Static Strength Analysis and Scheme Optimization of Mounting Seat of Energy Absorption Structure on Aluminum Alloy Metro vehicle

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Abstract. The strength of the mounting seat under static strength conditions determines the stability and reliability of the energy-absorbing structure on the metro vehicle. In this paper, five improvement schemes were proposed and the optimal scheme was determined under the worst static strength load condition for the mounting seat of energy-absorbing structure. The results showed that reinforcements had no obvious effect on the stress distribution at the weld seam of the mounting seat. According to the characteristic of transferring deformation and force, the effect of changing the position of the weld seam and moving it away from the stress concentration area was more feasible method.

1. Introduction

Since the beginning of the 21st century, developing urban rail transit has become an inevitable choice to relieve traffic pressure for the large and medium-sized cities in China, with the rapid development of China's economy, the increasing growth of urban population and the acceleration of urbanization [1]. So far, thirty five cities across the country have opened metro whose mileage has reached at approximately 5,250 km and there are still a large number of lines in the planning demonstration. With the rapid development of the rail transit industry, people are increasingly demanding the better and better overall performance of the car body [2]. So it is necessary to analyze and check the strength of the car body for the new metro produced for the newly-built line, which needs to meet more stringent standards.

The front end energy-absorbing structure of the metro vehicle is a very important component which can absorb most of the collision kinetic energy and prevent the vehicle overlapping to minimize casualties and property damage under the event of an accidental collision [3]. Therefore, to ensure the stability and reliability of the energy-absorbing structure which can work safely in the dangerous situation, first of all, it must meet the standard requests under static strength conditions. The energy-absorbing structure may fall off from some metros due to the design defects during normal operation and it may lead to a serious impact. Before the collision occurring, the energy-absorbing structure may not work due to the detached mounting seat, which will have an adverse impact on the safety of drivers and passengers.

In this paper, taking a metro vehicle as the research object, static strength were analyzed with finite element method according to EN12663-2010 standard [4-6]. At the same time, the improvements of
the mounting seat of the energy-absorption structure were put forward based on the calculation results, and according to the analysis of transferring force and deformation, the best improving scheme was given comparing a variety of solutions.

2. Characteristics of the car body structure
The main structure of the aluminum alloy metro car body is composed of five parts: the bottom frame, the side wall, the end wall, the roof and the driver's cab. The bottom frame of car body is a structure without middle beam, mainly composed of traction beam, body bolster, coupler seat and side beam. The car body adopts all-aluminum structure which is connected to the bogie frame by four air spring seats on first end and second end body bolsters. Due to the overall cylindrical structure, the transmission of force is integral bearing behavior. That is, when the key parts of the car body are subjected to the external variable load, the corresponding deformation is caused through the welded profiles which can transfer external local loads to every part of the car body [7].

3. Finite element calculation of car body structure

3.1 Finite element model
In this paper, Hypermesh software was used to establish finite element model. Most of the structures were meshed with four-node shell elements about 20mm, and massive equipments were simulated by MASS21 elements which were hanged in the corresponding position with the RBE3 elements. The remaining masses were paved on the top floor using the MASS21 elements. The car body finite element model included 2,183,206 elements and 1,663,561 nodes.

3.2 Static strength loadcases
According to the EN12663-2010 standard, 34 static strength loadcases were calculated for the metro vehicle. Considering the worst case, only two conditions were considered in this paper and the detail load application conditions could be seen in Table 1.

Table 1. The static strength loadcases

| Name | Load | Constraints |
|------|------|-------------|
| The synthesis condition of 800KN compression force and vertical load AW3 (AW3: The vertical load is the vehicle's own weight under the preparation condition and the overloaded passenger' weight) | 1.800KN compression force 2.FEM masses were applied in the form of gravitational acceleration, the rest of the masses were paved on the top floor | 1.Constrained longitudinal displacement at second end coupler seat; 2.Constrained lateral displacement at kingpin; 3.Constrained vertical displacement at 4 air springs. |
| The synthesis condition of 640KN tensile force and vertical load AW3 | 1.640KN tensile force 2.FEM masses were applied in the form of gravitational acceleration, the rest of the masses were paved on the top floor | |

3.3 Static strength calculation and analysis
After calculating finite element model and analyzing the static strength of the car body, the maximum stress point appeared on the coupler seat which was less than the allowable stress of the material. Under two static strength conditions, the unqualified stress points appeared at the weld of the mounting seat, therefore, it was necessary to optimize the weld structure to meet the design requirements.
4. Optimization and improvement of the mounting seat

4.1 Improvement schemes

The poor stress distribution was clearly shown at the welding seam of the mounting seat of energy-absorbing structure by analyzing the most dangerous working conditions. The whole deformation of the mounting seat was studied. The force transferring direction was from first end sill to the front sill, and then it acted on the mounting seat. The stress on the welding seam of the mounting seat on the side of the draft sill was bigger than the allowable stress. Therefore, to get a reasonable structure, it was necessary to reduce and restrain the deformation between the first end sill and the mounting seat, so that the force could be transferred from the draft sill to the mounting seat normally.

