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Modal Test and Analysis of High Speed Railway Pantograph Under Typical Working Conditions

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Abstract

The high-speed railway EMU obtains electric energy through sliding connection between pantograph and catenary. A reliable and stable connection between pantograph and catenary is helpful to improve the current collection quality of EMU, reduce the off-line rate of pantograph and catenary, reduce the arcing rate and improve the service life of pantograph and catenary. This paper carried the modal test experiments of CX-G pantograph assembled by China CRH 400 EMU under different working conditions, the effects of different raising height and static contact force are studied. Data shows that the resonant frequency of first order operational modal will change with pantograh raising hight and static contact force, which should be considered in catenary design and pantograph operation parameter configuration to optimize the relationship between pantograph and catenary.
Keywords: CX-G Pantograph, Modal Test, Operating Modal, Working Condition.

1 Introduction

The high-speed railway EMU obtains electric energy through the sliding connection between pantograph and catenary[1]. A reliable and stable connection between pantograph and catenary is helpful to improve the current collection quality of EMU, reduce the off-line rate of pantograph and catenary, reduce the arcing rate and improve the service life of pantograph and catenary. However, too close contact will aggravate the wear of pantograph contact strips and contact wire and reduce their service life[2]. At the same time, increasing the contact force between pantograph and catenary will also change the boundary conditions when the pantograph raised, which will lead to the change of operational modal and affect the relationship between pantograph and catenary[3]. Therefore, it is necessary to study the operational modal of pantograph under different constraints, so as to improve the relationship between pantograph and catenary under corresponding working conditions.

At present, the pantograph modal test experiments have been carried out mainly for DSA 380, DSA 250 and other earlier models[5,6]. The hammer excitation method or exciter vibration method is used to obtain the resonant frequency and modal of each order under certain rising state. There is little research on the pantograph operational modal under different working conditions. For DSA 380 pantograph, Wei Xiangdong et al. tested and analysed the modals of pantograph head under contact and free with catenary status respectively[7].

The differences of various pantograph working conditions are mainly reflect in the two aspects of raising height and static pantograph-catenary contact force. In this paper, the modal test experiments of CX-G pantograph assembled by China CRH 400 EMU are carried out under different combinations of pantograph raising height and pantograph catenary contact force, the effects of different working conditions during pantograph operation are studied.

2 Methods

In this paper, CX-G pantograph modals are tested by using hammering method. During the test, the pantograph base is connected to cast iron floor with bolts through insulators to simulate the rigid boundary conditions of the pantograph installation on the roof of EMU. The pantograph head bracket is elastically connected with the base through the elastic belt to simulate the elastic boundary conditions of contact with the catenary in the running state. The pantograph raising airbag is connected with the air compressor through the precision pressure regulating valve to obtain the air pressure required to adjust the pantograph raising height and pantograph catenary contact force. Before the test, the travel limit device of test bench equipped with force sensor was pre-positioned to the required pantograph raising height, adjust the precision voltage regulating valve until the pantograph head contacts the travel limit device and reaches the required contact force. After adjustment, shrink the elastic band to slightly separate the pantograph head from the travel limit device, move the travel limit device far away and start the hammering test. Figure 1 shows the pantograph modal test site.

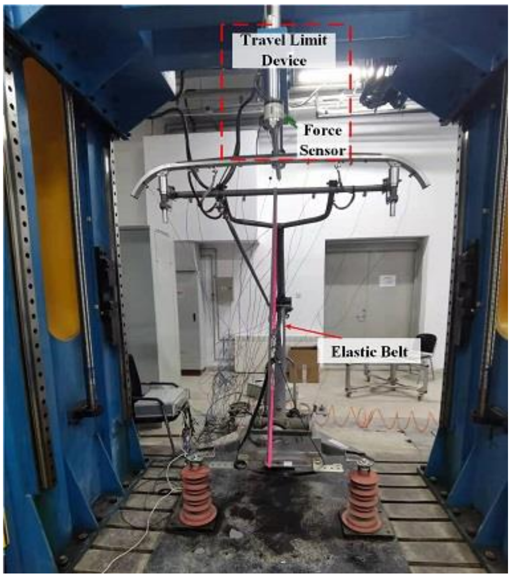


Figure 1: Pantograph modal test site.

