Mechanical Systems and Signal Processing 46 (2014) 481–493

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Application of sound intensity and partial coherence to identify interior noise sources on the high speed train

Rongping Fan [a,b], Zhongqing Su [b], Guang Meng [a,*], Caichun He [c]

[a] State Key Laboratory of Mechanical System and Vibration, Shanghai Jiao Tong University, Shanghai 200240, China
[b] Department of Mechanical Engineering, The Hong Kong Polytechnic University, Hung Kom, Hong Kong
[c] Zhuzhou Times New Materials Technology Co., Ltd., Zhuzhou 412001, China

ARTICLE INFO

Article history:
Received 4 May 2011
Received in revised form
26 November 2013
Accepted 29 November 2013
Available online 14 February 2014

Keywords:
Interior noise
Sound intensity
High speed train
Partial coherence

ABSTRACT

In order to provide a quieter riding environment for passengers, sound quality refinement of rail vehicle is a hot issue. Identification of interior noise sources is the prerequisite condition to reduce the interior noise on high speed train. By considering contribution of noise sources such as rolling noise, mechanical equipment noise, structure-borne noise radiated by car body vibration to the interior noise, the synthesized measurement of sound intensity, sound pressure levels and vibration have been carried out in four different carriages on high speed train. The sound intensity and partial coherence methods have been used to identify the most significant interior noise sources. The statistical analysis results of sound intensity near window and floor on four carriages indicate that sound intensity near floor is higher than that near window at three traveling speeds. Ordinary and partial coherent analysis of vibro-acoustical signals show that the major internal noise source is structural-borne sound radiated by floor vibration. These findings can be utilized to facilitate the reduction of interior noise in the future.

1. Introduction

The noises within the high speed train are caused by many noise sources, such as rolling noise, mechanical equipment noise, air conditioning noise, structural-borne noise radiated by car body vibration and aerodynamic noise. With traveling speed increase and vehicle weight-lighting, the rolling noise and aerodynamic noise of high speed trains are greatly increased.

In order to provide quieter riding environments for passengers, more attention [1] has been paid to reducing the steeply increased interior noise and vibration. The improvement in sound and vibration quality can be achieved in three aspects: source, transfer path, and receiver. It is the subject of this paper to identify the noise sources inside the high speed train in order to reduce the noise levels.

The finite element and boundary element method were used by Mohanty et al. [2] to distinct the interior acoustic field by the natural modes and shapes of cabs. Ding [3] developed the finite element method to evaluate panel acoustic contribution. Liu [4] analyzed the panel vibration and interior noise of vehicle cavity by structure strength. Liang [5] investigated panel acoustic contribution at the specific mode to identify the major sound source based on boundary element method and finite element method. Vehicle structures were complex, so the numerical models had to be significantly simplified. However, the correction of numerical results was highly dependent on accuracy of the models.

* Corresponding author. Tel.: +86 2134206332x816; fax: +86 21 34206006.
E-mail address: GMeng@sjtu.edu.cn (G. Meng).

0888-3270/$ - see front matter
http://dx.doi.org/10.1016/j.ymssp.2013.11.014

The acoustic arrays, sound pressure level and sound intensity have been measured to identify the main sources in the rail vehicles. Microphone arrays or combination of different sensors have proved useful to identify and predict the noise levels and location of major sources outside high speed trains [6–10]. Sound intensity measurement can offer both direction and position of sound sources. Sound intensity theory was used by Liu [10] to measure noise on high speed railway vehicle and analyzes the interior noise distribution. Sound intensity techniques were applied to identify engine front noise sources [11].

Although the force vector method and full matrix method were commonly used for noise path analysis [12,13], these two methods needed extra time and cost to deal with the problem of the connection between the sound and receiver. Spectral analysis method of partial coherence analysis [14,15] was used to identify vibro-acoustical sources of noise emitted inside vehicle compartments. The first step of signal conditioning in the partial coherence method is to rank the sources. Hilbert transform was used to check causality between signals by Fouladi [15] and Bee [16]. In this paper, the sound intensity is used not only to investigate the characteristics of sources but also to rank the potential sources.

