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Application of power spectrum, cepstrum, higher order spectrum and neural network analyses for induction motor fault diagnosis

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ABSTRACT

The power spectrum is defined as the square of the magnitude of the Fourier transform (FT) of a signal. The advantage of FT analysis is that it allows the decomposition of a signal into individual periodic frequency components and establishes the relative intensity of each component. It is the most commonly used signal processing technique today. If the same principle is applied for the detection of periodicity components in a Fourier spectrum, the process is called the cepstrum analysis. Cepstrum analysis is a very useful tool for detection families of harmonics with uniform spacing or the families of sidebands commonly found in gearbox, bearing and engine vibration fault spectra. Higher order spectra (HOS) (also known as polyspectra) consist of higher order moment of spectra which are able to detect non-linear interactions between frequency components. For HOS, the most commonly used is the bispectrum. The bispectrum is the third-order frequency domain measure, which contains information that standard power spectral analysis techniques cannot provide. It is well known that neural networks can represent complex non-linear relationships, and therefore they are extremely useful for fault identification and classification. This paper presents an application of power spectrum, cepstrum, bispectrum and neural network for fault pattern extraction of induction motors. The potential for using the power spectrum, cepstrum, bispectrum and neural network as a means for differentiating between healthy and faulty induction motor operation is examined. A series of experiments is done and the advantages and disadvantages between them are discussed. It has been found that a combination of power spectrum, cepstrum and bispectrum plus neural network analyses could be a very useful tool for condition monitoring and fault diagnosis of induction motors.

1. Introduction

Vibration and phase current analysis are widely used in condition monitoring and fault diagnosis of induction motors. Since variations of vibration and phase current contain valuable information about the condition of the machine, by analysing the signals people can in many cases predict whether a machine is about to develop a fault or not. Generally speaking the vibration signals picked up by an accelerometer and the phase current signals picked up by a Hall-effect sensor have to be processed in some way. The raw vibration and phase current signals are rarely used in practice. For example, the

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overall mean square value, variance value, skewness, kurtosis of a signal are likely to be used in time domain, while in frequency domain the Fourier analysis of a signal like the power spectrum (the second-order frequency domain measure) is commonly used. Although the power spectrum has been widely used in various fields like vibration, acoustic, radar, sonar, telecommunication and image processing, one of its inherited drawbacks is that it will lose the phase information between frequency components. Recently, more elaborate procedures are being studied, such as higher-order spectrum analysis [1]. The motivations behind the use of higher order spectrum analysis are as follows [2]. Firstly, the technique can suppress Gaussian noise processes of unknown spectral characteristics in detection, parameter estimation and classification problems. If a non-Gaussian signal is embedded in additive Gaussian noise, a transform to HOS will eliminate the noise. The non-Gaussian condition is satisfied in many practical applications, since any periodic or quasi-periodic signals can be regarded as a non-Gaussian signal, and self-emitting signals from complicated machinery can also be considered as non-Gaussian signals. Secondly, HOS preserves the phase information. For example, there are situations in practice in which the interaction between two harmonic components causes contribution to the power at their sum and/or difference frequencies. Thirdly, HOS can play a key role in detecting and characterising the type of non-linearity in a system from its output data. Although HOS has been developed as a signal processing tool over a period of 30 years it has been mostly used for speech signal processing and sonar signal processing. The application of HOS for condition monitoring and fault diagnosis of machinery is relatively seldom found. In [3,4] some excellent work has been done by Gu and Ball; however, they have concentrated on the application of HOS in electrical motor current analysis. Another approved useful method adopted by this paper for complicated multiband frequency analysis is the cepstrum analysis which is considered as the spectrum analysis of the logarithm spectrum of a signal. The cepstrum can be seen as information about the rate of change in the different spectrum bands. Besides its wide applications in engine gearbox and bearing condition monitoring and fault diagnosis [5,6], the application for induction motor fault diagnosis has not been found yet. In the condition monitoring and diagnostics of machinery, two fundamental problems exist, namely, (1) the identification and classification of fault patterns; and (2) the quantification of fault development. Mathematically, the former is a clustering problem and the latter is a trend analyses problem. Fault identification and classification involves the processing of a large amount of information contained in the monitored signals. Inevitably there exist some uncertainties and non-linearity in machinery due to system complexity and measurement errors. Neural networks represent one of the distinct methodologies that deal with uncertainty. Neural networks can represent complex non-linear relationships, and they are very good at classification of phenomena into pre-selected categories as used in the training process. Hence, they can be particularly useful for the problems of condition monitoring and diagnostics. This paper presents an investigation of power spectrum, cepstrum, higher order spectrum and neural network analysis for induction motor condition monitoring and fault diagnosis. For HOS the investigation is mainly concentrated on the bispectrum analysis (the third-order frequency domain measure) of vibration and phase current signals. All in all, power spectrum, cepstrum and HOS are signal processing techniques used for dynamic system analysis and condition monitoring. They all have its own advantages and disadvantages in applications. However it is expected that a combination of power spectrum, cepstrum and HOS techniques with neural network analysis should provide a very useful tool for condition monitoring and fault diagnosis of induction motors. This kind of research has not been reported in any publications yet. The following are the research findings and the paper is organised as follows: Section 2 introduces the basic theory of the power spectrum, cepstrum and bispectrum; in Section 3 the fundamental fault theory for induction motors is presented. The experimental results and analysis are shown in Section 4. Finally the conclusions are given.

2. The basic theory of power spectrum, cepstrum and High order spectrum

2.1. Power spectrum definition

The power spectrum is defined as the square of the magnitude of the FT of a signal. It can be written as

$$P(\omega) = \left| \int_{-\infty}^{+\infty} x(t) e^{-j\omega t} dt \right|^2 = X(\omega) X^*(\omega) \tag{1}$$

where $X(\omega) = \int_{-\infty}^{+\infty} x(t) e^{-j\omega t} dt$ is the FT of a signal, $X^*(\omega)$ is its complex conjugate, $\omega = 2\pi f$, and f is the frequency in Hz.

2.2. Cepstrum definition

A cepstrum is usually defined as the Fourier transform of the logarithm of the Fourier transform of a signal. The name of cepstrum was derived by reversing the first four letters of spectrum. There is a real cepstrum, a complex cepstrum, a power cepstrum and a phase cepstrum.

The real cepstrum of a signal $x(t)$:

$$c(t) = \frac{1}{2\pi} \int_{-\pi}^{\pi} log|X(\omega)| e^{j\omega t} d\omega \tag{2}$$