

WAVELET ANALYSIS FOR VIBRATION SIGNALS

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ABSTRACT

This paper presents an alternative method to classical Fourier transform approaches used in data analysis. In this manner, application of Continuous Wavelet Transform (CWT) was introduced for vibration data which is collected by an accelerometer replaced on an induction motor. Hence, related results were indicated as properties of the vibration signal and additional information was extracted from the raw data using the time-scale analysis. This extracted information was represented in high frequency region of the original data which is defined between 2 and 4 kHz.

Key Words: Continuous wavelet, vibration, feature extraction, information, data analysis.

1. INTRODUCTION

The increased need for monitoring and prognosis of process equipment in industrial systems has increased the efforts towards developing new and reliable signal analysis techniques for extracting degradation-sensitive information from physical measurements. The main goal of this technological improvement is to obtain more detailed information contained in the measured data than had been previously possible. Standard digital signal processing techniques, such as time series statistics, correlation analysis and fast Fourier transform (FFT) have been used in analysis of the physical system components [1-2].

In this study, continuous wavelet transform defined in the time-scale domain was presented as an alternative method to time-frequency methods like short time Fourier transform. Consequently, considering the smallest scale of the CWT analysis results, additional information related to the vibration measurement was extracted as a signal property.

2. WAVELET TRANSFORM

The use of wavelet transform is particularly appropriate since it gives information about the signal both in frequency and time domains [3-5]. Let $f(x)$ be the signal, the continuous wavelet transform of $f(x)$ is then defined as

$$W_f(a, b) = \int_{-\infty}^{+\infty} f(x)\psi_{a,b}(x)dx, \quad (1)$$

Where

$$\psi_{a,b}(x) = \frac{1}{\sqrt{|a|}} \psi\left(\frac{x-b}{a}\right) \quad a, b \in \mathbb{R}, a \neq 0 \quad (2)$$

And it provides the admissibility condition as below

$$C_\psi = \int_0^{+\infty} \frac{|\psi(\omega)|^2}{\omega} d\omega < \infty \quad (3)$$

And for this reason, it is

$$\int_{-\infty}^{+\infty} \psi(x) dx = 0 \quad (4)$$

Here $\psi(\omega)$ stands for the Fourier transform of $\psi(x)$. The admissibility condition implies that the Fourier transform of $\psi(x)$ vanishes at the zero frequency. Therefore ψ is called as a wave or the mother wavelet and it have two characteristic parameters, namely, dilation (a) and translation (b), which vary continuously. The translation parameter, “ b ”, controls the position of the wavelet in time. A “narrow” wavelet can access high-frequency information, while a more dilated wavelet can access low-frequency information. This means that the parameter “ a ” varies with different frequency. The parameters “ a ” and “ b ” take discrete values, $a = a_0^j$, $b = nb_0 a_0^j$, where $n, j \in \mathbb{Z}$, $a_0 > 1$, and $b_0 > 0$. The discrete wavelet transformation (DWT) is defined as

$$\text{DWT}[j, k] = \frac{1}{\sqrt{a_0^j}} \sum_n f[n] \psi\left[\frac{k - na_0^j}{a_0^j}\right]$$

3. APPLICATION

In this application, to be considered data is vibration data that come from an accelerometer type sensor, which is replaced on an induction motor, and its sampling frequency is 12 kHz. For this vibration measurement its time domain and frequency domain representations can be given as follows.

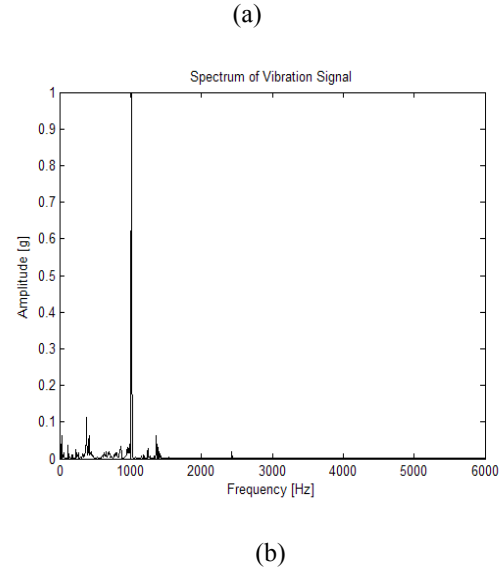
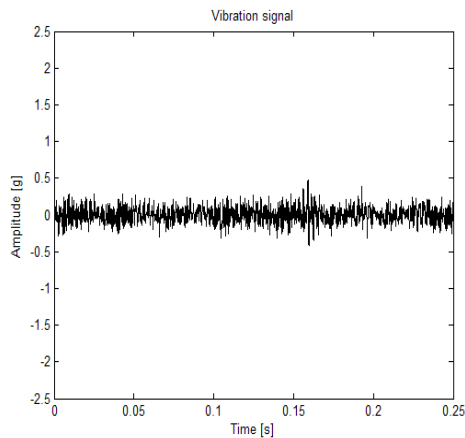


Figure 1. Vibration signal. a) Time domain. b) Normalized Power Spectrum Density.

