Research on Strength Test Technology and Fatigue Evaluation Method of Bogie Frame and Body Bolster

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Abstract—Bogie frame and body bolster are of vital importance to the reliable operation of the rolling stocks. There are two kinds of test methods for bogie frame and body bolster. One is separate test, and the other is joint test. To effectively detect the strength performance of bogie frame and body bolster as well as to improve the test efficiency, we adopted the method of joint test, and designed the test plan according to the standard. The strength test of bogie frame and body bolster is carried out where load analysis is studied and applied. The structural performance of bogie frame and body bolster is evaluated by means of Goodman fatigue limit diagram.

1. INTRODUCTION

As the key components of the bogie, the bogie frame and the body bolster, and their reliable operation are of vital importance to the safety of the railway system[1][2]. There are two kinds of test methods for the bogie frame and the body bolster, i.e., one is separate test, and the other is joint test. In the early stages of the development of high-speed rolling stocks, many indoor and simulated field tests on key components of rolling stocks were carried out in some foreign countries, and a large amount of test data were obtained in various aspects such as security, durability, fatigue reliability, and environmental verification, which helped manufacturers to improve technology as well as the development of high-speed railways[3][4]. In this paper, the method of joint test is adopted, and the strength test technology of the bogie frame and the body bolster is studied thoroughly[5].

2. TEST PURPOSES

- To combine automation technology to explore effective fatigue assessment methods in the strength test of the bogie frame and the body bolster, which will break through the limitations of traditional manually loading and ensure the accuracy and stability of the test data as well as the safety and reliability during the test[6].
- To research on the stress situation, focusing on the key technology of the bogie frame and the body bolster tests and their optimization[7]. By studying the way to simulate the operation condition of the bogie frame and the body bolster during the test more realistically, their strength performance can be accurately predicted, so that whether the bogie frame and the body bolster meet the design standards and requirements is determined [8].
3. TEST PLAN AND LOAD ANALYSIS
According to relevant standards and load conditions of the bogie frame and body bolster, the multi-channel loading test system is established which consists of multi-channel coordinated loading controller, control software, hydraulic oil source, and actuators (with servo valves, load sensors and displacement sensors attached), Hydraulic sub-station and hydraulic pipeline (hose), as well as the existing multi-channel coordinated loading system test platform, reaction frame, hydraulic pipeline (hard tube), etc. The wheelset model replaces the primary spring, the wheelset and the bearing box. All boundary conditions of the primary spring, the wheelset and the bearing box are simulated by the jig. The carbody model replaces the carbody and the secondary spring. All boundary conditions of the carbody and the secondary spring are simulated by the jig. The load shall be applied by the actuator and the actuator is controlled by measuring the force. According to European standards EN13749, under the condition of operating load, the basic calculated load for static and fatigue strength analysis of bogie frame structure is composed of the vibration acceleration of carbody and primary suspension structure and the lateral wind load borne by carbody. Vertical force caused by the secondary spring shall be applied to the carbody model through the contacting surface of the secondary spring. Lateral force shall be applied to the carbody model and to the lateral buffer. They may be applied by two separate actuators or by one actuator and a jointed jig system. The correct ratio of the two lateral forces shall be ensured. The fixture scheme of the joint test is shown in the Fig. 1.

![Test System Schematic Diagram](image1)

Figure 1. Test System Schematic Diagram

The coordinate system used in this paper is illustrated in Fig. 2.

![Coordinate System](image2)

Figure 2. Coordinate System

Variables are described in Table 1.
### TABLE 1. DESCRIPTIONS OF VARIABLES

| Variable    | Description                                                                 |
|-------------|-----------------------------------------------------------------------------|
| $F_{z1}, F_{z2}$ | Forces caused by the secondary suspension                                     |
| $F_ySS$     | Lateral force caused by the secondary suspension                              |
| $F_yLS$     | Lateral force caused by the lateral stop                                      |
| $F_{x,wh}$  | Longitudinal force by the wheel                                              |
| $F_{z,ARB1}, F_{z,ARB2}$ | Vertical force on anti-rolling torsion bar base                               |
| $F_X$       | Longitudinal force on bogie                                                  |
| $T_y\_mot1$ | Torque of the motor                                                          |
| $F_z\_Red1$ | Vertical force on gearbox                                                    |
| $F_X\_1$    | Longitudinal traction force on motor                                         |
| $F_X\_D$    | Force caused by the wheel brake unit                                         |
| $F_{x,mot1}, F_{x,mot2}$ | Longitudinal force from the inertia of the motor                           |
| $F_y\_mot1, F_y\_mot2$ | Lateral force from the inertia of the motor                              |
| $F_{z,mot1}, F_{z,mot2}$ | Vertical force from the inertia of the motor                            |

