A Study on the Contact Force between Catenary and Pantograph in Duplicate KTX-II Operation

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Abstract

Electric railway system driving the electric cars using power from catenary has been secured by performance of stable tracking between pantograph and catenary. The performance of the power collecting of pantograph is the one of the most important skills for high-speed train speed. The first Korea high-speed train(KTX) is 20 cars in one train set. In the meantime, collecting capability of single pantograph collector at one train set was confirmed through evaluation of the performance and the stability test. However, more research is needed to build for a stable collecting capability of coupled Korea's KTX-II High-speed system which is developed in Korea. In this study, actual vehicle test of coupled KTX-Sancheon was made to analyzing the data presented by the dynamic nature of catenary and pantograph, and the interface characteristics.

Keywords :Catenary, Pantograph, Contact force, KTX-Sancheon.

1. Introduction

Opening of the High Speed Rail (KTX) in 2004 can be called a new chapter that transforms Korea railroad history as a transportation revolution after laying of Gyeong-In railway line opened in 1899.

Korea railroad speed was stuck at 100 km/h more than 100 years. After transformation of the 300 km/h speed truly has turned the pattern of our daily lives as well as the social paradigm that can not be done without a KTX.

Measuring catenary uplift and contact force should be completed within a very short period of time during pantograph operation. For this reason, such a measurement requires a system with fast response speed, few errors and flexibility to variation in location. Uplift and contact force require diverse measurement technologies and standards for themselves in line with increasing railroad electrification and growing train speed. This research measured catenary uplift and contact force accompanied by the elevated speed of KTX-II, etc. and analyzed the outcome.

2. Main Points

2.1 Technological characteristics of high-speed-train power collector

Korea's metropolitan area subway receives power from 6 to 10 sets of power collectors through catenary contact. As for high-speed trains such as KTX-I, they gain power from 1 power collector among a set of two collectors and KTX-II duplicate operation is powered by contacting to catenary 2 sets of power collectors among 4 sets. Therefore, the interface between high-speed train's pantograph and catenary is essential technology for the entire driving quality of a train and its highest speed evaluation. As for KTX-II duplicate operation, in particular, each system should be individually powered and its pantograph is initialled separately as well. During high-speed train operation, front-

Fig. 1 Correlation between wave speed & catenary

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Fig. 2 KTX catenary system

pantograph-generated waves heavily affect rear pantograph operation. As such, catenary-pantograph interface grows more significant for duplicate operation.

EN50119 rule also sets high-speed train's driving speed at 70% or less than the speed of wave as shown in Fig. 1 for stable pantograph power collection.

There are two different methods of evaluation the power collection quality - EN and UIC - and only one of the two should be applied. One measured contact force between catenary and pantograph and regards the collection quality as good if $F_{mean} - 3\sigma$ value - the difference between average contact force and the triplication of standard deviation - exceeds a certain threshold. The other method involves electric arc. This method is used when contact force is hard to measure. It assesses if the ratio between arc's accumulated hours and collecting hours, when the arc lasted at least 10ms, is less than 1%. Users may chose either of them depending on the type of a catenary system.

South Korea's high-speed-train catenary system, as displayed in Fig. 2, is consisted of contact wire that supplies power, messenger wire that supports load, dropper, bracket, stead arm that mitigates and control shocks during train operation, electric pole, etc.

2.2 Equation for pantograph contact force measurement

When pantograph is driving while collecting power, contact force F_c established equilibrium with shear forces and inertial forces on the suspension of a collector plate and aerodynamic forces on the collector plate. In Fig. 3 above, contact force F_c maintains force equilibrium with shear forces and inertial forces on the collector plate's suspension and aerodynamic force on it. Thus, force equilibrium equation is gained as follows:

$$F_L + F_R - \sum m_i a_i = F_c - F_{aero}$$

Fig. 3 pantograph contact force

Here, shear forces F_R , F_L is obtained by using a strain gage. and equivalent masses m_1 , m_2 , m_3 are calculated based on the dynamic characteristics test of pantograph. a_1 is acceleration and collector plate aerodynamic force F_{aero} is measured in advance through aerodynamic test with an attached accelerometer since the bending resonance mode exists in the frequency.