As seen in figure 1, time domain vibration signal is converted to the frequency domain using the Fourier transform. Here, frequency characteristics of the vibration signal are localized between 0-1.5 KHz. However, during the data collection system, a low pass filter with a cut-off frequency defined at 4 kHz is used. Hence the all frequency band of the vibration signal is defined between 0-4 kHz instead of half sampling frequency.

4. CONTINUOUS WAVELET TRANSFORM FOR VIBRATION ANALYSIS

Continuous Wavelet Transform (CWT) is an integral transform as an alternative method to classical approaches like Fourier transform. For this aim, CWT calculation is represented in Time-Scale domain and the signal to be analyzed is decomposed to different scales which are proportional with frequency range. In this respect, the following 3-dimensional figure shows the time-amplitude plots for different scales.

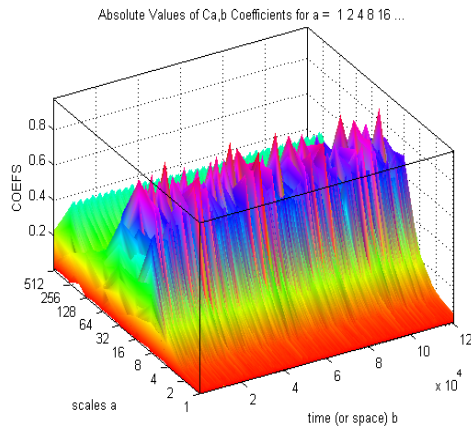


Figure 2. Continuous wavelet analysis in time-scale-amplitude space.

As shown in figure 2, big amplitude variations appear in high scale values which indicate the low frequency region of the data; whereas small amplitude variations are shown by the low scale values namely high frequency components. Therefore, the first scale of the CWT can be considered for indication of the all frequency band from the low to high. The normalized power spectrum density variation of the first scale is shown as below.

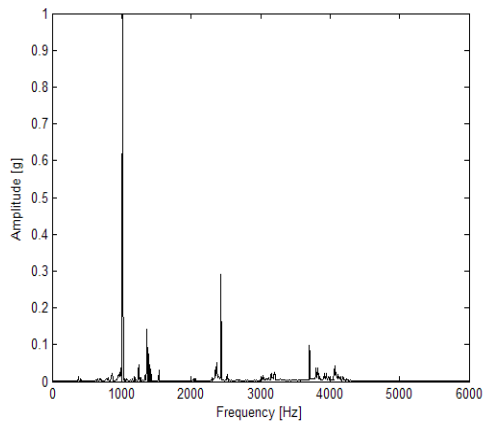


Figure 3. Normalized power spectrum of the first scale of the CWT.

Hence, using the CWT approach, high frequency components of the original vibration signal which is denoted between the 1.5 and 4 kHz are

extracted as hidden information in the vibration measurement.

5. CONCLUSIONS

This study basically provides the “feature extraction” related to the hidden information in the vibration signal. For this aim, it uses the time-scale transformation which is known as Wavelet Transform (WT). Hence it is revealed as an alternative tool to the other classical methods like Fourier transform. This exposed information covers the all frequency band. Thus, this feature extraction is compared as follows.

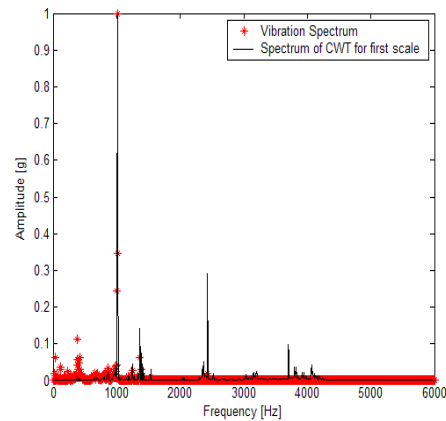


Figure 4. Comparison between Vibration Spectrum and CWT-spectrum for first scale.

As seen from the figure 4, CWT spectrum of first scale reflects the difference defined between 1.5-4 kHz.

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