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Reconstruction of Stress Spectrum of High Speed Wheel Axle Based on Time Domain Extrapolation

Junjie Zhu *, Zhuofani Zhong, Wengang Xie

School of Mechanical Engineering and Automation, Wuhan Textile University, Wuhan 430200, China

Abstract

The axle is one of the key parts for high-speed train operation, which is related to the safe operation of the train.In this paper, the wheelset model of high-speed train is taken as the research object, and the stress spectrum is reconstructed through finite element calculation and line measured data. Complete the establishment of the three-dimensional model of the axle, apply vertical load and lateral load to the model to obtain the stress distribution state of the axle, refer to the principle of reducing cross-interference, determine the position of the load identification point and the axle section measurement point, which is the test signal for amplifying the vertical load , Drill holes at the spoke positions of the wheels, and evaluate the static strength and fatigue strength of the wheels before and after processing. Based on the measured stress spectrum and the extrapolated stress spectrum, the fatigue strength and life analysis of the axles are evaluated.

Keywords

Wheel axle; stress spectrum; threshold peak method; time-domain extrapolation; rainflow counting method.

1. Introduction

As the key part of the train, the axle undertakes the task of train operation, and its structural strength and fatigue life also directly determine the safety of the train. The designed service life of the axle is generally considered to be more than 20 years. With the increase of the service life, fatigue damage is prone to occur. Therefore, it is particularly important to analyze the life strength of the high-speed axle, that is, the dynamic stress under the actual operating conditions of the train needs to be analyzed. Line test to analyze the load on the axle[1,2].

In this paper, a time-domain extrapolation method of axle stress spectrum based on the POT model is proposed. The POT model is established on the basis of extreme value statistics theory. The transcendence is fitted by generalized Pareto distribution, and new extreme points are randomly generated by the fitted GPD distribution function to replace the original extreme points to realize the extrapolation of time domain signals. Finally, the load cycle information is extracted according to the rainflow counting method, and the stress spectrum is reconstructed[3,4].

2. Building the wheelset model

According to the two-dimensional design drawings of the wheel and axle of the CRH380A EMU train, the three-dimensional solid model of the wheel and axle is completed in the SolidWorks software according to relevant standards. According to the actual situation, set the relevant material property parameters of the wheelset as rigid, its density is $7.9 \times 10^3 g/m^3$, Young's modulus MPa, and Poisson's ratio is 0.3. Before the finite element analysis, the mesh of the axle model needs to be divided first. When using Hyper mesh software to mesh the wheel, it is first

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necessary to remove the irregular features on the wheel, such as chamfers, oil injection holes, etc. Removing the irregular features will not change the finite element calculation results too much, but it can be more efficient. Easily mesh the wheels to avoid some singular elements.

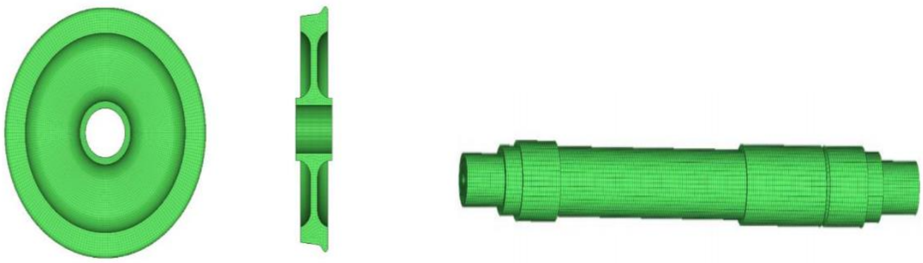

Figure 1.Wheel and axle meshing

3. Selection of the position of the axle measuring point

In order to simulate the constraints of the wheel under real operating conditions, all nodes on the mating surface of the wheel and the axle are fully constrained. Considering the mutual interference between the vertical load and the lateral load, which may affect the measurement results of stress, it is necessary to find the point on the wheel spoke where the two loads have the least mutual influence as the load identification position. In Hyper mesh, according to UIC510-5 The standard applies vertical and longitudinal loads to the wheels, respectively.

Generally, the force on the wheelset has three directions, namely vertical, horizontal and vertical. The vertical force mainly comes from the self-weight and load of the vehicle, the lateral force maintains the correct running direction of the vehicle, and the longitudinal force is generated in the starting and braking conditions of the vehicle[5]. Since the value of the longitudinal force is much lower than that of the vertical force and the lateral force, the fatigue effect on the wheelset is relatively small, so in general, the influence of the longitudinal force on the fatigue strength and fatigue life of the wheel axle is not considered.

