Measurement 64 (2015) 71–80

Contents lists available at ScienceDirect

Measurement

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

A hybrid approach for fault diagnosis of planetary bearings using an internal vibration sensor

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ARTICLE INFO

Article history:
Received 14 September 2014
Received in revised form 10 December 2014
Accepted 18 December 2014
Available online 27 December 2014

Keywords:
Fault diagnosis
Planetary gearbox
Bearing
Signal processing
Vibration condition monitoring

ABSTRACT

Planetary gearboxes exhibit unique challenges in bearing fault detection. This paper presents a hybrid approach for fault diagnosis of planetary bearings using an internal vibration sensor and novel signal processing strategies. An accelerometer is mounted internally on the planet carrier to address the issues of variable transmission path. An effective bearing faults detection algorism is developed by employing several advanced signal processing techniques, including Cepstrum whitening, minimum entropy deconvolution (MED), spectral kurtosis (SK) and envelope analysis. The adverse effect of the electromagnetic interference in the signal due to the use of a slip ring is tackled by optimizing the SK technique for demodulation band selection. The proposed method is assessed by analyzing experimental data from a planetary gearbox test rig with seeded bearing faults. The result shows that the new method can effectively detect both inner race and outer race faults of the planetary bearing.

1. Introduction

With the benefits of strong load-bearing capacity, compact, light weight and large transmission ratio, planetary gearboxes are widely applied in the fields of automobiles, helicopters, wind turbines, etc. [1]. Due to the harsh working conditions, some key components of planetary gearboxes, such as gears and bearings, are extremely vulnerable to faults after long-time operation. The failure of gears or bearings may cause the breakdown of the entire system [2]. Effective fault diagnosis methods are needed for preventing accidents and reducing the maintenance costs. However, planetary gearboxes exhibit unique challenges in bearing fault detection. They comprise many rotating components which lead to contamination by strong background noise. The transmission path between an externally mounted sensor and fault signal source is time varying. Thus traditional fault diagnosis methods developed for fixed-axis gearboxes may not work for planetary gearboxes.

There has been extensive research on condition monitoring and fault diagnosis of planetary gearboxes. McFadden and Howard [3] applied the technique of time synchronous averaging (TSA) for diagnosing the local defects in the planet gear and the sun gear. Antoni and Randall proposed a method called discrete random separation (DRS) [4] for the separation of gear signals and faulty bearing signals in planetary gearbox, in which the incipient bearing failure can be detected after the removal of deterministic gear signals. Feng et al. [5] presented a joint amplitude and frequency demodulation method for gear faults diagnosis of planetary gearbox. In [6], the methods of ensemble empirical mode decomposition (EEMD) and energy separation were combined by Feng et al. for detecting the sun gear faults of planetary gearbox. Barszcz and Randall [7] applied the technique of spectral kurtosis for

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http://dx.doi.org/10.1016/j.measurement.2014.12.030
0263-2241/

the ring gear crack detection of a planetary gearbox. Yu and Makis [8] used the continuous wavelet transform (CWT) or discrete wavelet transform (DWT) on the TSA signal for further optimizing the planet gear diagnosis. Lei et al. [9] proposed an adaptive stochastic resonance method (ASR) for the sun gear fault detection. Smidt and Ryan [10] mounted an internal sensor on the planet carrier for data collection and applied the TSA technique to the internal vibration signal for the fault detection of planetary gears. The results showed that the most obvious advantage of internal sensor based measurement was that the raw signal can be directly converted to the useful damage indicator for gear faults, such as kurtosis or root-mean-square (RMS) values, without any preprocessing steps.

