Simulation and Optimization of Body Structure of Electric Vehicles with Offset Collision

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Abstract. In recent years, as the rapid growth of the number of electric vehicles, people have more and more requirements on the safety performance of vehicles. However, compared with fuel vehicles, the structure of electric vehicles has its own particularity which makes the safety design of body structure more difficult. Thus, improving the passive safety of electric vehicles and protecting the passengers from injury in the collision to the greatest extent have become important issues for the automotive industry. This paper simulates the frontal offset impact simulation analysis of a certain type of SUV, and analyzes the safety performance of the vehicle from the perspective of member protection. The front side member structure and impact energy absorption which affect the passive safety of the whole vehicle are optimized and improved. The finite element model of the whole vehicle is rebuilt, and the frontal offset impact simulation test is carried out to verify the effectiveness of the optimization scheme.

Keywords: Electric vehicle; Passive safety; Body structure; Structural optimization; Offset collision.

1. Introduction

Due to the structural characteristics of electric vehicles, in order to place larger power batteries, we should lengthen the wheelbase and shorten the rear suspension as far as possible when designing. As a result, the space in the front compartment is compressed and the front side member can not conduct better conduction force. It is easy to bend the root of front side member and push it into the cockpit, resulting in a large amount of intrusion. Therefore, improving the crashworthiness of electric vehicles has become an important topic, and the front side member is also an important part of energy absorption. Scholars at home and abroad have done a lot of research on the optimization design of the front side member. Tu Wenbing and others explored the influence of different cross-sections on the impact performance of the front side member. Wang Nan designed the front-end structure of the vehicle body in front of overlap rate collision. In the paper of frontal crash safety analysis and optimization of a micro electric vehicle [4], Kong Guodong carried out thickness optimization of front parts of pure electric vehicles and structural optimization of front side member.

2. Rigid Barrier and Parameter Setting of Vehicle Model

A certain type of SUV electric vehicle is selected as the research object, and the finite element modeling is carried out by using HyperMesh. The body length is 3905mm, the width is 1670mm and the height is 1700mm. According to the IIHS frontal offset impact regulation, the initial speed is set at 64km / h, i.e. 17778mm / s. The battery is located under the rear seat and has a protective structure around it. It hardly deforms in the frontal bias impact test. It can be set as a rigid body in the modeling.
process. In addition, according to the electric vehicle modeling method of Tao Ze, the body is simplified. The CAD model was simplified and imported into HyperMesh for mesh generation. The 2D mesh of thin shell sheet metal parts and solid mesh of battery and suspension were carried out. The number of parts, number of units and quality of the whole vehicle model are counted. The pre-processing process of frontal offset impact is completed. In the process of vehicle simulation, the ground does not deform, which is generally simplified as a rigid wall. As shown in Fig.1.

![Vehicle model](image)

**Figure 1.** Finite element model of vehicle.

Vehicle parameters: the vehicle mass is 738kg; the total number of parts is 568; the total number of units is 450124; the total number of nodes is 434082.

3. Simulation Analysis of Offset Collision for Electric Vehicle

3.1. Vehicle Energy Change Curve

Using computer to simulate the process of vehicle collision, the obtained results need to get the reliability certification before use. This is because the collision process of the real vehicle follows the two laws of conservation of energy and mass. In the calculation with LS-DYNA, hourglass energy and mass will increase, which will lead to the difference between the calculation results and the actual situation. In the process of vehicle collision, most of kinetic energy is absorbed by vehicle parts and converted into internal energy, a small part into hourglass energy, and the total energy remains unchanged. Fig.2 shows the energy change curve.

![Energy change curve](image)

**Figure 2.** Energy change curve.

3.2. Vehicle Acceleration Change Curve

Acceleration curve is an important standard to verify the effectiveness of vehicle crash, and also an important index to evaluate dummy head and chest injury. It is found that there is a linear relationship between the acceleration peak value and the acceleration of the head and chest of the occupant. The greater the acceleration amplitude is, the greater the acceleration of the dummy head and chest is, and the greater the impact on the injury of the occupant. It is generally believed that in frontal impact, when the peak acceleration is less than 40g, the occupant will not be seriously injured. Fig.3 shows the acceleration curve.

