Strength Detection Method for Subway Vehicle Bogie Frame in Big Data Environment

Wang Shi[1](✉), Hu Hai-tao[1], Zhou Ye-ming[1], Wang Yu-guang[1], Zhao Wei[1], and Jin Feng[2]

[1] Crrc Qingdao Sifang Co., Ltd., Qingdao 266000, China
xuenxuen20@163.com
[2] Information and Communcition College National University of Defense Technology, Xi'an 710106, China

Abstract. Aiming at the problem that the accuracy of the frame strength detection method is not high, the strength detection method of the subway vehicle bogie frame is studied in the big data environment. Firstly, the new structure of the subway vehicle steering frame is taken as the research object. The CATIA software is used to carry out the solid modeling of the subway steering frame to construct the frame 3D model to obtain the frame strength detection parameters. Then, the frame test rig is built, and the strength test of the frame test rig is carried out by the finite element model of the frame strength detection to realize the strength detection of the subway vehicle bogie frame. The simulation experiment is carried out to verify the detection accuracy of the strength detection method of the metro vehicle bogie frame. The experimental comparison shows that the strength detection method of the metro vehicle bogie frame is higher than the traditional frame strength detection method.

Keywords: Big data environment · Subway vehicles · Bogies · Frame strength detection · CATIA software

1 Introduction

Since the structural reliability of rail vehicles is an important factor to ensure the safe operation of rail vehicles, and the running of rail vehicles has a tendency to develop at a high speed, its safety has received more and more attention [1]. However, in the current design, traditional quantitative design methods are still used, which often cannot meet the requirements of actual strength testing of vehicle parts. As an important part of the vehicle system, the reliability of the subway steering frame is extremely important for ensuring the safe operation of the subway vehicle, which is directly related to passenger safety and comfort [2]. During the operation of the subway vehicle, the bogie is subjected to various loads while ensuring that the vehicle has good dynamic performance. The bogie frame is an important component of the bogie. It integrates the wheel axle box device, the spring damper device, the traction drive device, the basic brake device, the vehicle body suspension device, etc., to bear the load and transmit the load. Whether the structure of the structure is reasonable or not directly affects the running quality, power performance and driving safety of the vehicle. The strength and rigidity

S. Liu and L. Xia (Eds.): ADHIP 2020, LNICST 348, pp. 442–451, 2021.
https://doi.org/10.1007/978-3-030-67874-6_41

of the frame will affect the service life of the metro vehicle bogie, the smooth running of the vehicle and the comfort of the passengers. It is also related to the economics of the subway operation.

At present, researchers have done a lot of research on the structural strength detection methods of metro vehicles. Reference [3] combined with the characteristics of nondestructive testing in strength test, the nondestructive testing scheme and damage assessment method in the strength test of CFRP structure are proposed by using the method of typical signal analysis. Finally, the effectiveness of the detection scheme and evaluation method is verified by experiments, but the accuracy of the test results is not high. Reference [4] analyzes the evaluation method for welding fatigue strength of bogie frame of locomotive and rolling stock. This method calculates and analyzes the welding fatigue strength of a B0 bogie frame under simulated operation conditions. By extracting the node stress at 2 mm from the outside of weld toe, the main weld of bogie frame and suspension seat of driving device, primary vertical shock absorber seat and brake seat are respectively analyzed, the fatigue strength of welding seam of traction seat is checked. The experimental results show that this method can obtain the strength coefficient of each component structure, but the detection results are accurate.

Therefore, it is particularly important to detect the strength of the subway frame bogie frame. The development of modern finite element technology and computer technology in the big data environment has laid a good foundation for the promotion of structural strength detection in the field of vehicle engineering [5].

2 Strength Detection Method for Subway Vehicle Bogie Frame

2.1 Structural Strength Detection Parameter Selection

There are two main structures of metro vehicle steering frame in China. Among them, Qingdao No. 11 and Chengdu No. 10 are old structures. The new structure is mainly changed in the upper structure of the steering frame mounting arm and the circular arc structure of the lower cover [6]. The new structure tangentially cuts the side arc of the positioning arm seat with the arc of the lower cover. This change reduces the stress on the most dangerous part of the frame and increases the safety of the frame [7, 8]. This paper is to study the new structure of the subway vehicle steering frame.

