Mechanical Systems and Signal Processing 54-55 (2015) 277–292

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

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

Planetary gearbox condition monitoring of ship-based satellite communication antennas using ensemble multiwavelet analysis method

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ARTICLE INFO

Article history:
Received 31 March 2014
Received in revised form
11 June 2014
Accepted 30 July 2014
Available online 6 October 2014

Keywords:
Planetary gearbox
Condition monitoring
Ship-based satellite communication antennas
Ensemble multiwavelet transform

ABSTRACT

Satellite communication antennas are key devices of a measurement ship to support voice, data, fax and video integration services. Condition monitoring of mechanical equipment from the vibration measurement data is significant for guaranteeing safe operation and avoiding the unscheduled breakdown. So, condition monitoring system for ship-based satellite communication antennas is designed and developed. Planetary gearboxes play an important role in the transmission train of satellite communication antenna. However, condition monitoring of planetary gearbox still faces challenges due to complexity and weak condition feature. This paper provides a possibility for planetary gearbox condition monitoring by proposing ensemble a multiwavelet analysis method. Benefit from the property on multi-resolution analysis and the multiple wavelet basis functions, multiwavelet has the advantage over characterizing the non-stationary signal. In order to realize the accurate detection of the condition feature and multi-resolution analysis in the whole frequency band, adaptive multiwavelet basis function is constructed via increasing multiplicity and then vibration signal is processed by the ensemble multiwavelet transform. Finally, normalized ensemble multiwavelet transform information entropy is computed to describe the condition of planetary gearbox. The effectiveness of proposed method is first validated through condition monitoring of experimental planetary gearbox. Then this method is used for planetary gearbox condition monitoring of ship-based satellite communication antennas and the results support its feasibility.

1. Introduction

Aerospace measurement ship is mainly responsible for the maritime measurement and control, communication, salvage and recovery of spacecrafts. Satellite communication antennas (SCA) are key devices of a measurement ship to support voice, data, fax and video integration services. Thanks to the advantages of high transmission accuracy, large transmission

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http://dx.doi.org/10.1016/j.ymssp.2014.07.026
0888-3270/

ratio and strong load-bearing capacity, planetary gearboxes play an important role in the transmission train of a satellite communication antenna or a telemetry, tracking, and command (TT&C) antenna for the aerospace industry [1]. Planetary gearboxes inevitably generate various faults because of chronically running under such complex and severe conditions as heavy load, ocean wave and tide, fatigue and corrosion. As the core components in the transmission train of a SCA, the performance of planetary gearboxes directly influences the measurement accuracy and the success or failure of tasks for a SCA. So planetary gearbox condition monitoring is significant for scheduling the proper maintenance and avoiding the consequences of the failure as well as realizing the safe operation of a SCA.

Regardless of the techniques, the capability of any condition monitoring system depends on two factors: the type and number of sensors, the associated signal processing and simplification methods applied to extract important information from the various signals [2]. Data acquisition refers to measuring the required variables (e.g. temperature, speed and voltage) as well as turning them into electronic signals. Vibration analysis continues to be the most popular technology employed in the condition monitoring of mechanical equipment [3]. The remaining important problem is how to process the data in order to obtain the diagnostic features. One solution is to treat the vibration signal as a process which can be parameterized using simple statistical analysis (mean, maximum, minimum) or advanced higher order statistics (kurtosis, etc.) [4]. Another approach is to process the vibration signal in the frequency domain (fast-Fourier transform, etc.) [4]. But this approach does not make much sense when the vibration signal is acquired under the non-stationary operating regime. Unfortunately, engineering practices indicate that information gathered from machine-integrated sensors is usually emerges non-stationary [5]. Thus, effective signal analysis method should be developed and introduced for planetary gearbox condition monitoring of ship-based satellite communication antennas.

