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A Study on the Method of Vibration Analysis for Korean High Speed Train by the On-line Test

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Abstract. The Korean High Speed Train (KHST) has been tested on the Kyongbu high speed line and the Honam conventional line since 2002. A data acquisition system was developed to test and prove the dynamic performance of the KHST, and the system has been found to be very efficient in acquiring multi-channel data from accelerometers located all over the train. Also presented in this paper is an analysis procedure which is simple and efficient in analyzing the acceleration data acquired during the on-line test of the KHST. The understanding of system vibration mode for a railway vehicle is essential to evaluate the characteristics of a dynamic system and to diagnose the dynamic problems of the vehicle system during tests and operations. Methods based on homogeneous linear systems are not realistic because real systems have nonlinear characteristics and are strongly dependent on environmental conditions. In this paper an efficient method of vibration analysis has been proposed and applied for the KHST to evaluate its vibration mode characteristics. The results show that this method is suitable to estimate the system vibration modes of the KHST.

Introduction

Korean High Speed Train (KHST) as shown in Fig. 1 has been tested on the KyongBu high speed line and the HoNam conventional line since it was developed in 2002. A main purposes of the test is to validate the train's design performance and the analysis of the measured data is also important to estimate the dynamic characteristics in the frequency domain [1,2]. Generally, an EMU (Electric Multiple Unit) is excited by external forces arising from the rail irregularity and the catenary system, and it is very important to understand the interactions between the train and the rail, and the catenary to understand the dynamic characteristic of the railway vehicle. Proposed in this paper is an efficient method of vibration analysis for a rail vehicle system and this method has been applied to KHST to evaluate its vibration mode characteristics at speed of 300km/h.

Fig. 1 A picture of KHST and its pantograph system.

Outline of the test

As shown in Fig. 2, accelerometers are installed on various locations of the car body, bogie frames and axle boxes to measure acceleration signals. They are also installed on the pantograph to analyze the dynamic effects of the catenary. Total 13 units of capacitive type accelerometers are installed on the car bodies, 74 units of ICP type accelerometers on the bogies and axle boxes, and 2 units of strain type accelerometers on the pantograph [3]. This measuring system controls the data acquisition modules by a fast network system, and hence is effective for the on-line test of a rail vehicle that requires acquisitions of synchronous multi- channel signals from many locations apart each other. This system is very flexible in that measurement sensors and locations can be changed very easily.

Frequency analysis of the system vibration characteristics.

Propose the procedure of frequency analysis. The flow chart shown in Fig. 3 is the procedure proposed in this paper and it is used to analyze the vibration characteristics of interaction between the vehicle, the rail system, and the catenary system. As shown in Fig. 3, first of all, the measured data set (**A_T, S_T**) synchronized with the time in ① is divided to the sub-data sets(**A_i, S_i**) having 2048(2^{11}) elements in ②. And then, they are transformed to frequency domain by FFT(Fast Fourier Transform) algorithm[4] in ③. The mean speeds are considered as the representative speeds of the sub-data sets, which are calculated by the equation (s_{mi}) in ③. In order to obtain the continuous and smooth frequency distribution of the acceleration at all speeds, it needs to slide the range of the sub-data set on interval of 512(2^9) data as shown in ④ and the frequency distribution of accelerations (**A_{fi}**) is recursively calculated by FFT at mean speeds of each sub-data sets. But the frequency distribution of acceleration can be just shown in high speed range because the amplitude of acceleration is varied as the speed and the high level amplitude of acceleration is distributed in the range of high speed. So, it needs to normalize the amplitude of acceleration to [0,1] as the equation shown in ⑤ to solve this problem. Therefore, the data set **A_{fi}** is transformed to the normalized sub-data set **A_{fni}** which has a_{fnik} elements calculated by ⑤. The data processing for the procedure is coded by LabView 7 program [5]. Applying this procedure to analyze the KHST dynamic characteristic about the interaction with the rail and the catenary system, it is as follows.

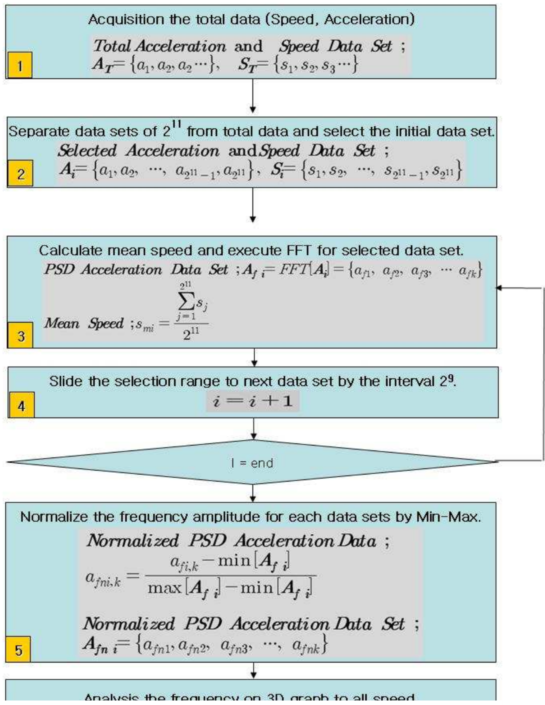


Fig. 2 Flow chart of the proposed procedure for the dynamic frequency analysis of KHST.