The CATIA software is used to carry out the solid modeling of the subway steering frame, starting with the 2D drawing design. Then use the methods of stretching, rotating, digging, slotting, scanning, etc. to create physical signs, and use the editing commands such as mirroring, copying, and array to edit the physical features. A 3D solid model is a combination of a number of feature commands. The 3D solid model is shown in Fig. 1:

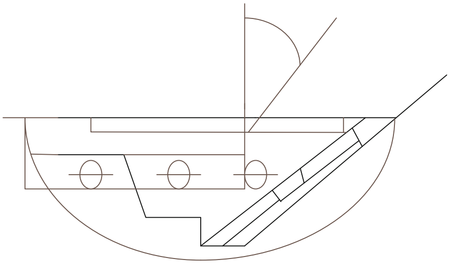

Fig. 1. Architecture 3D solid model.

It can be seen from the three-dimensional solid model that the main components of the frame are side beams, beams, longitudinal beams, pallets, spring bearings, etc. The main connection form is welded structure [9, 10]. The side sill is a variable-section hollow box-type welded structure. The middle and lower concave fish-belt design is adopted. The upper and lower covers are all steel plates with a thickness of 12 mm, and the lower surface of the side sill is also welded with a pallet. The beam is a seamless steel pipe structure, the surface is pickled and phosphated, the inner cavity is used as an additional air chamber of the air spring, and a through connection is adopted between the beam and the side beam. A sleeve is provided at the joint for reinforcement, and in order to increase the torsional strength of the entire frame, two longitudinal members are welded to the end of the beam adjacent to the side members. The thickness of other welded steel plates is also basically between 10 mm and 20 mm.

2.2 Build a Frame Test Bench

The frame test bench mainly includes a test bench base, a gantry, a vertical actuator, a longitudinal actuator, a lateral actuator, and a support restraint unit. First, the base of the entire test rig is built. The pedestal mainly provides a platform for the loading and restraining structures in the virtual test. The size depends on the size of the frame, and the size is roughly determined to be 3550 × 2930 × 50 mm. The size of the base thus established can meet the requirements of the virtual test of the subway bogie [11, 12]. The gantry is a 200 mm "U" shaped structural member. The "U"-shaped structure has a width of 2700 mm, which satisfies the width requirement of the bogie wheelbase and is 1725 mm high. The function of the gantry is mainly to withstand the reaction of the load loaded on the bogie and to establish a vertical actuator thereon to power the vertical load on the bogie frame. The vertical actuator is fixed on the gantry and is simplified into two cylinders with a diameter of 180 mm and a height of 200 mm; The support restraint unit is a relatively important structure of the virtual test rig. There are eight constrained support units, which can be simplified into a cylinder having a diameter of 230 mm, the height being determined according to the structure of the bogie; The position of the transverse actuator is on the lateral baffle of the bogie, because the constrained position of the bogie is still a certain height from the base. Therefore, an actuator receiving member is to be established when the lateral actuator is established to satisfy the load acting position and the actuator position; The establishment of the longitudinal actuator is basically the same as that of the transverse actuator, except that there are four sets of brake hanger vertical plates. The framework simulation test bench based on the above data and requirements is shown in Fig. 2.

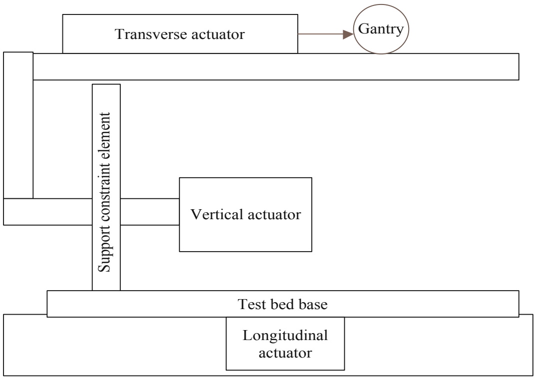

Fig. 2. Frame simulation test bench.

