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Evaluation of the Dynamic Characteristics of the Current Collection System

Jung Soo Kim* **and Byung Shik Koh**

Department of Mechanical Engineering and System Design, Hongik University

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Abstract : Apar The dynamic characteristics of the current collection system are evaluated during a test run. Signals from accelerometers attached to the pantograph assembly are acquired through a measurement system and analyzed. It is found that the train speed significantly influences the magnitude and frequency characteristics of the pantograph motion. The major frequency components of interest are found to be frequency components originating from the motion of the train along the catenary as well as the several resonance frequencies of the structural vibration of the pantograph. The contact force is also calculated by assuming the pantograph panhead as a rigid structure.

Key words: frequency analysis, current collection system, pantograph, catenary

1. Introduction

The current collection system provides the required electrical power to the train and hence can be crucial for reliable operation of the train. It consists of the catenary and the pantograph. The catenary is an overhead slender structure composed of wires, repeating spans, and hangers. The pantograph delivers electrical power from the catenary to the train and must remain in physical contact with the catenary during train operation. Separation causes power loss and high temperature arcs forming between the panhead and the contact wire. Therefore, proper understanding of the dynamic properties of the current collection system is essential to ensure reliable train performance.

Various studies have endeavored to understand the current collection system. Mathematical models and numerical simulations have been developed to analyze the response of the current collection system. [1-7] The analytical works have yielded useful insights but they are limited by modeling simplifications. Thus, actual experimental tests are required to verify mathematical modeling and simulation studies.

In this study, the dynamic properties of the current collection system are investigated using signals acquired during an actual test run of the train. The signals are suitably processed for analysis in both the time and frequency domains.

2. Signal Acquisition

The current collection process is illustrated in Fig. 1. The electrical current is supplied to the train through the contact wire connected to the messenger wire by hangers. The hangers serve to transmit the weight of the contact wire onto the messenger wire. The steady arms are used to provide lateral adjustment needed to protect the panhead from localized wear by moving the catenary sideways.

Fig. 2 shows the speed profile of the conducted test run from which the signals are acquired and analyzed.

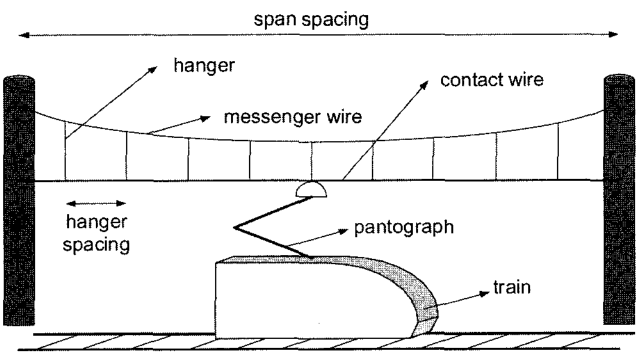


Fig. 1. Current collection system.

*Corresponding author: junsoo@hongik.ac.kr

Fig. 2. Test run speed.

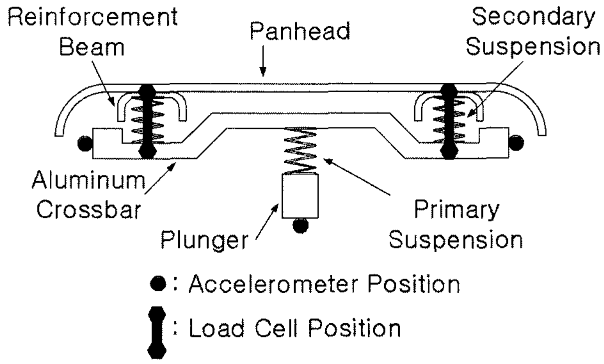


Fig. 3. Sensor positions.

The maximum speed obtained in the present test run is 200 km/hr, equivalent to 55.5 m/s.

It can be easily surmised that the pantograph will be exposed to harsher conditions as the speed of the train increases due to increased train motion and air resistance. Therefore, during the remainder of the paper, we will focus our attention on the analysis of signals at or near 200 km/hr.

