Mechanical Systems and Signal Processing ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

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

Optimised Spectral Kurtosis for bearing diagnostics under electromagnetic interference

Wade Alister Smith, Zhiqi Fan *, Zhongxiao Peng, Huaizhong Li, Robert B. Randall

School of Mechanical and Manufacturing Engineering, University of New South Wales, Sydney, NSW 2052, Australia

ARTICLE INFO

Article history:
Received 17 April 2015
Received in revised form
9 December 2015
Accepted 29 December 2015

Keywords:
Rolling element bearing
Bearing diagnostics
Demodulation band
Envelope analysis
Electromagnetic interference

ABSTRACT

The selection of the optimal demodulation frequency band is a significant step in bearing fault diagnosis because it determines whether the fault information can be extracted from the demodulated signal via envelope analysis. Two well-known methods for selecting the demodulation band are the Fast Kurtogram, based on the kurtosis of the filtered time signal, and the Protrugram, which uses the kurtosis of the envelope (amplitude) spectrum. Although these two methods have been successfully applied in many cases, the authors have observed that they may fail in specific environments, such as in the presence of electromagnetic interference (EMI) or other impulsive masking signals.

In this paper, a simple spectral kurtosis-based approach is proposed for selecting the best demodulation band to extract bearing fault-related impulsive content from vibration signals contaminated with strong EMI. The method is applied to vibration signals obtained from a planetary gearbox test rig with planet bearings seeded with inner and outer race faults. Results from the Fast Kurtogram and Protrugram methods are also included for comparison. The proposed approach is found to exhibit superior diagnostic performance in the presence of intense EMI.

Another contribution of the paper is to introduce and explain the issue of EMI to the condition monitoring community. The paper outlines the characteristics of EMI arising from widely-used variable frequency drives, and these characteristics are used to simulate an EMI-contaminated vibration signal to further test the performance of the proposed approach. Although EMI has been acknowledged as a serious problem in many industrial cases, there have been very few studies showing its adverse effects on machine diagnostics. It is important for analysts to be able to identify EMI in measured vibration signals, lest it interfere with the analysis undertaken.

1. Introduction

Rolling element bearings (REBs) are among the most widely used components in rotating machinery and their failure a common cause of machine breakdown [1]. Such failures can be catastrophic or can lead to the shutdown of entire production lines, potentially causing personal damage or economic loss [2], so it is essential to accurately detect and diagnose bearing faults at an early stage.

* Corresponding author. Tel.: +61 2 9385 6005; fax: +61 2 9663 1222.
E-mail address: wade.smith@unsw.edu.au (W.A. Smith).

http://dx.doi.org/10.1016/j.ymssp.2015.12.034
0888-3270/

Envelope analysis has been widely applied in bearing diagnostics for extracting the fault information. This is because the impulses caused by bearing faults usually excite resonances at much higher frequencies than the vibration generated by other machinery components, and this resonant response is considered to be amplitude modulated at the characteristic defect frequency [3]. Nevertheless, envelope analysis has a major challenge in the selection of the most suitable band for amplitude demodulation.

The band selection issue has largely been solved using spectral kurtosis (SK), a statistical tool which indicates the impulsivity of a signal as a function of frequency. Being sensitive to the non-stationary parts of the vibration signal, SK can reveal the frequency and bandwidth of the resonance(s) excited by the bearing fault and thus the most promising frequency band that should be used for demodulation and subsequent envelope analysis. A number of studies relating to SK and its practical implementation have been presented over the last decade. Antoni [4] gave a comprehensive theoretical framework of SK and presented an SK estimation method based on the short-time Fourier transform (STFT). Antoni and Randall [5] published a further study on how to apply SK in the diagnostics of rotating machinery, and they presented a tool called the Kurtogram, which shows SK values in a special band-pass structure as a function of two parameters, centre frequency and bandwidth of the filtered signal. The Kurtogram determines the optimal frequency band for demodulation by choosing parameters that maximise the SK value. Considering that it is time-consuming to compute the Kurtogram with all possible combinations of centre frequencies and bandwidths, the Fast Kurtogram was introduced by Antoni [6]. This method applies a 1/3-binary tree Kurtogram, which means it only investigates SK values in a few given bandwidths and greatly reduces the computing time.

A number of improved Kurtogram-based methods have since been proposed by other researchers. Sawalhi et al. [7] developed a Wavelet Kurtogram, based on complex Morlet wavelets. They argued that wavelets are well-suited to such an application because they have uniform resolution on a logarithmic frequency scale, which corresponds to impulse responses with a constant value of damping ratio. Lei et al. [8] adopted the wavelet packet transform (WPT) as the filter for the Kurtogram, with the purpose of ovecoming the drawbacks of STFT or FIR filters.

Arguing that the temporal-based kurtosis indicator of the Kurtogram performs poorly in the presence of strong non-Gaussian noise, Barszcz and Jabłoński [9] proposed a method called the Protrugram, which employs the kurtosis of the envelope (amplitude) spectrum rather than of the envelope time signal. A similar fault indicator was used in [10], in which the WPT-based Kurtogram was optimised by calculating the kurtosis of the envelope power spectrum.

In recent laboratory testing on a planetary gearbox test rig, the authors encountered a situation in which the Fast Kurtogram and Protrugram approaches failed to yield successful diagnoses of large seeded REB faults. Inspection of the measured signals revealed a form of impulsive wideband interference, which later investigations determined was in fact electromagnetic interference (EMI) arising from the variable frequency drive (VFD) controlling the induction motor of the test rig. It became clear that this interference was adversely affecting the diagnostics, rendering these established techniques incapable of diagnosing even large seeded faults. Since these tests, the authors have encountered a number of other instances of EMI contamination in vibration signals, most often, but not always, arising from VFDs (see Section 2).

This experience prompted the development of a simple SK-based approach to demodulation band selection, which the authors refer to as Optimised Spectral Kurtosis. Though applied here to vibration signals contaminated with EMI specifically from variable frequency drives, it is thought the approach will have broader applicability to other cases involving impulsive wideband[1] interference.

The remainder of this paper is organised as follows. Section 2 gives a brief explanation of the nature of the interference from VFDs. This is by no means an exhaustive treatise, but is rather intended to outline the most common type of EMI from VFDs—that arising from the pulse-width modulated (PWM) control signal used by VFDs. Section 3 provides a basic review of the Fast Kurtogram and Protrugram, and then introduces the Optimised SK approach for demodulation band selection. Section 4 explains the experimental and simulated data used in this study, and the diagnostic performance of the three methods – Fast Kurtogram, Protrugram and Optimised SK – is illustrated in Section 5. The discussion in Section 6 includes a comparison of the three methods, and conclusions are given in Section 7.

2. Electromagnetic interference from variable frequency drives

Electromagnetic interference is defined as any unwanted signal that is either radiated or conducted to electronic equipment and negatively affects the performance of the equipment [11]. The present focus is on the contamination of vibration signals with EMI generated from variable frequency drives. From the authors' experience, this type of EMI is very common. Indeed, VFDs are widely employed in industrial applications for controlling AC motor speed and torque by altering motor input frequency and voltage, and EMI is commonly associated with VFDs [12].

[1] The term 'wideband' is used here to describe a signal occupying a wide frequency range, regardless of its spectral form (such as its shape and whether it is dominated by discrete or random components); this is as opposed to 'broadband', which the authors believe implies a signal with a smooth, flat spectrum.