According to the calculation results, it was needed to improve the structure of the mounting seat. First, the surface area of a draft sill and front sill should be enlarged to transmit the force better. After calculation, it had been found that the stress value of the front-end sill was 150MPa, which was the same as the previous results. The design requirement had not been met by increasing the connection area between the cover plate and the front end sill. Therefore, five improvement schemes were proposed for this structure (as shown in Table 2).

Table 2. Original plan and improvement plan

| Original plan | Plan 1 | Plan 2 |
|---------------|--------|--------|
| Single-sided welding was used in the mounting seat of energy-absorbing structure and the front sill as shown in Fig.4.1(a). | Adding an inclined support plate between the front sill and draft sill as shown in Fig.4.1(b). | Stiffening longitudinal girder was added between the front end sill and the draft sill as shown in Fig.4.1(c). |
| Plan 3 | Plan 4 | Plan 5 |
| Adding a 20mm- thick plate behind the mounting seat as shown in Fig.4.1(d). | An L-shaped support plate was added between the front sill and the floor as shown in Fig.4.1(e). | The mounting seat and plate were made into an integral part to avoid the occurrence of welding seams as shown in Fig.4.1(f). |

(a) original plan  
(b) plan 1  
(c) plan 2  
(d) plan 3
4.2 The calculation results of the improvement plan

The calculation results of original plan and the five improved plans were shown in Table 3.

| Number | Scheme       | Calculation results (MPa) | Allowable stress (MPa) | Comment        |
|--------|--------------|---------------------------|------------------------|----------------|
|        |              | AW3+800KN compression force | AW3+640KN tensile force |                |
| 1      | Original plan| 150                       | 88                     | 115            | Welding seam  |
| 2      | Plan 1       | 150                       | 86                     | 115            | Welding seam  |
| 3      | Plan 2       | 131                       | 74                     | 115            | Welding seam  |
| 4      | Plan 3       | 162                       | 95                     | 115            | Welding seam  |
| 5      | Plan 4       | 162                       | 95                     | 115            | Welding seam  |
| 6      | Plan 5       | 162                       | 95                     | 250            | Base material |

Stress nephograms of the original plan were shown in Fig. 4.2(a)-4.2(b).

In plan 1, a 10mm thick inclined support plate was added near the draft sill to restrain the deformation of the front sill. The calculation results showed that there was no any change compared with the original plan results and this plan had no effect.

In plan 2, a stiffening longitudinal girder between the front sill and draft sill was added to further restrain the deformation of the front sill. The stress on the mounting seat was better than in plan 1. However, the stress at the welding seam still exceeded the allowable stress and still failed to meet the requirements.

In plan 3, changing the front structure was based on the first two plans. In this plan, the length of the collision sill was increased and the floor of the cab was changed to a corrugated one, as well as the inclined support plate in plan 1 was removed. A plate 420mm long and 20mm thick was retained between the energy-absorbing structure and the front sill. The stress on the weld of the mounting seat was increased comparing to the previous one, which obviously did not conform to the calculation requirement and need to be further improved on this basis.

In plan 4, a 10mm-thick L-shaped support plate was added in the middle of the draft sill to reduce the deformation of the front sill. The calculation results of weld stress were basically consistent with plan 3. It showed that the L-shaped support plate did not have any effect.

On the basis of summarizing the previous four plans, it was found that strengthening the front-end sill had certain effect on reducing the stress at the welding seam of the mounting seat, but it still failed to meet the calculation requirements. Considering that the allowable stress value at the welding seam of aluminum alloy material is 100MPa and at the base material is generally more than 200MPa, therefore, avoiding the occurrence of welding seams in the stress concentration area was a reasonable
modification plan.

In plane 5, it was based on the premise of avoiding welding seams. The installation seat and the reinforcing plate were made into one component. In this way, the welding seam in the stress concentration area could be avoided and the stress situation on the mounting seat could be effectively changed. Although maximum stress value increased according this plan, the stress point was far away from the welding seam and it occurred on the base material of mounting seat which met the design requirements. The Stress nephograms of the calculation results were shown in Fig.4.2(c)-4.2(d).

![Stress nephograms of the calculation results](image)

(a) original plan stress distribution of load AW3+800KN  (b) original plan stress distribution of load AW3+640KN
(c) plan 5 stress distribution of load AW3+800KN  (d) plan 5 stress distribution of load AW3+640KN

Figure 4.2 Original plan and plan 5 stress distribution

5. Conclusion

Static strength analysis of aluminum alloy car body and the mounting seat of energy-absorbing structure were studied and results showed that:

(1) Two static strength analysis of the metro vehicle was studied according to the EN12663-2010 standard. The maximum stress point appeared on the coupler seat which was less than the allowable stress of the material. But the stress value at the welding seam of the mounting seat exceeded the allowable value, it was necessary to optimize the weld structure to meet the design requirements.

(2) Five improvement schemes were proposed based on the calculation results. If there was an inevitable welding seam in the stress concentration area, only through adding reinforcement, the welded component could be turned into an integral component to make maximum stress point far away from the welding seam. The plan 5 of improved structure was reasonable optimization scheme which met the design requirements.

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