Comparative experimental study on phased array and X-ray detection of small diameter pipe weld

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Abstract: According to the principle of ultrasonic phased array technology, the phased array inspection technology for butt weld of small-diameter pipe is developed. The ultrasonic phased array and ray inspection tests are carried out on the sample pipe of small-diameter tube with typical specification of heating surface in Inner Mongolia thermal power plant, and the evaluation results obtained by the two inspection methods are compared and analyzed. It can be seen from the comparison of testing results that ultrasonic phased array testing has more advantages than X-ray testing in defect detection rate and defect parameter measurement. At the same time, ultrasonic phased array testing also has the advantages of environmental protection, intuitiveness and high testing efficiency.

1. Introduction

The small diameter tube of heating surface in power plant boiler is a metal part which is easy to fail. The small diameter tube of heating surface is in high temperature and high pressure environment during operation, and its working condition is relatively bad, which is prone to high temperature creep, fatigue, corrosion and wear. The defects continue to expand during operation, which will lead to serious tube explosion and leakage accidents. The problem of tube leakage on heating surface is very concerned in the operation and maintenance of utility boilers. According to the statistics of metal technical supervision of power plant boilers in 2019, the leakage of "four tubes of boiler" accounts for more than 60% of the failures of metal parts, so the failure of boiler heating surface is the primary cause of unplanned shutdown of power plant boilers. Therefore, it is particularly important to evaluate the safety condition of small diameter tubes on the heating surface of utility boilers through an efficient and accurate nondestructive testing method.

Due to the thin wall and small diameter of the small diameter tube on the heating surface of the utility boiler, the range is generally Φ 32 ~ Φ 89mm in outer diameter and 4mm ~ 14mm in wall thickness. In the past, the circular butt joint of small caliber thin-walled pipe was generally tested by radiography. There are obvious limitations in radiography: the interval between two adjacent heating surface tube rows is small, so it is impossible to realize multiple transillumination, and the detection blind area is large; because of small diameter tube, large wall thickness, and large transillumination thickness ratio, the effective evaluation range of radiographic negative image is small; at the same time, the radiographic detection radiation has safety and environmental protection problems, which will occupy the construction period; the radiographic negative can only show the defects Surface projection cannot detect the buried depth and height of defects, and has the inherent weakness of low
detection rate of surface defects. When conventional ultrasonic (A-type pulse ultrasonic) testing is used for this kind of weld, the wall thickness of small diameter pipe is thin and the curvature is large, and the ultrasonic wave is easy to be distorted and converted during testing, which makes it difficult to identify and judge the acoustic signal; the reliability of testing results largely depends on the operator's experience level and sense of responsibility; the testing results are lack of objective records and poor traceability, which is not enough to ensure the quality of testing. Therefore, to explore the feasibility and accuracy of ultrasonic phased array detection method for small pipe weld of heating surface is helpful to the safe and stable operation of power plant boiler.

Ultrasonic phased array technology has the characteristics of multi-angle scanning, unique focusing characteristics and a variety of imaging methods, which can effectively detect various surface and volume defects in welded joints. The results of the test are displayed in image form, which provides abundant information for defect location, quantification and rating quality. It is a recordable nondestructive testing method. Ultrasonic phased array testing technology has the incomparable advantages of radiographic testing. To develop a reasonable and effective testing process can effectively improve the detection efficiency and defect detection rate. In this paper, small diameter tube samples with different types of typical defects and different material specifications are selected, and the ultrasonic phased array and X-ray testing tests are carried out for each sample tube, and the different evaluation results obtained by the two testing methods are compared and analyzed, which makes an exploratory study on the process adaptability and defect detection reliability of using ultrasonic phased array technology to detect small diameter tube butt joints.

2. Radiographic inspection of butt weld of small diameter pipe

According to the installation of boiler heating surface tubes in thermal power plants in Mengxi area, representative samples of artificial defects in butt welds of small diameter tubes with different specifications were made. The outer diameter of the sample tube is Φ 42mm ~ Φ 51mm, the wall thickness is 4mm ~ 11mm, and the material is 20g. There are 21 samples in 4 specifications. The sample tubes are numbered according to SY1-SY21. There are various kinds of typical welding defects in the weld of sample steel pipe. The groove type of the sample steel pipe is V-shape, and the welding method is smawh and GTAW.

