Mechanical Systems and Signal Processing 100 (2018) 224–241

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

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

Multi-bearing weak defect detection for wayside acoustic diagnosis based on a time-varying spatial filtering rearrangement

Shangbin Zhang, Qingbo He *, Kesai Ouyang, Wei Xiong

Department of Precision Machinery and Precision Instrumentation, University of Science and Technology of China, Hefei, Anhui 230026, PR China

ARTICLE INFO

Article history:
Received 9 January 2017
Received in revised form 19 June 2017
Accepted 25 June 2017

Keywords:
Train bearing
Fault diagnosis
Doppler distortion
Multisource separation
Microphone array

ABSTRACT

The wayside Acoustic Defective Bearing Detector (ADBD) system plays an important role in ensuring the safety of railway transportation. However, Doppler distortion and multi-bearing source aliasing in the acquired acoustic bearing signals significantly decrease the accuracy of bearing diagnosis. Traditional multisource separation schemes using time-frequency filters constructed by a single microphone signal always show poor performance on weak signal separation. Inspired by an assumption that the spatial location of different sources is different, this paper proposes a novel time-varying spatial filtering rearrangement (TSFR) scheme based on a microphone array to overcome current difficulties. In the scheme, a zero-angle spatial filter and peak searching are proposed to obtain the time-centers of corresponding sources. Based on these time-centers, several time-varying spatial filters are designed to extract different source signals. Then interpolation and rearrangement are used to correct the Doppler distortion and reconstruct the corresponding separated signals. Finally, the train bearing fault diagnosis is implemented by analyzing the envelope spectrum of the corrected signals. Because the time-varying spatial filter construction is only dependent on the source location and has little relationship with the signal energy, the proposed TSFR scheme has significant advantages in weak signal separation and diagnosis in comparison with traditional ones. With the verifications by both simulation and experiment cases, the proposed array-based TSFR scheme shows a good performance on multiple fault source separation and is expected to be used in the ADBD system.

1. Introduction

Railway service, as a main component of modern transportation, plays a significant role in nation economy. To satisfy the people's demand for more efficient and more convenient transportation, increasing train speed is a necessary trend. However, it will increase the severity of catastrophes when the train accidents happen. As the key components of a train, hundreds of wheelset bearings support the entire weight of the train and rotate at a high speed. Their running statuses are bound up with the train safety. As reported, defective train-bearings may cause serious accidents and further make the railway transportation suffer huge losses [1,2]. Hence, it is of great significance for real-time bearing health monitoring and fault

* Corresponding author.
E-mail address: qbhe@ustc.edu.cn (Q. He).

http://dx.doi.org/10.1016/j.ymssp.2017.06.035

diagnosis in ensuring the safety operation of a train [3,4]. Currently, non-disassembling diagnosis techniques have attracted increasing attentions, such as oil monitoring [5], hot-box detection [6], acoustic emission [7], vibration signal analysis [8], wayside Acoustic Defective Bearing Detector (ADBD) system [9,10]. Among these techniques, the ADBD system as a non-contact measurement technology, sets a microphone array on the wayside as shown in Fig. 1, thus it costs lower in comparison with the on-board systems. The ADBD system acquires acoustic signals and detects bearing faults by assuming that the acoustic signal generated by the bearings of a passing train contains relevant diagnostic information. However, two issues, including Doppler distortion and multiple acoustic sources aliasing, bring considerable difficulties to accurate diagnosis for train bearings.