Fig. 3 shows the position of the sensors attached to the pantograph assembly during the test run. To measure the movement of the panhead that acts as contact points during current collection, two accelerometers are attached on top of the reinforcement beams that connect the front and rear panhead.

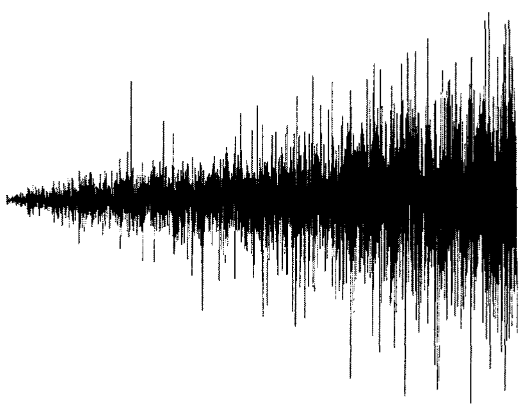


Fig. 4. Panhead acceleration.

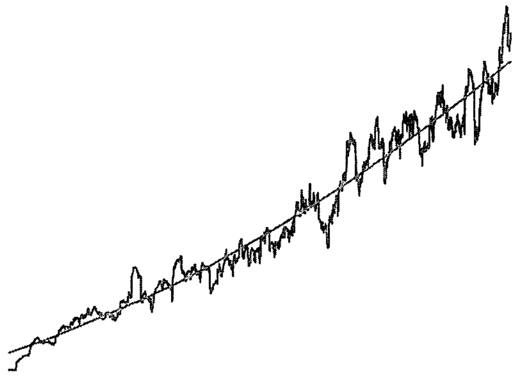


Fig. 5. Standard deviation of panhead acceleration.

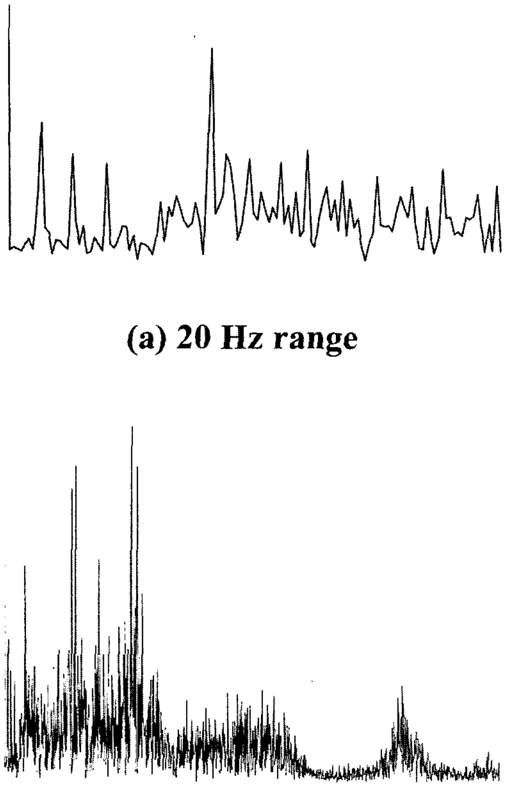
Figs. 4 and 5 show the panhead (left reinforcement beam) acceleration level and its standard deviation as functions of the train speed. Since the mean value is zero only the deviation tends to increase as the train accelerates. The rate of the increase is roughly proportional to the square of the train speed. Thus, the reinforcement beams and the panheads are exposed to substantially more vibration as the train gains speed.

3. Signal Analysis

Acquired acceleration signals are analyzed in the frequency domain. Figs. 6(a) and 6(b) show the accelerometer signal at the train speed near 200 km/hr in the frequency domain. Several major frequency components can be observed in Fig. 6(a). The first peak at 1.4 Hz is the span-passing frequency. The train speed is 196 km/hr and from the load cell data, the length of the span is found to be 40 m. The time elapsed for the train to traverse the span length is 0.73 seconds. Taking the inverse, the frequency is found to be 1.4 Hz. Also, higher harmonics of the span-passing frequency can be observed. These harmonics have the frequency of twice and three times the span-passing frequency. Since these components are due to the interaction between the pantograph and the catenary, they are speed dependent. The span-passing frequency increases in direct proportion to the increase in the train speed.

