The application of ultrasonic phased array technology in wind turbine blade defect detection system

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Abstract. Start The working environment of wind turbines is complex and harsh. If the early damage of blades is not found in time, it may develop into mechanical failure under bad working conditions. Once an accident occurs, the consequences will be serious. In this paper, we study the non-destructive testing of ultrasonic phased array technique in the application of wind turbine blade defect detection, and analysis all kinds of common defects of blade production stage. According to these defects, the corresponding test device is selected, and the fault library is accumulated through defect test blocks. The original data of blade ultrasonic detection were identified, compared and finally the defect type was determined.

1. Introduction
Blades are one of the core components of wind turbine. The design of reasonable and reliable blades is the key factor for safe, stable and efficient operation of wind turbine. The blade is a complex thin shell structure made of fiberglass reinforced composite material, generally composed of leading edge, trailing edge, web, and beam, as shown in Figure 1. There may be various types of defects on the blades in the field before hoisting. For example, during the production and manufacturing process, due to poor impregnation of resin and fiber, insufficient resin content, incomplete air crowding, foreign matter mixed in the processing process, resulting in glass fiber lamination, whitening, viscosity air cavitations, inclusion and other defects [1]. During the transportation and installation, external and internal damage to the blade are caused by external forces. Blade quality has a great relationship with the safe, stable and efficient operation of the wind turbine. If the blades of low quality or unqualified are put into operation, in the light case, the generating efficiency of the turbine will be low and the operating performance of the turbine will be affected; in the heavy case, the blades may be broken and cause major safety accidents. Therefore, it is necessary to inspect and detect the blades before hoisting.

At present, the more mature and practical means of blade detection are macroscopic inspection of blade surface by means of high-light flashlight, vernier caliper, contour ruler and other tools. Although macro inspection can detect blade quality to a certain extent, it has the following disadvantages: (1) low detection efficiency and high artificial labor intensity; (2) Internal defects of the blade cannot be detected; (3) Excessive reliance on the experience of personnel. Due to the above deficiencies in macro inspection, some new methods and means of blade detection are also developing vigorously. The main nondestructive detection methods for wind turbine blades include acoustic emission detection technology, vibration detection technology, optical fiber sensing detection technology and ultrasonic phased array detection technology, and so on [2, 3]. Among them, ultrasonic phased array...
detection method has been applied in wind turbine blade detection [4]. Mainly focused on the inspection of the adhesion of the blade main beam, and achieved good results. However, no significant breakthrough has been made in the delamination, cavitation, inclusion and other common defects of blade skin and web. It is mainly reflected in the inadequacy of the detectability of the device, and the reflection wave’s interpretation, the recognition aspect also has the certain degree blank.

In view of the above problems, this paper studies the non-destructive testing technology based on ultrasonic phased array to detect the blade defects of wind turbine, and analyzes the causes and mechanisms of various common defects occurring in the blade production stage. According to these defects, the corresponding test device is selected, and the fault library is accumulated through defect test blocks. The original data of blade ultrasonic detection were identified, compared and finally the defect type was determined.

2. Ultrasonic phased array detection technology

In recent years, ultrasonic phased array technology has attracted more and more attention due to its flexible beam deflection and focusing performance [5]. Due to the comprehensive application of piezoelectric composites, nanosecond pulse signal control, data processing and analysis, software technology and computer simulation in the field of ultrasonic phased array imaging. It makes the ultrasonic phased array detection technology develop rapidly. It is gradually applied in industrial nondestructive testing, including power plant, petrochemical, ship, aerospace, industrial on-line, boiler and pressure vessel, long distance pipeline, etc. At present, phased array technology is only widely used in the west-east gas transmission project in China, and it is also used in some sectors such as aviation system and nuclear industry system [6].

2.1. Principle of ultrasonic phased array detection

Ultrasonic phased array detection technology is a detection method to locate and measure the position, size and other relevant information of the target medium by measuring the energy, wavelength and frequency of the reflected wave and combining the difference of the acoustic impedance of the medium on both sides of the interface based on the propagation characteristics of ultrasonic waves excited at the interface of different acoustic impedance media. The working principle is shown in Figure 2 [7].

