

Fault Diagnosis of Wind Turbine Gearbox Based on Wavelet Transform

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Abstract. As a kind of clean and renewable energy, wind energy is attracting more and more attention from all over the world. But the development of wind power is always hindered by the failure of downtime. The gearbox of wind power unit is one of the components with the highest failure rate in the whole wind turbine. Therefore, it is of great significance to study the fault diagnosis of gearbox in wind turbine. This paper first introduces the mathematical principle of wavelet analysis, and takes Matlab as an experimental platform to analyze and deal with the pitting fault data of a fan gearbox, and identifies the fault frequency by wavelet packet energy method, and diagnoses the type of failure. Finally, the experimental results are compared with other methods to deal with the data. Through the research in this paper, we can see that the data processing method based on wavelet analysis is simple and practical, especially in the engineering field represented by gearbox fault diagnosis.

1. Introduction

Under the trend of the whole wind power, the hidden dangers inherent in the wind turbine have always existed. The transmission system, represented by the gear box of the wind turbine, because of the remote working environment and the wide distribution range. Whether the fault feature can be effectively extracted is directly related to whether the gear fault can be accurately diagnosed, and in the actual data collection of gear vibration data, due to the complex industrial field environment, the information of the gear fault feature is often submerged by the noise in the signal, and even the useful fault information is suppressed^[1,2,3]. The fault diagnosis process of rolling bearing is generally divided into three parts: data acquisition, signal processing and feature extraction, and fault identification^[4,5]. The wavelet transform is a method that has been used in the development of the signal to the noise, and it provides a way to process a localized frequency in the process of self-adaptation, and by scaling the signal to the signal and using a multi-resolution analysis, it can effectively extract useful information from the original signal at different levels of decomposition, so that the signal's going to go out.

In this paper, the fault frequency is identified by the wavelet packet energy method and the type of fault is diagnosed. Finally, the experimental results are compared with other methods to deal with the data. And through the analysis of the experimental signal of the rolling bearing, the validity and feasibility of the proposed method is proved.



2. Research on wavelet transform and feature extraction

2.1. Wavelet transform theory

The basic idea of wavelet transform is to use a locally compact basic wavelet function to translate and expand different scales to form a wavelet function system to represent or approximate signals or functions. In theory, the wavelet transform can be divided into two kinds: continuous wavelet transform and discrete wavelet transform^[6]. Continuous wavelet transform is the usual wavelet transform, which is the same integral transformation as Fourier transformation. Unlike Fourier transformation, the time integration of functions is different. Continuous wavelet transform is projecting a function of time to a two-dimensional plane on time scale. The two parameters are called continuous wavelet transform coefficients, and their physical meaning is the scale and displacement of the wavelet transform

$$W_f(a, b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(t) \varphi\left(\frac{t-b}{a}\right) dt \quad (1)$$

the form, a is a scale factor (or scaling factor), and b is a translation factor. $W_f(a, b)$ is a continuous wavelet transform that $f(t)$ depends on the parameter a and b .

Continuous wavelet analysis is not used in engineering practice and is used for theoretical analysis and research. In practical applications, signals are analyzed and processed in order to facilitate the use of computers^[7]. The signal should be discretized into discrete sequence in advance, which is the discrete wavelet transform. The general assumption $a_0 > 1$, Then the corresponding discrete wavelet $\varphi_{j,k}(t)$ can be expressed as

$$\varphi_{j,k}(t) = a_{-j/2} \varphi(a_0^{-j} t - kb_0) \quad (2)$$

The coefficients of discrete wavelet transform can be expressed as

$$C_{j,k} = \int_{-\infty}^{+\infty} f(t) \varphi_{j,k}(t) dt \quad (3)$$

2.2. Study on feature extraction of wavelet transform

Industrial equipment is efficient, reliable and safe operation is the key guarantee to promote the development of national economy sustained, rapid, and the fault detection and feature recognition is safety equipment, maintenance system and stable operation of important technical means^[8]. With the development of high speed devices and systems, motors and intelligent, to the faults in the operation of system characteristic extraction and analysis become the focus of fault diagnosis, the typical representative for equipment fault signal of non-stationary dynamic signal research become the difficulty of signal processing. The distribution of signals in time domain and frequency domain is interrelated. After the frequency slice wavelet transform, the signals will contain redundant information like wavelet transform, so the reconstruction of original signals can take many different forms.

