A Research of Wind Turbine Blade Delamination Detection
Technology Based on the Acoustic Impact

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Abstract
In this paper, a new method to detect delaminated defects through the analysis on the echo of wind turbine blade is studied. When delaminates appeared, the stiffness of defects was decreased and the duration of tap stress was increased. Based on this principle, the suitable quality of hammer is calculated and the structure is designed by using piezoelectric film as the dynamic impact sensors. Portable testing instrument is manufactured with FPGA, which can extract and process tap signal, calculate the width of stress pulse, and graphical display and communication. It is shown by the results of experience that the method can be used to size up the depth of delaminate based on the relationship between the depth and pulse width.

Key words: power plant, wind turbine blade, delaminates, acoustic impact, non-destructive testing

1. Introduction

In the wind power equipment, the blades are a core component of the wind turbine[1]. Fabric folds, dry fiber cloth, bubble, lack of bonding glue and other defects often appeared in the production and operation of blades. According to the analysis of the current running conditions of wind turbine, bonding cracking problems occur more frequently. As the important structure of wind turbines, blade is not allowed to break, delaminate and other quality problems in the 20-year term of service. Thus early detection of defects and damages through effective means is very important[2]. Compared to conventional composite materials, the detection method of wind turbine blades is more difficult due to the structural characteristics themselves. The basic shape of the blade is cambered, detection methods commonly used composite materials do not apply. For the operation of the wind turbine blades in the tens of meters of altitude, greatly increasing the difficulty of detection. Scholars have conducted research on non-destructive testing method for detecting composite material at laboratory and abroad. Sundaresan put forward an intelligent blade, the piezoelectric film sensor system was embedded in the blade in the production process of the blade. The system can continuously monitor the state of the blade, notice damage and provide the pressure acting on the blade[3]. Pitchford monitored the structure with the use of piezoelectric ceramics to identify the damage of the blade. Experimental data showed that the method is a reliable method for damage identification[4]. R.Raisutis reviewed some NDT techniques for wind turbine blades,
such as vibration analysis, thermography, X-ray images, acoustic emission, and ultrasonic[5]. Chia Chen Ciang make a complete overview about dozens of blades monitoring methods, including acoustic emission, thermal imaging, ultrasound, optical fiber and so on[6]. Currently various types of detection technology is still in the research stage, the detection system for the characteristics of the blade itself is not mature. In this paper, according to the material properties and shape features of wind turbine blade, a system through the analysis on the echo to detect delaminated defects is applied.

Striking blade surface using a small hard object, the status of the blade will affect the sound characteristics [7]. This method does not require coupling agent, simple operation, and suitable for field detection. In recent years, the development of electronic technology makes it possible to detect by intelligent percussion. Through tapping the blade, the instrument analysis characteristics of the stress signal in hammer to determine the health status of the blade. This method can avoid the misjudgment by lack of experience and environmental interference.

2. Principles of Acoustic Impact

\[ mx'' = mg - k(\lambda_s + x) \]  

(1)

Where \( k \) is spring stiffness, \( m \) is weight, \( x \) is displacement, \( \lambda_s \) is the static deformation of the spring under the weight of the object. Under static equilibrium, equation 2 can be obtained.

\[ mg = k\lambda_s \]  

(2)

According to equation 1, we can get the natural vibration differential equation of the systems

\[ mx'''' + kx = 0 \]  

(3)

\[ \omega_n = \frac{k}{\sqrt{m}} \]  

(4)
Equation 3 can be written as

\[ x'' + \omega_n^2 x = 0 \]  

(5)

The general solution is

\[ x = c_1 \cos \omega_n t + c_2 \sin \omega_n t \]  

(6)

Where \( c_1 \), \( c_2 \) are constant.

Equation 6 is the solution of the system's inherent vibration, system in the absence of external influence movements are simple harmonic motion, and the vibration frequency is

\[ f_n = \frac{\omega_n}{2\pi} = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \]  

(7)

Natural period is

\[ T = 2\pi \sqrt{\frac{m}{k}} \]  

(8)

After the percussion hammer rebound immediately, impact duration can be expressed as

\[ \tau = \frac{T}{2} = \pi \sqrt{\frac{m}{k}} \]  

(9)

Blades contain layered is similar to have spring in it (Figure 2).

![Figure 2: The delaminated blade model](image)

Where \( k_d \) is the coefficient of elasticity, \( k_c \) is the coefficient of contact when hammer tapping the structure. When the blade is delaminated, the equivalent elastic coefficient

\[ k = \frac{k_d k_c}{k_d + k_c} < k_c \]

and \( k \) decreased and impact duration increased.