The force equilibrium between catenary and pantograph can also be described in the following equations (1) and (2). Contact force applied to pantograph and catenary can be estimated by using aerodynamic force obtained based on left/right shear forces as well as aerodynamic force test. The equation is as follows:

$$F_i = -F_c + F_a + F_s \quad (1)$$

Here, F_i : inertial forces[N], F_c : contact force [N]
 F_a : aerodynamic force[N], F_s : lifting force [N]

From the equation above, the average value of inertial forces converge to "0" as upward/downward forces appear from the equilibrium point depending on the acceleration movement of pantograph collector plate. Therefore, it can be expressed as the equation (2) below:

$$F_{c(mean)} = F_a + F_s \quad (2)$$

In the equations (1) and (2), aerodynamic force F_a is related to train speed and high-speed train's aerodynamic force can be obtained via high-speed driving test and experimental relation expression to be shown in the equation (3) below:

$$F_a = K_a \times \left(\frac{V}{200} \right)^2 \quad (3)$$

Here, V : train speed [km/h]

K_a : aerodynamic constant $(N/(km/h))^2$

F_a : aerodynamic force[N]

Fig. 4 KTX-II(Sancheon) pantograph

2.3 KTX-II pantograph technological review

KTX-II (Sancheon) pantograph, unlike KTX-I, is designed as a separated type, not an integrated type as in Fig. 4 for efficient catenary contact.

F_c , power generated by the contact of pantograph Contact Strip and catenary, can be largely divided into aerodynamic force(F_{aero}) applied to static lifting force(P_a) and pantograph as a whole; and inertial forces(F_{inf}) by acceleration.

That is, $F_c = F_{aero} + F_{inf}$.

Here F_{aero} is applied to the entire pantograph and can be divided into aerodynamic force(F_{sp}) working on Collector Head and aerodynamic force(F_{nsp}) for others.

Therefore, $F_c = P_a + F_{aero} + F_{inf} = P_a + F_{sp} + F_{nsp} + F_{inf}$ and here, Suspension's Spring Force(F_{sus}) equals to the sum of P_a and F_{sus} .

That is, $F_{sus} = P_a + F_{nsp}$. Thus, the entire contact force can be expressed as follows:

$$F_c = F_{sus} + F_{inf} + F_{sp}$$

$$F_{sp} = F_c - F_{inf} - F_{sus} \quad (1)$$

F_{sp} can be theoretically expressed as being proportional to the square of the speed based on aerodynamic characteristics as follows:

$$F_{sp} = A + Bv^2 \quad (2)$$

Here, A is a constant made by offsetting measurement errors and environment conditions between measurement systems. B refers to aerodynamic force coefficient and v is speed.

Aerodynamic test was performed by setting static lifting force at 90N, Air Spoiler angle at 20 degrees, Air Foil angle at 0 degree, and basic test speed at 300 km/h.

Fig. 5 Measuring equipment configuration

Fig. 6 Measuring equipment installation pantograph

Fig. 5 is about measurement equipment configuration.

Outdoors

sensor (displacement, variable velocity)

battery wireless switch sensor signal measuring equipment

wireless LAN communication

electrical insulation

Indoors

integrated measuring system

LAN communication

measurement data (driving speed)

measuring computer (data saving, sending, monitoring)

Measuring equipments were installed as in Fig. 6. Four Load Cells were fixed on Base Frame. F_c is the sum of forces measured in the 4 Load Cells.

Fig. 7 aerodynamic force characteristics on the pantograph

Fig. 7 Displays the relationship between speed and aerodynamic characteristics.

Table 1. Evaluation Threshold

item	threshold
average contact force	average contact force ($F_{mean} \leq 200N$)
loss of contact rate	loss of contact rate: $F_{mean} - 3\sigma \geq 0$

Table 2 Loss of Contact Rate and Contact Force Threshold

item	AC1	AC2	AC3	AC4
catenary wave speed v (km/h)	$v \leq 160$	$160 < v \leq 220$	$220 < v < 250$	$v \geq 250$
average contact force F_m (N)	not exceeding 200N below the limit set according to speed			
statistical minimum contact force at the highest speed	$F_m - 3\sigma$			
loss of contact rate at the highest speed (%)	1	1	1	1
minimum duration of arc under consideration (ms)	10	10	10	10
maximum duration allowed (ms)	25	25	25	25

2.4 Pantograph contact force evaluation threshold

In this thesis, in line with the UIC standard, de-wiring from the contact wire and contact force were examined to test pantograph performance in KTX-II (Sancheon) duplicate operation. Contact force, here, refers to the contact force between collector plate and catenary. As in Fig. 8, average contact force is the average value of the contact force between pantograph and catenary. De-wiring rate is minimum statistics contact force gained by subtracting the triplicated average deviation value from average contact force.

EN50119:2001 regulates contact forces as in Fig. 9.

Fig. 8 Dynamics between front and rear pantograph in duplicate operation

Fig. 9 Displacement of fittings at 300 km/h

2.5 KTX-II(Sancheon) duplicate operation's pantograph contact force test methodology

① Set intervals

② Get average of data in each interval: $F_{mean} = \frac{\sum_{i=1}^n F_i}{n}$

Here, measure F_i for the i th time. n represents the total data number.