In this paper, acoustic-vibrational measurements are carried out and sound intensity and partial coherent methods are used to distinguish major interior noise sources inside a specific high speed train. The paper is organized as follows: firstly, a short description of the sound intensity theory along with partial coherence is given; in Section 2, the methodology of sound and vibration measurement within high speed train is described in details; in Section 3, the measurement data will be processed to identify the main sources of interior noise on carriage; finally, the conclusion of noise source identification will be made and the method to reduce the interior noise will be suggested.

1.1. Partial coherence analysis

For the system with multi-input X_i and single output Y, input signals are correlated. Partial coherence analysis can rule out linear effects of other inputs from problem by taking advantage of conditional output method. Coherence function is an indication of linear relationship between input X and output Y for a system. Ordinary coherence analysis often confuses the contribution of each input X_i to the output. Partial coherence technique has been applied to find the contribution of sources to overall response in the vehicle interior vibrio-acoustic problems [14,15]. Partial coherent method can remove linear effects of other inputs and make a set of inputs irrelevant. For example, consider X_i^{i-1} and X_j^{i-1} as two partially correlated inputs. The conditioned signal X_j^{i-1} from signal X_i^{i-1} can be obtained using Eq. (1)

$$X_j^i = X_j^{i-1} - H_{ij}^{i-1} X_i^{i-1}, \tag{1}$$

where H_{ij}^{i-1} is the frequency response function between the two signals X_j^{i-1} and X_i^{i-1}

$$H_{ij}^{i-1} = \frac{G_{ij}^{i-1}}{G_{ii}^{i-1}}, \tag{2}$$

where G_{ii}^{i-1} is autospectrum of signal X_i^{i-1} and G_{ij}^{i-1} is cross-spectrum of signals X_j^{i-1} and X_i^{i-1}. The two sides of Eq. (1) are multiplied by conjugate X_r^*. The conditional power spectrum can be given by

$$G_{rj}^i = G_{rj}^{i-1} - H_{rj}^{i-1} G_{ir}^{i-1}, \tag{3}$$

where G_{rj}^i, G_{rj}^{i-1} and G_{ir}^{i-1} are the cross spectra. If we replace j with r and insert Eq. (2) into Eq. (3), conditional autopower spectrum G_{jj}^i of signal X_j^i can be obtained by

$$G_{jj}^i = G_{jj}^{i-1}(1 - r_{ij}^{i-1}), \tag{4}$$

where G_{jj}^{i-1} is conditional autopower spectrum of signal X_j^{i-1} and partial coherence value r_{ij}^{i-1} is defined by

$$r_{ij}^{i-1} = \frac{(G_{ij}^{i-1})^2}{G_{ii}^{i-1} G_{jj}^{i-1}}. \tag{5}$$

X_j^i will rule out the linear effects of the stronger signal X_i^{i-1} from signal X_j^{i-1}. Then the effect of each input on output is identified by conditional output power spectrum.

1.2. Sound intensity theory

Sound intensity is defined as the sound power per unit area. The sound source contribution can be determined by the sound intensity [13]. The time-averaged sound intensity $\mathbf{I}$ at a point A in a sound field can be expressed as

$$\mathbf{I} = \frac{1}{T}\int_T \mathbf{I}_i dt = \frac{1}{T}\int_T \mathbf{I}_i dt = \langle p\mathbf{v}\rangle_t \tag{6}$$

where the instantaneous sound intensity $\mathbf{I}_i$ is the product of sound pressure p and particle velocity $\mathbf{v}$, and T is the average time. Particle velocity $\mathbf{v}$ is related to sound pressure by the following equation:

$$\mathbf{v} = -\frac{1}{\rho_0}\int_{-\infty}^{t} \nabla p d\tau \tag{7}$$