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# Extraction of Gearbox Fault Features from Vibration Signal Using Wavelet Transform

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**Abstract.** Vibration signals from a gearbox are usually noisy. As a result, it is difficult to find early symptoms of a potential failure in a gearbox. Wavelet Transform is a powerful tool to signals de-noising and disclose transient information down in nonstationary vibration signals. Combined with practice example, this paper shows the effectivity of the WT in two facets about signals de-noising and fault extraction.

## 1. Introduction

Vibration signals are often used for fault signals diagnosis in mechanical systems since they often carry dynamic information from mechanical elements. These mechanical signals normally consist of a combination of the fundamental frequency with a narrowband frequency component and the harmonics. Most of these are related to the revolutions of the rotating system since the energy of vibration is increased when a mechanical element is damaged or worn. Some of the conventional techniques used for fault signals diagnosis include power spectra in time domain or frequency domain, and they can provide an effective technique for machinery diagnosis provided that there is the assumption that the signals are stationary. However, the conventional methods are not always effective for application under certain critical conditions such as using a fixed sampling frequency for fast Fourier transform (FFT) analysis and rapid changes of the shaft speed. The Fast Fourier transform (FFT) represents a signals by a family of complex exponents with infinite time duration. FFT is useful in identifying harmonic signals. But, due to its constant time and frequency resolutions, it is less effective for analysis of transitory signals. Such as impulse signals which are short in time duration and usually hidden in noise. Wavelet transform overcomes the weakness, it has particular advantages for characterizing signals at different localization levels in time.

## 2. Continuous and Discrete Wavelet Transform technique

The wavelet transform is defined as the “resolution” of a signal into a set of basis functions called wavelets. It is a linear transform over the space  $L^2(R)$  (space of signals such that  $\int |f(t)|^2 dt < \infty$ ) that gives a time-resolved description for a large variety of signals.

Wavelet transforms are inner products between signals and the wavelet family, which are derived from the mother wavelet by dilation and translation.

Let  $\Psi(t)$  be the mother wavelet, the daughter wavelet will be:

$$\Psi_{ab}(t) = |a|^{-\frac{1}{2}} \Psi \left[ \frac{t-b}{a} \right] \quad b \in R, a \in R^*$$

where  $a$  is the scale parameter and  $b$  is the time translation. By varying the parameters  $a$  and  $b$ , we can obtain different daughter wavelets that constitute a wavelet family. Wavelet transform is to perform the following operation:

$$W(a, b) = \frac{1}{\sqrt{a}} \int x(t) \psi_{a,b}^*(t) dt$$

Where '\*' stands for complex conjugation. According to the original definition of wavelet transform, there is a universal reconstruction equation for any type of wavelet:

$$x(t) = C_{\psi}^{-1} \iint W(a, b) \psi_{a,b}(t) \frac{da}{a^2} db$$

where

$$C_{\psi} = \int_{-\infty}^{\infty} \frac{|\hat{\psi}(w)|^2}{|w|} dw < \infty$$

$$\hat{\psi}(w) = \int \psi(t) \exp(-j\omega t) dt$$

We attempt to discover feature signals by reconstructing the wavelet coefficients at selected scales or the wavelet coefficients shrunk through certain methods.

Discrete wavelet decomposed algorithm of the function  $f(t)$  is as follow:

$$f(t) = S_J f(t) + \sum_{j=1}^J D_j f(t)$$

Where

$$S_J f(t) = \sum_{k \in Z} c_{j,k} \phi_{l,k}(t)$$

$$D_j f(t) = \sum_{k \in Z} d_{j,k} \psi_{l,k}(t) \quad (1)$$

$S_J f(t)$  are called the low-frequency of the function  $f(t)$ ,  $\sum_{j=1}^J D_j f(t)$  are called the high-frequency of the

function  $f(t)$  under different resolutions. Where  $j$  is the scale parameter and  $k$  is the time translation,  $j = j_0, j_1, \dots, J$ ,  $k = 0, 1, \dots, 2^{j-1}$ . Based on Mallat fast algorithm, We can get the scale parameters  $\{c_{j,k}\}_{k \in Z}$  and wavelet coefficients  $\{d_{j,k}\}_{k \in Z}$  in Eqs. (1) by recursion algorithm. Process the wavelet coefficients for the different applications, such as signals compact, signals de-noising etc, then reconstruct the processed wavelet coefficients accuracy.

