Test Research on Vibration State of Transformer in High Speed EMU

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Abstract. Transformers are important under-vehicle equipment for high-speed EMUs and play an important role in ensuring the power transmission of EMUs. This article first introduces the vibration reduction theory of the equipment under the EMU, and then briefly introduces the structure of the transformer and the arrangement of the measuring points. Afterwards, The vibration data of the transformer in the middle and late stages of wear are analyzed. It can be obtained that: some line sections of the vehicle have hunting movement, and the lateral acceleration of the frame has harmonics, the main frequency is 7Hz, and the amplitude is 0.6g (3-9Hz band-pass filter). The bogie vibration will be transmitted to the carbody and the equipment under the carbody, which has a greater impact on the vibration of the auxiliary converter body, that is, the lateral main frequency of the auxiliary converter is about 7Hz.

1. Introduction

When the vehicle body occurs elastic vibration, the equipment under the will also cause resonance. When the equipment under the carbody vibrates abnormally, it will also affect the comfort of passengers. Long-term operation will cause suspension components to break. Transformers are important under-vehicle equipment for EMUs, and they are rarely studied separately in multi-body dynamics research. However, its quality is large and needs to be considered separately. Many scholars have studied the vibration characteristics of suspension parts caused by vehicle body vibration. Pingbo et al. [1] studied the vibration response of the elastic carbody of high-speed trains, and studied the elastic vibration of the carbody under semi-active control. G. Diana et al. [2] established a numerical model of vehicle comfort and verified it through test methods. Zhou J S et al. [4] studied the effect of vertical elastic vibration of the carbody on passenger comfort. Takigami T et al. [5-6] studied the influence of carbody modal order on carbody elastic vibration. Schandl G et al. [7] analyzed and studied the influence of carbody elastic vibration on passenger comfort. Some literatures have conducted research on the principle of dynamic vibration absorption, and the equipment under the carbody can be used as a dynamic vibration absorber to further reduce the elastic vibration of the carbody. Therefore, this article first introduces the theory of elastic vibration absorbers, then introduces the structure of its transformer, and finally analyzes and studies its vibration characteristics in the middle and late stages of wear recycle.
2. Mass tuning vibration absorption theory

Since some under-vehicle equipment has vibration excitation sources, a two-stage vibration isolation system is used to isolate the excitation from being transmitted to the carbody. Therefore, this paper establishes a coupled vibration model considering the two-level vibration isolation system adopted by the under-vehicle equipment, as shown in Figure 1. Similar to the system vibration equation with a single undercarriage device, the carbody vibration equation remains unchanged. Only the device is divided into two mass bodies. It is not difficult to write the vibration equations of the device bracket and the carbody.

According to the vertical coupling vibration relationship between the elastic beam body model and the equipment, the model is shown in Figure 1. The mechanical model combined with the dynamic vibration reduction of the elastic system is simplified as a hybrid dynamic system composed of the elastomer and discrete mass.

![Figure 1. Coupling vibration model of carbody and equipment](image)

R. G. Jacquot used the modal analysis method, modal truncation and modal synthesis method to give the approximate solution of dynamic vibration absorption of general elastic components. For a uniformly straight elastic beam, it is equivalent to solving the dynamic absorption problem of a single degree of freedom vibration system with a main mass of $\rho Al$ excited by a concentrated force $e_jw$. The amplitude frequency characteristic method of the discrete vibration system is adopted for the dynamic absorption of the uniform straight beam. The equation of motion of the whole system can be derived by using the mode truncation method and the mode synthesis method. Then the dynamic amplification coefficient of the generalized coordinate $x_1$ to the generalized force can be obtained. After the dynamic absorber is installed, the dynamic amplification coefficient is equal to the dynamic amplification coefficient of the dynamic absorption of the single degree of freedom system with the main mass of $M$. The main mass calculation formula is as follows:

$$M = \frac{\rho Al}{Y_1(a)}$$  

(1)

Where: $\rho Al$ is the mass of elastic vehicle body, $\rho$ is the density of unit length, $A$ is the cross-sectional area of carbody, $l$ is the length of carbody; $Y_1(a)$ is the first mode function of elastic beam.

The above formula shows that if the dynamic vibration absorber is installed at the position with the maximum vibration amplitude of the vehicle body, its equivalent mass $M$ can be minimized. Compared with the determined mass $m$ of the absorber, the mass ratio $\mu = m/M$ will get the maximum value, so the best vibration absorption effect can be obtained. The calculation of the optimal frequency ratio and damping ratio of the dynamic vibration absorber of the uniform beam is as follows:

$$f_{opt} = \frac{1}{1 + \mu Y_1(a)}$$  

(2)

Where, $\mu$ is the mass ratio of the equipment to the elastic quantity; $Y_1(a)$ is the first mode function of the elastic beam; $f_{opt}, \zeta_{opt}$ are respectively the optimal suspension frequency ratio (the first bending frequency of the vehicle body) and damping ratio of the equipment.

