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AE Signal Processing for Propagating Crack of Wind Turbine Blade Based on Optimized Morlet Wavelet

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Abstract. Because the AE (Acoustic Emission, AE) characteristics of crack propagating of wind turbine blade is sudden and impactive, Shannon entropy is adopted to optimize the Morlet wavelet basis function by bandwidth parameters. Experimental results show that wavelet scale has relatively concentrated time-frequency characteristics when optimal bandwidth spectral parameter is 5.1. Compared with situation without optimization, it improves the noise interference phenomenon and be able to clearly show the impact characteristics of spectrum, which indicates that optimized wavelet scale is suitable for the extraction of the AE signal characteristic in wind turbine blade crack propagation.

Introduction

Wind power gets more and more attention from countries all over the world as a kind of clean renewable energy. Blades are key components in wind turbine for wind power. Under harsh natural environment and complex load, huge amount of cracks appears on the blade, which leads increasing wind turbine maintenance costs and downtime losses [1]. So the wind turbine blade damage monitor, which ensure the safety and reliability of wind turbine, is of great significance.

Due to the rapid regional release of energy, parts of blades would generate Acoustic Emission (Acoustic Emission, AE) signals. The AE signals contain important information about the characteristics of the acoustic emission source. Through the collection and analysis of AE signals, the generation and development situation of blade crack can be dynamically monitored[2]. But because of the complexity of the AE signal itself, extracting the characteristic parameters of AE source would be difficult. Wavelet analysis is an signal analysis method of time - frequency. It has the characteristics of multi-resolution analysis and the ability of denoting local signal characteristics in time-frequency domain. And most AE signals of composite materials are unsteady transient.The more traditional de-noising method is difficult to achieve the ideal effect. But by using wavelet,we can effectively remove the noise signal and ensure that edge leakage phenomenon will not occur [3].

With sudden and impact AE signal, this paper adopts the method of Shannon entropy to optimize the bandwidth parameter fb of Morlet wavelet basis function, then using the window function in wavelet transform and the characteristic component that AE signals of crack propagation extract have the largest similarity .This method also provides technical means for the AE signal feature extraction wind tutrbine blades composite crack propagation stage.

The Choice of Wavelet Basis Function

As the signal $x(t)$ with limited energe, its continuous wavelet transform can be represented as inner product of it with wavelet function. The analytical model is[4]:

$$W(a,b)=\langle x(t),\psi_{a,b}(t)\rangle=|a|^{-1/2}\int_{-\infty}^{+\infty}x(t)\psi^{*}\left(\frac{t-b}{a}\right)dt \tag{1}$$

In the equations, $a\neq 0$ is the scale factor, b is displacement factor, "*"is conjugate, $\psi_{a,b}(t)$ is the wavelet function of the formation of base wavelet $\psi(t)$ by scaling and translation. Eq.1 show that the wavelet coefficient $W(a,b)$ can measure the similarity of signal with the wavelet. And larger the $W(a,b)$ is more similar.

According to convolution properties of Fourier transform, Wavelet transform can also be expressed as [4]:

$$W(a,b)=\sqrt{a}F^{-1}\left\{X(f)\psi^{*}(af)\right\} \tag{2}$$

In the equations, $X(f)$ is Fourier transform of $x(t)$ and $\psi^{*}(f)$ is Fourier transform of $\psi^{*}(t)$, F^{-1} is Fourier inverse transformation.

In the wavelet analysis, the most crucial role for the results of the analysis is the selection of wavelet generating function. In order to achieve a more precise approximation, we determine wavelet generating function according to different signals and processing purpose. Morlet wavelet is one of the most commonly used wavelets in the continuous wavelet transform. Morlet wavelet is defined as [5]:

$$\psi(t)=e^{-t^{2}/2}e^{j\Omega t} \tag{3}$$

The result of the Fourier transform is [5]:

$$\Psi(\Omega)=\sqrt{2\pi}e^{-(\Omega-\Omega_{0})^{2}/2} \tag{4}$$

By Eq.4 the mother wavelet is a single frequency sine function within gaussian envelope. Then, in view of the wind turbine blade fatigue crack acoustic emission signal,we should choose the corresponding mother wavelet analysis. The selection of mother wavelet spectrum are also crucial for wavelet scale results Due to the acoustic emission signal in the frequency domain with similar to the shape of the gaussian window function.So the Morlet wavelet base can be adapted to acoustic emission signals were collected and extract the signal feature better, So the paper uses the Morlet wavelet as mother wavelet.

