Pantograph and catenary system with double pantographs for high-speed trains at 350 km/h or higher

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Abstract: The paper is aimed at developing an optimized design of the pantograph and catenary system with double pantographs at a speed of 350 km/h for the Wuhan-Guangzhou high-speed railway. First, the pantograph and catenary system for the Beijing-Tianjin high-speed railway was analyzed to verify whether its design objective could be fulfilled. It shows that the system is not able to satisfy the requirement of a sustainable running speed of 350 km/h. Then a new scheme for the pantograph and catenary system is proposed through optimization and renovation of the structure and parameters of the pantograph and catenary system, including the suspension type of the catenary, tension of the contact wire, and space between two pantographs. Finally, the dynamic performance of the new system was verified by simulation and line testing. The results show that the new scheme of the pantograph and catenary system for the Wuhan-Guangzhou high-speed railway is acceptable, in which the steady contact between the rear pantograph and the catenary at the space of 200 m can be maintained to ensure the current-collection quality. A current collection with double pantographs at a speed of 350 km/h or higher can be achieved.

Key words: catenary; pantograph; dynamic performance; double pantographs

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1. Introduction

The Wuhan-Guangzhou high-speed railway is the southern section of the Beijing-Guangzhou high-speed railway. It runs through Hubei, Hunan, and Guangdong provinces, and is 1 069 km long. The existing Beijing-Guangzhou railway is at its full transport capacity, and the conflict between cargo and passenger demand is increasing. Construction of the Wuhan-Guangzhou high-speed railway is meant to reduce the traffic pressure on the Beijing-Guangzhou railway. Targeting the pantograph and catenary system of the Wuhan-Guangzhou high-speed railway, a design objective with double pantographs is proposed to achieve the sustainable running speed of 350 km/h.

When two high-speed trains are linked together in operation, double pantographs have to be employed due to the restriction of current capacity. However, when the trains are running, pantographs slide along the catenary and cause it to vibrate. This vibration is propagated in the form of a wave along the contact wire. The vibration wave of the contact wires caused by the front panto-

graph may lead to an unfavorable influence on the dynamic performance of the rear pantograph. The contact force between pantograph and catenary may vary considerably [1-2]. Furthermore, if the space between the two pantographs is not appropriate, the influence of the vibration becomes more evident and may result in zero contact force, arcing, and wear of the rear pantograph. Therefore, it is essential to highlight the influence of the space between two pantographs on the dynamic performance of pantograph and catenary system, to choose a reasonable space, and propose a design scheme of the pantograph and catenary system for speeds of 350 km/h or higher.

The paper is organized in five sections. Following the introduction, the pantograph and catenary system for Beijing-Tianjin high-speed railway was analyzed to verify whether its design objective could be fulfilled in Section 2. In Section 3, a new scheme for the pantograph and catenary system is proposed by means of optimization and renovation of the structure and parameters of the pantograph and catenary system for the Beijing-Tianjin high-speed railway, including the suspension type of the catenary, tension of the contact wire, and space between two pantographs. Before concluding the paper, the dynamic performance of the new system was verified by simulation and line testing in Section 4.

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2. Analysis of pantograph and catenary system for Beijing-Tianjin high-speed railway

The Beijing-Tianjin high-speed railway was opened to traffic in August 2008. It is the first railway line in China with a speed of 350 km/h, and only half of an hour is required to travel from Beijing to Tianjin. The pantograph and catenary system used on the Beijing-Tianjin high-speed railway adopts a simple catenary with a tension of 48 kN (the tension of the contact wire is 27 kN and the tension of the support wire is 21 kN), whose structure and parameters are shown in Fig. 1. The matching pantograph is TSG 19, as shown in Fig. 2.

As for the scheme of the pantograph and catenary system for the Beijing-Tianjin high-speed railway, an analysis of the dynamic performance of the system with double pantographs was carried out to check whether the design objective mentioned above can be fulfilled or not [3-4]. Fig. 3 describes the contact forces of the front and rear pantograph at the speeds of 300 km/h and 350 km/h.