2.3 Finite Element Frame Strength Detection

A finite element model is a discrete model of a structure or component that contains the physical properties of the structure, the displacement and the boundary conditions of the force. Therefore, the establishment process of the framework finite element model includes selecting the unit type that expresses the structural characteristics, dividing the reasonable grid distribution, defining the material and attribute information, and defining constraints and loads on the nodes or geometry to be generated [13]. The basic principles that must be followed in the establishment of a finite element model in a big data environment are: On the one hand, the accuracy of the calculation results is guaranteed; on the other hand, the scale of the model is moderately controlled, thereby improving the calculation efficiency.

2.3.1 Mesh Generation

The finite element pre-processing software HyperMesh is used to process the three-dimensional solid model of the framework to establish a finite element model of the bogie frame. The finite element pre-processing software HyperMesh's meshing function is recognized by the industry and has interfaces with mainstream CAD software such as CATIA, PRO/E, UG, IGES, STEP, etc. The rationality of the finite element calculation model is largely determined by the form of the grid. According to the characteristics of the actual component geometry, it can be divided into categories, as shown in Fig. 3.

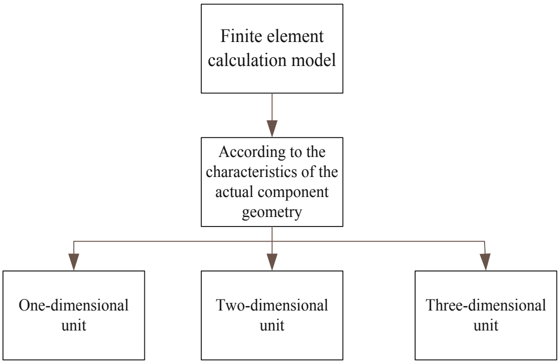

Fig. 3. Finite element calculation model classification.

In this paper, the one-dimensional unit is mainly used for the connection of components; when the dimensions of the components in the frame are much larger than the dimensions in the other direction, such as the upper and lower covers of the side beams, the shell-shell unit is used for simulation; When the dimensions of the structural members in the three directions are not much different, basically another order of magnitude, such as a spring bearing, this article uses a three-dimensional unit to simulate.

Before dividing the shell-and-shell unit, the inner surface of each member is extracted. The thickness of the member is represented by a numerical value instead of geometric representation. After the middle surface is extracted, the mesh of the shell-and-shell unit is divided on the middle surface [14]. When dividing the grid, pay attention to the size of the control grid and the density of the grid. The size of the grid and the density of the grid directly determine the number of elements of the finite element model, which in turn affects the calculation time and calculation accuracy. For components that require a large gradient of strength analysis data, a dense mesh simulation is used, and other components can be moderately sparsely meshed. With the development of computer technology, the computational storage capacity is also becoming less and less restrictive for the number of grids and calculation time in finite element analysis [15]. Based on the structural characteristics of the integrated structure and the configuration of the computer, the mesh size of the component that can withstand large loads on the frame is 10 mm, and the other components are divided by 20 mm mesh size. In the process of dividing the two-dimensional unit, the plate-shell unit is mainly composed of a quadrilateral plate unit, and the triangular plate unit is supplemented by a combination of automatic mesh division and manual mesh division. For the supporting members of the frame, such as the spring seat and the spring seat plate, the dimensions in the three directions are basically the same order of magnitude, and the difference is not large, so the hexahedral element is used for simulation.

2.3.2 Grid Quality Check

In the process of meshing, mesh deformation is easy to occur. If the deformation exceeds a certain limit, the calculation accuracy will decrease significantly with the degree of deformation, and the cell with poor mesh quality will not pass the mesh quality check. The mesh quality of the unit is directly related to the accuracy and convergence of the finite element model calculation analysis results. The general mesh quality check is accompanied by meshing simultaneously. Grid quality inspection includes: unit continuity check, unit normal direction check, repeat unit check, and unit quality check. Software HyperMesh provides tools for checking grid quality based on user-defined values—Check Elems and Quality Index panels. The Check Elems panel can be used to check the free end of a one-dimensional unit, the minimum and maximum internal angles of a two-dimensional unit, and the Jacobian value, the warpage and distortion of a three-dimensional unit. The Quality Index panel provides a comprehensive quality assessment of grid quality, and quality indicators can be defined by the user.