In Fig.3, red represents acceleration time history curve of impact side, green curve represents acceleration change of non impact side, and blue thick line is analysis auxiliary line. As can be seen from the figure, it is proved that the vehicle has good crashworthiness, but the duration of CD phase is long, which indicates that the dummy has a long time under the action of large impact acceleration during the collision process, and has room for improvement.
3.3. Vehicle Deformation Analysis
The frontal offset collision time is 150ms. The vehicle collision deformation is divided into six time points, which are 0ms, 30ms, 60ms, 90ms, 120ms and 150ms.

![Vehicle Deformation](image)

**Figure 4.** Front view of vehicle deformation.

It can be seen from Fig.4 that the energy absorption stage of front side member is 0ms ~ 60ms, and the front side member still has good energy absorption effect at this time. However, after 60ms, the front side member was completely crushed. The period from 120ms to 150ms is a stable period. During this period, the parts on the vehicle are no longer deformed, the vehicle offset reaches the maximum, and the values tend to be stable, and the collision process ends.

3.4. Energy Absorption Analysis of Front Side Member
According to the provisions of C-NCAP, the assessment of dummy injury value in frontal offset impact test can be divided into four parts: head and neck, chest, thigh and knee, leg and ankle. The front side member is the most important part of energy absorption in vehicle collision. The research on the energy absorption of front side rail can make clear their influence on vehicle safety, which has important guiding significance for planning the overall Crashworthiness of automobile. According to the data, the energy absorption of the left front side member is the largest, reaching 25.8kj, accounting for 21.86% of the total energy. In the offset impact test, its energy absorption effect has not reached the generally accepted industry standard. Secondly, the energy absorption of the front cabin girder structure reached 8.98kj, accounting for 7.61% of the total energy. The right front side member on the non collision side absorbed the least energy in the test, which almost did not work. In the offset crash test, as the main energy absorbing component, the energy absorption effect of the left front side member directly affects the safety performance of the whole vehicle.

4. Optimization Research and Simulation Verification

4.1. Optimization of Energy Absorption Effect of Front Longitudinal Beam
To optimize the energy absorption effect of the front side member, the key point is to improve the energy absorption of the front side member, without adverse effects on the components connected
with it. To optimize the structure of the front side member, we should start from improving the energy absorption efficiency of the front section of the front side member, strengthen the strength of the middle and rear section of the front side member, and improve the bending resistance of the side member, so that the front side member can better transmit the force backward in the collision, and avoid the energy concentration at the root of the side member.

Optimization scheme design of front side member. Option 1: Add stiffeners to the bend area. Option 2: Add support plate at bending position. Option 3: Take local structural weakening to the middle and rear area of front longitudinal beam. Option 4: Increase the width and depth of the second collapse inducing groove.

Determine improvement plan. The above four optimization schemes on the front longitudinal beam structure constitute 16 combinations. If all the tests are verified, 16 tests need to be carried out, and the task is relatively heavy. In the test analysis, for the test analysis with less than two factors, the comprehensive test method can be used to determine the test scheme.

It can be seen from Table 1 that eight tests are needed to find the best horizontal combination of four factors affecting the energy absorption effect of the front longitudinal beam on the impact side by using the scheme of orthogonal test design. In order to ensure that the optimized results are in accordance with the uniqueness of the frontal offset impact, except for changing the structure of the front side member, other test conditions remain unchanged. According to the test scheme in Table 1, eight vehicle crash tests were carried out. The energy absorption and maximum bending angle of the front side member on the impact side were recorded in each test. The statistical results are shown in the table below.

| Number of tests | Test scheme | Maximum energy absorption(KJ) | Percentage of total energy |
|-----------------|-------------|-------------------------------|---------------------------|
| 1               | A1B1C1D1    | 25.83                         | 21.70%                    |
| 2               | A1B1C2D2    | 21.34                         | 17.93%                    |
| 3               | A1B2C1D2    | 28.68                         | 24.10%                    |
| 4               | A1B2C2D1    | 22.52                         | 18.92%                    |
| 5               | A2B1C1D2    | 29.97                         | 25.18%                    |
| 6               | A2B1C2D1    | 24.23                         | 20.36%                    |
| 7               | A2B2C1D1    | 30.87                         | 25.94%                    |
| 8               | A2B2C2D2    | 25.21                         | 21.18%                    |

In terms of the total energy absorption of the front side member, adding reinforcement plate and support plate to the bending area of the front side member can make the front side member absorb more energy and play a greater role in energy absorption in the frontal offset collision.

