Research on Strength Test Technology of Bogie Frames

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Abstract. The bogie frames play a vital role in the reliable operation of rolling stocks. In order to more effectively test the performance of the bogie frames’ strength, a test plan of bogie frames’ static tests and fatigue tests is designed according to related standards which is carried out by calculating the load and applying the load spectrum and combined with Goodman diagram to evaluate the structural performance of bogie frames. The research on the strength test technology of bogie frames provides an important guarantee for the operation safety of the railway system.

1. Introduction
As a key component of the bogie, the reliable operation of the bogie frame is of the top priority for the operation safety of the railway system[1]. Therefore, it is particularly important to test the quality of the bogie frame. The actual stress situation of the bogie frame is so complicated that it bears the effects of various loads in operation such as track disturbance, traction and braking, vibration from suspension components[2-5]. These loads are mutually coupled and jointly affect the fatigue strength of the bogie frame. In order to more realistically simulate the actual operating conditions, more effectively verify the structural strength of the bogie frame, and more accurately assess its fatigue limit, it is necessary to conduct in-depth research on the strength test technology of the bogie frame.

2. Test requirements and objectives
At present, the strength test for bogie frames applied in domestic test agencies is according to the test methods specified in standards such as EN 13749, UIC 615-4, UIC 515-4, TB/T 3548 and TB/T 3549.1, which is including static tests and fatigue tests[6]:

- Static tests under exceptional loads: the test purpose is to verify that there is no permanent deformation when the bogie frame is under the combined effects of maximum loads that may occur during operation.
- Static tests under normal service loads: the test purpose is to verify that there is no fatigue cracks when the bogie frame is under the combined effects of normal service loads.
- Fatigue tests: The test purpose is to determine the overall lifespan of the bogie frame, to evaluate the safety margin, and to check the potential weak points that are not confirmed in the static tests. The fatigue tests are usually carried out after the completion of the static tests.

3. Test plan
In order to simulate as realistically as possible the stress situation of the bogie frame when in operation, the test strain gauges shall be affixed at the sensitive positions of the bogie frame as shown in figure 1.
During the test, the carbody and the primary and the secondary suspensions are replaced by the actuator and the test fixtures. All the boundary conditions of the carbody and the primary and secondary suspensions are simulated by test fixtures. The design of the test bench and test fixtures complies with the principles of safe use, advanced technology, and reliable performance, with which Vertical forces, Transverse forces, Longitudinal lozenging forces, Twist loading and Anti-rolling loads in addition special loads (e.g. braking loads, Longitudinal shunt loads, dampers loads) can all be applied. A test fixture that replaces the axlebox is shown in figure 2. The test fixture is designed with ball bearings, which can effectively decouple the loads and simulate the actual operating situation of the bogie frame more realistically.

4. Test programs

4.1. Static tests

4.1.1. Tests under exceptional loads.
Exceptional loads consist of the loads from simulated rolling stocks running on straight tracks, longitudinal shocks, emergency braking, derailment, etc[7]. The calculation of loads is shown in Table 1.
Table 1. Exceptional loads.

| Load type                              | Calculation                                      |
|----------------------------------------|-------------------------------------------------|
| Vertical forces a                      | $F_{z1\text{max}} = F_{z2\text{max}} = \frac{kg}{2n_b} (M_v + C_1 - n_b m^{'})$ |
| Transverse forces a,b                  | $F_{y\text{max}} = 2 \times 10^4 \left( \frac{(M_v + C_1)g}{3 \times n_b n_y} \right)$ |
| Longitudinal lozenging forces a,c      | $F_{x1\text{max}} = 0.2 \times (F_{z\text{max}} + 0.5 m^{'})$ |
| Twist loading                          | The loads resulting from track twist of 1 %     |
| Anti-rolling loads d                   | $F_{z_{ABB}} = -F_{z_{ABB}} = \frac{K_\theta \times \theta}{2b}$ |
| Longitudinal shunt loads a             | $F_s = 5 \times m^{'} g$                        |

a $F_{z1\text{max}}, F_{z2\text{max}}$ are vertical forces on both sides of the bogie, $M_v$ is the vehicle mass in running order, $C_1$ is the exceptional design payload, $n_b$ is the number of bogies, $m^{'}$ is the bogie mass.
b $F_{y\text{max}}$ is the total Transverse forces on bogie, $n_e$ is the number of axles.
c $F_{x1\text{max}}$ is Longitudinal forces per wheel.
d $K_\theta$ is Anti-rolling torsion bar device stiffness, $\theta$ is Maximum rotation between carbody and bogie under exceptional loads, $2b$ is Lateral spacing between mounts of anti-rolling torsion bar bearing.