According to the standard <NB/T 47013.2-2015>, the double wall double shadow oblique transillumination ellipse imaging was performed on 21 small diameter tube samples. The exposure was 10-15 MA.min, the focal length F was 600 mm, and the film density was 2.5-4.0.

Fig.1 MAPT-25 X-ray equipment
After the completion of radiographic testing, the defects of negative films are evaluated. The radiographic testing results and quality evaluation of some typical defects are shown in Table 1.

Table 1 Results of ray examination

| Sample  | Specifications/mm | Defect type               | The number of defects | Defect size/mm | Quality rating |
|---------|-------------------|--------------------------|-----------------------|----------------|----------------|
| SY1     | $\Phi51\times4$   | Incomplete Fusion        | 1                     | 15             | IV             |
| SY3     | $\Phi51\times4$   | Incomplete penetration   | 1                     | 6              | II             |
| SY15    | $\Phi51\times6$   | Incomplete Fusion, Group stomata | 3                         | 15, $\Phi3\times3$, $\Phi1\timesN$     | IV             |
| SY17    | $\Phi45\times8$   | crackle, Circular defect | 3                     | 5, $\Phi2\times1$, $\Phi1\times1$     | IV             |
| SY21    | $\Phi42\times11$  | Circular defect          | 1                     | $\Phi3\times1$   | IV             |

3. Phased array testing of butt weld of small diameter pipe

The phascan portable phased array ultrasonic detector of doppele company is used in this test. The equipment has a variety of imaging modes such as A-scan, B-scan, C-scan and s-scan, and has a variety of focusing modes, which can realize the rapid scanning and imaging of workpiece.

Before testing, the system sensitivity of ultrasonic phased array needs to be calibrated with csk-1a standard test block. Phased array calibration settings include sound velocity calibration, focusing law delay calibration, sensitivity calibration and TCG (time gain correction) calibration. The standard test block is GS-1 for small diameter pipe inspection specified in Nb / T 47013.3

In order to ensure that the sound beam can cover the weld as much as possible in the sector scanning, the primary reflection wave is used to detect the root of the weld, and the secondary reflection wave is used to detect the upper part of the weld, so as to achieve the complete sound beam coverage of the small-diameter pipe weld and heat affected zone. The step offset value should be set correctly according to the weld width and weld height. In the scanning inspection, the weld size parameters should be set according to the actual measurement or construction drawing size, and the reasonable scanning range should be set to show the coverage of the acoustic beam in the weld section and different angles.

Fig.2 Phascan Portable phased array ultrasonic testing system

Take $\Phi 42 \times 8.5$mm as an example, the thickness of pipe wall is 8.5mm, the weld width is 10mm, the groove is V-shaped, the surface surplus is 1.5mm, the groove clearance is 2mm, the initial angle of fan scanning is 40°, the end angle is 70°, and the angle is stepped in 1DEG. When the front edge of probe is 3mm away from the weld edge, 100% detection of the weld and heat affected zone can be
realized, so the step angle is set to be -10 mm. According to the above process parameters and relevant standards, 21 butt joints of sample pipes are scanned along one side and two sides of ultrasonic phased array. See the table 2 below for some typical defect sample pipe detection results.

Table 2 Ultrasonic phased array test results of some typical defect sample tubes

| Sample  | Specifications/mm | Defect number | Defect type                  | Starting position | length/mm | Burial depth/mm | heigh t/mm | Quality rating |
|---------|-------------------|---------------|------------------------------|-------------------|-----------|----------------|-----------|----------------|
| SY1     | Φ51×4             | 1             | Incomplete Fusion            | 127               | 19        | 2.1            | 1.8       | III            |
| SY3     | Φ51×4             | 1             | Incomplete penetration       | 80                | 15        | 1.9            | 1.9       | III            |
| SY15    | Φ51×6             | 1             | Incomplete Fusion            | 28                | 21        | 1.6            | 4.4       | III            |
|         |                   | 2             | Group stomata                | 111               | 24        | 1.4            | 4.6       |                |
|         |                   | 1             | crackle                      | 22                | 9         | 4.2            | 1.9       |                |
| SY17    | Φ45×8             | 2             | Circular defect              | 72                | 4         | 3.2            | 3.9       | III            |
|         |                   | 3             | Circular defect              | 79                | 3         | 3.7            | 2.8       |                |
|         |                   | 1             | Incomplete Fusion            | 54                | 6.0       | 3.9            | 2.5       |                |
| SY21    | Φ42×11            | 2             | Circular defect              | 110               | 5.0       | 3.9            | 2.5       | III            |