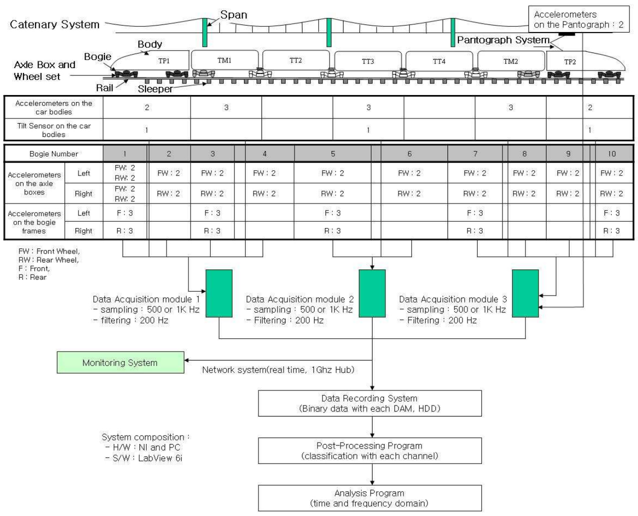


Fig. 3 The composition of the data acquisition systems for KHST's dynamic analysis.

Frequency analysis of the interaction between the pantograph and the catenary system. Fig. 4 is the original measured data from the accelerometers installed on the pantograph and it shows the amplitude increases in proportion to the speed. Fig.5 is the non-normalized frequency distribution of the pantograph acceleration produced by the data processing up to ④ of Fig. 3. Fig. 6 is the normalized frequency distribution produced by the final data processing of Fig. 3. As shown in Fig. 6, the frequency distribution in the total range of speed (0~300km/h) can be obtained from the normalizing process, while Fig. 5 cannot show the frequency distribution below the speed of 150km/h.

Also, Fig. 6 is able to be analyzed the variation of vibration mode according to the variation of speed, while Fig. 7 cannot be done it because Fig.7 is the simple frequency distribution without the speed.

Analyzing the Fig. 6, we can see the natural frequency of pantograph is located around 8.5Hz as shown in A section because that frequency sharply appears at all speed. In the contrary, the frequencies ranged between 1Hz and 2Hz have the variation with speed as shown in B section because the spans which are supporting the catenary system have the distance of 40m~50m and the frequencies arising from the spans are similar to those frequencies. Therefore, we can conclude that the span frequency according to the speed is the dominant frequency effecting to the pantograph behavior and it is around 1Hz~2Hz.

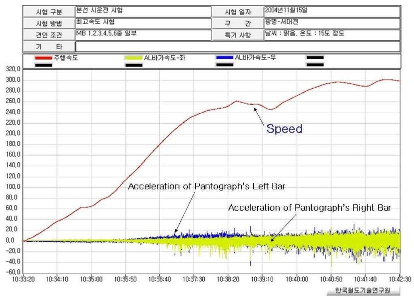


Fig. 4 Speed and acceleration of the bar (left and right).

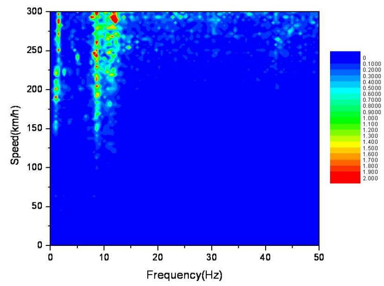


Fig. 5 Amplitude of the acceleration vs the speed and frequency (before normalizing, left).

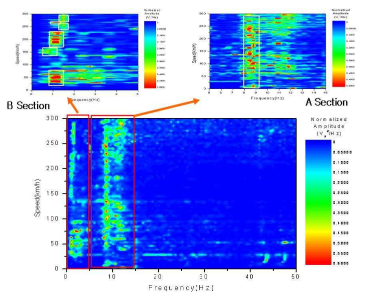


Fig. 6 Amplitude of the acceleration vs the speed and frequency (after normalizing, left).

