Simulation Verification of Phased Array Ultrasonic Detection Scheme for Wind Turbine Main Shaft in Service

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Abstract. The main shaft is the key link in the wind turbine drive. Based on the previous scheme design of phased array ultrasonic testing of wind turbine and the results of transducer parameter range determined, simulation verification is carried out in this study. It is verified that the preliminary theoretical design scheme can effectively detect the early defects of the main shaft shoulder position of the wind turbine, which lays a good foundation for the field implementation in the future.

1. Introduction

In recent years, the renewable energy industry represented by wind power has attracted much attention and developed rapidly[1-3]. However, the safety detection in the operation of wind power equipment lags behind to some extent. At present, there are many problems such as single detection mean, weak detection content and project operability[4]. In view of the above problems, phased array ultrasonic detection scheme and transducer parameter range of the wind turbine main shaft are determined after preliminary study, and the feasibility of the scheme is determined theoretically. However, simulation verification and implementation are still needed. This research carries out follow-up research on the above two aspects.

2. Simulation of phased array ultrasonic testing

SimuPA2 software is used to simulate probe parameter selection, acoustic beam coverage, acoustic field distribution and imaginary defect coverage of phased array ultrasonic detection scheme involved, and the scheme is verified.

2.1. Flange end face detection

2.1.1. Probe parameters. Considering the high cost of phased array probe customization, combining with the design of theoretical scheme, the existing probe sequence 2L64-A2 of phased array manufacturer is preferred for preliminary screening, and its parameters are shown in Table 1 below.

| Parameter type                  | Value    |
|---------------------------------|----------|
| Element number                  | 64       |
| Element size (length×width)/mm  | 12×0.65  |
| Center frequency/MHz            | 2        |
| Element spacing/mm              | 0.1      |
2.1.2. **Wedge parameters.** SA2-0L 2L64 zero wedge for use in combination, and its parameters are shown in Table 2 below.

| Parameter type                        | Value                  |
|---------------------------------------|------------------------|
| Wedge size (length × width × height)  | 65 × 12 × 20           |
| Angle/degree                          | 0                      |
| Position of the first chip /mm        | Y = 8.9 mm, Z = 20 mm   |
| Longitudinal wave sound velocity (m/s)| 2700                   |
| Shear wave sound velocity (m/s)       | 1100                   |

2.1.3. **Acoustic beam coverage simulation.** The detection is based on the primary wave, and the sound velocity of coupling medium is 1480 m/s. 32 elements are selected for simultaneous excitation. The angle range is ±15 degrees, and the angle step is 1 degree, and the depth of focus is set at 300 mm according to the theoretical design. The acoustic beam coverage of different views is shown in Figure 1 below.

![Acoustic beam coverage diagram](image)

Figure 1. The acoustic beam coverage diagram of all views with flange end face detection.

When the probe position with maximum scan angle range, namely toroidal surface close to the boundary location Φ 440 mm, as shown in Figure 2. It can be seen from the figure that, at this maximum angle, the acoustic beam can cover the study position. Combined with circular manual sawtooth scanning, it is proved that other positions can cover the study position on this detection surface.
2.1.4. Sound field simulation. The distribution of axial and off-axis acoustic fields of phased array ultrasound detection is simulated, as shown in Figure 3 below. It can be seen from the figure that the ultrasonic sound field has the most concentrated energy and the highest sound pressure level at the focal position of 300mm, and the off-axis energy is well controlled, indicating that its directivity and focusing characteristics are good and meet the design expectations.