Frequency resolution η , time-frequency resolution factor σ , slicing function and other parameters are selected to carry out the frequency slice wavelet transform. Wavelet transform by frequency slice^[9].

$$W(t, \omega, \sigma) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \hat{x}(u) \hat{p}^* \left(\frac{u - \omega}{\sigma} \right) e^{j\omega t} dt \quad (4)$$

The time-frequency domain features of the signal are fully described, and the time domain resolution and frequency domain resolution are guaranteed to achieve their optimal values under Heisenberg principle. Rate reached their optimal value in Heisenberg principle; observation of time-frequency distribution, according to the need to select the target area, extraction and reconstruction of

signals, frequency slice interval $[t_1, t_2, f_1, f_2]$ obvious frequency slice wavelet inverse transform, The reconstructed signal is obtained. If the target area feature is not obvious, the region can be filtered again. The step can be repeated according to the actual situation of the signal until the feature of the target signal segment is obvious.

3. Wavelet analysis is used in fault diagnosis of gearbox

3.1. The wavelet noise reduction

A threshold denoising method based on wavelet transform is used to screen the coefficients of the wavelet transform domain. After wavelet transform, the amplitude of the wavelet coefficients of the noise signal is larger and the number is less, mainly concentrated in the low frequency, while the corresponding wavelet coefficients of noise are small, and the number is mainly concentrated in high frequency^[10]. By selecting appropriate thresholds at different scales, the wavelet coefficients are greater than the threshold, the useful signals are retained or processed accordingly, and finally the wavelet coefficients are reconstructed. Signal denoising is achieved.

The wavelet threshold denoising method is mainly divided into three steps: the first step: the wavelet decomposition of the noisy signal. The suitable wavelet is selected and the number of decomposition layers M is determined, and the denoised signal is decomposed by M layer wavelet. The second step: the threshold processing of the wavelet decomposition coefficient. The high frequency coefficient of the suitable layer is selected for threshold processing. The main methods are hard threshold method and soft threshold method. The third step is to reconstruct the wavelet coefficients and get the signal after the de-noising.

3.2. Signal envelope and Hilbert transform

Technology as a kind of high availability spectral envelope signal processing technology, can effectively resolve the problems in signal processing, and therefore is widely used in mechanical fault diagnosis, and other engineering fields. Envelope spectrum technology used in fault diagnosis: the basic principle of mechanical parts of local defects are often difficult to detect from outside, but in the machinery in the operation of these defects may cause structural impact, causing some periodic pulse. These impulses cause a mechanical component to resonate at one or more times. The amplification of resonance is used to extract these high impact frequencies by envelope spectroscopy. In this paper, the characteristics of fault signals in the background of strong noise interference are realized, and the purpose of fault diagnosis is realized^[11,12].

Taking into account the above issues, wavelet analysis has the characteristics of multi-scale analysis of signals, which can be combined with the two methods, namely, using wavelet transform to perform signal processing on multi-frequency scales, and applying envelope decomposition to each scale in wavelet analysis techniques. The signal was analyzed separately. This can effectively avoid the difficulty of accurately locating the resonant frequency band. After the analysis, the wavelet coefficients are used to reconstruct the original signal, thus the envelope spectrum analysis of the whole signal in the whole frequency domain is realized.

4. Analysis of wavelet analysis in gearbox fault diagnosis

4.1. Fault signals eliminate noise

Given at the time of data collection has not been a certain noise prevention measures or acquisition data of the working conditions of the unit itself is relatively good, no artificial de-noising, this experiment instead of directly using the raw data for processing.