![Figure 2. Working principle of ultrasonic phased array.](image-url)
At launch, the detector sends the trigger signal to a phased array controller, which converts the signal into a specific high-voltage electrical pulse. Each chip receives only one electrical pulse, and the resulting ultrasonic beam is angled and focused to a certain depth. When the beam encounters a defect, it bounces back. After receiving the echo signal, the phased array controller transforms the time according to the receiving focusing law, and gathers such signals together to form a pulse signal, which is transmitted to the flaw detector for analysis and obtains the corresponding information.

2.2. Technical difficulties of ultrasonic phased array blade detection
The existing wind power blades are mainly made of glass fiber composite materials, some are carbon fiber composite materials, and some are intersticed with foam, wood and other structures [8]. Take the most commonly used glass fiber composite material as an example. The production process is to lay the layers of glass fiber cloth together and use resin as the binder between the fiber cloth to make it a whole.

UT, PT, MT and RT, the most commonly used conventional detection methods in NDT, have different degrees of limitations in wind turbine blade detection [9].
1) Wind turbine blades are large in size, usually 40-60 meters long, which requires an efficient detection method. In this way, if RT is used, the hoisting time and cost will be huge.
2) Wind power blades are non-metallic materials; MT cannot be carried out here.
3) Defects such as wind turbine blade detection, internal stratification, and disbonding are the main factors affecting its life. Therefore, surface detection methods such as PT are limited in use, and RT is extremely insensitive to such defects.
4) The penetrability of the glass fiber structure to UT is very poor. It requires very low frequency probe to penetrate the workpiece and detect internal defects.
5) For the workpiece with foam or wood interlayer, its penetrability will be worse, so some special methods are needed for detection.
6) Blade structure of each manufacturer is different, so it is difficult to use a single technology to detect all positions and structures.

2.3. Ultrasonic phased array blade detection test scheme
For producer of wind turbine blade, blade parts of delamination, air-pocket, less glue, bad glue is common defects. In the case of uniform blade surface coating, glass fiber layer, main beam layer, adhesive layer and web structure, in which the ultrasonic wave propagates, the reflection wave sign is not obvious. If the medium is discontinuous, such as air cavitation and too narrow adhesive layer between web and main beam, reflection waves with obvious characteristics will be excited at the interface. Therefore, ultrasonic phased array technology can be used to detect the nature and size of such defects.

Ultrasonic phased array detection is a common method to detect and evaluate the quality of composite materials. The test of ultrasonic phased array flaw detection was carried out on the field blades. For different test sites and different blade structures, test blocks with artificial defects were
made, and different probes were selected for testing on the blocks to ensure that ideal test results could be obtained on the blocks. Finally, the test was carried out on real workpiece to verify the test effect.

In the preliminary test, the main detection object is the fiberglass and carbon fiber composite material, and the foam and plank structure area is not considered. The main defect types and parts are shown in Figure 3, that is, the various defects inside the composite body and the adhesion between the composite skin and the internal support beam.

The equipment used is OmniScan SX ultrasonic flaw detector + phased array probe. The required configuration is shown in Figure 4.

At present, the application of blade detection based on ultrasonic phased array is only for the detection of the bonding surface of the main blade beam, and various defects in key parts such as blade root, maximum chord strength, blade tip, skin and web have not been carried out. In this paper, according to the failure mechanism characteristics of wind turbine blades, standard samples were made for different defects in key parts of the blades, and test specimens (Figure 5) were prepared to provide research samples for the study of ultrasonic phased array detection technology.

According to various defect characteristics of the test blocks, ultrasonic probes and test hosts with different configurations are selected to test each block. According to the testing principle of ultrasonic phased array, the influence of scanning mode on defect recognition was studied, and corresponding characteristic quantities were extracted to characterize all kinds of defects.