3. Detection System Design
Detection system is designed based on the characteristic of duration when hammer tap the object, which includes tap hammer, detection circuit, FPGA, LCD monitor and computer (Figure 3).

![Detection system diagram](image)

**Figure 3: Detection system**

By tap the blade to get the stress signal to detect tap hammer. The function of the detecting circuit is impedance matching, scaling up or down, polarity adjustment and converting the analog signal to a digital signal which can be processed by FPGA. FPGA module analysis the signal which obtained by detection circuit, calculate the duration of the signal, and show the results on the LCD or upload.

### 3.1 Tap Hammer Design

Tap hammer struck on the specimens directly, size of the force, application point and the mode will directly impact the force signal and the voice signal, so select the appropriate hammer is particularly important. Figure 4 show the 3D effect design of the hammer.

![3D hammer design](image)

**Figure 4: The 3D effect design of the hammer**

Hammer head 2 contacts with the blade directly, its stiffness must greater than the stiffness of the blade to ensure that the signal can resonate with blades. When the hammer struck, hammer head 2 transmitted the striking force to hammer head 1. In order to avoid a measurement error due to the resonance of hammer head 1, the stiffness of hammer 2 need to less than the stiffness of hammer 1.

### 3.2 Detecting Circuit Design

The signal obtained by the sensor is negative voltage signal, and contain the aftermath of oscillation, so it is need to have a detecting circuit before the signal enter FPGA. Detecting circuit contains signal conditioning modules (Figure 5) and voltage comparing modules (Figure 6).

The output impedance of the sensor is $10M\Omega$, and the output voltage is negative. Voltage amplitude is 4-10V when struck. First, we use the impedance matching circuit and the polarity
inversion circuit to reduce the voltage. Then the signal changed into positive polarity voltage signal, and the output impedance reduced, contained the aftermath of oscillation. Second, after a single voltage supplied follower and a blocking capacitor we can have stable single-pulse voltage signal. The last, we use a phase and output impedance adjustment circuit to limit the voltage to 5V for voltage comparing module.

![Signal Conditioning Module](image)

**Figure 5: Signal Conditioning Module**

We use hysteresis comparator circuit in the voltage comparing module, which can avoid the influence of interference signals. In this circuit, threshold voltages are 1.8V and 0.6V, the output voltages are 3V and 0.25V, which can enter the FPGA directly to measure.

![voltage comparing module](image)

**Figure 6: voltage comparing module**

When the tap hammer tapped the blade, the sensor in the hammer output the stress signal, and then shaped by conditioning circuits and voltage comparing circuit. The waveform shaping process is shown in Figure 7.
4. Experimental Analysis

In the experiment, we use the specimens cut from blades, there are three kinds of delaminated region with different size and depth, which is shown in Table 1. Use the hammer tap the blade, and compare the duration of tap stress. We tap 5 times at each points, experimental data is shown in Table 2.

![Diagram](Image)

Figure 7: The Waveform shaping Process

<table>
<thead>
<tr>
<th>Table 1: The Size of Delaminated Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness of blade (mm)</td>
</tr>
<tr>
<td>Delaminating 1</td>
</tr>
<tr>
<td>Delaminating 2</td>
</tr>
<tr>
<td>Delaminating 3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: The Duration of Tap Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (us)</td>
</tr>
<tr>
<td>Blades with no delaminating</td>
</tr>
<tr>
<td>Delaminating 1</td>
</tr>
<tr>
<td>Delaminating 2</td>
</tr>
<tr>
<td>Delaminating 3</td>
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</tbody>
</table>

Through the above experimental data, we have the following conclusions:

1. When the difference of the size of delaminating is not obvious, the distance from blade surface to delaminating will affect the duration directly.

2. It is shown by the results from delaminating 1 and 2 that when the distance from blade surface to delaminating less than 1/2 the thickness of the blade, we can judge the delaminating by the measured data directly.

3. It is shown by the results from delaminating 3 that when the distance from blade surface...
to delaminating is 2/3 of the thickness of the blade, the characteristic is not obvious.

(4) The standard deviation of sample data has little difference, which shown that the detection system has certain stability. In practical applications, we can detect the delaminating of the blade by striking.

5. Conclusions

In this paper, the principles of delaminate detection method is analyzed in detail. Based on the duration of the stress signal and the structural properties of the wind turbine blades we chose the piezoelectric film sensor and designed the tap hammer and detection circuit. The detection system is developed based on FPGA. The system can identify defects under the surface of wind turbine blade and clearly judge the position of the delaminating when the distance from blade surface to delaminating less than 1/2 the thickness of the blade. This system can be easily applied on the scene.

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References