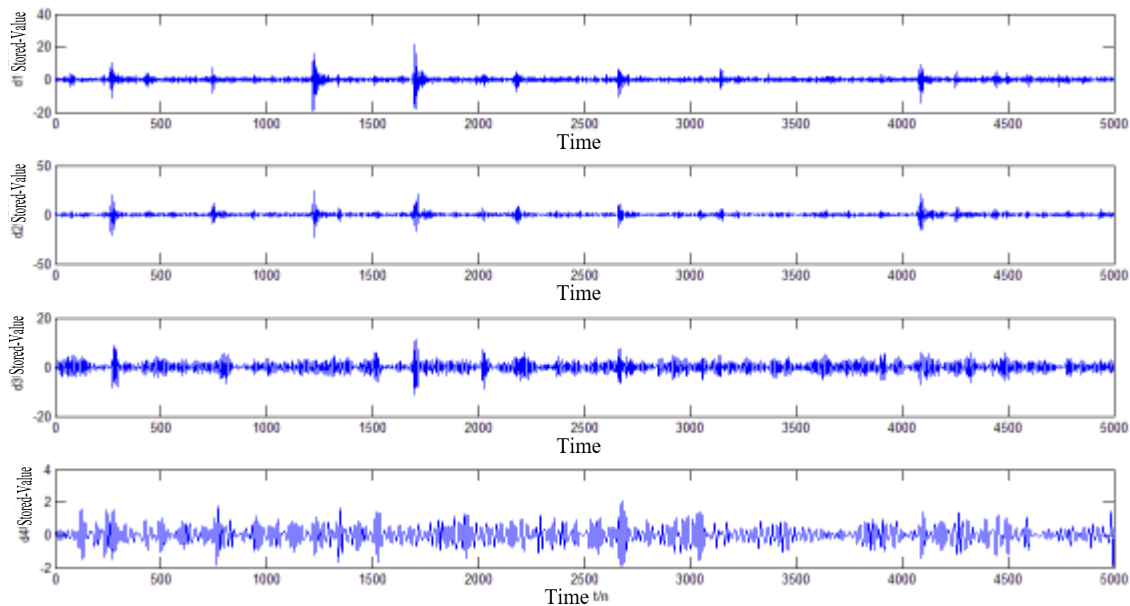


Figure 1. Point erosion data four layers of wavelet decomposition

It can be seen from the above image that the fault frequency of the cycle can already be seen in the signal of the fourth layer, but the frequency and judgment of the signal in the time domain cannot be compared, and the fault diagnosis function cannot be realized. Therefore, according to the wavelet packet energy method described previously, it is necessary to compare and judge the signal from the time domain to the frequency domain.

The specific method of judgment is to first use Hilbert transform and Fourier transform to complete the original signal of normal state and the original signal of fault state to the frequency domain. After obtaining the result, the two can be compared to get the possible fault frequency. Then see if these possible fault frequencies occur periodically in multiples of the fault spectrum. If such a frequency exists, the frequency is the fault characteristic frequency.

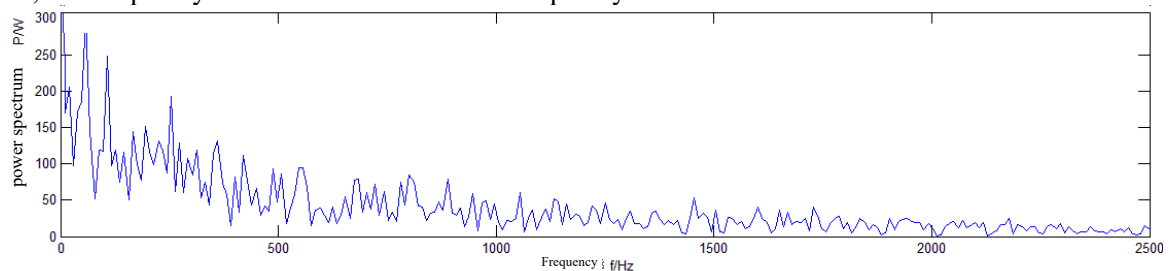


Figure2. Wavelet transform pitting fault data frequency spectrum

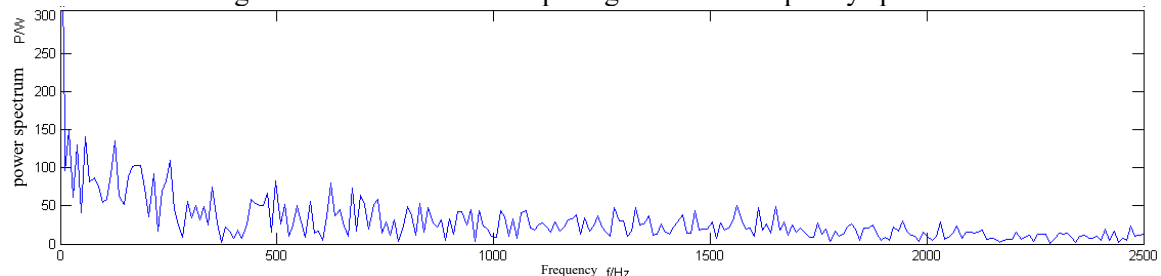


Figure3. Wavelet transform normal data frequency spectrum

By comparing the two images above, we can see several prominent failure frequency spectrum frequency signal in the normal image does not exist, of which 253.9 Hz is special, its multiple (507.8

Hz, 761.7 Hz, etc.) are in the back of the image, so can determine 253.9 Hz is the unit of gear box fault characteristic frequency.