3 Implementation of Frame Strength Detection

3.1 Strength Check

Before the calculation, the structural finite element of the frame test rig shall be checked for stiffness and strength by the finite element model of the frame strength test. Only when the stress is less than the allowable stress of the material and tends to be 0 deformation, the whole frame test bench can be avoided to have a great influence on the strength test result of the bogie frame. Therefore, the structural finite element analysis of the frame test rig is first performed before the strength measurement of the bogie frame is performed.

In this paper, the turning brake condition is selected. Under this condition, the bogie frame receives vertical load, lateral load, additional vertical load, longitudinal inertial force, and additional vertical load. Each load is distributed to the components of the gantry, wherein the vertical brakes are subjected to loads of 100250 N and 129659 N, respectively; the transverse actuators are subjected to loads of 31856 N; and the longitudinal actuators are subjected to loads of 20916 N; The eight support units are required to bear the quality of the bogie and the dynamic load of the car during operation. The load sizes are 25062.5 N and 32414.75 N respectively. The main components of the test bench stiffness test bench are made of Q235 series steel, which has lower cost and reliability. The ribs are welded between the column and the base to enhance the structural strength. The allowable stress of Q235 series steel is 245 MPa, and the bench design meets the requirements as long as the calculation result is less than its allowable stress. Through the finite element model of frame strength detection, the maximum stress is 122 MPa, which is less than the allowable stress of the material. The structural strength meets the design requirements, while the maximum deformation of the gantry is 0.855 mm, and the deformation is small, meeting the design requirements.

3.2 Intensity Detection

The stiffness determines the deformation of the component, and the strength has a great relationship with the stress of the component. Therefore, it is especially important to detect the strength and stiffness of the frame in the strength detection of the bogie frame. C-B modal analysis and stiffness and strength valency check of the frame test bench are carried out by the finite element model of the frame strength test, and the C-B modal analysis can greatly reduce the calculation amount. On the other hand, C-B modal analysis also realizes the rigid-flexible coupling and flexible body constraints of the bogie frame and the virtual test rig. Finally, the stiffness and strength of the frame are detected by the modal analysis results.

From the basic knowledge of multi-body dynamics, the expression of kinetic energy T can be written in the following form:

$$T = \frac{1}{2}\xi^T M(\xi)\xi \tag{1}$$

Where, ξ is the rigid-flexible coupling degree and M is the mass matrix, which consists of a 3 × 3 matrix, the matrix form is as follows:

$$M(\xi) = \begin{bmatrix} M_{tt} & M_{tr} & M_{tm} \\ M_{tr} & M_{rr} & M_{rm} \\ M_{tm} & M_{rm} & M_{rr} \end{bmatrix} \tag{2}$$

Where, t is the displacement, r is the rotation, and m is the modality of freedom. The rigid-flexible inertial coupling is determined by the above mass matrix, and can be divided into four rigid-flexible coupling modes according to the expression of the mass matrix: rigid coupling, static coupling, partial dynamic coupling, full dynamic coupling. The commonly used rigid-flexible coupling simulation analysis is basically a method of applying partial dynamic coupling. Deriving the equation of motion of a flexible body from the Lagrangian equation yields:

$$\xi = [X\Omega q] \tag{3}$$

Where, ξ is the rigid-flexible coupling, X is the displacement coordinates; Ω is the euler angle coordinates; q is the modal coordinates. From Eq. 3, the actual constraints of the flexible body can be divided into two categories: primary constraints and secondary constraints. Through the detection of the finite element model of the frame strength detection, it is known that the frame test rig realizes the constraint of rigid-flexible coupling and flexible body.

Before the C-B modal analysis, the boundary conditions of the bogie frame are constrained. The correctness of the boundary conditions is significant for the finite element analysis. To establish the boundary conditions, the actual working conditions are first quantified, and the quantified working conditions are defined as the boundary conditions in the model. Therefore, the constraints should be simulated realistically according to the actual stress conditions of the framework.

