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Review

Spectral kurtosis for fault detection, diagnosis and prognostics of rotating machines: A review with applications

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ABSTRACT

Condition-based maintenance via vibration signal processing plays an important role to reduce unscheduled machine downtime and avoid catastrophic accidents in industrial enterprises. Many machine faults, such as local defects in rotating machines, manifest themselves in the acquired vibration signals as a series of impulsive events. The spectral kurtosis (SK) technique extends the concept of kurtosis to that of a function of frequency that indicates how the impulsiveness of a signal. This work intends to review and summarize the recent research developments on the SK theories, for instance, short-time Fourier transform-based SK, kurtogram, adaptive SK and protrugram, as well as the corresponding applications in fault detection and diagnosis of the rotating machines. The potential prospects of prognostics using SK technique are also designated. Some examples have been presented to illustrate their performances. The expectation is that further research and applications of the SK technique will flourish in the future, especially in the fields of the prognostics.

Contents

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1. Introduction

Condition-based maintenance (CBM) is a maintenance program that recommends maintenance decisions based on the information collected through condition monitoring [1]. Diagnostics and prognostics are two important aspects in a CBM program. CBM plays an important role to reduce unscheduled machine downtime and avoid catastrophic accidents in industrial enterprises.

A variety of methods have been developed and summarized for rotating machinery fault diagnostics, such as vibration analysis [2], acoustic emission (AE) [3], temperature trend analysis [4] and wear debris analysis [5]. Commonly used technique for fault detection is vibration-based signature analysis. Signal processing in vibration-based monitoring of rotating machinery offers very important information about anomalies formed internally in the structure of the machinery [6]. Hundreds of papers in this field, including theory and practical applications, appear every year in academic journals, conference proceedings and technical reports. Space lacks for a detailed description of all these methods, interested readers can refer to some review works in the field of the vibration-based fault detection and diagnosis using the wavelet transform [7], multiwavelet transform [8], empirical model decomposition [9] and time–frequency analysis [10], etc. Moreover, all these fault diagnosis methods mentioned above have been used not only on the test rig of the bearings or gears, but extensively in practical equipments, such as helicopters [11], wind turbine [12–14], induction machines [15,16] and permanent magnet machines [17].

Diagnostics is conducted to investigate or analyze the cause or nature of a condition, situation or problem, whereas prognostics is concerned with calculating or predicting the future as a result of rational study and analysis of available pertinent data [18]. Prognostics has the potential to give the greatest economic benefits from the condition monitoring, but it is probably the least developed technique compared with fault detection and diagnostics methods. The information gained from vibration signal analysis enables us to plan a maintenance action [19]. Based on this analysis, the health assessment at the various stages of degradation is crucial for predicting failure and making maintenance decisions. Therefore, some methodologies in prognostics have been broadly developed based on the approaches of statistical reliability, data-driven evolutionary trend, dynamic systems, physics-based modeling, etc. Most of these methodologies and their applications in prognostics of rotary machines have been introduced in the corresponding review works [1,18,20,21].

Spectral kurtosis (SK) is one of the powerful techniques for vibration signal analysis. In recent years, SK has been paid a considerable amount of attention to the fault diagnosis of rotating machines. Knowledge of this prior works is also necessary for any future research efforts to be conducted. However, there is not a comprehensive overview that states the previous and ongoing efforts of SK. This paper thus attempts to summarize the development of SK, especially on the algorithms and their applications for fault detection, diagnosis of rotating machinery. Through the literature review, some increasing trends appear in the research field of machine prognostics using the SK technique are also discussed.

The remaining part of the paper is organized as follows. Section 2 briefly introduces the development of SK theory. Different algorithms for SK and its estimations are given in Section 3. Section 4 shows the applications of the SK in fault detection and diagnosis of the crucial parts in rotating machine, namely bearings and gears. The two prospects of SK in the prognostics using SK are presented in Section 5. Finally, Section 6 concludes the paper and provides a short list of references for applications of SK in other fields.

2. A brief history

Diagnostics and prognostics are the two important aspects of time series analysis, which individually uses signal processing and prediction technique. The higher order statistics (HOS) is an important branch of time series analysis, and has been conducted an extensive research in the past few years. Many works lead to several HOS analysis, complementary to classical second order methods. In 1983, frequency domain kurtosis (FDK) was first developed as the kurtosis of its frequency components in the frequency domain by Dwyer [22], and then it was used as a complement to the power spectral density to detect “randomly occurring signals” in [23,24]. In 1994, Pagnan and Ottonello proposed a modified definition