2.1.5. Hypothetical defect coverage simulation. According to the study location and defect type characteristics, cuboid model is used to replace the defect for acoustic beam coverage verification, as shown in Figure 4 below. It can be seen that cuboid defects can reflect sound beam to a large extent, which can be speculated to have a good detection effect. It should be noted that, the orientation of defects is not certain in fact. According to relevant literature[5], the main shaft characteristics of actual defects such as early cracks tend to develop at a small angle towards to the Y-axis, which is basically consistent with the simulation. Selecting circular manual sawtooth scan and phased array sector scan can expand a certain angle range, and the detection effect of defects can be guaranteed.
2.2. Shaft surface detection

2.2.1. Probe parameters. According to the theoretical analysis, it is more appropriate to select a probe with lower frequency and larger aperture for larger shaft thickness. However, considering the actual use scenario, if multiple probes are used for the detection of the same object, it may involve the replacement of the detection host, which is bound to greatly increase the detection cost. On the other hand, the defect orientation tends to the Y-axis, which is more parallel to the acoustic beam detected by the secondary shear wave on the bearing surface, and the defect detection rate is low. Therefore, this detection sequence is more of an assistant to the flange end face detection sequence. Considering the above factors, 2L64-A2 type phased array probe is still selected as the detection probe.

2.2.2. Wedge parameters. SA2-N45S 2L64 wedge for use in combination, and its parameters are shown in Table 3 below.

| Parameter type                              | Value               |
|---------------------------------------------|---------------------|
| Wedge size (length×width×height)/mm        | 76.7×30×37.5        |
| Angle/degree                                | 31                  |
| Position of the first chip /mm              | Y=2.3mm, Z=7.0mm    |
| Longitudinal wave sound velocity/(m/s)      | 2700                |
| Shear wave sound velocity/(m/s)             | 1100                |

2.2.3. Acoustic beam coverage simulation. The detection is dominated by secondary waves, and the sound velocity of coupling medium is 1480m/s. Select the mode of simultaneous excitation of 32 arrays, the angle range is 30 to 60 degree, the angle step is 0.5 degrees, and the depth of focus is set at 480mm according to the theoretical design. The probe position is adjacent to the variable section of the axial body. It can be seen from Figure 5 that the sound beam can better cover the research position with the above parameters at this detection position. (Note: Sound beam automatically defaults at the contact position of the curved surface, which can actually be overridden)
2.2.4. **Sound field simulation.** It can be seen from Figure 6 that after the angular deflection of the sound field through the wedge, the energy concentration Angle also deflects, mainly focusing on the central position of the 45 degree sound beam. Meanwhile, the off-axis energy is well controlled (the sound beam Angle is upward in the right figure), which meets the design expectation.

2.2.5. **Hypothetical defect coverage simulation.** The 90 degree cuboid model is also used to replace the defect for sound field coverage verification, as shown in Figure 7 below. It can be seen from the figure that the cuboid defects can better reflect sound beam, which can be speculated to have a better detection effect. But at the same time, it can be seen that the reflection area of the defective acoustic beam is significantly less than that of the flange end face detection, which confirms that the detection sequence can only be used as an auxiliary means again.
3. Conclusion
By simulating and verifying the phased array ultrasonic detection scheme, the following conclusions can be drawn:

(1) The process scheme with the vertical wave detection on the flange end as the main and the shear wave detection on the shaft surface as the auxiliary has the best detection effect;

(2) 2L64-A2 phased array probe is selected for detection, and met the requirements after simulation verification.

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References
[1] Christoph, B., Gerda, D., Sebastian, B., Christoph, Z.(2020)The future need for flexibility and the impact of fluctuating renewable power generation. Renewable Energy, 149.
[2] Poul, A., Neven, D., Younes, N., Hrvoje, M., Soteris, K.(2020)Sustainable development using renewable energy technology. Renewable Energy, 146.
[3] Will, G., Andrew, M., Mark, B., Ryan, W., Nikita, G.S., Erik, E, Eric, O’S(2020)Motivations and options for deploying hybrid generator-plus-battery projects within the bulk power system. The Electricity Journal, 5:33.
[4] Cao, H.(2018)Research on ultrasonic Testing Technology of Fan Spindle in service. Large Casting and Forging Parts, 01:48-49.
[5] Zeng, C.(2011)Modeling research and Application of Wind turbine Spindle System Structure Analysis. Chongqing University.