# Wavelet Transform for Bearing Faults Diagnosis

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***Abstract*—Fault diagnosis is useful for ensuring the safe running of machines. Vibration analysis is one of the most important techniques for fault diagnosis of rotating machinery; as the vibration signal carries the dynamic information of the system. Many signal analysis methods are able to extract useful information from vibration data. In the present work, we are interested to the vibration signal analysis by the wavelet transform. The monitoring results indicate that the wavelet transform can diagnose the abnormal change in the measured data.**

***Keywords—fault diagnosis; vibration analysis; rotating machinery; monitoring; wavelet transform***

## I. INTRODUCTION

Fault diagnosis is extremely important task in process monitoring. It provides operators with the process operation information. Early diagnosis of process faults like bearing faults can help avoid abnormal event progression and reduce productivity loss. Various monitoring techniques have been developed, such as dynamics, vibration, tribology and non-destructive techniques [1], [2], [3].

The vibration signal analysis is one of the most important methods used for fault diagnosis, because it always carries the dynamic information of the system. Vibrations caused by defective bearing elements account for the vast majority of problems with rotating machinery. Each element such as inner race or outer race has a characteristic rotational frequency. With a fault on a particular element, an increase in the vibration energy at this element rotational frequency may occur. The monitoring of these elements has a primary importance for the correct operation of the machine.

Effective utilization of the vibration signals, however, depends upon the effectiveness of the applied signal processing techniques. A wide variety of techniques have been introduced to monitor vibration signals such as: time domain and frequency domain [4], [5], [6]. Unfortunately, they are not able to reveal the inherent information of non-stationary signals. These methods provide only a limited performance for machinery diagnostics. In order to solve this problem, Wavelet Transform (WT); also called time-frequency analysis, has been proposed. WT is a kind of variable window technology, which uses a time interval to analyze the frequency components of the signal.

In this work, we propose to implement the WT for bearing faults diagnosis. It is evaluated using the vibration measurements obtained from accelerometer sensors. The main goal of this technique is to obtain more detailed information contained in the measured data.

The remainder of this paper is organized as follows. Section 2 presents system and bearing faults descriptions. Signal processing techniques and monitoring results are presented and discussed in section 3. Finally, Section 4 concludes our contributions.

## II. EXPERIMENTAL SETUP AND DATA ACQUISITION

The experimental measurements presented in this paper are entirely based on the vibration data obtained from the Case Western Reserve University Bearing Data Centre [7]. As shown in Fig. 1, the motor is connected to a dynamometer and torque sensor by a self-aligning coupling. The data were collected from an accelerometer mounted on the motor housing at the drive end of the motor. Data was obtained from the experimental system under the four different operating conditions: (1) normal condition; (2) with inner race fault; (3) with outer race fault; and (4) with ball fault. The data is sampled at a rate of 12 kHz and the duration of each vibration signal was 10 seconds. More details about experimental setup were reported in [7].

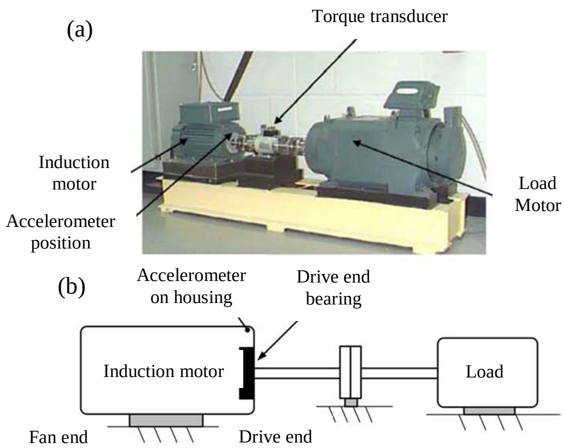


Fig. 1. (a) Bearing test rig and (b) its schematic description [8].

The bearings used in this study are deep groove ball bearings manufactured by SKF. Faults were introduced to the test bearings using electro-discharge machining method. The defect diameters of the three faults were the same: 0.018, 0.036, and 0.053 mm. The motor speed during the experimental tests is 1797–1720 rpm. Each bearing was tested under the four different loads: 0, 1, 2, and 3 horse power (hp).

