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Measurement and Analysis of Current Collection Signals in Korean High-speed Railway

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Abstract : A data acquisition and processing system for measuring the current collection signals of the Korean High-speed Railway is developed. The current collection system is composed of a pantograph and the overhead catenary that supplies electrical power to the train through the pantograph. The system simultaneously measures the signals generated at the interface between the catenary and the pantograph through the accelerometers, load cells and strain gauges placed at various locations. The on-track test data are processed to evaluate the current collection reliability. The frequency analysis of the signals reveals the presence of several structural vibration modes in the pantograph, as well as the components arising from the periodicity in the structure of the catenary and pantograph at the interface. The feasibility of predicting the contact performance from the measured signals is also demonstrated.

Key words: catenary, high-speed railway, measurement system, pantograph, vibration

1. Introduction

The performance of the current collection system is a key factor which determines the maximum speed and power of a train. Proper design of the current collection system is one of the fundamental technologies needed to ensure safe and reliable train operation. The current collection system can be divided into two parts; the catenary and the pantograph. Countries have developed unique catenaries and optimized the pantograph to be compatible with their catenary design. To keep pace with the increase in the maximum train speed, catenaries are being designed to maintain uniform compliance under high tension. [1,2] The enhancement of the current collecting ability has also been made possible by reducing the weight and aerodynamic drag of the pantograph.

Numerical simulation and performance testing of the catenary/pantograph system have played a major role in the development of the current collection technologies, and proper verification of the current collection system is vital to ensure its safety. [3,4] The point of contact between the catenary and the pantograph need to maintain a continuous mechanical and electrical activity during the operation of a train. Since these mechanical and electrical interactions limit the upper boundaries of the current collection system performance, the core of the current collection system performance testing lies in the evaluation of the contact interactions between the catenary and the pantograph.

The separation ratio is an important index in evaluating the contact performance of the pantograph. But it may depend on the amount of the current being collected and on the particular evaluation methods employed. The contact force, on the other hand, can serve as a criterion in which the evaluation of the current collection performance involves only a single physical quantity. It can also be applied to wear prediction of the catenary since it has a close relationship with abrasion. The force acting between the catenary and the moving pantograph occur at the interface. But, in order to avoid modifications which may alter the characteristics of the pantograph that have been optimized, load sensors for measuring the contact force are placed below the panhead which causes the inertial force due to the up and down movement of the panhead to be non-negligible. Consequently, the actual contact force need to be estimated by adding the inertial force derived from the measured panhead acceleration signals

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*Corresponding author: jungsoo@hongik.ac.kr to the measured load sensor signals. [5]

The paper is organized as follows: Section 2 briefly describes the signal measurement system. It is capable of simultaneously measuring 16 channels of signal from various sensors and displaying in real-time the signals in the time and frequency domains. In Section 3, the acceleration signals of the panhead and the supporting links which make up the panhead assembly are measured and analyzed. The characteristics of the load cell signal are also evaluated, and the feasibility of predicting the contact force from the inertial force derived from the acceleration signal and the measured load cell signal is demonstrated. Section 4 presents the major conclusions of the study.

2. Data Acquisition System

The HP VXI system that serves as the data acquisition platform is capable of processing data at a high rate of speed and measuring/processing multiple signals in real time. The component hardware that make up the HP VXI system have the following characteristics: The HP E1432A module has two main input channels. The module can handle up to 16 input data via the 8 input terminals on each channel. It can process data at a rate of 51.2 kbps. This module is capable of signal manipulations, anti-alias protections, A/D conversions, and high rate measurement/processing using an embedded DSP chip.

The software for processing acquired signals has the following capabilities:

(a) Controls E1432A while acquiring data

(b) Stores and displays data while acquiring signals of up to one-hour length

(c) Displays acquired data such as acceleration, strain, temperature, fluid velocity in real time

(d) Calculates and displays the stagger, total shear force, and dynamic contact force

(e) Performs FFT while acquiring time domain data to evaluate major frequencies

(f) Displays evaluated results for safe current collection performance

3. Signal Measurement and Analysis

3.1 Signal Measurement

Before proceeding with the analysis, various parts constituting the panhead assembly as well as sensor locations are briefly explained. The front and top view of the panhead is shown in Figs. 1(a) and 1(b). The two panheads are connected by the reinforcement beams which sit on top of the secondary suspensions. The panhead, reinforcement beam, and the secondary suspension are attached above the aluminum crossbar which is assembled over the plunger that acts as the primary suspension. This whole panhead assembly then connects to the linkage arms.