According to the free vibration differential equation of the uniform beam, the vibration mode function can be derived. Combined with the boundary constraints of the free beam, the frequency equation and the natural frequency form can be obtained as follows:
Natural frequency equation of free beam:

$$1 - \cos \lambda_i \cosh \lambda_i = 0$$  \hspace{2cm} (3)

Free beam boundary conditions:

$$\ddot{Y}(0) = \ddot{Y}(l) = 0, \quad \dddot{Y}(0) = \dddot{Y}(l) = 0$$  \hspace{2cm} (4)

Substituting formula (4) into formula (3), the natural frequency is obtained:

$$\lambda_i = (2n + 1) \pi / 2$$  \hspace{2cm} (5)

According to the vibration differential equation of free beam, the vibration mode function of elastic uniform beam is obtained as follows:

$$Y_i(x) = \cosh \beta_i x \cos \beta_i x - A (\sinh \beta_i x + \sin \beta_i x)$$  \hspace{2cm} (6)

Where:

$$A = \left( \cosh p_i x - \cos p_i x \right) / \left( \sinh p_i x - \sin p_i x \right), \quad \beta_i = \lambda_i / l$$

3. Structure of the Transformer

The transformer body has a mass of 7000 kg and is connected to the carbody through 4 points, and each connection point adopts 2 sets of elastic hoisting. The cooler has a mass of 500 kg and is connected to the carbody through a 4-point method, and each connection point is only one set of elastic hoisting. The elastic lifting structure types of the transformer body and the cooler are similar, but the internal elastic element forms and parameters are different. Transformers have significant magnetically induced vibration characteristics. The structure diagram and physical picture are shown in Figure 2 and Figure 3.

![Transformer structure diagram](image)

Figure 2. Transformer structure diagram

![Physical picture of transformer elastic hoisting components](image)

(a) Body \hspace{2cm} (b) Cooler

Figure 3. Physical picture of transformer elastic hoisting components

4. Converter vibration analysis with wear mileage of 134,000 kilometers

The operation mileage after the reprofile the wheel was 134,000 kilometers, and the equivalent
conicity of 8 vehicles was above 0.3, as shown in the figure 4. The operating lines are Harbin-Dalian Line and Changchun-Jilin Line. The interval is Shenyang-Changchun-Jilin-Changchun-Shenyang. The operating speed of Harbin-Dalian Line is 250km/h and the operating speed of Chang-Jilin Line is 200km/h.

By analyzing the test data, the following conclusions can be drawn:
Part of the line section of the vehicle snaking motion, the frame lateral acceleration appears harmonic, the main frequency is 7Hz, the amplitude is 0.6g (3-9Hz band-pass filter); the bogie vibration will be transmitted to the carbody and the equipment under the car, and the auxiliary converter. The vibration of the main body of the converter has a greater impact, that is, the lateral dominant frequency of the auxiliary converter is about 7 Hz.

When the bogie is hunting significantly, the time-domain amplitude comparison shows that the lateral acceleration amplitude of the auxiliary converter is about 5 times that of the carbody, and corresponding to the vibration of about 7 Hz, the equipment acceleration is an order of magnitude larger than the carbody.
The running mileage of the is 259,000 kilometers, and the equivalent conicity is 0.3~0.4. The vehicle operating interval is Shenyang-Dalian-Shenyang-Changchun-Shenyang. The maximum operating speed is 250km/h, and the full speed is 250km/h. Comparing the lateral vibration characteristics of the frame, analyze the vehicle body measurement points at the connection point between the equipment and the vehicle body, and the lateral and vertical acceleration time-frequency diagrams of the equipment measurement points, analyze the frequency modal distribution characteristics, and summarize the natural vibration of the equipment and the vehicle body modal vibration characteristics.

By analyzing the test data, the following conclusions can be drawn. With the increase of the wear mileage, significant harmonic vibration of the bogie appears in the later stage of wear, the main frequency is 6~9Hz, this vibration will be transmitted to the carbody, affecting the carbody modal and the vibration of the equipment under the carbody.

Both the carbody and the traction auxiliary converter have the same frequency lateral and vertical vibration, that is, the carbody structure mode and the equipment suspension frequency are also in this frequency range.

The high frequency part of the traction transformer mainly manifests as magnetic vibration, but the high frequency magnetic vibration is effectively isolated by elastic lifting and is not transmitted to the carbody; the low frequency is mainly the carbody rigid body mode, the transformer suspension frequency and the carbody structure mode.

The horizontal and vertical vibration amplitudes of the high-voltage box and braking unit are slightly smaller than the vibration of the carbody, mainly due to the rigid suspension, and the vibration is transmitted from the carbody to the equipment.

Transformer vibration law. At the moment of bogie instability, the lateral acceleration amplitude of the equipment is significantly larger than that of the carbody, and the phase is reversed at the harmonic moment. The vertical acceleration level of equipment and vehicle body is consistent.
5. Conclusion
This article first introduces the vibration reduction theory of the equipment under the EMU, and then briefly analyzed the vibration data of the transformer in the middle and late stages of wear. It can be obtained that: some line sections of the vehicle have hunting movement, and the lateral acceleration of the frame has harmonics, the main frequency is 7Hz, and the amplitude is 0.6g (3-9Hz band-pass filter). The bogie vibration will be transmitted to the carbody and the equipment under the carbody, which has a greater impact on the vibration of the auxiliary converter carbody, that is, the lateral main frequency of the auxiliary converter is about 7Hz. The high frequency part of the traction transformer is mainly manifested as magneto-induced vibration. The high-frequency magnetic vibration is effectively isolated by elastic hoisting and is not transmitted to the carbody, and the amplitude is 0.6g (3-9Hz band-pass filter). The bogie vibration the low frequency is mainly the carbody rigid body mode, the transformer suspension frequency and the carbody structure mode.

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