### 3. Signals de-noising using Wavelet Transform

Vibration signals are always used for mechanical fault diagnosis, because they carry the dynamic information of the machines. However, these vibration signals sampled on the spot often contain a lot of noise. If the noise is too heavy, the useful information will be corrupted such that the working state cannot be recognized or even wrong conclusions will be drawn. Therefore, elective methods for feature extraction from these noisy signals should be used.

A signals modal with noise can be looked as follow:

$$s(k) = f(k) + \varepsilon \cdot e(k), k = 0, 1, \dots, n-1.$$

Where,  $s(k)$  are called the original signals  $f(k)$  are called the useful signals,  $e(k)$  is the noise. Firstly, decomposed the signals with wavelets. Generally, noise is drawn in the high frequency range. Secondly, Process the decomposed wavelet coefficients in Eqs. (1) with the soft-threshold, That is to

say, set the coefficients whose absolute value is bigger than certain soft-threshold to zero, retain the coefficients surplus and reconstruct the signals with the processed coefficients. It's the course of signals de-noising. Essence of the signals de-noising is eliminate the invaluable part, comeback the valuable part of signals.

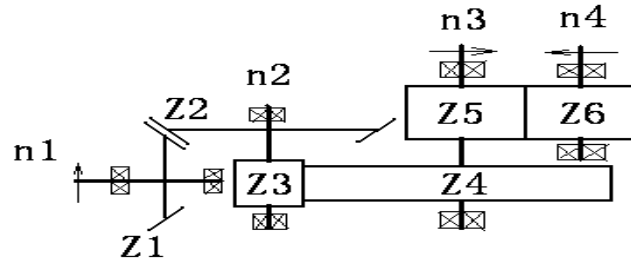


Figure 1. Structure graph representation of gearbox.

Structure graph representation of a gearbox is shown in Figure 1, As known, rotation frequency of shaft 1 is 9.2HZ and that of the shaft 2 is 4.8HZ, etc. Figure 2 is the original vibration signals of shaft 2, It describes the running condition about the rotating shaft. Figure 3 is the purified signals obtained by the de-noising based on symlet wavelets applied the wavelets de-noising theory. From Figure 2 and Figure 3, it can be seen that the de-noising method based on symlet wavelets is very effective for extracting features of the signals of gearbox. Although the impulse in the signals of gearbox are still unclear, it is become easier to tell the impulse than the original signals.

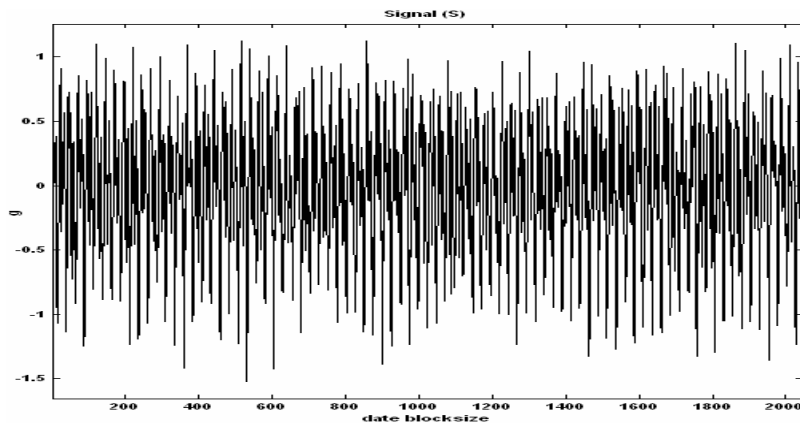


Figure 2. The original vibration signals of a gear box.

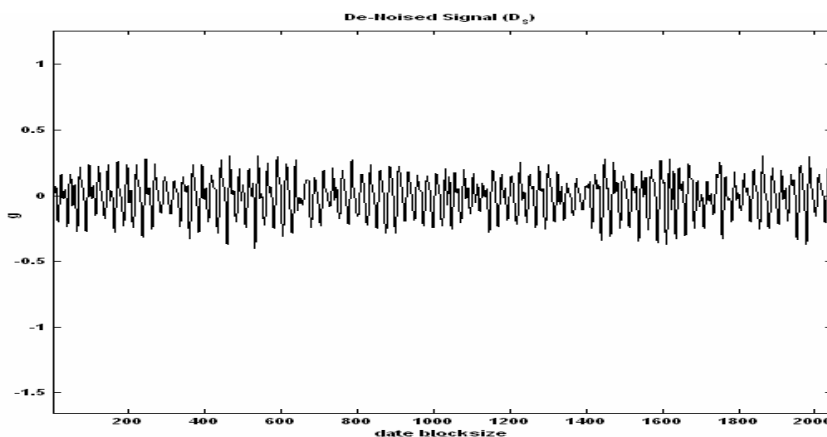


Figure 3. The purified signals obtained by the de-noising based on symlets wavelet.