The accelerometers are placed on the reinforcement beams, aluminum crossbar, and on the linkage arm below the primary suspension. Four strain gauges are placed on the panheads and two load cells are placed at the bottom of the panheads. The accelerometer signals are used to determine the dynamic characteristics of the pantograph as well as the inertial force of the panhead assembly. The load cells and strain gauges can be used to predict the contact force. Only the load cell data will be used for the present investigation.

The simultaneous measurement of the sensor signals is carried out during a test run of the Korean High-speed railway. The speed profile of the test run is shown in Fig. 2, in which the maximum speed of approximately 200 km/h has been attained. The measured data are analyzed with particular focus on the dependence of the accelerometer and load cell signals on the train speed. The speed-dependent and speed-independent components of the interface dynamics are also elucidated.

3.2 Signal Analysis

Figs. 3 and 4 show the response of the panhead (i.e.

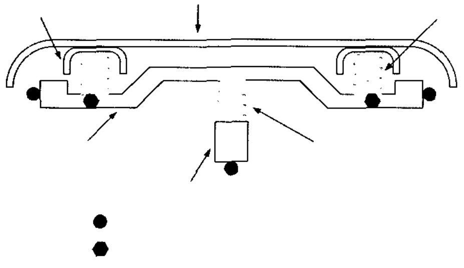

Fig. 1(a). Front view of the panhead

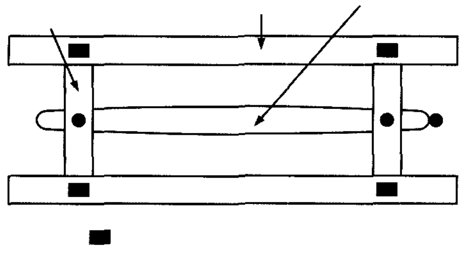

Fig. 1(b). Top view of the panhead

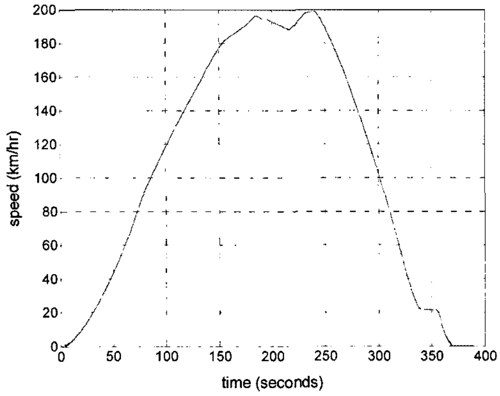

Fig. 2. Speed profile of test run

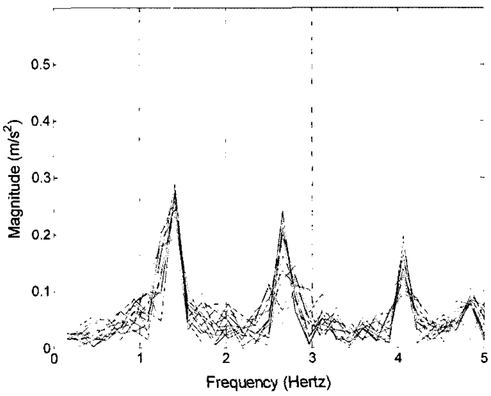

Fig. 3. Low frequency vibration

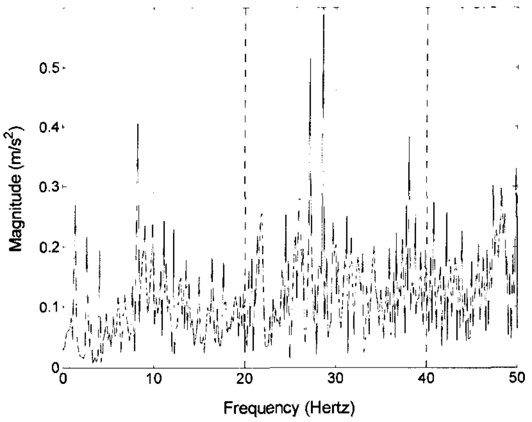

Fig. 4. Panhead structural vibration

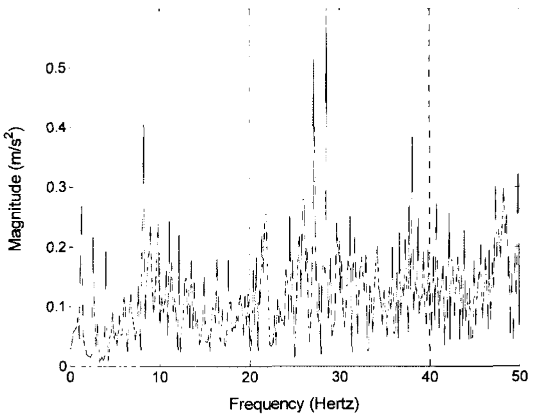

Fig. 5. Aluminum crossbar vibration

