Vibration test and structural optimization analysis of axle box bracket

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Abstract: The bracket cracked and ground cable broken have occur to axle box many times on certain line metro vehicle. In view of this kind of accident, vibration test, vibration analysis, modal analysis as well as structure optimization are carried out for the axle box bracket of the subway. The test results show that the first transverse bending mode of the bracket is excited by the line vibration, so, it breaks due to vibration fatigue in the resonant state. The simulation results show that the modal frequency can be increased by thickening the bracket and optimizing its structure, so that avoiding resonance phenomenon and increasing its fatigue life. Finally, experiments are carried out to further verify the conclusion, and the structure that performs best can be chosen among multiple optimizations.

1. Introduction
Cantilever structure is widely used in the design of rail vehicles and is also a common type in mechanical structures. Under the effect of complex vibration, noise, temperature, humidity and other working environment factors, the structural failure of cantilever structure often occurs, and resonance is the fastest and most effective effect among the structural failures. Resonance is also the most common phenomenon due to its structural characteristics. The cantilever structure refers to: one end of the beam is a fixed support that does not have axial, vertical displacement or rotation, and the other end is a free one (It can provide forces parallel to the axle and perpendicular to the axle). In the force analysis of engineering mechanics, it is a typical simplified model. In practical engineering analysis, most of the stressed parts can be simplified as cantilever beams.[1-3]

Axle box bracket is widely used to fix the parts such as grounding cable in the design of axle end parts of urban rail transport, which proved to be effective. However, the maintenance of urban rail transport line cannot be guaranteed in time, so the line conditions gradually deteriorate with the increase of the operating years. Factors such as track irregularity, deterioration of ballast, mismatching of operating speed and curve radius, etc. leads to the deterioration of the interaction between wheel and rail. The wheel-rail excitation to the vehicle becomes larger and so does the abnormal vibration of the axle box.[4] As a cantilever structure, it will amplify the vibration and cause fatigue fracture and other accidents, which will endanger the safety of the vehicle. The fixed part of the bracket will vibrate abnormally affected by resonance, which will be further damaged based on the initial damage.[4-5]

The main reason for the structure failure of axle box bracket is the fatigue failure of mechanical components caused by resonance, so it is necessary to test its vibration, stress and other indicators. After the preliminary results are obtained, modal analysis and structural optimization methods are combined to prepare for the next comparative test of selection.[6] In order to improve the test efficiency, multiple axle box bracket optimization schemes were selected for the second stage test, and the optimal bracket structure will be selected by means of comparative test.[7]
2. Initial test and analysis
The axle box brackets cracked successively after the metro vehicle running about 300,000km. In view of this phenomenon, method such as testing the vibration environment, testing the stress state and real-time monitoring are used on site to solve this problem. The test scheme is shown in Figure 1 and Figure 2.

![Bracket vibration test and strain test position](image1)

![Axle box vibration test position](image2)

2.1. Time domain analysis
The vibration data on test line includes the vibration acceleration of axle box and bracket in longitudinal, transverse and vertical directions.

![Vibration signal-Axle box(a)](image3)

![Vibration signal- Axle box bracket(b)](image4)
During the overall operation, the vibration acceleration value of every axle box and axle box bracket at measuring points generally maintained in the range of 20g~30g, but there are shock phenomena in some parts, and the maximum acceleration value is about 50g.

2.2. Frequency domain analysis
Figure 5 shows the FFT result of partial data of the original signal. It can be seen that the main vibration frequencies of measured points on axle box and cable bracket of Mp car and Tc car are all around 100Hz, and the vibration amplitude of the bracket is greater than that of the axle box, so the vibration of the bracket is amplified.