### TABLE 2. OPERATING LOAD TEST CONDITIONS

| No. | $F_z1$ (kN) | $F_z2$ (kN) | $F_ySS$ (kN) | $F_yLS$ (kN) | $T_wz$ (mm)  |
|-----|-------------|-------------|--------------|--------------|--------------|
| 1   | 132.4       | 132.4       | 0            | 0            | 0            |
| 2   | 119.2       | 92.7        | 0            | 0            | 0            |
| 3   | 119.2       | 92.7        | 6.5          | 70.3         | 0            |
| 4   | 172.1       | 145.6       | 0            | 0            | 0            |
| 5   | 172.1       | 145.6       | 6.5          | 70.3         | 0            |
| 6   | 92.7        | 119.2       | 0            | 0            | 0            |
| 7   | 92.7        | 119.2       | -6.5         | -70.3        | 0            |
| 8   | 145.6       | 172.1       | 0            | 0            | 0            |
| 9   | 145.6       | 172.1       | -6.5         | -70.3        | 0            |
| 10  | 119.2       | 92.7        | 6.5          | 70.3         | 6.25         |
| 11  | 172.1       | 145.6       | 6.5          | 70.3         | 6.25         |
| 12  | 92.7        | 119.2       | -6.5         | -70.3        | 0            |
| 13  | 145.6       | 172.1       | -6.5         | -70.3        | 0            |

### TABLE 3. OPERATING LOAD TEST CONDITIONS OF LONGITUDINAL FORCE BY TRACTION MOTOR

| No. | $F_{z1}=F_{z2}$ (kN) | $T_y\_mot1=T_y\_mot2$ (Nm) | $F_{z,Red1}= -F_{z,Red2}$ (kN) | $F_x\_wh$ (kN) |
|-----|----------------------|-----------------------------|--------------------------------|----------------|
| 14  | 132.4                | -2658.7                     | 33.8                          | 15.4           |
| 15  | 132.4                | 2658.7                      | -33.8                         | -5.4           |

### TABLE 4. OPERATING LOAD TEST CONDITIONS FROM INERTIA OF MOTOR

| No. | $F_{z1}=F_{z2}$ (kN) | $F_x\_mot1=F_x\_mot2$ (kN) | $F_y\_mot1=F_y\_mot2$ (kN) | $F_{z,mot1}= F_{z,mot2}$ (kN) |
|-----|----------------------|-----------------------------|-----------------------------|-------------------------------|
| 16  | 132.4                | 0                           | 0                           | 43.3                          |
| 17  | 132.4                | 0                           | 0                           | -30.9                         |
| 18  | 132.4                | 0                           | 30.9                        | 0                             |
| 19  | 132.4                | 0                           | -30.9                       | 0                             |
| 20  | 132.4                | 15.5                        | 0                           | 0                             |
| 21  | 132.4                | -15.5                       | 0                           | 0                             |
TABLE 5. OPERATING LOAD TEST CONDITIONS FROM WHEEL BRAKE UNIT

| No. | Fz1=Fz2 (kN) | Fz_D (kN) | Fx_wheel (kN) |
|-----|---------------|-----------|---------------|
| 22  | 132.4         | 17.1      | 10.1          |
| 23  | 132.4         | -17.1     | -10.1         |

TABLE 6. OPERATING LOAD TEST CONDITIONS FROM ANTI-ROLLING BAR

| No. | Fz1=Fz2 (kN) | Fz_ARB1 (kN) | Fz_ARB2 (kN) |
|-----|---------------|--------------|--------------|
| 24  | 132.4         | 19.7         | -19.7        |
| 25  | 132.4         | -19.7        | 19.7         |