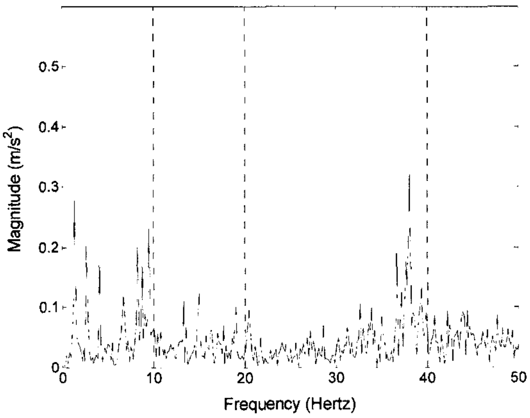

Fig. 6. Plunger vibration

the reinforcement beam) in the frequency domain. Fig. 3 displays the low frequency components of the accelerometer signal that vary with the train speed. The first peak at 1.35 Hz corresponds to the passing frequency, i.e., the inverse of the time required for the train to traverse a span of the catenary at the train speed of 194 km/h. This frequency value varies linearly with the train speed. The second and third peaks represent the integral multiples of the first peak, and hence also speed-dependent.

Fig. 4 displays wider frequency components of the panhead accelerometer signal, and reveals large peaks at 8.3 Hz and 28.6 Hz, and they are speed-independent. The 8.3 Hz component represents the resonant frequency of the panhead assembly associated with the secondary suspension, while the 28.6 Hz component arises from the first bending mode of the reinforcement beam. Since the accelerometer sits on top of the reinforcement beam, a large 28.6 Hz peak can be expected. Figs. 5 and 6 represent the motion of the aluminum crossbar and of the location immediately below the plunger, i.e., the location below the secondary and primary suspensions, respectively. A large 38.1 Hz component observed in Figs. 4 and 6 represent the resonant bending mode of the bow of the aluminum crossbar.

The role of the suspensions can be made readily apparent by taking the ratios of the amplitude of the accelerometer signals in the frequency domain, as shown in Fig. 7, for instance. It is seen that the suspen-

