric vehicles, the dynamic and static performance of the battery box is closely related to the safety of the whole vehicle. Therefore, it is very important to study the stress and displacement distribution of the battery box under specific working conditions to optimize the design of the weak parts of the battery box’s stiffness and strength. At first, this paper establishes the three-dimensional entity model and finite element model, and the stress state of battery box under extreme conditions of steep turning and braking on uneven road surface is calculated. At the last, the static strength analysis is carried out on the battery box. By analyzing the modal characteristics and the harmonious response to vibration characteristics of the battery box, the dynamic performance of the battery box has been comprehensively mastered. Finally, based on the static and dynamic analysis results of the battery box, the weak points and unreasonable points are improved. The results show that the modified model has a good improvement effect and has basically reached the established design requirements, which verifies the rationality of the structural improvement scheme.

1. Introduction

Domestic and foreign research institutions and automobile enterprises have carried out a lot of research work on the structural design and optimization of battery boxes, dynamic and static characteristics analysis, etc. Zhao, H.W [1] carried out topology optimization based on variable density method for battery boxes of electric vehicles, and designed a new battery box structure. Yang, S.J [2] analyzed the dynamic and static characteristics of the battery box for an enterprise's electric vehicle. Sun, X.M [3] analyzed the dynamic characteristics and fatigue life of the battery pack of a certain type of electric vehicle by means of virtual experimental method, and carried out structural optimization. Zhang, H.B [4], based on the finite element analysis of the dynamic and static characteristics of the battery box of an electric vehicle, studied the stiffener of the battery box top cover.

Kazuo [5] introduced the experimental methods to measure the internal resistance of the battery, the thermal conductivity and the convection exchange system, and established the battery model based on the experimental results. Hartmann, M [6] optimized the structure of the battery box with the structural optimization software OptiStruct. When studying the battery box of electric cars, Klaus, H [7] achieved the purpose of reducing the weight of the battery box by optimizing the design space of the battery pack.
Castano, S \cite{8} established the air cooling system of the battery box by designing the cooling structure. Vaidya \cite{9} designed and simulated the thermoplastic battery box.

In this paper, the relatively comprehensive three-dimensional modeling of the battery box inside the vehicle is carried out. The analysis process is not limited to the static analysis of the battery box during the vehicle operation, and the vibration of the battery box is simulated. In the simulation process, we can clearly see the relationship between the strength of the battery box and the vibration frequency and amplitude, so as to find out the weak points of the battery box structure and optimize it.

2. Materials and method

2.1. The establishment of finite element model of battery box

The battery box studied in this paper is composed of top cover, side circumference, bottom plate, bracket and supporting foot, etc. Steel DC03 is selected to make battery box top cover, side circumference, bracket and plate, and steel SAPH440 is selected to make supporting foot. In the modeling process, CATIA is mainly used to construct 3d model, and assembly is mainly to constrain the axis and contact surface to achieve the purpose, as shown in Figure 1 and Figure 2. The top cover and side circumference are connected by bolts, while the bottom plate and side circumference, supporting foot and side circumference, bracket and bottom plate and other parts are connected by welding. There is no rigid connection between monomer and monomer, and between battery and side enclosure. The battery is positioned by contacting side enclosure.

![Figure 1. 3d diagram of battery box (a).](image1)

![Figure 2. 3d diagram of battery box (b).](image2)

After the 3d solid model of the battery box is established in CATIA, it is converted into IGES format and imported into Hypermesh software for grid division. Then, it is necessary to carry out geometric cleaning of the model. As the battery box is mainly composed of a series of stamping thin-wall parts, so the shell element should be considered for grid division. The size of the unit should be determined according to the actual shape of the structure. The node coupling method is used to simulate spot welding, and the BEAM element in Hypermesh is used to simulate welding spot during static and modal analysis. The top cover and side circumference are connected by bolts, which can be simulated by using rigid elements, as shown in Figure 3. The welding seam is usually rigidly connected and simulated by coupling the joints at the welding seam of the two plates together. The simulation mode of welding seam between the supporting foot itself and the supporting foot and the supporting frame is shown in Figure 4.

![Figure 3. Bolt simulation mode.](image3)

![Figure 4. Weld simulation mode.](image4)

![Figure 5. Finite element model of battery box.](image5)
The thickness and material property information of each component are added to their respective finite element models, thus the finite element modeling of the battery box is completed, as shown in Figure 5.

2.2. **Dynamic and static characteristics analysis of battery box**

The stress and deformation of the battery box under typical working conditions are obtained by using the finite element software ANSYS.

2.2.1. **Battery box static analysis.** Since the acceleration of the car is small at the beginning, only three conditions, namely road bumping, emergency braking and sharp turning, are considered. When it comes to specific analysis, the combinations of road bumping + emergency braking, road bumping + sharp turning are considered, and the boundary condition is the constraint of all degrees of freedom at the foot. When loading is added, the impact load generated by the battery block is equivalent to static load evenly applied to the inner and bottom nodes of the battery box. The effect of the battery on the soleplate, the side enclosure and the partition is applied to the joints of the soleplate, the side enclosure and the partition in a manner of distributing force.