4. Comparative analysis of test results

From the above test data, it can be seen that the ultrasonic phased array can detect the buried depth and the defect proportion of the weld seam, while the radiograph can only show the plane projection of the defect, and the buried depth and the proportion of the defects cannot be obtained; however, in the aspect of defect character discrimination, the ray detection is more intuitive than the ultrasonic phased array detection. For the determination of the defect position in the weld, the ultrasonic phased array is more accurate than the ray detection. Because of the blind area in the direction of 3:00 and 9o'clock, the fusion defects of sy21 sample tube were not detected. The length of the non fusion defect is 6mm, which is not allowed in the requirements of the regulations. If the defect is missed, it will directly lead to the wrong quality assessment of the weld. Take sy21 tube as an example, and the specification is Φ 42 × 11 sample pipe. In order to eliminate the blind area of detection, when the small diameter tube adopts inclined illumination, when t/d0 ≤ 0.12, it should be separated from 120° or 60° for three times.

Crack defect: for the crack defects in the weld, both detection methods can be easily detected. However, the ultrasonic phased array detection has a longer crack length than the radiograph display length. This is because the phased array detector chip has a gate lobe and the measured length is the length of the defect arc, and the length of the defect measured by ray detection is the chord length (plane projection). So phased array detection is used to detect the crack. It is more accurate in measuring the length of defects. For the small cracks in the weld, due to the influence of the transmittance angle, blind area and black degree of the negative film, the ray detection is difficult and the leakage rate is very high.

Non fusion defects: for non fusion defects, the ray can detect the non fusion defects at the appropriate transillumination angle, while the ultrasonic phased array is insensitive to the detection direction and can detect from multiple angles. The phased array has no missing inspection for non fusion defects. In the aspect of defect location and length measurement, phased array inspection is more accurate than radiographic inspection.

Incomplete penetration defect: ultrasonic phased array is feasible in the measurement of length, depth and self height of incomplete penetration defect. Because the radiographic film can only reflect
the plane projection of incomplete penetration defect, it can only measure the length and position of incomplete penetration defect, and can not measure the buried depth and self height of incomplete penetration defect.

Dense pores: ultrasonic phased array can detect the buried depth of dense pores, but it is difficult to determine the number of pores due to the low reflected wave intensity of pores and the limitation of system resolution. At the same time, because the reflection echo of dense pores is low, the ultrasonic phased array detection is easy to miss; the display of pores on the radiograph is more intuitive, so the radiographic detection has more advantages for the detection of dense pores.

5. Conclusions and suggestions

According to the two detection methods, different test results are obtained. The comparative analysis of the test results shows that ultrasonic phased array detection has the advantages of intuitive, environmental protection and high detection efficiency. At the same time, it has advantages in defect detection rate and defect parameter measurement. The ultrasonic phased array testing of butt weld of small diameter tube of power plant boiler has the following characteristics in defect detection and quantification.

1) The phased array has the advantages of fast detection speed, no radiation hazard and high defect detection rate. The test results can be displayed in various forms, and the data can be stored, played back dynamically and analyzed offline, which is conducive to data traceability and meets the requirements of special equipment recordable ultrasonic testing.

2) The phased array probe is a self focusing probe made of composite material, which has high signal-to-noise ratio and resolution. It can quickly measure the defect parameters and accurately locate the defect. It successfully solves the problems of poor coupling, sound wave divergence and waveform distortion caused by wall thickness and curvature in conventional ultrasonic testing.

3) The results show that the height and buried depth of defects can be measured by phased array detection of butt weld of small diameter pipe, and the nature of defects can be determined by combining the geometric structure of weld, which is superior to radiographic testing and conventional ultrasonic testing.

4) When phased array is used to detect area type defects, the detection rate is high, and the missed detection rate is high when radiographic inspection is used to detect this type of defects. Taking the sample tube sy21 (specification: Φ 42 × 11) as an example, if only one transillumination is carried out, the missed detection rate is 66%. Compared with phased array, ultrasonic phased array can't effectively detect the small dense porosity, and the missing rate is 100%. Phased array quality rating is more strict than radiographic testing.

5) For the micro crack defects, non fusion defects and dense porosity defects which are easy to be missed, if the ray and ultrasonic phased array are used to detect at the same time, the defect detection rate can be effectively improved and the missed inspection can be avoided.

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