4.1.2. Tests under normal service loads.
Normal service loads consist of the loads from simulated rolling stocks running through curves, simulated braking conditions, simulated dampers conditions, etc[8]. The calculation of loads is shown in Table 2.

Table 2. Normal service loads.

| Load type                              | Calculation                                      |
|----------------------------------------|-------------------------------------------------|
| Vertical forces a                      | $F_{z1} = F_{z2} = \frac{g}{2n_b} (M_v + 1.2 C_2 - n_b m^{'})$ |
| Transverse forces                      | $F_y = 0.5 (F_z + 0.5 m^{'}) g$                   |
| Longitudinal lozenging forces          | $F_{x1\text{max}} = 0.1 \times (F_z + 0.5 m^{'}) g$ |
| Twist loading                          | The loads resulting from a track twist of 0.5 %  |
| Anti-rolling loads b                   | $F_s_{\text{atra}} = F_s \cdot \frac{D}{l_{rh}}$   |

a $C_2$ is Normal service payload.
b $\alpha$ is Roll coefficient, D is Distance between secondary suspension, $l_{rh}$ is the distance between the both sides of the anti-roll device and the connection position to the carbody.

4.2. Fatigue tests
The loads conditions in the first stage of fatigue tests are equivalent to the static loads of normal service. The load is simulating the process of acceleration and deceleration of rolling stocks running in both two directions through an S-curve. In the second and the third stages, the test loads are multiplied by 1.2 and 1.4, respectively.
4.3. Test evaluation

4.3.1. Evaluation of static tests under exceptional loads.
Under the exceptional load case, whether the load conditions are applied separately or simultaneously, there shall be no permanently deformation, and the stress at any measuring point on the bogie frame must not exceed the allowable stress. The structural material parameters are shown in the table 3.

\[ \sigma = E \times \varepsilon \]

\( \sigma \) is stress at the measuring point. \( E \) is Young's modulus. \( \varepsilon \) is strain at the measuring point.

| Type      | Trademark | Yield strength (MPa) | Allowable stress (MPa)               |
|-----------|-----------|----------------------|--------------------------------------|
| Sheet     | P355NL1   | 355                  | 355 (Base material) /320 (Welded joint) |
| casting   | G20Mn5    | 300                  | 300 (Base material) /273 (Welded joint) |
| Pipe      | 275NLH    | 275                  | 275 (Base material) /250 (Welded joint) |
| Forging   | Q345E     | 345                  | 345 (Base material) /313 (Welded joint) |

4.3.2. Evaluation of static tests under normal service loads.
Under the normal service load case, the average stress value \( \sigma_m \) and stress amplitude \( \sigma_d \) that result from combination of any two load conditions on the bogie frame shall be within the limit of the Goodman curve of the corresponding material or welded joint.

\[ \sigma_m = \frac{\sigma_{\text{max}} + \sigma_{\text{min}}}{2} \]
\[ \sigma_d = \frac{\sigma_{\text{max}} - \sigma_{\text{min}}}{2} \]

After the maximum and minimum stresses that measured at each measuring point under normal service load conditions are plotted on the Goodman diagram, all the measuring values shall be within fatigue limit respectively, which are shown in figure 3 and figure 4. Note that curve a1 is valid for measuring points located in the butt-welded areas or in the cross-sectional change areas with low notch effect, and curve a2 is valid for measuring points located in other types of weld areas or in the cross-sectional change areas with high notch effect, and curve b is valid for measuring points located in areas without notch effect of non-welded materials.
4.3.3. Evaluation of fatigue test.
Flaw detections are required after each stage of the fatigue test of the bogie frame. There shall be no flaws in first and second flaw detections and in the third flaw detection, flaws that do not need to be repaired immediately during normal service are acceptable.

5. Conclusion
By studying the strength test technology of bogie frame, conclusions are drawn as follow:
- The extreme stress values of measuring points of the bogie frame are less than the material’s respective minimum allowable stress values of measuring points. The ultimate stress of the bogie frame is measured on the base material of the sheet metal (P355NL1), and the value is -268.5MPa.
- The stress measured at each measuring point meets the requirements of the material’s Goodman diagram.
- No cracks are detected in the bogie frame during the three flaw detections after each stage of fatigue tests.
- The research on the strength test technology of the bogie frame provides an important guarantee for the safe and reliable operation of the bogie. At the same time, it provides important references for the strength test schemes of bogie frames in other similar projects.

Reference
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