3. Modal analysis and structural optimization
In order to determine the vibration characteristics of the bracket structure in the working environment, the modal analysis and calculation are carried out, as Figure 6. The constraint was modified repeatedly to make the simulated modal frequency basically consistent with the measured modal frequency, that is, the simulation model was verified. Then the same simulation method was used to optimize the bracket structure, and the appropriate optimization results can be selected from the perspective of structure and vibration isolation.
3.1. Modal analysis
The modal calculation results are shown in Table 1.

| Mode | Frequency /Hz | Modal description       |
|------|---------------|-------------------------|
| 1<sup>st</sup> | 101.33        | First transverse bending |
| 2<sup>nd</sup> | 496.29        | First torsional         |
| 3<sup>rd</sup> | 711.22        | First longitudinal bending |
| 4<sup>th</sup> | 1033.00       | Second transverse bending |
| 5<sup>th</sup> | 1810.90       | Second reverse          |

3.2. Optimization measures
The simplest and most direct way to improve the first mode frequency of the axle box bracket is to increase the mass of the bracket and optimize its structural model. By increasing the thickness of the bracket, the modal frequency is increased through the preliminary analysis of simulation analysis. As for the response of the running line vibration, it needs further verification. The types of designed bracket are shown in Table 2.

| Location | Type of statistical value | 2# | 3# | 5# | 8# |
|----------|----------------------------|----|----|----|----|
| Size     | thickness (mm)             | 15 | 13 | 10 | 8  |

4. Comparison validation (The second stage test)
In the second stage test, four axle box positions were selected for line testing, equipped with different axle box brackets. The lateral acceleration of the axle box and bracket is mainly concerned.

4.1. Time domain analysis

![Figure 7. Time domain curves of lateral vibration acceleration of each axle box](image)

![Figure 8. Time domain curves of lateral vibration acceleration of each bracket](image)
4.2. Vibration transfer

According to the results of time frequency signal analysis, the main frequency of the lateral vibration of the 4 axle boxes is about 90Hz in the whole process, the main frequency and amplitude of the vibration of 2#, 3# and 8# brackets are basically consistent with the corresponding axle boxes. The main frequency of the vibration of 5# brackets is about 105Hz in the whole process. The vibration amplitude is greater than that of 5# axle box.

During running process, # 5 bracket resonates with the axle box, and the lateral vibration is significantly amplified. The lateral vibration of # 8 bracket is also amplified relative to that of the axle box, but the amplification factor is less than that of # 5 bracket. No obvious resonance occurs to # 2 and
4.3. Statistical analysis

| Location | Type of statistical value | 2# | 3# | 5# | 8# |
|----------|---------------------------|----|----|----|----|
| Size     | Thickness (mm)            | 15 | 13 | 10 | 8  |
|          | Maximum RMS (m/s²)        | 60.40 | 76.63 | 50.52 | 65.50 |
|          | Effective RMS (m/s²)      | 4.80  | 4.52  | 6.33  | 5.46  |
| Axle box | Maximum RMS (m/s²)        | 117.07 | 48.28 | 193.75 | 155.58 |
|          | Effective RMS (m/s²)      | 9.01  | 5.98  | 16.69 | 9.25 |
| Bracket  | Maximum RMS (m/s²)        |       |       |       |      |
|          | Effective RMS (m/s²)      |       |       |       |      |

There was no significant difference between acceleration RMS of four axle boxes, and value of 5# axle box is slightly larger than that of other axle boxes. The acceleration RMS of four brackets vary greatly, with the value of 3# bracket being the smallest and that of 5# bracket being the largest.

The amplification factor of 2# and 3# bracket vibration amplitude relative to axle box is small, that of 8# bracket is slightly greater, and that of 5# is the largest.

4.4 Time frequency analysis

Figure 13. The time domain curve of vibration transfer when the bracket resonates (a)

Figure 14. The frequency domain curve of vibration transfer without the bracket resonates (b)

It can be seen from the time frequency characteristic diagram that the resonance energy of the bracket is very large, which seriously affects the service life of the bracket. The vibration energy of optimized bracket structural meets the standard requirements of vibration impact.

5. Conclusion

In this paper, the test-simulation-retest method is adopted to solve the axle box bracket fracture problem of certain metro vehicle. The optimal structure is selected based on the experiment and simulation analysis, with comprehensively contrast analysis. The results are as follows:

①The transverse bending mode frequency and the line excitation frequency of the original 10mm thickness axle box bracket is all 100 Hz, which causes the resonance, and leads to fatigue failure.
By increasing the thickness of the axle bracket, the modal frequency can be improved and the line excitation can be avoided.

After the simulation structure optimized, an optimization scheme can be selected to optimize the vibration and fatigue life.

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