Application of Ultrasonic Phased Array Detection Technology in Steam Turbine Components

ZHANG Xuechao¹, YUN Feng¹, LV Lei¹, FENG Tong²

¹Inner Mongolia Electric Power Science&Research Institute Huhhot, China
²Dalate Power Plant Northern United Power Co., Ltd. line 3: City, Country Dalate, China
azhangxuechao@impc.com.cn
azxcheat@qq.com

Abstract—Ultrasonic phased array detection technology has the characteristics of fast, high sensitivity and recordable. The application of ultrasonic phased array detection technology to diaphragm, rotor, bolt and other turbine metal parts can effectively improve the detection rate of micro defects. At the same time, the development of reliable detection process can avoid the limitations of its detection and ensure the safety and reliability of turbine metal equipment.

1. INTRODUCTION

In recent years, with the rapid development of the national power industry, the construction of large capacity and high parameter generating units is the current development trend. The improvement of operation parameters has higher requirements for the safety of the metal parts of the unit, so it is very important to do a good job in the supervision of the metal parts. DLT / 438-2016 code for technical supervision of metals in thermal power plants. For the metal equipment of steam turbines, it mainly includes steam turbine rotors, impellers, blades, roots, diaphragms, diaphragm sleeves, high-temperature fastening bolts, etc. Strict metal supervision is conducive to timely detection of defects in the manufacturing, installation, welding, operation and other processes.

With the increase of the installed capacity of 660 MW and 1000 MW thermal power units, the wall thickness, material grade and detection difficulty of the supervised parts of steam turbine gradually increase. Especially in recent years, the turbine equipment accidents caused by the severe lack of penetration, lack of fusion defects and the fracture of high-grade material bolts have serious consequences [1]. In addition, with the accumulation of the service time of a batch of 300MW units, the aging of the supervised equipment of steam turbine, and the initial micro cracks of high-temperature fastening bolts was formed. They need high-sensitivity detection technology to intervene to improve the defect elimination rate and the influence of technical supervision.

As a new non-destructive testing method, ultrasonic phased array technology has been widely used in various industries with its superior testing ability. By controlling the synthesis, deflection and focusing changes of ultrasonic beam, it can scan complex structure workpieces and thick workpieces, effectively solving the problems of poor accessibility and limited testing space existing in traditional ultrasonic testing[2]. Through software, it can optimize the control the focus depth, focus size and beam direction of the acoustic beam significantly, to improve the resolution, sensitivity, signal-to-noise ratio and other performance during detection. The defect detection sensitivity is high, which can make qualitative and quantitative analysis of defects more intuitive. The probe of phased array technology is
array probe, whose size is small, combined with the advantages of multi angle scanning, so the detection speed is improved by moving less or even not moving the probe. The graphical display interface can display the test results in the form of A, B, C, S scanning, and special software can be used to conduct complex analysis on the test data.

At the same time, there have been some researches on the application of phased array technology in the detection of turbine metal equipment in thermal power plants [3,4]. The application of phased array technology in the detection of turbine metal equipment is of great significance to ensure the safety of turbine equipment.

2. APPLICATION OF ULTRASONIC PHASED ARRAY TECHNOLOGY IN DIAPHRAGM DETECTION

At present, the inspection of diaphragm is mainly aimed at welded diaphragm. Welded diaphragm is to weld the two ends of the stationary blade between the diaphragm body and the outer edge of the diaphragm, which also forms the outer and inner ring welds. There are two common types of diaphragms [5]: type I and type II, which are respectively applied to high-pressure stage and low-pressure stage diaphragms, and their structural schematic diagram is shown in Figure 1 and Figure 2. The main welding seam of diaphragm adopts narrow gap welding or electron beam welding in the welding process. The width of groove is small, the penetration is deep, and the welding is difficult. After forming, there are a lot of welding defects such as lack of fusion, which leads to serious shortage of strength and rigidity.

![Figure 1. Structural diagram of the type I diaphragm](image1)

![Figure 2. Structural diagram of the type II diaphragm](image2)

For the type I diaphragm, because the outer ring structure is relatively straight, the straight probe can be used to scan the detection surface to cover the whole weld detection area, and 5L64-1.0×10-B93 or 5L128-0.8×12-SD11 linear array probe can be selected. Because the scanning area is relatively large, a large probe with a large number of probe array elements is required, and for the 64 element probe, SA2-N55S wedge block can be equipped. However, because of the outer ring, the wedge block with a certain curvature can be selected with a 0° surface wedge.
For the inspection of inner ring weld, the angle probe is used to scan the B and C inspection surfaces. The 5L32-0.5×10-D2 probe with SD3-N55S wedge can be selected.

For the type II diaphragm, the outer ring structure is relatively complex. The upper area of the outer ring weld can be scanned with straight probe, while the lower area can only be scanned with angle probe and straight probe to meet the scanning coverage; the inner ring weld also needs to be scanned with angle probe on the C and D scanning surfaces.

Sometimes, due to the structural form of the diaphragm, the location of bolt holes, shape geometry and other reasons, there will be a certain detection blind area, as shown in Figure 3. In the actual operation process, it is necessary to adjust the probe collocation and position to meet the scanning coverage as much as possible according to the actual situation.