Optimization of Wavelet Transform

Morlet wavelet is a negative exponential function under the Gauss envelope and can be expressed as follows:

$$\psi(t)=\frac{1}{\sqrt{f_{\mathrm{b}}\pi}}\exp\left(-t^{2}/f_{\mathrm{b}}\right)\exp\left(i2\pi f_{\mathrm{c}}t\right) \tag{5}$$

So Fourier transform can be expressed as:

$$\psi(af)=\exp\left(-\pi^{2}f_{b}\left(af-f_{c}\right)^{2}\right) \tag{6}$$

The f_b of Eq.5 and Eq.6 is to control the bandwidth parameters of the shape of wavelet base and balance Time frequency resolution of wavelet and determines the speed of the wave oscillation attenuation. f_c is the center frequency(the constant)which determines the frequency of the wavelet. If the parameters f_c is constant, the shape of the Morlet wavelet is controlled by the bandwidth parameter f_b, Therefore, if the f_b is optimized in a certain range, it can be obtained the most suitable wavelet basis function waveform.

In this paper, we use the method of Shannon entropy to optimize the bandwidth parameters of Morlet wavelet basis functions f_b. Shannon entropy is the "information entropy", which has solved the problem of quantitative measurement of the information. In probability space by the definition of probability given the amount of information, the definition of all transmission and processing of information communication system has a common applicability, so this definition is very successful.

The size of entropy reflects the uniform probability distribution, the probability distribution is not uniform with maximum entropy[3]. But Shannon entropy is a statistic, so Shannon entropy is described in a large number of events in the collection regularity. In the optimization process of wavelet base function, Firstly, the wavelet coefficients are processed into a probability distribution sequence p_i:

$$p_i = \frac{|W_x(a_i, t)|}{\sum_{j=1}^{M} |W_x(a_j, t)|} \tag{7}$$

Eq.7 calculated the entropy that sparse degree of this group of wavelet coefficient matrix, $W_x(a,t)$ is the value of wavelet coefficient, M is wavelet coefficients of different scales. By calculating the entropy called Shannon wavelet entropy, defined as:

$$H(p) = -\sum_{i=1}^{n} p_i \log p_i \text{ ,and } \sum_{i=1}^{n} p_i = 1 \tag{8}$$

When the value of Shannon wavelet entropy is minimum, the parameters of wavelet basis function constitute the wavelet basis matching the ingredient of signal characteristic. Hence, when the f_b changes in a certain range and the value of f_b makes the H(p) minimum, the bandwidth parameter of Morlet wavelet is optimized.

Signal Processing Results and Analysis

In the wind turbine blade root is a crack,the crack propagation behavior is induced by the excitation device. When the blade is subjected to the excitation device, the acoustic emission signal of the crack propagation is collected at the moment of the blade root leading edge, as shown in Figure 1.

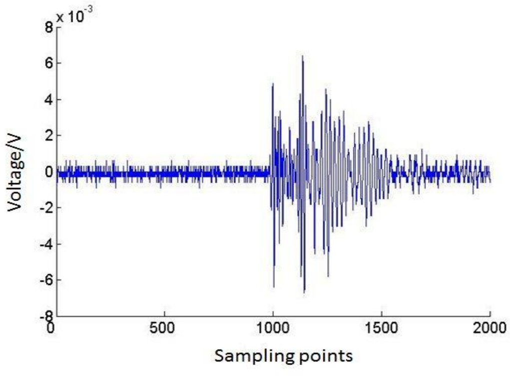


Figure 1. The AE signal of the experiment.