#### 4. Example of the extracted features using Wavelet Transform

It is known that the signals date blocksize is 2048, Analysis frequency is 2000 Hz, Sample rate is 5120 samples/sec, Date Block Width is 0.4 seconds. Soft-threshold is set to 0.265.

Decomposed the de-noised signals with sym6 wavelet, Approximation of the first decomposition of the signals is shown in figure 4, It represents key features of the original signals.

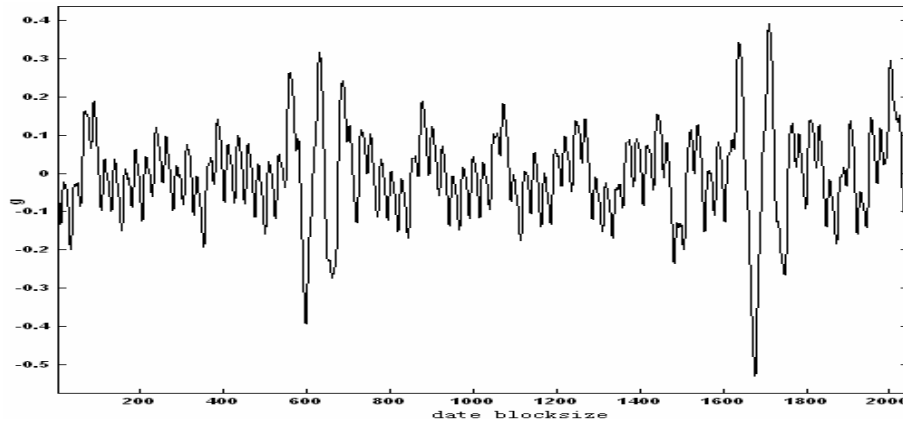


Figure 4. Approximation of the first decomposition.

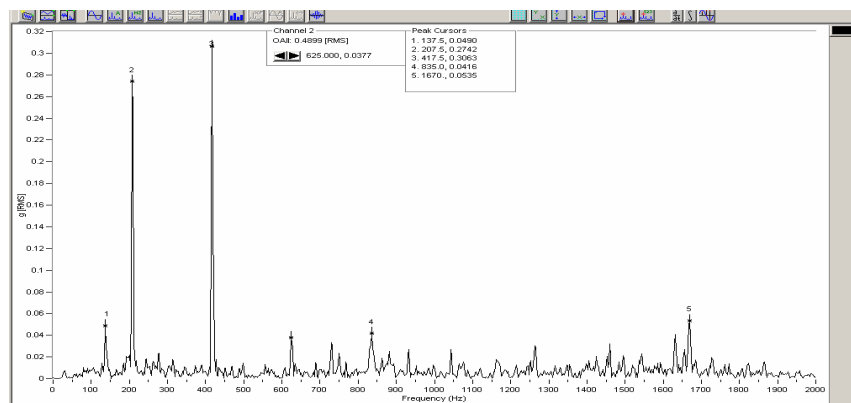


Figure 5. FFT of the signals.

Seen from Figure 4, there exist instantaneous impulse and periodic harmonic vibration signals in the original signals. The period is about 0.2 seconds (Date Block Width is 0.4 seconds), equal 5 Hz, which is the rotation frequency of shaft 2. It can be concluded that there could be some damage in gear Z2 on the shaft 2. FFT of the original signals is shown in Figure 5, it can't recognize the impulse. So Wavelet Transform is an effective method for extracting the instantaneous fault signals down in the nonstationary vibration signals.

#### 5. Conclusion

The results show that the effect of WT in locating the gear defects is superior to that of FFT. This phenomenon is primarily because WT exhibits excellent time resolution in the high frequency range at the compromise of poor frequency resolution in the high frequency range. It is known that high frequency resolution in high frequency range is of no practical advantage. Compared with the Figure 4 and Figure 5, the signals consist of multi-frequency harmonics and tiny abrupt changes, the accuracy in localizing the impulse by using WT is better than that by using FFT from the results. This property makes WT a powerful tool for accurately distinguishing short events that happen in the high frequency range. On the basis of the example, WT can successfully detect and locate the fault in the gearbox. This research properly verifies the effectiveness of WT in detecting gear failures and shows

that WT is a promising technique for gear condition monitoring. At present , WT was widely used in signals processing, image processing, pattern recognition, seismology, machine fault diagnosis, etc.

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