This type of subway bogie frame is supported by 8 spring supports at the bottom of the side members, so these supports are constrained. The side beam is simulated by the shell element, and any unit node has 6 degrees of freedom, which are translational freedom in three directions along the x, y, and z axes and freedom of rotation in three directions around the x, y, and z axes. The spring support and spring support plate are simulated by hexahedral elements, which have 3 degrees of freedom, which are the translational degrees of freedom along the x, y, and z axes. Therefore, only the translational freedom of the three supports along the x, y, and z axes can be constrained. The intensity calculation results are extracted and edited by C-B modal analysis, and the corresponding loads are applied according to different working conditions and calculated. The calculation results show that the maximum stress of the frame is 77.1 MPa, 99.9 MPa, 110 MPa, 109 MPa and 109 MPa under full load static, full load, cornering, braking and turning braking conditions. The frame material is 16Mn R and its allowable stress is 345 MPa. It can be concluded that the maximum stress value does not exceed the elastic limit of the material, indicating that the strength of the frame meets the design requirements; Under the five working conditions, the maximum deformation of the frame is only 0.137 mm, which indicates that the structural strength of the steering frame of this type of subway vehicle meets the design requirements.

4 Simulation Test

In order to ensure the effectiveness of the strength detection method of the steering frame of the subway vehicle, a simulation experiment was designed. During the experiment, a metro vehicle steering frame was taken as the experimental object, and the frame test bench was built and the strength detection of the subway vehicle bogie frame was carried out by the frame strength detection finite element model. In order to ensure the validity of the experiment, the traditional frame strength detection method is used to compare the accuracy of the frame strength detection with the strength detection method of the subway vehicle steering frame designed in this paper, and the test results are observed. The results of the strength detection of the subway vehicle bogie frame using the conventional frame strength detecting method are shown in Table 1. The results of the strength detection of the subway vehicle bogie frame using the strength detection method of the subway vehicle bogie frame designed in this paper are shown in Table 2.

Table 1. Strength measurement of traditional frame strength test method.

Location	Unit node ID	Stress value (MPa)
Frame right side beam assembly upper cover and guide post joint	12095	109
Frame left joint assembly upper cover and guide post joint	18163	104
Frame left joint assembly upper cover and guide post joint	18164	101
Frame right side beam assembly upper cover and guide post joint	12097	99.2
Frame left joint assembly upper cover and guide post joint	18162	97.1
The left side beam upper cover is connected to the outer edge of the air spring seat plate	12056	93.1
The right side beam upper cover is connected to the outer edge of the air spring seat plate	49415	92.3
The left side beam upper cover is connected to the outer edge of the air spring seat plate	12053	91.8
Accuracy		83.6%

Table 2. Strength detection method for strength measurement of subway vehicle bogie frame.

Location	Unit node ID	Stress value (MPa)
Frame right side beam assembly upper cover and guide post joint	18160	109
Frame left joint assembly upper cover and guide post joint	18162	108
Frame left joint assembly upper cover and guide post joint	12092	105
Frame right side beam assembly upper cover and guide post joint	12095	93.6
Frame left joint assembly upper cover and guide post joint	49410	93.5
The left side beam upper cover is connected to the outer edge of the air spring seat plate	12053	87.9
The right side beam upper cover is connected to the outer edge of the air spring seat plate	49415	87.5
The left side beam upper cover is connected to the outer edge of the air spring seat plate	39089	87.0
Accuracy		98.2%

It can be seen from Table 1 and Table 2 that the strength detection method of the bogie frame of metro vehicles is more accurate than that of the traditional frame strength detection method, which shows that the method in this paper is more reliable. This is because this method is based on CATIA software to establish a three-dimensional model of the frame, through which the strength detection parameters of the frame can be obtained. According to the obtained parameters, combined with the finite element model, the strength test of the frame test-bed is carried out to realize the strength detection of the metro vehicle bogie frame, so as to improve the accuracy of the detection results and the detection performance of the detection method.