While many studies on monitoring gear faults have been published, it seems that there is still lack of effective approaches for the fault diagnosis of planetary bearings. This is because the bearing related vibration signals are strongly masked by gear signals. In addition, the signal from planet gear bearings is transmitted through the ring gear to the fixed external sensor via a time varying transmission path, which means that the fault signal is subject to both noise contamination and modulation [2]. In order to overcome these problems, Smith et al. [11] employed an internal accelerometer mounted on the planet carrier and an externally fixed accelerometer for identifying planetary gear bearing defects. It was demonstrated that the internal sensor based measurement has potential superiority in inner race fault detection over the external sensor, while both the external sensor measurement and internal sensor measurement provided similar diagnostic performance for the outer race fault. It was also pointed out in [10] that a limitation of internal sensor based measurement was that the signal might be contaminated by electromagnetic interference due to the use of a slip ring for the signal transmission.

This paper presents further development of fault diagnosis approaches by using the internal vibration sensor. It aims to improve the fault detection effectiveness by solving the problems of demodulation band selection of internal sensor signals caused by electromagnetic interference. The new fault diagnosis method, which is developed by employing several advanced digital signal processing (DSP) techniques, will be introduced. The performance of the proposed approach on detecting both the inner race faults and outer race faults of planetary bearings will be assessed.

2. Methodology

2.1. Sensing by using internal vibration sensor

For vibration-based condition monitoring of planetary bearings, the traditional mounting location is on the external housing or the ring gear for the ease of installation and maintenance. However, bearing fault signals from the external sensor measurement are attenuated after the transmission through the gear mesh between the planet gear and ring gear. Moreover, the transmission path from the source of fault location to the externally mounted stationary accelerometer is time-varying. This varying path will lead to the modulation of the key vibration signals.

A new approach is to mount an accelerometer internally on the planet carrier to solve the issues of variable transmission path and receiving more direct vibration signals. A slip ring is used for the transmission of the vibration signal from the internally mounted sensor. A schematic view of the external and internal sensor locations is illustrated in Fig. 1.

However, due to the use of a slip ring for signal transmission, the internal accelerometer signals are contaminated by electromagnetic interference in the high frequency range, as shown in Fig. 2. The interference may come from the variable frequency controller and/or the ground loop effect. Therefore, as illustrated in Fig. 3, the bearing fault signal is masked by deterministic gear signals, random noise and the electromagnetic interference.

To filter out undesired components in the measured signal and to improve the signal to noise ratio (SNR), a hybrid signal processing approach is developed as shown in Fig. 4. Cepstrum pre-whitening is the first step for removing the discrete frequencies from the raw vibration signal.

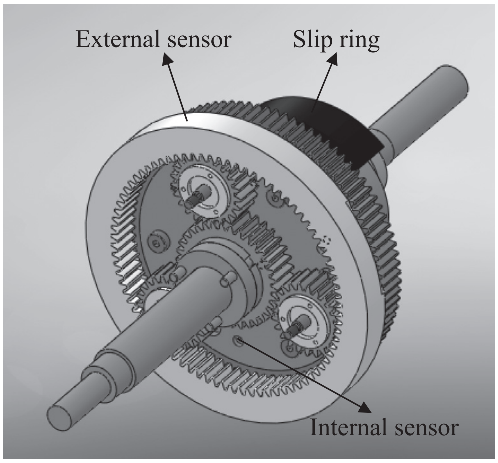

Fig. 1. A schematic for the locations of accelerometers.

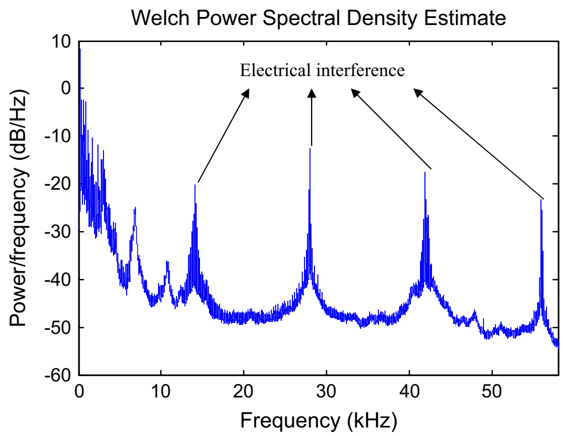

Fig. 2. Power spectral density of internal acceleration signal.