From Figure 1 it is obvious that the impact component can be clearly seen, and the AE signal in the time domain is always mixed with all kinds of noise signals. To make f_c=1, the relationship between the Shannon entropy and the bandwidth parameters is obtained by using the optimized wavelet scaling method, as shown in Figure 2.

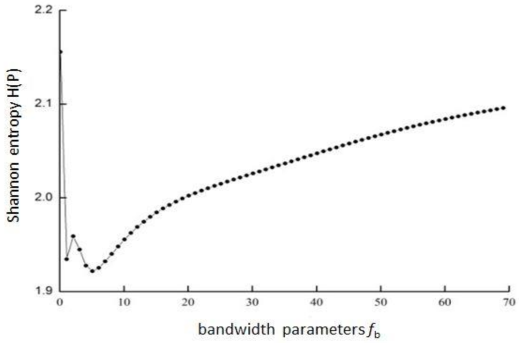
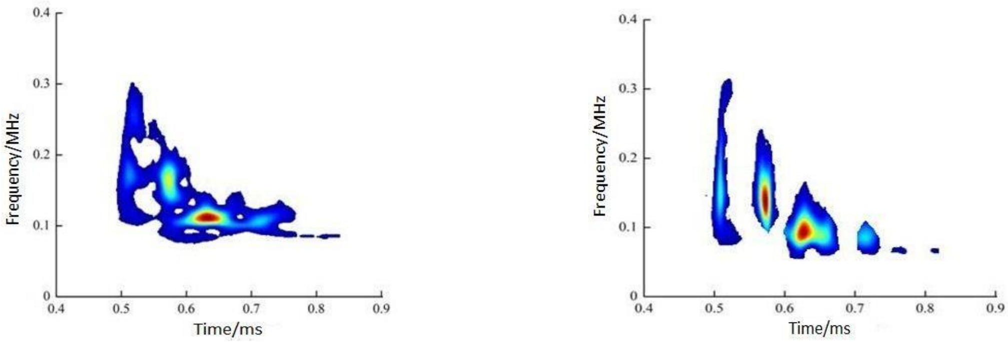


Figure 2. Relationship curve of Shannon entropy and bandwidth parameter.

By the previous paper, when the Shannon wavelet entropy of the corresponding mother wavelet is the most matched with the characteristics of the wavelet. So the wavelet entropy is the f_b minimum of the shape parameter of the Morlet wavelet. In Figure 2, it can be concluded when the f_b =5.1 has a minimum of wavelet entropy, the Morlet basis function is obtained to calculate the wavelet scale and weight distribution of the acoustic emission signal of the crack. Bring f_b and f_c =1 were brought into the Eq.5. Morlet wavelet base function of AE signal is obtained. The processing results of the extended crack AE signal are shown in Figure.3. In Figure 3(a) is a No optimization wavelet scale, (b) is the optimized wavelet scale



(a) Wavelet scale spectrum (b) Optimized wavelet scale spectrum

Figure 3. AE signal processing.

From Figure 3(a), Interference in the excitation device and crack is very small in the experimental blade, the wavelet scale spectrum of the blade crack is disturbed by the noise. In Figure 3(b), he optimal bandwidth parameter （f_b=5.1） of the wavelet scale spectrum have a relatively concentrated time frequency characteristic. Compared with Figure 3(a),The phenomenon of the noise interference has been improved, and some of the high frequency impulse characteristics of the signal can be clearly demonstrated. So the optimized wavelet scale spectrum can suppress the noise interference in the AE signal, and show the impact characteristics in the mean time.

Conclusions

The wavelet scale spectrum has a high time frequency clustering and the characteristics of the suppression of noise immunity, which can effectively eliminate the noise disturbance, and provide an effective method to accurately reflect the time frequency characteristics of the wind turbine blade crack AE signal. The optimized wavelet scale spectrum can effectively identify the state of the wind turbine blade and the high frequency components of the AE signal.

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