In order to evaluate the proposed method, the data measured under 0-load (0 hp) at rotation speed of 1797 rpm including the faults on the inner and outer races were used. The original data were divided into segments of samples that each sample covered 4096 data points.

Figs. 2a, 2b and 2c represent respectively a vibration signal collected at 1797 rpm (30 Hz) from the normal state, inner race fault and outer race fault.

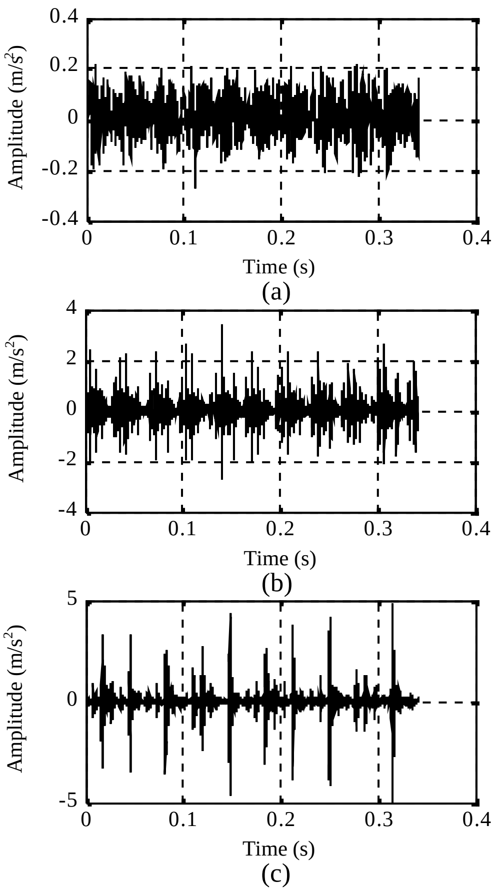


Fig. 2. Vibration signals of: a) normal state, b) inner race fault and c) outer race fault.

The fault frequency can be calculated from the geometry of the bearing and element rotational speed. Frequencies associated with defective inner and outer races are as follows:

$$f_{IR} = (n/2) f_r \left(1 + (d/D) \cos\alpha\right) \tag{1}$$

$$f_{OR} = (n/2) f_r \left(1 - (d/D) \cos\alpha\right) \tag{2}$$

where, $f_r$ is the rotational frequency, $d$ the ball diameter, $D$ the pitch diameter, $n$ the number of balls and $\alpha$ the contact angle. The fault frequencies of inner race and outer race are, respectively, calculated 162 and 107 Hz.

## III. FAULT DIAGNOSIS METHODS

In order to predict any anomalies that may occur under different measurement conditions, some cases require simply a calculation or statement of an indicator followed by a comparison with a threshold. Others require a more detailed analysis by signal processing techniques. We present in this section some signal processing methods appropriate for fault detection and diagnosis.

### A. Temporal Analysis

The first possible observation of a vibration signal is the temporal representation. Several parameters or indicators are evaluated from the temporal signal, such as peak value, peak to peak value, root mean square value, kurtosis, and crest factor [4]. The computed indicator can give some interesting information about the process faults.

The condition monitoring using these indicators is referred to the overall vibration level. To illustrate this method, we use the kurtosis as an indicator of bearing faults detection. The computed values are: 2.76 in normal state, 7.44 with inner race fault and 21 with outer race fault.

These parameters are simple to implement. However, the computed parameter allows to track the machine states, but it does not establish a diagnosis. The monitoring by these indicators represents only a security policy.

With the rapid development of signal processing techniques, it became possible to extract useful information from the vibration data.

### B. Spectral Analysis

The characteristic frequencies of the bearing elements are proportional to the rotational frequency. The spectral analysis allows to identify the different frequencies of the original signal $s(t)$. To obtain the spectrum $S(w)$ of $s(t)$, we apply the Fourier Transform (FT):

$$S(w) = \int_{-\infty}^{+\infty} s(t) e^{-iwt} dt \tag{3}$$

where, $w$ is the frequency.

The vibration signal of the bearing with inner race fault in frequency domain is shown in Fig. 3. Obviously, it is difficult to extract the fault information i.e. the characteristic fault frequency is not clear from the frequency spectrum. As illustrated in Fig. 3, the dominant frequency component is 2880Hz, which was attributed to the resonance frequency.

