Influencing Factors on Dynamic Characteristics of Pantograph of Korean High Speed Train

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Abstract

Running test of the Korean High-Speed Train using remote controlled measuring system have been executed on the high speed track in order to evaluate and verify the performance of the train. In this paper, influencing factors on the contact force which represents dynamic characteristics between the pantograph and contact wire are analyzed, according to the track condition, span type and running condition. By the analytical study on the test data, we figured out that contact force and dynamic characteristics of the pantograph are mainly affected by running behavior of the train and the span distance which the train passes.

Keywords: Current collection, Pantograph, Catenary system, Contact wire, Contact force, Span, Remote controlled measuring system

1. Introduction

In the electric train system which uses electric power, the current collection system is composed of catenary system which supplies electric power and pantograph that collects electric energy by contacting with the catenary wire. The current collection system of the high-speed train is one of the core technologies that determine the maximum operating speed of the train. Even with the dynamic interaction of pantograph and catenary system occurring while a high-speed train is running, the technology that can minimize a loss of contact by keeping the contact stable without the concern of external variables, is required. And especially, considering dangerous conditions of high-voltage electricity, effective method for testing the characteristics of the system have been required when analyzing and optimizing the many performance variables, which affect the dynamic behaviors of current collection system. In this reason, many researches had been executing to improve the current collection performance of high speed train and test method. [1-3,6,7] Studies on catenary and pantograph in Korea had been performed only in the field of operational research until 1990s, but the Kyung-Bu high-speed rail project and the Korean High-Speed Train (KHST) project became a starting point of promoting full scaled studies on the current collection system. [4,5].

This paper put its aim on identifying the influencing factors on dynamic characteristics of KHST pantograph by analyzing the variation of contact force of the pantograph according to the external variables such as span distance, track condition, and the accelerating condition of the train.

2. Out-line of Current Collection System

2.1 Catenary System and the Pantograph of the KHST

The KHST is composed of 2 motor cars and 5 passenger cars, and two pantographs are installed on roof of each motor car, which collects 25 kV electric power by uplifting and contacting to contact wire of catenary system. Fig. 1 shows a pantograph of the KHST, main frame and major parts are linked by pin joints. As shown in Fig. 1, 1st spring restrains high-frequency vibration between pan head and Al cross bar, and 2nd spring absorbs low-frequency vibration between pan head with free rotational structure and upper arm [6]. Fig. 2 shows catenary system in high-speed track which supplies electric energy to the train. The catenary system is composed of contact & messenger wire, droppers, moving bracket, and steady arm.
pulling contact wires in horizontal plane to make staggered (zig-zag) shape to prevent regional wear of carbon strip in pan head caused by concentrated and continuous sliding contact in same point.

### 2.2 Distribution of the Span Types in Catenary System of High Speed Track

In the catenary system, ‘span’ means the distance between hanging points of contact wire at two adjacent supports, and it is one of the major factors which influence on the dynamic characteristics of contact wire. In order to analyze dynamic characteristics of pantograph according to span distance, status of span types was investigated in high-speed track from KP 24 to KP 125. Total 58 span types with different span distance were classified among 2,160 spans from this investigation. Table 1 manifest typical 7 span types by order of distributed numbers regarting the open field, tunnel, straight or curved line, and transition curve. Fig. 3 shows distribution of span length in that track.

From table 1 and Fig. 3, we found out that s50(50 m), s40(40 m) and n3(54 m) span are major 3 span types far
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more than any other span types in whole test track area, and these major 3 span types are considered as the 3 representative span types of high speed track in this study.