4.2. Improved Vehicle Offset Crash Simulation Test

For the optimization scheme of frontal overlap collision, it is not only necessary to play the relevant optimization effect in the frontal offset impact test, but also need to ensure that the safety of the vehicle can not be reduced in other conditions.

Acceleration curve of impact side. In offset impact, the acceleration change of impact side is the most obvious. The acceleration curve of impact side in two tests before and after optimization is obtained as shown in Fig.6.
It can be seen from the acceleration curve in Fig. 6 that the optimization of the model structure makes the acceleration change curve more gentle, the time to reach the peak value is delayed by about 5ms, and the maximum value is reduced from 30.7g to 28.9g, which is reduced by 5.86%. In addition, the optimization scheme reduces the unloading force time of the whole vehicle.

### Figure 7. Energy absorption curve of front side member before and after optimization.

After optimization, 5.04kJ more energy is absorbed than before, and the energy ratio is increased by 4.24%. This part of energy absorbed is mainly due to the addition of reinforcing plate and support plate at the bending point. The two plates absorbed 2.32kJ of energy due to compression deformation. Therefore, the front longitudinal beam actually absorbs 2.72kJ more energy under this optimization scheme.

### 5. Conclusion

In this paper, the crashworthiness of an electric vehicle with small overlap ratio is simulated and analyzed, and the vehicle body structure is optimized and designed to improve the crashworthiness of the whole vehicle. This paper introduces the key steps of building the whole vehicle model, improving and verifying the front longitudinal beam and key parts. In the research on the crashworthiness of the vehicle body structure in offset impact, the front longitudinal beam bending area is added with support plate and reinforcing plate to make the front longitudinal beam absorb energy to achieve the best scheme, and the energy absorption box is placed at the bumper. The optimization results of the improved vehicle offset collision show that the optimization measures for the front longitudinal beam and other key parts improve the crash safety of the vehicle, and the optimization scheme is practical and effective.

### References

[1] Xie Hui, Tao Ze, Li Fan. Lightweight optimization design of electric vehicle front longitudinal beam [J]. Computer simulation, 2017, 34 (3): 142-146.

[2] Tu Wenbing, He Haibin, Luo Ya, Wang Chaobing. Analysis of the impact of cross section shape on the crashworthiness of front longitudinal beam [J]. Computer simulation, 2017, 34 (11): 123-127.
[3] Wang Nan. Front end structure design of vehicle body in front of 25% overlap rate collision [D]. Changchun: Jilin University, 2018

[4] Kong Guodong. Frontal crash safety analysis and optimization of a micro electric vehicle [D]. Changsha: Hunan University, 2017.

[5] Tao Ze. Research on frontal crash safety simulation of a mini pure electric car [D]. Changsha: Hunan University, 2016.

[6] Feng X, Dengfeng W, Zhengdong M. Lightweight optimization of the front end structure of an automobile body using entropy-based grey relational analysis[J]. Proceedings of the Institution of Mechanical Engineers, Part D: SCISCOPUSEI, 2019, 233(4): 917-934.

[7] Xiong Feng. Research on multi-objective collaborative optimization design method of vehicle body structure lightweight and crashworthiness [D]. Changchun: Jilin University, 2018.

[8] Shang en Yi, Zhou Dayong, Li Yueming, Zhang Yi. Study on abnormal chest acceleration of Q3 dummy in frontal crash test [J]. Automotive technology, 2020 (3): 45-49.

[9] Kuang Fang, Chen Lin, Liu Hongda, Zhang Huiyun, Chen Lin. comparative study on driver leg injury in different types of offset collision [J]. Automotive technology, 2020 (2): 65-69.

[10] Xu Tao, Liu Nian. Optimization of structural parameters of automobile energy absorption box with rolling thickness gradient [J]. Vibration and impact, 2018, 37 (10): 269-274.