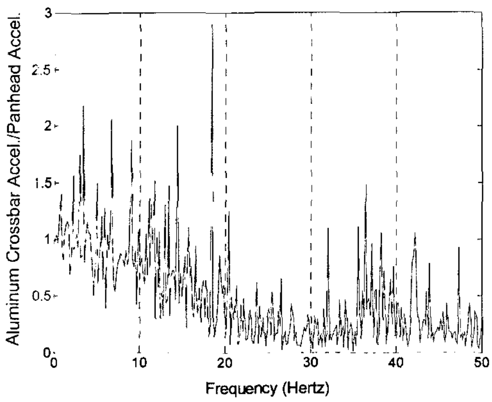

Fig. 7. Aluminum crossbar / panhead

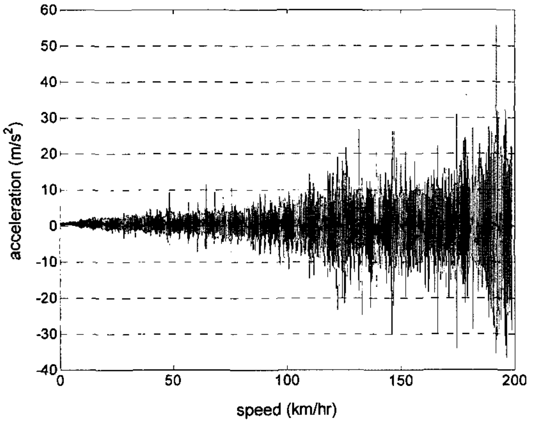

Fig. 8. Amplitude vs. train speed

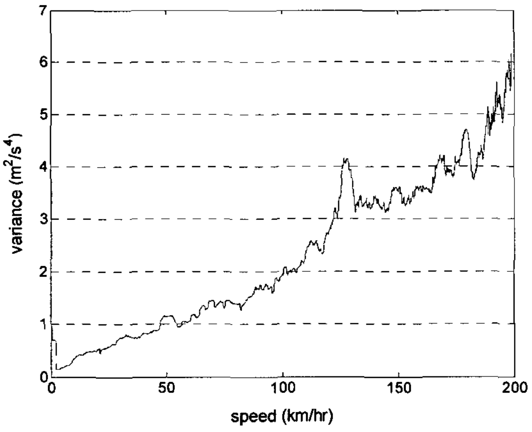

Fig. 9. Variance vs. train speed

sion acts as a mechanical low-pass filter, as it is designed to be. Next, the amplitude of the motion of the panhead is investigated for varying train speed. A strong dependence is shown in Figs. 8 and 9. Both the absolute value and the variance of the accelerometer signal rapidly increase as the train speed is increased. A similar dependence is observed for the load cell signals

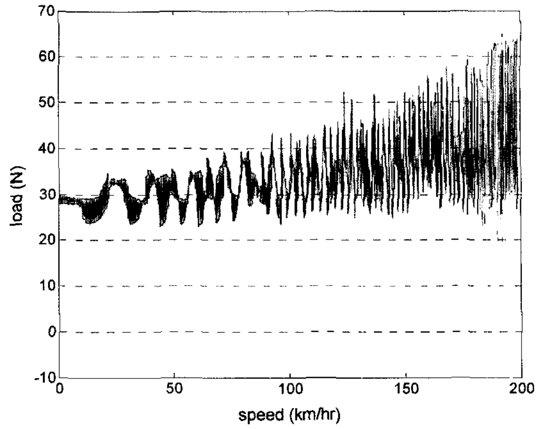

Fig. 10. Amplitude vs. train speed

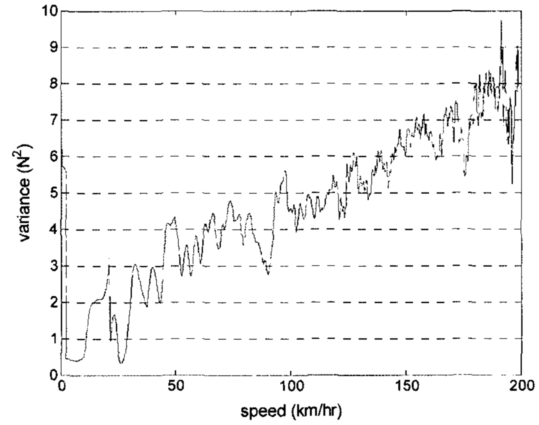

Fig. 11. Variance vs. train speed

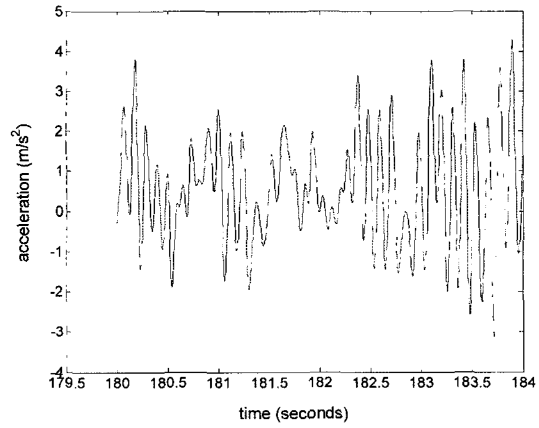

Fig. 12. Accelerometer signal

as well, as shown in Figs. 10 and 11.