The identification and the monitoring of the bearing faults using the spectral analysis are difficult, due to the non-stationary. In order to make a correct diagnosis, it is useful to push investigations using more appropriate techniques.

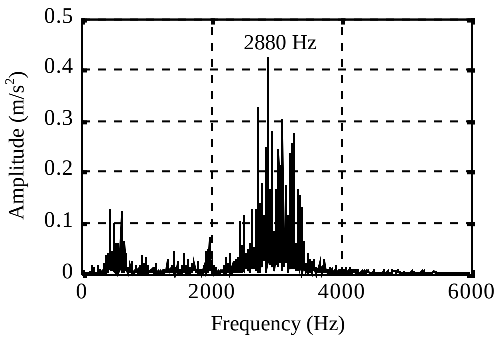


Fig. 3. Spectrum of vibration signal with inner race fault.

### C. *Envelope Analysis*

Envelope analysis is especially suitable for fault diagnosis inducing periodic shocks or amplitude modulations such as gears and bearings. It is the method of extracting the modulating signal from an amplitude-modulated signal. Envelope analysis consists in filtering the vibration signal by a band-pass filter. The resulting signal is then processed by the Hilbert Transform (HT) in order to obtain the envelope and its spectrum. For a given signal *s(t)*, the HT in time domain is defined as [9]:

$$\tilde{s}(t)=\frac{1}{\pi}\int\left(s(\tau)/(t-\tau)\right)d\tau \tag{4}$$

The analytical signal $\hat{s}(t)$ of signal *s(t)* can be constituted trough *s(t)* and its HT $\tilde{s}(t)$:

$$\hat{s}(t)=s(t)+j\tilde{s}(t) \tag{5}$$

The process can be followed by taking the absolute value of analytic signal to generate the envelope:

$$\left|\hat{s}(t)\right|=\sqrt{s(t)^2+\tilde{s}(t)^2} \tag{6}$$

Generally, the faults generating shocks cause a modulation of the signal. Using envelope analysis, the peak present in the envelope spectrum corresponds to the characteristic frequency of the fault.

To identify the nature of the anomalies using this technique, we use the vibration signals of inner and outer races. Figs. 4b and 5b show the characteristic frequencies of the two races. The filter is selected according to the resonance frequencies. After filtering the signals in the bandwidth [2400-3200] Hz, the envelope spectrum presents many frequency components, at the rotation frequency, also at the characteristic frequency and its harmonics, which could be related to inner and outer races bearing faults.

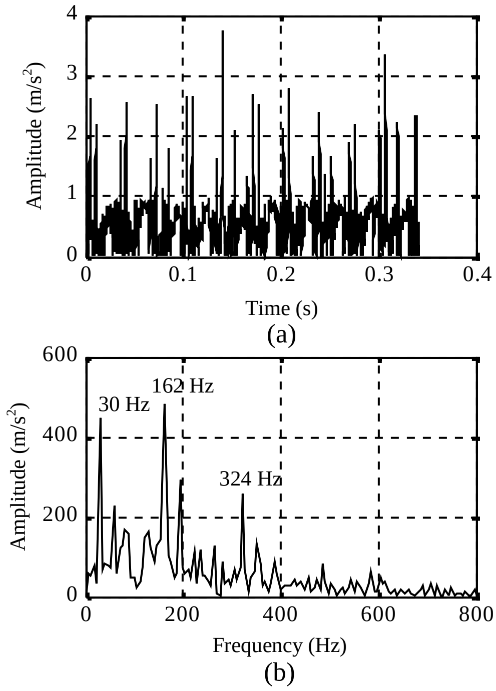


Fig. 4. (a) Envelope of inner race fault and (b) its spectrum.