In practical situations, it is generally necessary to paste strain gauges on specific positions on the wheel spokes to form a bridge to measure the vertical and lateral loads during train operation, which requires determining the respective load identification points for the vertical and lateral loads. In order to reduce the mutual interference between the two loads, it is required that at the position of the vertical load identification point, only the vertical load has a response and no response or a small response to the lateral force. In the same way, at the position of the lateral load identification point, only the lateral load has a response but no response or a small response to the vertical force.

The stress contours under the lateral load and vertical load cases are calculated in ANSYS as follows.

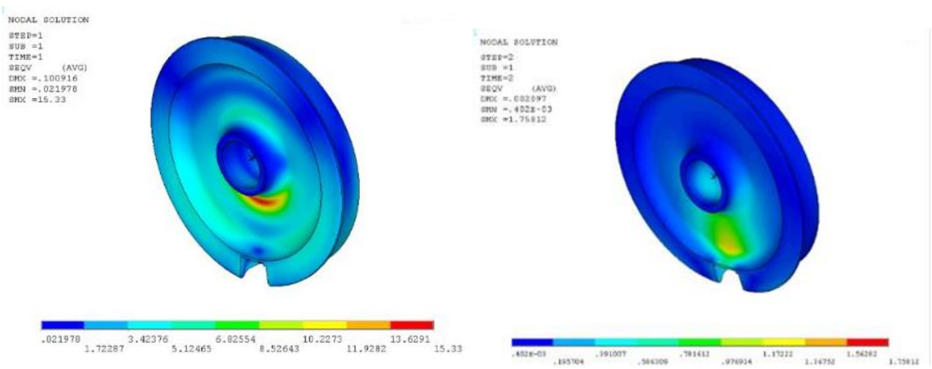

Figure 2 Wheel stress contours under lateral and vertical loads

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When a vertical load is applied to the wheel, each position has a corresponding stress response, but the value is not obvious. Therefore, the radius of the wheel when the response changes the most when a lateral load is applied is selected, that is, 180mm away from the central axis of the wheel as the lateral load identification point. . In order to reduce the influence of external interference factors on the wheelset in the actual circuit test and improve the test accuracy, a strain gauge is attached to the thickness center of the wheel spoke hole along the radial direction. According to the principle of Wheatstone bridge[6], a vertical load is formed. Strain gage set for testing bridges.

4. Processing and Analysis of Measured Data

4.1. Data Processing of Measured Signals

Ideally, the test signal can perfectly reflect the required data, but in practice, it is often subject to various interferences in the test process, resulting in noise signals, glitch signals, etc., which will affect the time domain characteristics of the compiled load spectrum. and frequency domain characteristics, resulting in a decrease in the accuracy of the actual measured data, so it is necessary to perform data processing on the measured signal to improve the signal-to-noise ratio and data accuracy. Commonly used processing includes signal zero drift removal, signal conversion, deburring processing, and filtering processing. During fatigue analysis, the amplitude of the load cycle is an important factor in determining fatigue damage, and the prepared load spectrum amplitude can reflect the fatigue life budget and the reliability of the test results. Statistical counting is required in the process of compiling the load spectrum, and the load-time history is transformed into a series of load complete cycles through specific operations. , which affects the fatigue calculation results.

The measured data are irregularly distributed time domain signals, which are often difficult to be directly used for fatigue assessment. The fatigue damage of mechanical structures is mainly affected by the cycle amplitude and cycle frequency. Therefore, the measured time domain signals can be classified according to their amplitudes. Loop count [7]. The counting principle of the rainflow counting method is consistent with the material fatigue damage mechanism. It is considered that plastic deformation is a necessary condition for fatigue failure. The amplitude of each load cycle and the corresponding cycle number can be obtained by counting the collected test data. It can comprehensively show the characteristics of random stress spectrum, count the change trend of load, and reflect the effect of load change on fatigue damage, so it is suitable for many engineering fields.

The counting rules of the rainflow counting method are as follows[8]:

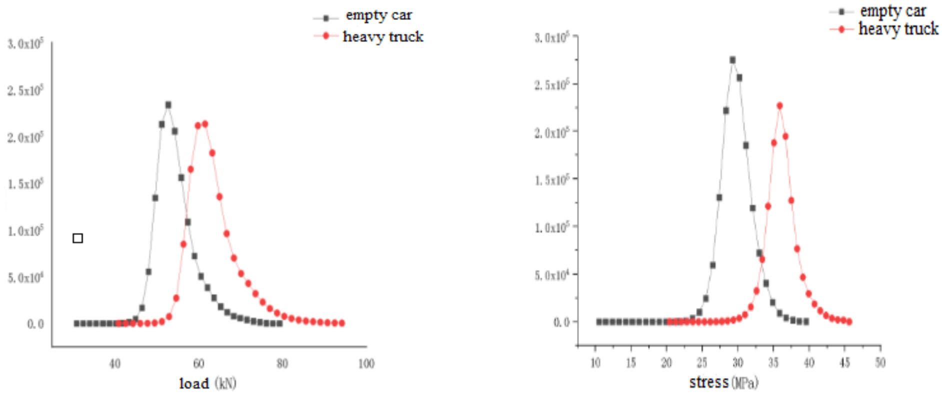
(1): Rotate the measured stress time history by 90°, place it vertically, the vertical axis is time, the direction is downward, and it is regarded as a multi-layered roof. Select the maximum peak or maximum valley in the process as the starting point of the rain flow. When the rain flow flows down to the end point along the maximum peak and valley, if there is no roof blocking, the rain flow will flow in the opposite direction and continue to flow downward until the flow direction Endpoints, which determine the cycle according to the line the rain flow passes through.

(2): Record the maximum peak and valley value of the rain flow, and take the path of the rain flow as a cycle.

(3): Extract the part that rainflow flows through and delete it from the stress time history, then continue to count the rainflow for each remaining time history, repeat the above steps, and end the counting when there is no remaining time history.

4.2. Compilation of measured load spectrum and stress spectrum

The measured time domain signal is analyzed. The measured signal includes all line conditions. Because the test time is long and the total frequency is large, a 32-level spectrum is used to better reflect the distribution of load and stress. In addition, there are many test sections of the axle, and the sampling time-domain extrapolation method requires a huge amount of calculation and a long calculation time. Therefore, only the B section with the largest stress amplitude is used for the calculation example. The figure below shows the load spectrum and stress spectrum compiled according to the measured time domain signal, and the rainflow counting method is used for the compilation method.



Vertical load spectrum of empty truck (b) Stress spectrum of section B of empty truck

Figure 3 Measured load spectrum and stress spectrum

By analyzing the vertical load spectrum and B section stress spectrum of empty and heavy trucks, it can be seen that due to the difference in load, the vertical load and stress corresponding to the main frequency of heavy trucks are greater than the vertical load and stress corresponding to the main frequency of empty trucks. stress. The shapes and changing trends of the vertical load spectrum and the B section stress spectrum of the empty truck are roughly the same. At the same time, the stress range of the heavy vehicle stress spectrum is wider than that of the empty vehicle.

5. Equivalent stress calculation

The fatigue life problem of the axle is generally solved by the design method of variable amplitude stress conditions. It can be known from Miner's law that when the structure is subjected to variable amplitude stress, even the stress cycle below the fatigue limit will cause damage to the structure. Therefore, when evaluating the fatigue strength of the structure, it is necessary to calculate the sum of the damage caused by all levels of stress[9]. In the actual evaluation process, it is necessary to compile the stress spectrum of each section according to the measured strain time history, and then combine the Miner's law to calculate the damage. At present, the commonly used method is to calculate the stress spectrum as equivalent stress according to the material S-N curve and Miner's law, and compare and analyze it with the fatigue allowable stress. Miner's law and the relevant parameters of the fatigue life curve are used to calculate the equivalent stress values of the B section of the axle before and after extrapolation in the empty vehicle state.

6. Conclusion

This paper takes the wheel and axle system of the EMU as the research object. Through geometric modeling, combined with UIC510-5 standard, constraints and loads are applied to the wheel axle and static strength analysis is carried out to analyze the stress state of the wheel axle and determine the load identification point.

(1) Create a three-dimensional model of the wheel and axle according to the EMU’s wheel and axle drawings and parameters, perform mesh division through Hyper mesh software, apply

constraints and loads with reference to the UIC510-5 standard, and find the vertical load by applying vertical and lateral loads to the wheelset respectively. The response at each position is not significant. It is necessary to punch holes to amplify the test signal. The static strength and fatigue strength of the punched wheels are checked, all of which meet the requirements.

(2) Through data processing of the measured signal, the load spectrum and stress spectrum are compiled based on the data, and the rainflow counting method is used for the compilation method. It can be seen that since the test time is much shorter than the design life, the load action frequency under the measured signal is much smaller than the load action frequency under the full life, and extrapolation is required.

(3) Calculate the equivalent stress and accumulated damage of the axle section by using the measured stress spectrum and the extrapolated stress spectrum respectively. The calculation results show that the requirements for use and design are met, and a certain safety margin is also guaranteed.

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