Since the load cell is located at the bottom of the panhead, while the contact force acts at the top of the panhead, the inertial force of the panhead derivable from the accelerometer filtered signal must be added to the load cell signal to properly obtain the actual contact

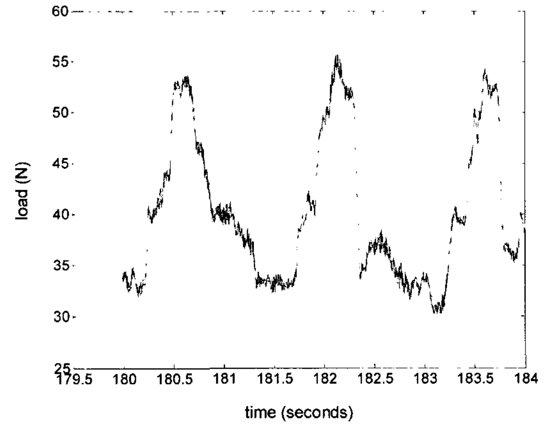

Fig. 13. Load cell signal

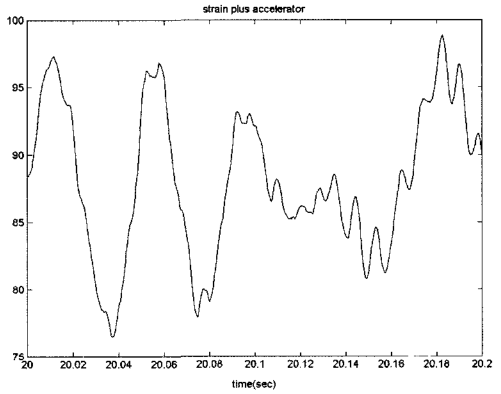

Fig. 14(a). Sum of sensor signals

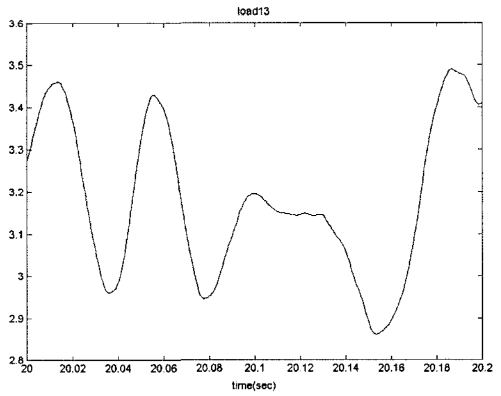

Fig. 14(b). Exciter load sensor signal

force. The panhead accelerometer and load cell signals in the time-domain are shown in Figs. 12 and 13, respectively. The two signals need to be suitably combined to yield the meaningful contact force estimation. In order to test the feasibility of such procedure, a test was performed by utilizing a vibration exciter equipped with a load sensor that can directly measure the input load. Since the input load of the vibration exciter acts on top of the panhead, i.e. at the interface, the measured exciter input load can be considered to be the actual contact force.

Fig. 14(a) depicts load cell signal and filtered accelerometer signal added together, while the exciter load sensor signal on Fig. 14(b) is shown for comparison. Disregarding the high frequency components, a close resemblance between the figures on the left and on the right is observed. The result suggests that a fairly accurate contact force prediction is possible provided the accelerometer signals are suitably smoothed to discard high-frequency components.

4. Conclusion

In this study, a data acquisition and signal processing system has been developed and utilized during a test run of the Korean High-speed Railway. The accelerometer and load cell signals have been measured and analyzed. The frequency response characteristics show several dominant frequencies. These frequencies are due to the interaction between the catenary and the pantograph at the interface and to the structural vibration modes of the pantograph. The feasibility of predicting the contact force by combining the load cell and accelerometer signals has also been demonstrated.

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