The acquired acoustic signals in the ADBD system suffer from the Doppler distortion severely due to the train moving. The spectrum of the acquired signal is shifted and extended in comparison with the source signal. It is an obstacle to identify the fault frequency and further diagnose the bearing fault. So far, many works focus on reduction of Doppler distortion especially in the wayside acoustic diagnosis for train bearings [11–13]. Dybala and his co-workers firstly proposed a disturbance-oriented dynamic signal resampling method [14]. The core of the method is searching for the instantaneous frequency (IF) from the acquired signal to calculate its corresponding resampling time vector. The method is simple and effective, but does not perform well in a high background noise. He et al. combined this method with the stochastic resonance to overcome the noise influence [15]. However, knowing a characteristic frequency beforehand limits its application. Liu et al. proposed a time-domain interpolation resampling method based on a kinematic model analysis [16]. The problems of IF calculation and knowing characteristic frequency beforehand are effectively avoided. Nevertheless, its result accuracy is dependent on estimation of the geometry parameters. Subsequently, Liu et al. further proposed a data-driven method based on multiple parameter matching [17]. However, it's limited by failure to build the real-time Doppler correction diagnosis system because of the huge computation requirement.

Note that all the methods mentioned above are in the assumption that the fault signal is from a single train bearing. However, in fact, the acquired signal is a superposition of signals from multiple bearings because a train is supported by many train bearings. The bearing signals from different bogies can be identified easily because the distance between them is long enough. However, in the same bogie, the distance between two train bearings is only about 2.3 m. When the train moves fast, the signals from the two bearings will be significantly disturbed with each other in the time domain. Moreover, as the natural frequencies of these bearings are in the same frequency band, the frequency shift and expansion caused by Doppler distortion will result in spectrum aliasing. Although we can correct the acquired signal to conform to one of the multiple sources, the time- and frequency- domain aliasing caused by other sources will not be eliminated, which still decreases diagnosis accuracy. Therefore, multi-bearing sources separation and correction is the basis of accurate diagnosis for train bearings. Recently, several publications aimed to solve the issue. Emerging methods include pseudo time-frequency and Dopplerlet filtering [18], time-frequency data fusion and time-frequency filtering [19], and generalized S-transform and morphological filtering [20]. These schemes separate the multiple source signals by searching the time-centers (the time when the train bearing moves in front of the microphone) from different sources and building corresponding time-frequency filters to separate the sources in the time-frequency domain. However, all these traditional schemes should satisfy two premises: (1) different acoustic sources should have similar energy magnitude; (2) background noise cannot be too heavy. These schemes always calculate the time-centers by assuming that the time-centers are energy extreme points in the whole time-frequency distribution (TFD) or pseudo TFD, and use the signal energy as an indicator to decide the time-frequency filter boundary. Therefore, for the weak fault source, its time-center will be submerged in a strong fault source or noise and the corresponding time-frequency filter cannot be constructed, which are fatal drawbacks of these schemes limiting their practical application.

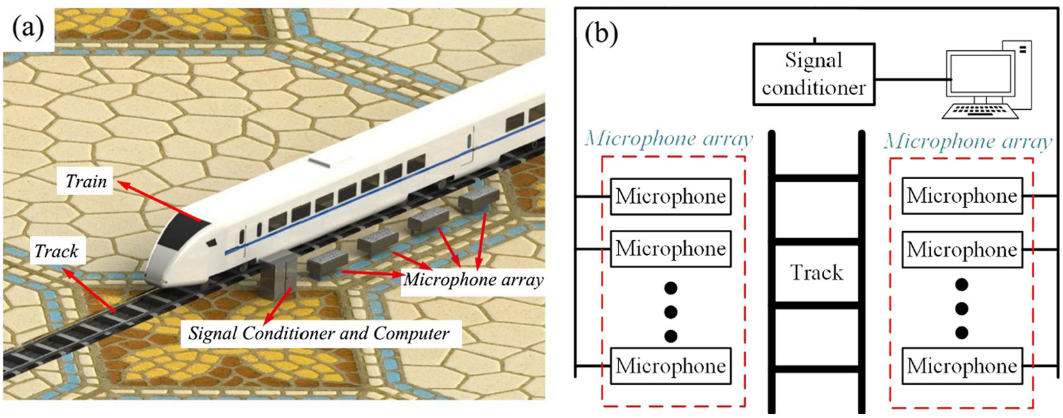

Fig. 1. Basic model of the ADBD system: (a) solid model view, and (b) schematic diagram.