The hanger-passing frequency component, i.e., the frequency corresponding to the train traversing the hanger length which is 1/9 of the span length, as there are nine hangers per span, is also speed dependent. However, this component is not pronounced in the current study.

A large peak observed at 8.5 Hz is due to the resonance



(a) 20 Hz range

(b) 200 Hz range

Fig. 6. Panhead acceleration.

of the panhead. Unlike the span-passing frequency component, this component is independent of the train speed.

Higher frequency components are illustrated in Fig. 6(b). The 28 Hz and the 160 Hz component are the 1st bending frequencies of the reinforcement beam and the panhead, respectively. The 52 Hz component is believed to be originating from the structural vibration of the panhead assembly.

Fig. 7 shows the transfer function between the accelerometer signals of the aluminum cross bar and the panhead. Disregarding the spikes due to the structural vibration, the acceleration ratio drops below 0.5 at 20 Hz. This suggests that the suspension installed between the panhead assembly and the aluminum cross bars works as a vibration isolator for high frequencies, as it is designed to be.

To illustrate the speed-dependent nature of the acceleration signal, Fig. 8 compares the frequency components of the panhead at two different speeds. The speed for the upper graph is 147.6 km/hr and the lower is 193.29 km/hr. Since the train speeds of the two graphs differ, the speed dependent span-passing component must also differ. The first peak for the upper graph is placed at 1.09 Hz and the lower graph is at 1.33 Hz. The first peak shifts to a higher frequency as the train speed increases. As expected, this shifting of the first peak occurs continuously as the train speed varies throughout the test run. It can also be seen that the frequency of the speed-independent 8.5 Hz component remains constant.

Fig. 9 shows the response of the load cell attached to the pantograph assembly together with the accelerome-

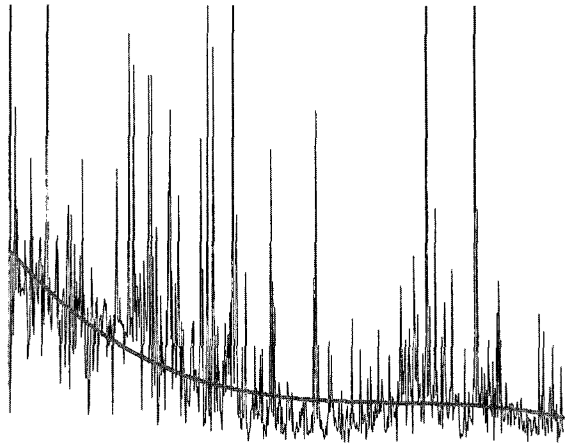


Fig. 7. Transfer function (Al X-bar/Panhead).

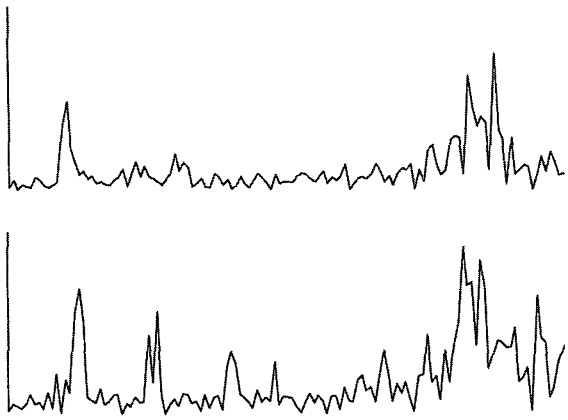


Fig. 8. Shift in span-passing frequency.

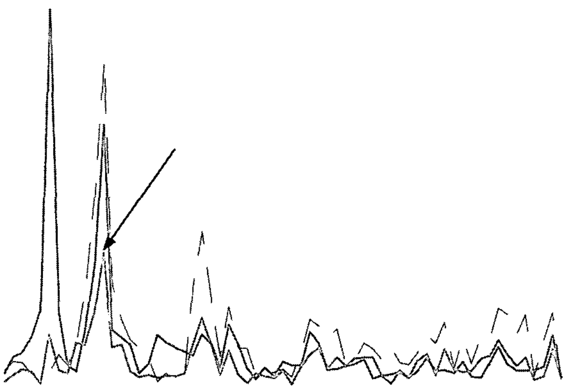


Fig. 9. Frequency components of load cell, accelerometer, and strain gauge.