Among them, the parameters of the signal crystal element and the host unit of the detector should be determined and selected according to the main calculation formula of phased array sound field parameters. The main parameter calculation formulas are as follows:

1. Diffusion Angle formula: $\sin \theta = 0.5 \ast \lambda / A$;
2. Near field distance formula: $N = A^2 / (4 \ast \lambda)$;
3. Beam diameter formula: $d = \lambda \ast Z / A$;
(4) Focusing coefficient formula: \( K = F/N \).

In the above formula, \( \theta \) is the diffusion angle, \( \lambda \) is the wavelength, \( A \) is the excitation aperture, \( N \) is the near field distance, \( d \) is the beam diameter, \( K \) is the focusing coefficient, and \( F \) is the focusing distance.

3. Analysis of field test results

In order to verify the feasibility of the blade defect detection method for wind turbine based on ultrasonic phased array technology, the researchers conducted ultrasonic phased array flaw detection for three field blades in a wind farm in Yunnan province in June 2019. The OminiScan instrument was used to detect the real blades in the field in Figure 6 below. It can be seen from the C-scan image in Figure 7 that all layers can be recorded with a single scan.

![Figure 6. Real blade detection.](image1)

![Figure 7. Real blade C-scan image.](image2)

3.1. Detection contents and methods

Blade detection is mainly carried out around important load-bearing parts and important accessory parts, mainly including, leaf blade girder web, front and back edge of blade and hub, counterweight box, etc., check whether there is a hierarchical, air bubble, drape, pale, dry fiber, core material clearance is too large, crack width, viscose glue, glue and surface flow hanging burrs, surface defects such as bubbles.

In order to identify the internal and external defects of the blades more comprehensively, the researchers used ultrasonic phased array detection technology combined with macroscopic examination to detect the blades in the field. Through detection, defects of the three blades were found to varying degrees. Among them, the field detection scanning results of #3 blades are shown in Table 1 and Figure 8.

| Serial number | Defect types                          | Defect location          | Defect description       |
|---------------|---------------------------------------|--------------------------|--------------------------|
| 1             | The lower part of the windward face of the skin lacks glue | About 18m from the blade root | About 33 mm length       |
| 2             | Air pocket on windward surface of front web | About 23.2m from the blade root | At many points           |
| 3             | Glass fiber inside front web damaged   | About 2m from the blade root | The length of about 100 mm |
| 4             | Air pocket on windward surface of front web | About 23.8m from the blade root | At many points           |
The lower part of the windward face of the skin lacked glue.  
Glass fiber inside front web damaged  
Air pocket on windward surface of front web (about 23.2m from blade root)  
Air pocket on windward surface of front web (about 23.8m from blade root)

**Figure 8.** #3 Blade field test results.

The field blades were detected by means of field macro inspection and ultrasonic phased array inspection, etc. The detected blades had the following defects:

1. #1 blade has 9 defects, such as delamination of the glass fiber in the back web, bubble in the front reinforcing cloth, and white of the glass fiber in the front web, which must be treated.
2. #2 blade has 8 defects, such as insufficient adhesive width on the windward side of the front web, burr, and damaged glass fiber on the leeward side of the skin, which must be treated.
3. #3 blade has 7 defects such as air cavitation on the windward side of the front web and lack of glue on the lower windward side of the skin, which must be treated.

Due to the limited working conditions on site, the tests carried out do not cover all parts, regions and projects. Generally speaking, the quality of the tested blades has some problems to some extent, some of which are serious and need to be dealt with. It is suggested to timely repair the relevant defects of the inspected blades according to the issued test report, and follow up and detect the blades in the field later.

### 4. Analysis of field test results

In this paper, according to the failure mechanism characteristics of wind turbine blades, standard samples were made for different defects in key parts of the blades. Through tests on different specimens, corresponding characteristic quantities were extracted to characterize all kinds of defects. Used to extract the defect features, Ultrasonic phased array blade defect detection was carried out in a wind farm in Yunnan province. Through the detection, we found a variety of defects in the blade and the problem that the manufacturer's quality control is not in place. The feasibility and applicability of the wind turbine blade defect detection method based on ultrasonic phased array technology proposed in this paper are verified. The test report issued can provide a strong technical basis for the subsequent acceptance of blades on the site and defect repair.
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