It can be seen that, at the speeds of 300 km/h and 350 km/h, the contact forces between the pantograph and catenary vary greatly: the contact may be lost, and the quality of current-collection may worsen. Thus, it may be concluded that the scheme is not reasonable enough to satisfy the requirement of the sustainable running.

Fig. 1 Structure and parameters of the catenary for the Beijing-Tianjin high-speed railway (unit: m)

Fig. 2 TSG19 pantograph

(a) 300 km/h

(b) 350 km/h

Fig. 3 Contact forces of the front and rear pantograph at different speeds for the Beijing-Tianjin high-speed railway

3. Redesign of pantograph and catenary system for Beijing-Tianjin high-speed railway

3.1. Suspension type and tension of the catenary

The contact forces for the stitched catenary are larger than that for the simple catenary under the same conditions, such as tension, material, span length, dropper space, etc., and the propagation speed of the wave on the contact wire may rise with an increase in the tension, thus raising the maximum running speed of the train [5]. Therefore, when resigning the pantograph and catenary system for the Beijing-Tianjin high-speed railway, the stitched catenary is preferred, and the assistant wire is added to reduce the difference of the static stiffness of the catenary. Meanwhile, the tension of the contact wire is increased from 27 to 30 kN to raise the propagation speed of the wave. After this renovation, a new scheme is obtained as shown in Fig. 4.

3.2. Space between two pantographs

When two high-speed trains are linked together in operation, the space between the two pantographs plays an important role in the current collection on the rear pantograph. By analyzing the propagation progress of the vibration wave on the catenary, an optimal space be

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Fig. 4 Structure and parameters of the catenary after the reconstruction (unit: m)

tween the two pantographs can be determined to ensure a stable current-collection.

When the pantograph moves along the catenary at high speed, the coupled vibration between the pantograph and catenary is inevitable and will be propagated in the form of a wave along the contact wire, due to the difference in the static stiffness of the catenary. When the vibration wave arrives at either end of the contact wire, it will lead to wave reflection. After multiple reflections, the waves will be synthesized and counteracted: it is the basic wave that imposes a major effect on the vibration of the contact wire. The solid line in Fig. 5 describes the vibration waveform on the contact wire at contact points. It is seen that the waveform at contact points varies periodically with each span, and the maximum of the waveform is located in the middle of each span, while the minimum exists near the pillar.

When two pantographs run along the contact wire in a coupled form, a vibration waveform of the pantograph moving in the same frequency and parallel direction will result, due to the coupled action between the pantograph and catenary. In Fig. 5, the dot line is considered as a vibration waveform resulting from the pantograph at the back of contact points (L_g), and the solid line is considered as a vibration waveform of the contact wire at contact points. It can be seen that vibration waves of the

pantograph and of the contact wire share a phase difference of 180° , and move in opposite directions. Moreover, the interaction and overlap between waves would decrease the vibration at contact points, reduce the difference in the static stiffness of the catenary, and improve the quality of the current collection at the rear pantograph. A conclusion here can be drawn that the vibration wave caused by the pantograph is at an opposite direction against that caused by the contact wire at contact points when the space between the two pantographs is optimal. This condition can happen if the time for the rear pantograph moving to the position (L_g) at the back of contact points of the front pantograph is half of odd multiples of the period time for the vibration wave of the contact wire. This relation can be expressed in the following form:

$$\frac{L_g}{u} = (k + \frac{1}{2}) \frac{\lambda}{v}, \quad k = 1, 2, 3, \dots \quad (1)$$

where L_g is an optimal space, u is the running speed, λ is the wavelength of the vibration wave, and v is the speed of the vibration wave. Then, through the determination of λ and v , the formula of the optimal space between two pantographs may be inferred, as follows:

$$L_g = (2k + 1) \frac{Lu}{\alpha \sqrt{T/\rho}}, \quad k = 1, 2, 3, \dots \quad (2)$$

where L is the span length of the catenary, T is the tension of the contact wire, ρ is the linear density of the contact wire, α is the modified coefficient, and it is 0.8 under a stitched catenary.