All the degrees of freedom of the center node at the bolt hole are restrained, and the finite element analysis software ANSYS is submitted for calculation. Figure 6 and Figure 7 show the stress cloud diagram and deformation displacement of the battery box bottom plate and side enclosure when the car is driving on a bumpy road when braking sharply. Figure 8 and Figure 9 show the stress cloud diagram and displacement of the battery box bottom plate and side circumference when the car is driving on a bumpy road when making a sharp turn.

When driving, the maximum stress on the battery box is 209.02MPa under the condition of abrupt braking on bumpy road, mainly at the corner of the battery box side, and it is 223.98MPa under the condition of sharp turning on bumpy road. The maximum strain of the battery box is 0.46mm, which is mainly at the bottom of the box. The maximum stress suffered by the battery box under the above two working conditions is all greater than the yield limit of steel DC03--170Mpa, used as bottom plate and diaphragm material, which needs to be improved.
2.2.2. Modal analysis of battery box. Modal analysis is mainly used to calculate the low-order modes of the battery box, where the constraint mode of the battery box is to limit all degrees of freedom of the nodes around the anchor bolt hole. The several parts of the first seven natural modes are shown in Figure 10–13.

Figure 10. Modal shape  Figure 11. Modal shape  Figure 12. Modal shape  Figure 13. Modal shape

1. 5. 6. 7.

The first seven orders of the battery box are mainly the vibration of the upper cover of the box, which indicates that the stiffness of the structure is relatively low compared with other parts. Generally speaking, the battery box structure is relatively reasonable.

2.2.3. Analysis of harmonic response of battery box. To simulate the vibration analysis of the battery box on the test bench, the mounting hole of the battery box supporting foot and the nearby mounting hole are restrained completely. The structural damping of the battery box is set at 0.03, the starting frequency is 20Hz, the termination frequency is 100Hz, the step length is 2Hz, the number of steps is 40 steps, and an acceleration load of 1g is applied in the vertical direction of the battery box. Figure 14 and Figure 15 show the cloud diagram of internal stress distribution and deformation displacement of the battery box. It can be seen from the Figures that the maximum stress occurs at the side circumference of the battery box, where the stress is 39.37mpa, which is far less than the yield limit of steel DC03. The maximum displacement is 0.63mm in the middle of the cover.

Figure 14. The stress distribution cloud diagram of the battery box.  Figure 15. Deformation and displacement cloud image of the battery box.

3. Result

In the structure of the battery box, there are a large number of sheet metal parts, such as top cover, side circumference and bottom plate, which must meet certain requirements of strength, stiffness and mode to ensure that the battery box has normal bearing capacity and anti-deformation force. According to the analysis results of the above three working conditions, in addition to the phenomenon of local stress concentration and large stress value, the overall stress has room for improvement of the design. Therefore, the design idea of the improvement is determined: to improve the structure of the stress concentration area.

In the static analysis of the battery box, the stress at the corner of the side enclosure bottom plate exceeds the material yield limit, which is because the unreasonable side enclosure structure is easy to cause stress concentration. The improvement of it is shown in Figure 16. As the side enclosure structure changes, the top cover and bottom plate should also be correspondingly changed, as shown in Figure 17 and Figure 18.
All the changed parts are assembled and saved into a format acceptable to the finite element software Hypermesh. Then the model is divided into grids.

Figure 19–22 show the stress cloud diagram and deformation displacement of the battery box bottom plate and side enclosure when the car is driving on a bumpy road when braking sharply and making a sharp turn.

The maximum stress of the new battery box is 138.46mpa when the electric vehicle is in a bumpy braking condition, and the position is at the welding place between the side enclosure and the bottom plate. When the electric vehicle is in a bumpy sharp turning condition, the maximum stress of the new battery box is 150.17mpa, meeting the yield strength of steel DC03 and improvement requirements.

The 5th and 6th modal shapes of the new model are shown in Figure 23 and Figure 24. The natural modal shape is floor vibration.

When the new battery box is in steady state vibration, the displacement cloud diagram of its top cover and the displacement time curve of the center node are shown in Figure 25 and Figure 26. By comparison, it can be seen that the maximum displacement in the middle of the top cover is reduced by 50%, and the
anti-deformation ability of the top cover is slightly improved. The maximum stress is basically unchanged, and the new battery box still meets the vibration requirements.

Figure 25. The stress distribution cloud diagram of the new battery box.
Figure 26. Deformation and displacement of cloud image of the new battery box.

4. Conclusion
In this paper, the dynamic and static characteristics of the battery box of an electric vehicle are analysed, and according to the results, the structural improvement scheme of the battery box is made. By analysing the stress of battery box in the common limit state of electric vehicle, designers can have a preliminary understanding of the static performance of battery box. The modal calculation results of the battery box can enable engineers to find the defects of the dynamic characteristics of the battery box in time. The simulation calculation and analysis of the harmonic response vibration experiment of the battery box show that the maximum stress appears in the battery box, but it is less than the allowable stress of the material. According to the simulation results of the dynamic and static characteristics of the battery box, it is decided to improve the design of the side enclosure and the bottom cover. It is proved that the new battery box has higher static characteristics than the original battery box, higher natural frequency of the first 7 orders, and higher anti-deformation ability of the bottom plate under harmonic vibration response.

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