3. Analysis of Dynamic Characteristics

3.1 Measuring System for Dynamic Characteristics of Pantograph

In identifying dynamic characteristics of pantograph, it is important to measure physical values directly at contact point between pan head of pantograph and contact wire, but also very dangerous because of high voltage electricity energized up to 25 kV at contact wire of catenary system. So we used remote controlled measuring system with wireless LAN telemetry device which measures and transmits the physical values of 12 channels, including contact force and acceleration of pantograph pan head. Fig. 5 shows schematic diagram of measuring system in the KHST. The measuring system consists of measuring and transmitter part with telemetry device on the roof, and data receiving and DAQ module in the train.

The variation of contact force between pantograph and contact wire is one of the most important parameters which determines the characteristics of current collection system, and finding out the influencing factors to the contact force is helpful for optimizing and improving the function of current collection system of the train.

When the pantograph contacts to the contact wire, applied forces can be described as equilibrium state shown in Fig. 6. The contact force $F_c$ between pan head and contact wire could be identified by aerodynamic uplifting force, $F_a$ and static force, $F_s$.

$$F_i = F_c = F_a + F_s$$

(1)

where, $F_i$; inertia force[N], $F_c$; contact force[N], $F_a$; aerodynamic force[N] and $F_s$; static force[N]

In the equilibrium equation of (1), under acceleration movement of pan head, inertia force varies positive and negative value vertically from the balanced position and if the mean value of contact force $F_c$ is taken in time domain, inertia force $F_i$ can be considered as “0”, and the mean contact force in equation (1) could be described as equilibrium equation (2) [7-9].

$$F_{C\text{mean}} = F_a + F_s$$

(2)

where, $F_{C\text{mean}}$; a mean contact force between pan head and contact wire [N]

As for aerodynamic lifting force $F_a$, in the equilibrium equation (1) and (2), are proportional to the square of train running speed $(V)$. The aerodynamic coefficient of pantograph could be obtained through air tunnel test, and was verified by measuring the actual aerodynamic force at each train speed up to 200km/h in trial running test [10].

From equation (1) and (2), with applying experimental aerodynamic coefficient, we can eventually find out the mean contact force from equation (3).

$$F_{C\text{mean}} = f_s + 4.96 \times 10^{-4} \times V^2$$

(3)

where, $V$; train speed, [km/h]

The static force can be measured as the left & right compression forces by load cell sensors installed on the bottom of 1st spring of the pantograph pan head. Fig. 7 shows the load cell sensor installed under the spring housing of pan head.

Fig. 8 presents measured signal for right and left contact
forces at lower graph, and mean contact force at upper one, through running test. The right and left contact force repeat it in a frequency of 2 spans with the left contact force appears one span of phase difference before the right contact force. This phase difference shows the stagger effect of contact wire which sets up at the hanging point of contact wire in every support, so the actual contact points between pant head and contact wire move to left and right periodically. The mean contact force, showed on upper graph in Fig. 8, repeatedly varies with 1 span cycle, as summed value of left and right contact force and aerodynamic uplifting force.

3.2 Contact Force of Pantograph According to Each Condition

3.2.1 Analysis on the correlation of measured data and running conditions

Fig. 9 show the distribution of data set which are measured and used in this study, in relation with span type-train passing speed. The horizontal axis of graph in Fig. 9 represents the code number of span type shown in Table 1. As Fig. 9 shows, measured data includes more than 50 kinds of span types in high-speed track. So the data set have to be classified and grouped according to diverse speed levels on each major of span types, and also to be grouped according to track configure and driving conditions. So all the measured data are grouped according to diverse speed levels on each major 7 span types i.e., s50(50 m), s40(40 m), n2(58.5 m), n3(54 m), n4(49.5 m), n5(45 m), and n6(40.5 m). As those major 7 span types are occupied almost 74.5% of whole length of test track (100.2 km), it can be considered that the measured data obtained passing those 7 span types could possibly represent the general characteristics of whole catenary system of the high speed test track.