5 Conclusion

A large number of studies have shown that the damage form of the vehicle bogie is mostly the fatigue failure caused by random load. The structural strength testing of bogies has become one of the necessary processes in the early development of new products for bogies. The effective frame strength detection method to detect the strength of the bogie frame is an important means of structural design of the bogie frame. The strength of the bogie frame is the core indicator of the frame design. Therefore, in order to ensure the safety of subway vehicles, it is very important to detect the steering frame of subway vehicles. In this paper, the strength detection method of metro vehicle bogie frame is proposed in the big data environment. Taking the new structure of metro vehicle bogie as the research object, the three-dimensional frame model is established based on CATIA software, and the frame strength detection parameters are obtained. The finite element model is used to test the strength of the frame test-bed to realize the strength detection of the metro vehicle bogie frame. The experimental results show that the detection accuracy of this method is high, which shows that the method has strong practical application.

References

1. Tao, L., Ding, P., Shi, C., et al.: Shaking table test on seismic response characteristics of prefabricated subway station structure. Tunn. Undergr. Space Technol. **91**(9), 102994 (2019)
2. Keyu, Z., Zikai, H.: Failure analysis and strength testing of bone screws. J. Med. Biomech. **33**(03), 280–284 (2018)
3. Dan, W., Ning, N., Pengfei, Y., et al.: Non-destructive testing technology for carbon fiber reinforced polymer composite in the aircraft structure strength test. Sci. Technol. Eng. **18** (18), 313–322 (2018)
4. Cao, J.W., Xu, C.B.: Application of engineering method for welding fatigue strength of locomotive bogie frame. Chin. J. Constr. Mach. **016**(001), 81–86,94 (2018)
5. Yao, S., Xiao, X., Xu, P., et al.: The impact performance of honeycomb-filled structures under eccentric loading for subway vehicles. Thin-Walled Struct. **123**(2), 360–370 (2018)
6. Guoxin, Z., Yuhuan, L., Su, H., et al.: Development of dynamic vehicle exhaust emission inventory based on traffic big data: a case study of Guangzhou inner ring. Environ. Pollut. Control **40**(06), 723–727 (2018)
7. Shengwa, L., Junming, S., Xiang, G., et al.: Analysis and establishment of drilling speed prediction model for drilling machinery based on artificial neural networks. Comput. Sci. **46** (1), 605–608 (2019)
8. Dan, S., Shengyan, L., Yanting, A., et al.: Dynamic characteristics of journal bearing and stability of rotor system based on work of oil film force. J. Drainage Irrig. Mach. Eng. **37**(8), 699–704 (2019)
9. Shuai, L., Weiling, B., Nianyin, Z., et al.: A fast fractal based compression for MRI images. IEEE Access **7**, 62412–62420 (2019)
10. Junping, H., Yukai, Q., Kejun, L., et al.: Stability analysis of the mast of continuous flight auger driller with double braces under direct-drill-lifting condition. Chin. J. Eng. Des. **25** (02), 151–158 (2018)
11. Connick, M.J., Beckman, E., Vanlandewijck, Y., et al.: Cluster analysis of novel isometric strength measures produces a valid and evidence-based classification structure for wheelchair track racing. Br. J. Sports Med. **52**(17), 1123 (2018)
12. Liu, S., Liu, G., Zhou, H.: A robust parallel object tracking method for illumination variations. Mob. Netw. Appl. **24**(1), 5–17 (2018). https://doi.org/10.1007/s11036-018-1134-8
13. Lu, M., Liu, S.: Nucleosome positioning based on generalized relative entropy. Soft. Comput. **23**(19), 9175–9188 (2018). https://doi.org/10.1007/s00500-018-3602-2
14. Xuyun, F.U., Luo, H., Zhong, S., et al.: Aircraft engine fault detection based on grouped convolutional denoising autoencoders. Chin. J. Aeronaut. **32**(02), 86–97 (2019)
15. Dongliang, W., Xiaolei, F., Yiming, C., et al.: Research on evaluation method of plastic tensile yield strength testing laboratory. New Build. Mater. **46**(04), 128–131 (2019)