Some interesting studies regarding condition monitoring and fault diagnosis of planetary gearbox have been reported recently in the literature. Blunt et al. used the root mean square of the averaged signal based on a planet and the carrier respectively for detecting a crack in the carrier of helicopter planetary gearbox [6]. Bartelmus et al. investigated the influence of the varying load on condition monitoring of planetary gearboxes and proposed a feature for monitoring planetary gearboxes under time-variable operating conditions [7]. Lei et al. introduced methods based on new condition monitoring parameters and adaptive stochastic resonance method to classify different damage modes in a planetary gearbox [8–9]. Barszcz et al. applied the spectral kurtosis technique to crack detection of the ring gear in the planetary gearbox of a wind turbine [10]. Zhang et al. integrated a blind deconvolution algorithm and vibration modeling for detecting a seeded fault in the helicopter planetary gearbox [11]. Samuel et al. proposed a technique based on the constrained adaptive lifting algorithm for detecting gear fault with all teeth spalled in the planetary gearbox of a helicopter transmission [12]. Zimroz et al. investigated the cyclo-stationary properties of vibration signals for multi-fault detection in multi-stage gearboxes: fixed axis and planetary [13]. Bartkowiak et al. found outliers in a large data of two excavator planetary gearboxes under good and bad condition respectively, and used them for condition monitoring of planetary gearbox [14]. Feng et al. carried out planetary gearbox fault diagnosis based on torsional vibration signal analysis [15]. The above studies have provided critical insight on fault monitoring and diagnosis of planetary gearbox. There are still lots of issues to be addressed in condition monitoring and fault diagnosis of planetary gearbox. One of them is how to effectively discover the weak condition feature from noisy vibration signal of faulty component in planetary gearbox and exactly identify the operation condition.

Due to the advantage of multi-resolution analysis, wavelet transform (WT) [16], a very effective tool for non-stationary signal processing, has already shown its tremendous usefulness in weak condition feature extraction [17–18]. WT has more choices on the basis functions to match a specific fault symptom than the Fourier transform, which is greatly beneficial to the condition feature extraction. However, a scalar wavelet in the wavelet basis function library does not possess the properties of symmetry, orthogonality, compact support and higher order of vanishing moments simultaneously [19]. These properties are significant for characterizing a signal comprehensively and precisely. Multiwavelet transform as the newer development of the wavelet transform theory was firstly proposed by Geronimo et al. [20]. Multiwavelet not only realizes multi-resolution analysis but also simultaneously possesses important properties such as symmetry, orthogonality, compact support and higher order of vanishing moments that traditional scalar wavelet does not have [21]. Because it possesses multiple wavelet basis functions, multiwavelet does well in extracting features with multiple kinds of shape for condition feature extraction. However, an inappropriate mother wavelet employed in the engineering application often lower the accuracy of the fault detection and condition identification [22]. So it is very important to select an appropriate wavelet basis for the signal processing. In fact, the fixed basis function which is not related to the analyzed signal would influence the accuracy of fault detection. Moreover, multiwavelet transform only focuses on the multi-resolution analysis in low frequency band, which may leave out the useful condition feature. Furthermore, an important problem to be solved is how to describe and evaluate the condition of planetary gearbox through a simple rule based on the abundant multiwavelet transform coefficients. To overcome the shortcoming of multiwavelet transform and realize the condition identification of planetary gearbox, ensemble multiwavelet analysis method is proposed in this paper.

There are three parts in the ensemble multiwavelet analysis method for planetary gearbox condition monitoring. Firstly, new multiwavelet basis function is obtained by performing increasing multiplicity (IM) on a known Chui-Lian (CL) multiwavelet, so as to gain the greater free parameter for building vibration data-driven multiwavelet [23–24]. By means of the idea of Chui and Lian, a new and general scheme for constructing the customized multiwavelet called IM is proposed by the author [25]. The free parameter is optimized via genetic algorithm according to minimum envelop spectrum entropy fitness objective. Then, ensemble multiwavelet transform is conducted based on the adaptive multiwavelet basis function to