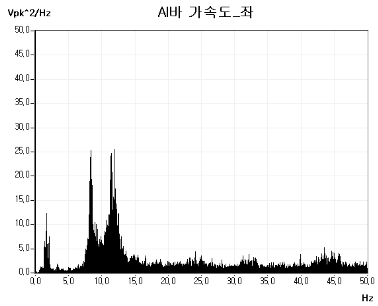
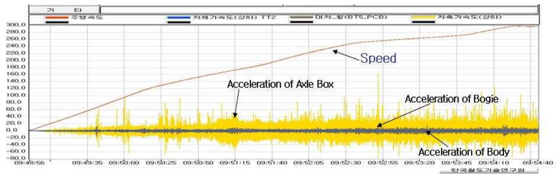
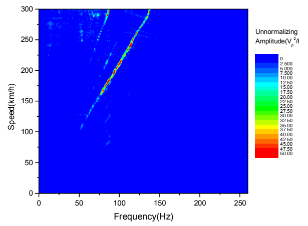
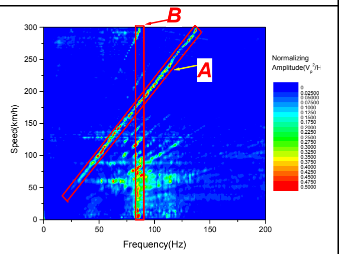
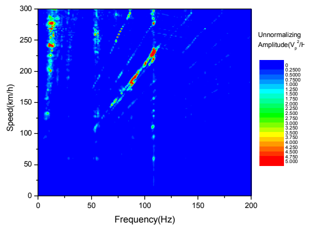
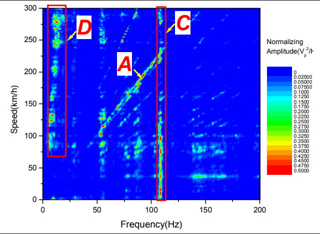
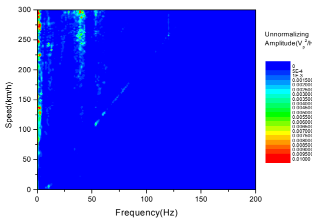
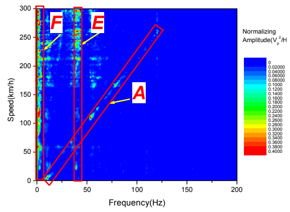


Fig. 7 Result of FFT from the acceleration of pantograph for all data.

Frequency analysis of the interaction between the vehicle and the rail system. Masses of a railway vehicle generally consist of the wheel, the bogie and the body, and the interaction between the vehicle and the rail irregularity pass through the wheel, the bogie and the body in proper sequence. Table 1 shows the frequency analysis of each mass according to the procedure of Fig. 3 up to speed of 300km/h. The original measuring data shows that the accelerations of each masses increase with speed like the case of pantograph. So, it needs to normalize the frequency distributions of accelerations in sub-data sets to analyze the frequency distribution of acceleration in the range of total speed as shown in Table 1. As shown in the results after normalizing, the frequency distributions appear well under the low speed and the some frequency bands are distinctly came out in the graph. The frequency band of **A** appearing in all is the frequency arising from the mounting distance of sleepers which are mounted under the rail with the distance of 0.6m~0.8m as shown in Fig. 2. Therefore, we can see that frequency is dominantly effect to vehicle vibration as a external interaction. The frequency bands of **B**, **C**, **E** and **F** can be considered as the natural frequency originated from the rigid body motion or the structure flexibility because those have not any changes according to the variation of speed. But in case of **D**, it is clearly come out in just case of bogie and it is varied with speed. So, it needs to be analyzed more in future about the effects of the self-moving parts which is mounted in bogie frame. In this overall perspective, we can see that proposed in this paper is a very useful method to describe the vibration characteristics of a railway vehicle.

Table 1 Results of the frequency analysis for the interaction between the vehicle and the rail.

Original Measuring Data		
FFT Data	Before normalizing	After normalizing
Acceleration of Axle Box		
Acceleration of Bogie		
Acceleration of Body		

Summary

This paper has attempted to establish an efficient method to analysis the vibration modes for a railway vehicle. Although, the techniques used in this paper have been widely used, the procedure proposed in this paper is useful for a special purpose handling the large amount of data obtained from the on-line test of railway vehicles and evaluating the vibration characteristics of the vehicle. To prove these advantages, the method has been applied for KHST to identify the vibration characteristics as well as the interactions between the vehicle, the rail and the catenary systems. Various results have been shown to demonstrate vibration characteristics in the frequency domain and to find out the sources of the vibration. In conclusion, the proposed method has been found very useful in identifying the dynamic characteristics of the railway vehicle and it is suitable for the on-line measurement system

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