TABLE 7. OPERATING LOAD TEST CONDITIONS FROM SECONDARY VERTICAL DAMPER

| No. | Fz1=Fz2 (kN) | Fx_sn (kN) | Fz_vd (kN) | Fy_td (kN) | Fz_pv (kN) |
|-----|---------------|------------|------------|------------|------------|
| 26  | 132.4         | 15         | 7.9        | 5.3        | 4.5        |
| 27  | 132.4         | -15        | 7.9        | -5.3       | 4.5        |
| 28  | 132.4         | 15         | -7.9       | 5.3        | -4.5       |
| 29  | 132.4         | -15        | -7.9       | -5.3       | -4.5       |

4. TEST DETAILS

4.1. Strain Gauge Placement and Data Process

The strain gauges are arranged at the sensitive positions corresponding to the load conditions of the bogie frame, with a total of 132 measuring points, of which 117 are attached to unidirectional strain gauges and 15 are three-directional strain gauges. And the same way to arrange strain gauges on the body bolster, but a total of 37 measuring points, of which 34 are unidirectional strain gauges and 3 are three-directional strain gauges.

Here are the ways of processing the data obtained from three-directional strain gauges force measuring strain gauge:

4.1.1. Tests under Exceptional Loads.

Thus, von Mises stress can be synthesized according to the fourth strength theory as in (1):

\[
\sigma_{\text{von Mises}} = \sqrt{\frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]} \tag{1}
\]

In this test, \(\sigma_1 = \sigma_{\max}\), \(\sigma_2 = \sigma_{\min}\) and \(\sigma_3 = 0\).

4.1.2. Tests under Simulated Normal Service Loads.

Each three-directional strain gauge is treated as 3 independent stress measuring points.

4.2. Fatigue Assessment Method

The material of the bogie frame and the body bolster must meet the requirements of corresponding Goodman diagram. The bogie frame and the body bolster are made from a variety of materials. So, the maximum and minimum stresses of sheet metal (P355NL1), forging (Q345E) and casting (G20Mn5) under simulated normal service loads are considered as anchor points and are plotted respectively in fatigue limit diagram of steel with tensile strength \(\geq 420\) MPa. Since the tensile strengths of sheet metal (P355NL1), forging (Q345E) and casting (G20Mn5) are all greater than 470 MPa, the fatigue limit diagram of steels with tensile strength \(\geq 420\)MPa is reasonable and reliable.
After the maximum and minimum stresses measured at each point under simulated normal service loads are plotted on the Goodman diagram, it turns out that all data are within their respective fatigue limits, which is demonstrated in Fig. 3 and Fig. 4.

![Goodman Diagram (Bogie Frame)](image1)

Figure 3. Goodman Diagram (Bogie Frame)

![Goodman Diagram (Body Bolster)](image2)

Figure 4. Goodman Diagram (Body Bolster)

4.3. Fatigue Test
The fatigue test of the bogie frame and the body bolster consists of 10 million cycles fatigue test on the major structure and 2 million cycles supplementary fatigue test on the traction and brake system parts, where the loads in the former test consist of combinations of vertical loads, transverse loads, anti-rolling loads and twisting loads, and the loads in the latter test consist of the inertial loads of the motor hanger in three directions, the vertical force on the gearbox, the vertical force of the brake, and the longitudinal force of the traction hanger.
5. CONCLUSION

- The extreme stress values of each measuring point of the bogie frame and the body bolster are less than the minimum allowable stress limit value of the material. The ultimate stress of the bogie frame is measured at the base material of the sheet metal (P355NL1), and the value is - 313.3MPa. The ultimate stress of the body bolster is measured at the weld of the sheet metal (P355NL1), and the value is 137.5MPa.

- According to the Goodman diagram, the fatigue performance of the bogie frame and the body bolster is evaluated. All measured data are within their respective fatigue limits. After the fatigue test, the bogie frame and the body bolster are subjected to magnetic particle inspection and are confirmed that no cracks occurred.

- In this paper, a joint test method is applied to study the test technology of the bogie frame and the body bolster and it turns out that the test plan is feasible. The force condition is studied, and the simulation of working conditions of high-speed train bogie frame and body bolster is successful. Thus, the strength performances of the bogie frame and the body bolster are reasonably predicted, and it is verified by experiments that the bogie frame and the body bolster meet the requirements in relevant standards.

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