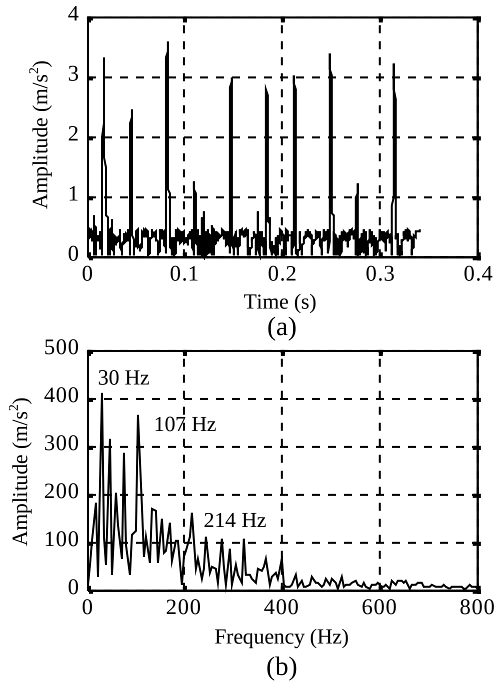


Fig. 5. (a) Envelope of outer race fault and (b) its spectrum.

The envelope method is robust to noise ratio; due to filtering around the resonance frequency. It is beneficial for the identification of the bearing faults. However, this method has its drawbacks: the preliminary research of the resonance frequencies is required. To extract the fault information, the wavelet transform will be applied to the vibration signals.

*D. Wavelet Transform*

WT is one of the most important methods in signal analysis. It is particularly suitable for non-stationary measures. WT is a time-frequency analysis technique. Due to its strong capability in time and frequency domain, it is applied recently by many researchers in rotating machinery [10], [11], [12].

WT is described below: let $s(t)$ be the original signal; the WT of $s(t)$ is defined as:

$$WT(a,b) = \left(1/\sqrt{a}\right)\int_{-\infty}^{+\infty} s(t)\,\psi^*\left(\left(t-b\right)/a\right)\,dt \tag{7}$$

where, $\psi^*(t)$ is the conjugate function of the mother wavelet $\psi(t)$ (8), $a$ and $b$ are the dilation (scaling) and translation (shift) parameters, respectively. The factor $1/\sqrt{a}$ is used to ensure energy preservation.

$$\psi(t) = \left(1/\sqrt{a}\right)\,\psi\,\left(\left(t-b/a\right)\right) \tag{8}$$

The mother wavelet must be compactly supported and satisfied with the admissibility condition:

$$\int_{-\infty}^{+\infty}\left(\left|\psi(w)\right|^2 / \left|w\right|\right) dw < \infty \tag{9}$$

The selection of the appropriate wavelet is very important in signals analysis. There are many functions available can be used such as Haar, Daubechies, Meyer, and Morlet functions [13].

In the present study, the identification of the bearing faults is possible by using the Morlet wavelet; it is also called continuous wavelet transform. It can be seen from Fig. 6 and 7 that the peaks at the rotation frequency of the shaft (30 Hz), also at the characteristic frequencies of the inner race fault and outer race fault and their multiples are present in the frequency spectrum.

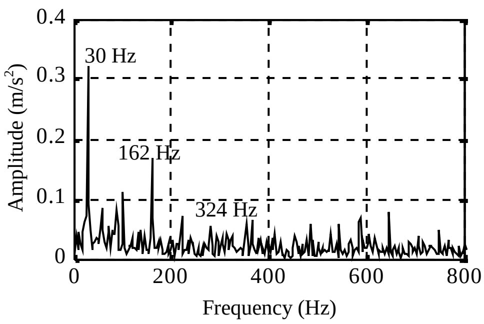


Fig. 6. Spectrum of inner race fault obtained with Morlet wavelet.

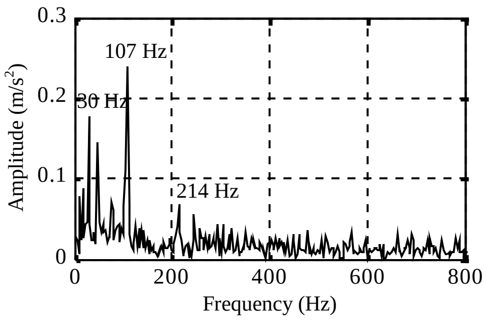


Fig. 7. Spectrum of outer race fault obtained with Morlet wavelet.

## IV. Conclusion

In this paper wavelet transform was presented in order to improve the faults diagnosis of rotating machinery. It was applied on real measurement signals collected from a vibration system containing bearing faults. Better results are obtained by identifying the type of fault. It remains to test its application on a signal containing other types of faults.

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