③ Calculate standard deviation of data in each interval:

$$3\sigma = 3 \sqrt{\frac{\sum_{i=1}^n (F_{mean} - F_i)^2}{n}}$$

④ Calculate $F_{mean} - 3\sigma$

⑤ Calculate the range of Air Spoiler aerodynamic force characteristics at 300 km/h.

⑥ Re-calculate F_{mean} outcome in consideration of Air Spoiler aerodynamic force characteristics and spring hysteresis at the set speed.

⑦ Test Method : Measured equipment installation on pantograph

Fig. 10 Forces applied to front/rear pantograph

Fig. 11 KTX-Sancheon duplicate operation pantograph location (driving direction ⇒)

2.6 KTX-II(Sancheon) duplicate operation's pantograph contact force test

For high-speed train's duplicate operation, its front/rear pantograph contact force is closely related to its speed and the related waves also deliver significant vibration and forces to dropper and fittings. Recognizing such an aspect, the researchers, for the study, have performed a test by increasing speed in phase.

Fig. 10 shows dynamics caused by pantograph contact during train duplicate operation.

At a driving speed of 300 km/h, the displacement of the steady arm and dropper caused by the pantograph contact force is expressed in Fig. 11.

As the Figure above shows, at the speed of 300 km/h, displacement according to pantograph contact swings greatly for approximately 2 seconds and 166 m, distance for the 2 seconds after pantograph slide, causes significant vibration and impacts to rear pantograph. After the 2 seconds, displacement is reduced sharply as supports absorb vibration.

Fig. 12 shows the difference of forces working on front/rear pantographs (set every 200 m) in duplicate operation.

In KTX-II (Sancheon) duplicate operation test drivings started from June 2010, the researchers elevated speed in a phased manner to measure pantograph contact force. This study examined pantographs #1 and #4 to analyze contact forces at speed of 250 km/h ~ 300 km/h.

(1# Panto and 4# Panto are 362 m away from each other).

Fig. 13 is about the location of pantographs #1 and 4 in their duplicate operation.

The section examined in the experiment is between

Gwangmyeong~Seodaeseon~Dongdaegu. For this study, we operated round trip from Seoul Station to Dajeon and Dongdaegu after service hour.

① pantograph contact forces at the average speed of 248 km/h

Table 3 Contact Force at the Speed of 248 km/h

subject of measurement	outcome	threshold	note
average lifting force(F_{mean})	158	200 or under	
lifting force standard deviation (σ)	43		-average speed: 248 kph
$F_{mean} - 3\sigma$	29	0 or over	-static lifting force: 90/90 N
$F_{mean} + 3\sigma$	288	350 or under	
conclusion	appropriate

Fig. 12 Test data

② pantograph contact force at the average speed of 269 km/h

Table 4 Contact Force at the Speed of 269 km/h

subject of measurement	outcome	threshold	note
average lifting force(F_{mean})	170	200 or under	
lifting force standard deviation (σ)	48		-average speed: 269 kph
$F_{mean} - 3\sigma$	26	0 이상	-static lifting force: 90/90 N
$F_{mean} + 3\sigma$	314	350 이하	
conclusion	appropriate

Fig. 13 Test data

③ pantograph contact force at the average speed of 284 km/h

Table 5 Contact Force at the Speed of 284 km/h

subject of measurement	outcome	threshold	note
average lifting force(F_{mean})	178	200 or under	
lifting force standard deviation (σ)	55		-average speed:284 kph -static lifting force:90/90N
$F_{mean} - 3\sigma$	13	0 or over	
$F_{mean} + 3\sigma$	343	350 or under	
conclusion	appropriate

Fig. 14 Test data

④ pantograph contact force at the speed of 301 km/h

Table 6 Contact Force at the Speed of 301 km/h

subject of measurement	outcome	threshold	note
average lifting force(F_{mean})	174	200 or under	
lifting force standard deviation (σ)	57		-average speed: 301kph -static lifting force:90/90N
$F_{mean} - 3\sigma$	3	0 or over	
$F_{mean} + 3\sigma$	345	350 or under	
conclusion	appropriate

Fig. 15 Test data

3. Conclusion

This study assessed pantograph contact forces in KTX-II (Sancheon) duplicate operation in cooperation with the Korea Railway Research Institute to measure contact force and loss of contact rate by elevating speed in a phased manner. The resulting power collection was also evaluated for its quality. During the test, the researchers adjusted upward the angles of Air poil and the direction of Air spoiler attached on pantographs to find the optimal contact force through diverse methods. Studies on catenary system, pantograph wave, contact forces, etc. related to duplicate operation are still in their initial stage in South Korea. And pantographs should be further developed for better customization to satisfy the country's specific needs for catenary. In this situation, the researchers believe there should be more studies on how to improve the interface with catenary in duplicate operation.

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