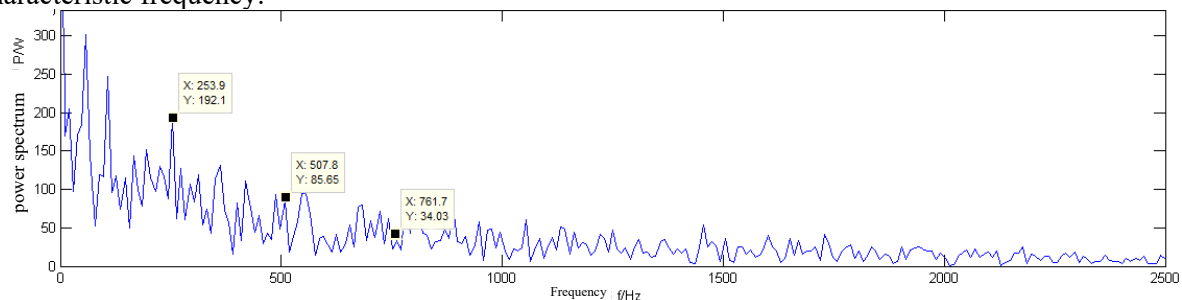


Figure4. The characteristic frequency of the fault of the wavelet transform

By pitting the wavelet transform fault characteristic frequency detail as you can see, we can accurately locate the fault characteristic frequency of 253.9 Hz, the pitting given with the data providers fault characteristic frequency (253.90 Hz) is consistent, can determine the fan gear a little bit of corrosion failure of gear box. At this point, the fault type of the fault unit was successfully diagnosed by wavelet analysis.

In order to contrast with the above experimental results, the same fault data and drawing method will be used to repeat the experiment, but the data analysis method is replaced by the pure classical Fourier transform.

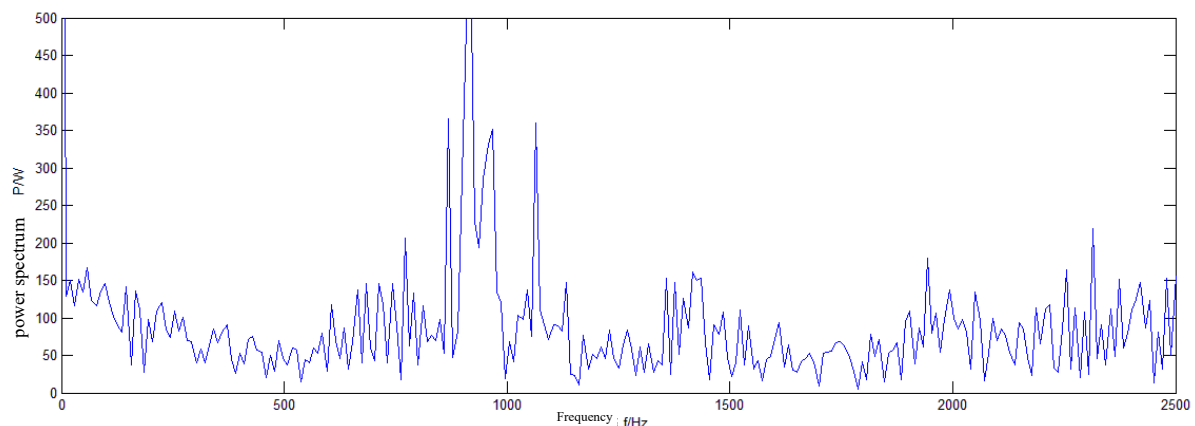


Figure 5. Fourier transform frequency spectrum

Image is obtained by experiment shows that by using Fourier transform to get the frequency spectrum of no law, comparing with normal signal cannot, so it is impossible to find out the fault characteristic frequency. Therefore, the simple Fourier transform cannot be used for fault signal processing.

By contrast can be seen above, the wavelet analysis in the field of fault detection and diagnosis has incomparable advantage by Fourier transform, wavelet analysis also demonstrated the applications in wind turbine gearbox fault detection is necessary. Through the wavelet analysis, the fault of the gearbox can be detected more timely and accurately and the fault can be dealt with in time. Reduce damage caused by failure.

5. conclusion

The gearbox of the wind turbine is one of the most important parts of the whole unit. It is responsible for the transmission and transmission of the main bearing of the fan to the generator. But its precise structure and the harsh environment of wind turbines also determine its high failure rate. In view of the traditional analysis methods such as Fourier analysis in local analysis and limitations in the field of signal de-noising, etc. this paper proposes a signal based on wavelet analysis method, and uses this method implements a simple fault diagnosis. The main research results and conclusions are as follows:

Several practical properties of wavelet analysis are discussed, and several mathematical analysis methods based on wavelet analysis are presented. According to these properties and methods, wavelet analysis is used in the field of fault diagnosis.

The common failure types of two parts of gear and rolling bearing in wind turbine gearbox are discussed, and the cause mechanism and possible consequences are analyzed. For these faults, several mathematical analysis methods and data processing methods based on wavelet analysis are proposed, such as wavelet denoising, signal envelope and wavelet packet energy method.

At the end of the paper, theory is paid to practice. Finally, the feasibility of signal processing method based on wavelet analysis is proved in the field of signal analysis and fault diagnosis. The comparison of experimental results with Fourier transform shows that the signal processing method based on wavelet analysis is superior to traditional signal processing method.

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