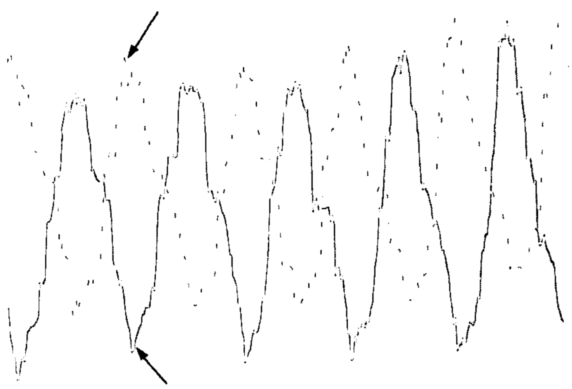


Fig. 10. Rolling motion of panhead.

ter and strain gauge signals in the frequency domain. The first peak of the accelerometer coincides exactly with the second peak of the load cell and the first peak of the strain gauge, which is the span-passing component.

The first peak observed in the frequency domain of the load cell is half of the span-passing frequency and is due to the rolling motion caused by the stagger introduced into the catenary by the steady arms. The load cell, which is not placed at the center of the pantograph, must pass across two spans to complete a rolling motion. The presence of the rolling motion is further demonstrated by the opposite phases of the left and right load cells, as shown in Fig. 10.

4. Contact Force Calculation

The contact force existing between the catenary and the panhead is an important factor in determining the reliable performance of the current collection system. If the contact force is too low, increased separation rate will result in excessive arcs and lead to the erosion of localized areas of the panhead. On the other hand, if the contact force is too high, the panhead will maintain contact with the catenary but at the cost of increased wear of the panhead. Therefore, the contact force needs to be maintained within the design specifications.

Measuring the contact force would require sensors to be placed directly between the catenary and the panhead. However, this is not possible because of the relative motion between them and the high current/voltage passing through the current collection system. This obstacle is overcome by placing the load cells below the panhead. But by doing so, the inertia force due to the movement of the panhead must be considered, i.e., the measured load cell signals need to be compensated by acceleration multiplied by the mass of the panhead.

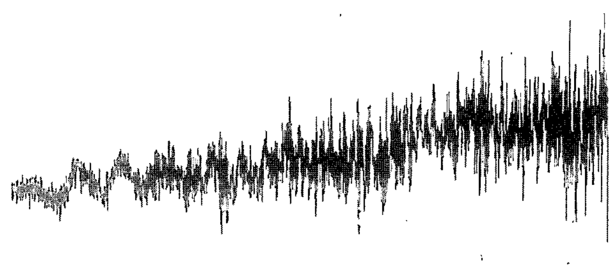


Fig. 11. Predicted contact force.

$$F_{contact}=F_{load\ cell}+m_{panhead}\cdot a_{accelerometer} \quad (1)$$

The issue of calculating the inertia force from the accelerometer signals is now addressed: In our calculation of the inertia force, we will for now assume a rigid body acceleration of the panhead which allows us to ignore i.e., to filter out high frequency components originating from the structural vibrations of the panhead. Since the 8.5 Hz resonant component is the major component below any structural vibration frequencies, a 12 Hz filtering is deemed adequate. Fig. 11 shows the predicted contact force assuming a rigid body panhead.

5. Conclusions

The dynamic properties of the current collection system are investigated by examining signals acquired during a test run. The time domain analysis of the signals shows that the train speed is the major factor in determining the magnitude of the fluctuations in pantograph motion. The deviation of the accelerometer signal representing the fluctuation of the panhead steeply increases as the train speed is increased. An additional panhead motion can be studied by observing the load cell and strain gauge signals. These show that a rolling motion occurs throughout the train run.

Frequency domain analysis of the accelerometers and the load cells is conducted to isolate major components due to the span-passing, hanger-passing, panhead resonance components, and the structural bending vibrations. The contact force can be calculated by summing the load cell signals with the inertia force derived from the accelerometer signals filtered at a suitable cutoff frequency.

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