Because of diversity of span types which are distributed on the high speed track and driving patterns, data for contact force in certain span type through the whole running speed range of the train could not be obtained sufficiently; so the regression curve was used to find out the physical characteristics of each span type. Fig. 10 shows individual measured data of contact force in s50 span with a mark () and regression curve (solid line) of used data measured at whole speed range up to 300 km/h. The determination coefficient of this regression curve, R^2 was 0.9319, so it can be considered that the formed regression curve represents the typical characteristics of measured data set very well.

3.2.2 Contact force according to track conditions

Fig. 11 shows the measured contact force according to the track conditions classified by tunnel or open field, in case of s50 span. The measured data shows that contact forces at any train speed have similar characteristics even in tunnel (marked □) or open field (△) condition.

Fig. 12 shows measured data for contact force of pantograph according to the track condition which classified straight (marked □), curved track (△) and transition curved track (∗) in case of s50 span. The measured data shows
that contact forces according to the train speed have same characteristics in each track condition, even in straight, curved track, and transition curved track.

As can be seen from Fig. 11 and 12, it appears that neither the track configuration (i.e. whether the track is housed in tunnel or not) nor the track shape (i.e. whether it is curved or not) has significantly influenced the contact force of the pantograph in high speed train.

3.2.3 Contact force according to span type

As described in Table 1 and Fig 3, there are 7 span types in majority among 58 span types in high speed test track. Fig. 13 shows the regression curve of measured data for contact force in major 7 span types. In a viewpoint of span distance, because the couple of n6 span (40.5 m) and s40 span (40 m) or n4 span (49.5 m) and s50 span (50 m) have just 0.5 m difference in span distance, those two coupled span types can be considered as the same span respectively and applied to group the data and to form the regression curve for (s40+n6) and (s50+n4). From the regression curve in Fig. 14, characteristics and variation trend of contact force for 5 data group classified with span type can be found. The contact force of pantograph has the biggest character in (s40+n6) (marked as □) and has the smallest character in "n2 span (58.5 m, marked as ▶) at same speed.

Fig. 13 shows that when all the trains traveled at the same speed the largest contact force was observed at the shortest span (s40+n6) whereas the smallest contact force was observed at the longest span (n2). Based on the data presented in Fig. 13, it would be suggested that the contact force of the pantograph is inversely proportional to the span length.

3.2.4 Contact force according to the running behavior of high-speed train

Apparently as the train accelerated or decelerated the external force was exerted to the pantograph because it is a simple linked arm structure with a pin joint shown in Fig. 1. Fig. 14 shows a set of the regression curves for the contact force measured at the span type s50+n4 when the train was coasting, hauling and braking respectively. It was
found that the contact force of pantograph in braking condition is 9-11 N or 5.5-6% bigger than that in coasting mode running i.e., acceleration=0 in 250-300 km/h speed range, in s50 span. This analytical study would recommend that the acceleration (or deceleration) of the high speed train due to hauling (or braking) is likely to be one of the most important factors influencing the contact force between the pantograph and the catenary system.

4. Conclusion

As the findings presented above, we can summarize our study as follows:

(1) In the test range of the high-speed track, 2,160 spans of 58 types with each different length are placed mixed, and s50, s40, and n3(54 m) span type are much used far more than any other span types. So these 3 span types can be considered as the major 3 representative span type of the high speed track in Korea.

(2) We confirmed that a contact force between pantograph and contact wire is rarely influenced by the track conditions such as straight or curved tracks, but is highly affected by the span type. Through the analytical study on a correlation between the span type and the contact force, the contact force of pantograph has been found to get smaller as the span distance becomes longer. Thus, it is highly desirable to apply the long distance spans for high-speed running in terms of the current collection system, if the geographical features of the track and cost values are taken into account.

(3) The acceleration characteristics of the train caused by running behavior is one of the major influencing factors on dynamic characteristics and contact force between the pantograph and catenary system. The mean contact force of pantograph in braking condition is 9-11 N (5.56%) bigger than that in coasting mode running of the train at 250-300 km/h, in case of passing through s50 span.

Reference