China high-speed railway catenary mainly include 5300mm, 6000mm and 6450mm three different kinds of design height. The height of EMU equipped with CX-G pantograph is 4050mm, and the height of pantograph base together with insulator is 400mm. Therefore, the pantograph is set to three different raising heights of 900mm, 1600mm and 2000mm. According to "Railway applications – current collection systems – technical criteria for the interaction between pantograph and overhead contact line (IEC 62486:2017)[8]", the static contact force between pantograph and catenary of alternative current traction power supply system should be within range of 70N to 90N. Therefore the static contact force is set to 60N, 80N and 100N. Through the combination of pantograph raising height and contact force, the modal tests under nine groups of working conditions are carried out.

3 Results

In order to minimize the noise impact of input and output signals, H4 method is used to estimate the real frequency response of the system for the data of each knock. The calculation method of H4 estimation is:

$$H_4(f) = ((G_{IO}(f) \cdot G_{OO}(f))/(G_{II}(f) \cdot G_{IO}(f)))^{½} \qquad (1)$$

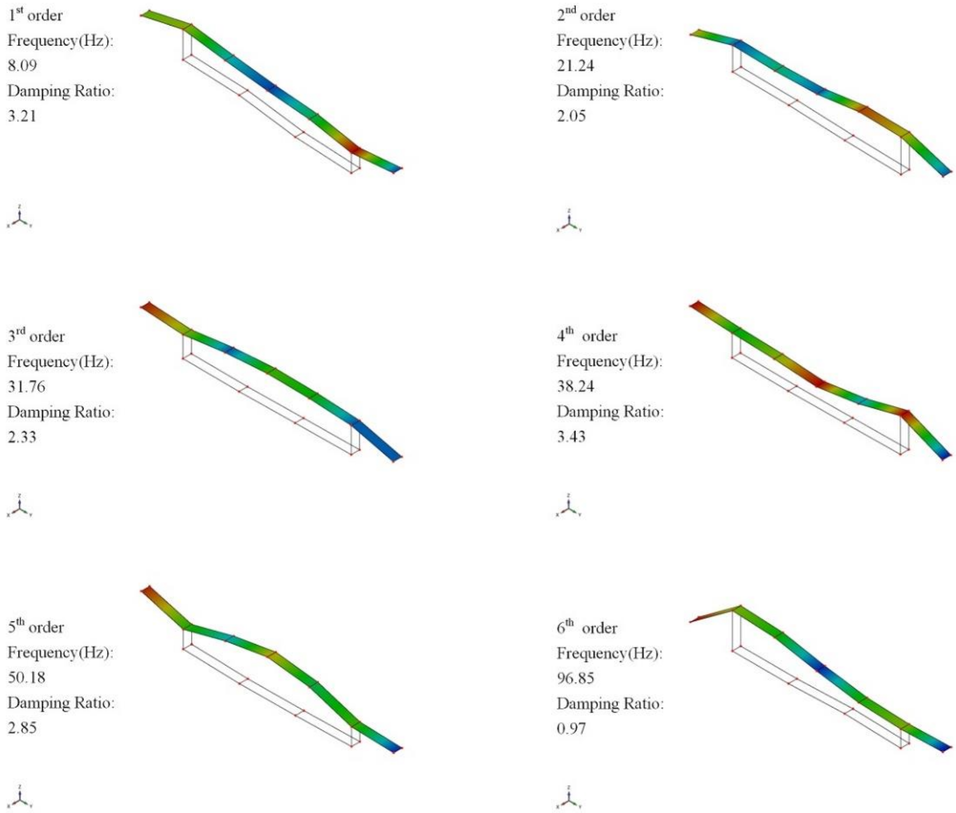
Where $G_{IO}(f)$ represents the input-ouput coss spectrum, $G_{II}(f)$ and $G_{IO}(f)$ represents the self spectrum of input and output separately. Multiple times of knock was carried out under each working condition, chose the data with flat frequency spectrum and no double knock of hammer signal to calculate the frequency response function, the interference between hammer signal and acceleration sensor signal should also be relatively ideal. Take the average value of multiple knock data as the final estimation result of frequency response function, so as to further reduce the experimental error. After obtaining the frequency response function matrix, the modal is estimated by the poly reference least squares complex frequency domain (PolyMAX) method. The objective function of PolyMAX method is:

$$obj(\theta) = \sum (o=1 \sim O) \sum (f=1 \sim F) \ tr((\varepsilon(\omega_f, \theta))^H \cdot (\varepsilon(\omega_f, \theta))) \qquad (2)$$

Where θ means parameter matrix to be solved, *O* represents row number of frequency response matrix, *F* represents modal order involved in calculation, ε represents error function which is defined as:

$$\varepsilon=|H_o(\omega_f)|/var(H_o(\omega_f))(H_{Eo}(\omega_f, \theta)-H_o(\omega_f)) \quad (3)$$

Where *Ho* represents *o* row of experimental frequency response matrix, H_{Eo} represents *o* row of estimated frequency response matrix. The resonant frequency and damping ration could be solved out by minimizing the following objective function. Since the pantograph head and the pantograph frame are connected by spring instead of rigid connection, their modal are also tested and analyzed separately. Figure 2 shows first sixth orders of vertical modal shapes and corresponding resonant frequency with damping ration of pantograph head and frame under the working condition of 1600 mm raising height and 80 N static contact force.



(a) Pantograph head

(b) Pantograph frame

Figure 2: Pantograph modal and corresponding resonant frequency with damping ratio.

4 Conclusions and Contributions

According to the above experimental methods, the modal test experiments under various working conditions are completed. It is found that the modal shapes of each order basically do not change with the working conditions. The resonant frequency of first three order modal of pantograph head under different working conditions are shown in Table 1, data shows that under the same pantograph raising height, with the increase of static contact force, the resonant frequency of first order operational modal will decrease firstly, reach the minimum at contact force of 80N and then turn to increase. While under the same contact force, the resonant frequency of first order operational modal will decrease with raising height.

Raising Hight		900mm			1600mm			2000mm		
Modal Order		1	2	3	1	2	3	1	2	3
Force	60N	9.899	19.91	29.388	8.354	25.778	32.289	8.17	23.35	33.905
	80N	8.296	20.594	33.614	8.093	21.246	31.761	7.95	23.47	32.27
	100N	8.61	21.28	33.47	8.451	25.678	29.388	8.421	23.653	31.182

Table 1: Resonant frequency of pantograph head in different condition.

The resonant frequency of first three order modal of pantograph frame under different working conditions are shown in Table 2, data shows that under the same pantograph raising height, with the increase of static contact force, the resonant frequency of first order operational modal will decrease firstly, reach the minimum at contact force of 80N and then turn to increase. While under the same contact force, the resonant frequency of first order operational modal will increase with raising height.

Raising Hight		900mm			1600mm			2000mm		
Modal Order		1	2	3	1	2	3	1	2	3
Force	60N	25.783	33.886	48.286	25.77	33.513	48.469	25.833	33.408	48.487
	80N	24.678	33.959	48.103	25.377	33.408	48.465	25.479	33.408	48.643
	100N	25.92	33.959	48.103	25.43	33.391	48.479	25.608	33.539	49.271

Table 2: Resonant frequency of pantograph head in different condition.

During the operation of pantograph, due to the action of anchor section joints, locators, suspenders and other structures, there are relatively stable frequency components related to the design parameters of catenary in the excitation spectrum. The research results show that the static contact force and raising height of pantograph will affect the operational modal of pantograph. This influence should be considered in catenary design and pantograph operation parameter configuration to optimize the relationship between pantograph and catenary.

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