On the other hand, if the dot-dash line in Fig. 5 is considered as a vibration waveform caused by the pantograph at the back of contact points (L_b), one can see that the phase difference between the vibration waves of the pantograph and that of the contact wire is zero, and the waveforms are in the same direction. Therefore, it undesirably leads to the vibration enhancement of the pantograph and the catenary at contact points, and the enlargement of the difference in the static stiffness of catenary, and worsens the quality of current collection.

Fig. 5 Vibration waveforms of the contact wire and the pantograph at different locations

Furthermore, the formula of the unfavorable space may also be inferred, as follows:

$$L_b = 2k \frac{Lu}{\alpha \sqrt{T/\rho}}, \quad k = 1, 2, 3, \dots \quad (3)$$

For the new scheme of the catenary system, the formula (2), is used to calculate the optimal space between two pantographs at the speeds of 270, 300, 330, and 350 km/h. The results of the optimal spaces are shown in Table 1.

It can be seen in Table 1 that, when the running speed is around 330–350 km/h, the optimal space ($k=2$) is approximately equal to 200 m. This shows that, for the new scheme of the catenary system, the space of 200 m between two pantographs is preferable for the current collection of pantographs at the speed of 350 km/h.

Table 1 Optimal space for the new scheme of the catenary

Speed (km/h)	Optimal space (m)		
	$k=1$	$k=2$	$k=3$
270	94.33	157.22	220.11
300	104.82	174.70	244.57
330	115.30	192.16	269.03
350	122.29	203.81	285.33

4. Validation

4.1. Simulation

Based on the redesigned catenary and the same pantograph as that on the Beijing-Tianjin high-speed railway, the dynamic performance of the pantograph-catenary system with double pantographs has been analyzed to validate whether the new scheme can meet the requirement of its sustainable operation at the speed of 350 km/h. Fig. 6 describes the contact forces of the front and rear pantograph at the speed of 270, 300, 330, and 350 km/h.

It can be observed that, for the new pantograph and catenary system, when the space between two pantographs is 200 m, the contact forces of the rear pantograph fluctuate slightly and are basically consistent with those of the front pantograph. The design objective of the sustainable operation at the speed of 350 km/h may be fulfilled.

4.2. Line test

According to the test schedule of current-collection performance for CRH2 high-speed train, a line test for the new pantograph and catenary system was carried out. During the test, two No. 6 pantographs were elevated.

Fig. 6 Contact forces of the front and rear pantograph at different speeds

The space of two pantographs was 200 m, and the test equipment was fixed on one of the two pantographs.

Then, the current-collection performance at the speeds of 300, 320, 330, 340, and 350 km/h was measured. Fig. 7 depicts the contact forces of the measured pantograph as the front pantograph and the rear pantograph at the speed of 350 km/h [6].

It can be seen in Fig. 7 that, at the speed of 350 km/h, fluctuation of the contact force is more volatile when the test pantograph is being used as the rear pantograph than when the test pantograph is the front one, and the minimum of the contact forces is smaller. However, the contact loss is still not detected. This indicates that the quality of current collection can satisfy the regulation concerning the test standard. Through the line testing, it is also shown that the new scheme of pantograph and catenary system with double pantographs and a space of 200 m may achieve the sustainable running speed of 350 km/h.

Fig. 7 Test results of the contact forces at the speed of 350 km/h

5. Conclusion

For the pantograph and catenary system of the Wuhan-Guangzhou high-speed railway, a design objective to achieve the sustainable running speed of 350 km/h with double pantographs is put forward. First, the pantograph and catenary system for the Beijing-Tianjin high-speed railway was analyzed to verify whether its design objective could be fulfilled, and it was shown that the system is not able to satisfy the requirement of the sustainable running speed of 350 km/h. Then a new

scheme for the pantograph and catenary system was proposed by means of optimization and renovation of the structure and parameters of the pantograph and catenary system, including the suspension type of the catenary, tension of the contact wire, and space between two pantographs. Finally, the dynamic performance of the new system was verified by simulation and line testing. The results show that the new scheme of the pantograph and catenary system for the Wuhan-Guangzhou high-speed railway is acceptable, in which the steady contact between the rear pantograph and the catenary at the space of 200 m can be maintained to ensure the current-collection quality. Thereby, the current collection with double pantographs at a speed of 350 km/h or higher is achieved.

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