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A novel method for real time gear fault detection based on pulse shape analysis

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ABSTRACT

Early identification of faults in gearboxes is a challenging task, especially when the time is a critical factor. In this paper, a novel method for real time fault detection in gearboxes is proposed using adaptive features extraction algorithm to deal with non-stationary faulty signals. Moreover, integration of different techniques is presented in order to detect faults in a real time environment. Evolutionary algorithms are commonly used in different applications and have strong ability for optimization. However, they are inherently slow and not suitable for real time applications. The proposed method is based on a combination of conventional one-dimensional and multi-dimensional search methods, which showed high performance and accurate fault detection results compared with evolutionary algorithms. The effectiveness, feasibility and robustness of the proposed method have been demonstrated on experimental data. An average speed up factor of 87% has been successfully achieved with approximately 5% quality degradation in the results as compared with evolutionary algorithms like genetic algorithms.

1. Introduction

Gears are an inseparable part of most of rotating machines in the industry today. Their applications include production, manufacturing, medical, space, and other industries. Gears are commonly used to transfer speed and power from one shaft to another. Therefore, they are critical components of any rotating machinery where the availability of the entire system depends on the smooth function of gears or gearboxes.

In any mechanical process, the detection of faults is the first and foremost priority of a maintenance function before diagnosis, prognosis and root cause or consequence analysis. Decisions are taken by interpreting available information and by acquiring necessary information that is not yet available. The decision making process is a critical task which is difficult, especially in an environment of complex machines and process measurements. Detection and diagnosis is inevitable to solve problems in maintenance and operations. Many detection techniques are able to detect different faults. However most of these techniques suffer from low detection quality and/or slow response time, which restricted their use in online or real time fault detection applications. Diagnosis is not an easy task for the maintenance technician because there could be many factors involved that would affect the performance of the technician or the abnormal deviation itself. Type of alarms, frequency of alarms and number of alarms, operator's response time and type, effectiveness of the fault data presentation, time delay in fault detection and complexity of the plant, operators training, experience and response to stress are some examples of these

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complex linear and nonlinear factors. All these factors make the fault diagnosis procedure very difficult. Hence, there is a requirement for a real time automated fault diagnosis to aid in decision making.

The purpose of this research is to present real time fault detection and features extraction method for further faults classification. The proposed fault detection method is implemented as part of an integrated fault diagnostic system (FDS) presented in [14,15]. The proposed method is a time based features extraction, which offers reduced complexity that is suitable for real time implementation. It provides better response time than compared with evolutionary algorithms, e.g. genetic algorithm.

2. Related work

Features extraction system extracts characteristic signatures from the incoming raw sensor signals. The extracted features should be sensitive to the machine condition and therefore should reflect the changes in the machine condition or possible fault development over time. There exist many methods for features extraction in open research. These methods can be classified into two groups based on the nature of the incoming signals. Stationary and non-stationary signals are dealt differently in terms of features extraction methods as features extraction methods for non-stationary signals also accounts for time resolutions. For stationary signals, features extraction methods are divided into time domain and frequency domains. Time domain methods include statistical based, model based and signal processing based methods. Frequency domain methods include, spectrum and cepstrum based methods. For non-stationary signals, features extraction methods are divided into time domain, time–frequency domain and wavelet domain [1,3]. Short time Fourier transforms (STFT) and wavelet analysis are some examples for time frequency representations (TFR).

There exist different studies in faulty features extraction for gears and gearboxes. The vibration based signal processing analysis is the most common technique because of its advantage of being nondestructive testing (NDT). Also, through vibration analysis, it is possible to obtain and extract information that best represents the faulty conditions present in the signal [16,17,18]. Also artificially intelligent techniques like neural networks, genetic algorithms, genetic programming, with the combinations of wavelet analysis for features extraction, have been successfully used for fault detection and diagnosis of gears and gearboxes [19–21,28]. In time domain features extraction, kurtosis and spectral kurtosis based [27,29,30], statistical based and transient based features detection studies have been performed in the past [22–24]. A comprehensive list of time domain features and fault detection based on them is also discussed in [25].

The major work in fault detection of gears and gearboxes through evolutionary algorithms, focus in quality on the expense of computation time. There hardly exists any previous study where a real time fault detection scheme has been proposed and its performance has been compared with that of evolutionary algorithms like genetic algorithm. In this proposed study, not only we present a real time features extraction algorithm, but also compare its quality with that of genetic algorithms optimization abilities.

3. Adaptive time based features extraction

Transients are generally short duration pulses present in the signal coming from faulty machine components [1]. In time domain, the duration of transients usually lasts 1–10 ms and in frequency domain, the transients are spanned over a wide range [2]. Transients contain important information about the machine faults and the severity of the faults can be estimated by analyzing their shapes, amplitudes and slopes.

Time frequency representation methods are most widely used for features extractions especially when they exhibit transient behavior. Continuous, orthogonal and adaptive wavelet transforms are normally used to detect signal transients. In time frequency representation methods, the transient time signal is reconstructed by inverse transform after noise reduction and transient coefficients identification. This involves a critical step of determining reconstruction threshold which is usually a difficult process [4]. Also the reconstruction process involves loss of useful information.

We propose a real time transient analysis method for extraction of faulty features. The flowchart of the proposed method is shown in Fig. 1. After data acquisition and conditioning, a fast kurtogram is computed for the raw vibration signal [5]. The fast kurtogram gives an initial estimate about the center frequency and bandwidth span of the faulty pulses. The fast kurtogram computational complexity is $N \log N$ similar to that of fast Fourier transform (FFT) and is computationally suitable for real time applications. A bandwidth filter is initialized and the filter parameters are set according to initial estimates from fast kurtogram. Direct search method with derivative free search is used to fine tune the band pass filter and kurtosis is used as an optimization cost function. Combination of genetic algorithms with fast kurtogram for detection of rolling element bearings faults is proposed in [6]. Although, genetic algorithm is given with initial parameters in order to search for the minima, the process is still inherently slow if considered for real time implementation. In order to speed up the performance, a coarse tuning step is included, that performs a speedy one dimensional search on decision variables one by one and reduces the search space for further fine tuning. Derivative free direct search methods like Nelder–Mead are a good candidate for fast convergence and outperform evolutionary search algorithms in terms of computational complexity. The coarse tuning step makes use of golden section search combined with parabolic interpolation for fast and guaranteed convergence [7]. The Nelder–Mead method then provides enough information and reasonable extraction of transients for features extraction and faults classification in reasonable amount of time as compared with evolutionary algorithms. In each step of our features