According to the existing research [6], when the groove angle is greater than 7.5°, the signal of large area of incomplete fusion defect is equivalent to that of Φ4mm flat bottom hole. At this time, if the detection sensitivity is set as Φ4mm flat bottom hole, the defect may not be found. Therefore, the Φ2mm cross-hole can be used as the detection sensitivity.

3. APPLICATION OF ULTRASONIC PHASED ARRAY TECHNOLOGY IN ROTOR FLANGE DETECTION
The flange structure widely used in the low-pressure rotor of steam turbine of thermal power unit is the external bacteria type and the axial loaded fir tree type, as shown in Figure 3. For the above two types of flange structure, the stress is the largest at the position where the flange engages with the blade root, and the corrosion crack is also produced by stress corrosion at this position [7].
At the same time, there are many limitations in the detection of turbine rotor flange: the space is narrow, which is not conducive to the movement of operators and scanning devices; the detection surface is small, and the probe is lack of moving space; the structure is complex, and the qualitative and quantitative echo is lack of reliability. This kind of problem can be overcome by using phased array detection technology.

5L64-A2 longitudinal wave probe with 36° wedge is selected and placed on the surface of turbine impeller disc for sector scanning. The deflection angle of beam is 30° ~ 70°, which can realize the detection of the stress concentration on the flange.

**Figure 4.** Common flange structure of low pressure rotor

4. **APPLICATION OF ULTRASONIC PHASED ARRAY TECHNOLOGY IN HIGH TEMPERATURE FASTENING BOLT DETECTION**

Fracture of the bolt is a serious threat to the safe operation of the turbine equipment. According to the statistics of the existing cases, there are very few cases of bolt fracture caused by corrosion, wear, manufacturing defects, etc. And about 90% of the articles on bolt failure analysis are fatigue failure [8]. Moreover, cracking often occurs at the root of the first three threads. In the process of conventional ultrasonic testing of bolts, it is found that the structural wave and deformation wave caused by the complex structure of the thread will cover up the defect wave generated by the micro cracks, and the beam sometimes can not cover the root of the thread when the longitudinal wave probe is tested from the end. The application of ultrasonic phased array detection technology can effectively improve the sensitivity of bolt inspection.
The 5L16-0.5×10 probe with longitudinal wave and small angle is used to scan from the end, and the same side thread can be detected. Because the spread range of the beam increases with the increase of the propagation distance, the detection of the long-distance position is avoided, and the insufficient sensitivity or interference of other structure echo is prevented. For the long bolts of the turbine cylinder block, the threads on the both side can be detected from same ends. When there is a central hole in the bolt, the probe can be moved manually to conduct a circular scanning to ensure the coverage of the threads in all directions, and if it is necessary to scan the rod, the angle probe with a wedge with curvature is required.

Using ultrasonic phased array detection technology to detect the root crack of bolt thread has a high sensitivity, and it is easy to distinguish the defect echo or the structure echo.

5. SUMMARY
The application of ultrasonic phased array technology in the detection of turbine metal equipment, such as diaphragm, rotor, bolt, etc., has been relatively mature. At present, the research in this direction is also gradually in-depth. Various probes and scanning devices for different parts and different structural forms have been developed, and corresponding processes have also been formulated. It is very important to make full use of the advantages of ultrasonic phased array technology, such as convenient, high sensitivity and good reliability to ensure the safe operation of steam turbine equipment.

ACKNOWLEDGMENT
The authors would like to acknowledge the financial support from 2019 Self Prepared Science and Technology Projects (first batch) of Inner Mongolia Electric Power Science & Research Institute (Grant No. 510241190009)

REFERENCES
[1] Gu Y, Xu J, Chen D, et al. Overall review of peak shaving for coal-fired power units in China[J]. Renewable and Sustainable Energy Reviews, 2016, 54: 723-731.
[2] Gao J, Wang K, Sun J. Study on the technology of ultrasonic imaging detection based on phased array[J]. International Journal of Signal Processing, Image Processing and Pattern Recognition, 2013, 6(5): 71-78.
[3] Lamarre A. Improved Inspection of Composite Wind Turbine Blades with Accessible Advanced Ultrasonic Phased Array Technology[C]/15th Asia Pacific Conference for Non-Destructive Testing (APCNDT2017), Singapore. 2017: 1-8.
[4] Yang X, Chen S, Jin S, et al. Crack orientation and depth estimation in a low-pressure turbine disc using a phased array ultrasonic transducer and an artificial neural network[J]. Sensors, 2013, 13(9): 12375-12391.
[5] Shulzenko N G, Asaenok A V, Zaitsev B F, et al. Creep analysis of steam turbine welded diaphragm[J]. Strength of Materials, 2012, 44(4): 419-428.
[6] Zhou L, Fu M, Xu W. Research on Phased Array Ultrasonic Testing for the Girth Weld of 4mm~10mm Austenitic Stainless Steel Pipeline[C]/ASME 2018 Pressure Vessels and Piping Conference. American Society of Mechanical Engineers Digital Collection, 2018.
[7] Burton Z, Ingram G L, Hogg S. A literature review of low pressure steam turbine exhaust hood and diffuser studies[J]. Journal of Engineering for Gas Turbines and Power, 2013, 135(6).
[8] Chen J, He R, Kang X, et al. Simulation and experiment for the inspection of stainless steel bolts in servicing using an ultrasonic phased array[J]. Nondestructive Testing and Evaluation, 2015, 30(4): 373-386.