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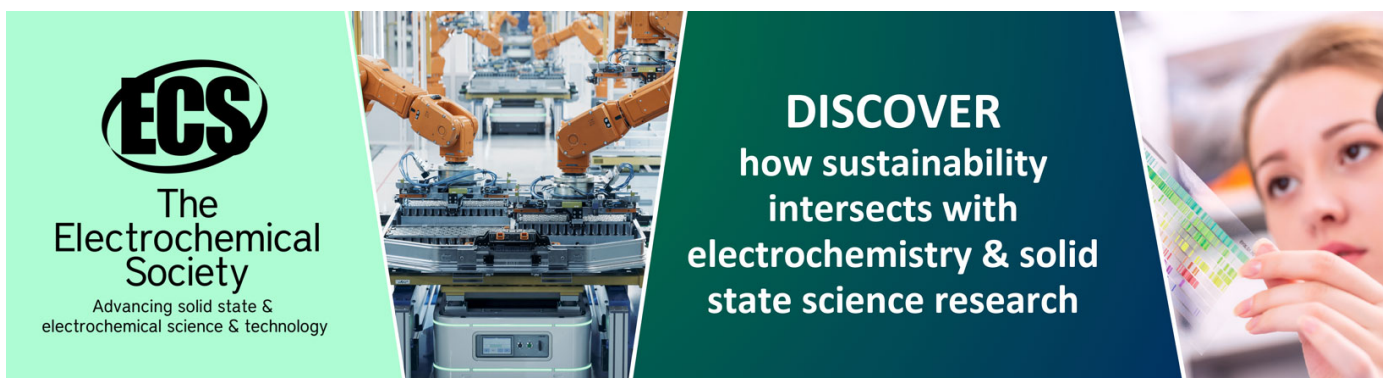
Detection of transverse crack in weld by dual probe cross-weld scanning imaging

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Detection of transverse crack in weld by dual probe cross-weld scanning imaging

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Abstract. In order to solve the problem of transverse crack detection, the method of dual probe cross-weld scanning is proposed. Based on the designed artificial specimen containing two groups of pre-located defects, through the comparison study of CIVA simulation and experimental testing of the specimen, the variation of the gain of different sizes of cracks was obtained with the optimal eccentricity angle of 40~50 degree. It was proved that this method has high detection sensitivity and high engineering application value.

Keywords: weld transverse crack; dual probe scanning; imaging; eccentricity angle.

1. Introduction

With the development of economy and society, the demand for electricity and energy is becoming more and more vigorous. As the concept of "green energy" is widely welcome, as well as technological progress, the demand for power generation efficiency is higher, and the use of supercritical and supercritical boilers is more common. However, in recent years, frequent accidents of boiler water wall tube leakage had seriously affected the economic efficiency and safe operation of power plants. Based on the analysis of the tube leakage, it is found that the transverse crack produced in the inner wall of the water wall tube is the direct cause of the leakage. Further analysis shows that the transverse crack is due to the thermal fatigue crack caused by the axial alternating stress caused by temperature fluctuation[1]. If the transverse cracks in the inner wall of the water wall pipe can be detected as soon as possible and repaired in time, the economic benefits of the power station can be maintained and its safe operation can be ensured.

Detection of transverse crack of water wall tube, due to influences of weld, small diameter tube and field operating conditions, cannot be achieved by penetration and magnetic particle inspection, eddy current detection technology is also difficult in terms of inspection procedure[2]. Radiographic inspection is insensitive to crack defects. Compared with other detection methods, ultrasonic testing is more flexible and has higher sensitivity and reliability. This paper attempted to detect transverse crack in weld by cross-weld scanning method using dual probe. A plate comparison specimen is designed and fabricated designed, on which the simulating and testing researches of transverse crack detection were conducted. The simulation and experiments results show that the dual probe cross-weld scanning method can indeed detect the weld transverse crack effectively.



2. Ultrasonic testing method for transverse cracks in welds

2.1. Conventional ultrasonic testing method for transverse cracks in welds

For the detection of transverse cracks in welds, the method of weld-riding scanning is generally used by putting the probe directly above the weld seam with the weld reinforcement grinded. As shown in Fig. 1(a). Thus, the problem of insufficient acoustic energy reflection of transverse crack in weld is solved. However, in engineering application, under the condition of in-service inspection or under the condition of insufficient detection period, it is often not allowed to polish the weld reinforcement. At this point, oblique parallel scanning is feasible according to the standards, the probe can be arranged close to weld edge so that the probe points to the central line of the weld at an angle of $10\sim 20$ degrees[3]. As shown in Fig. 1(b). However, the detection sensitivity of oblique parallel scanning is not high because the direction of the beam is not perpendicular to the crack surface. In the course of experiment, the results of oblique parallel scanning also verified this statement. Therefore, the method of dual probe cross-weld scanning was considered to detect the transverse cracks in welds. The method uses two probes, one as emitter and the other receiver. Thus, it shields the initial wave interference, and has higher sensitivity in detecting bottom surface crack.

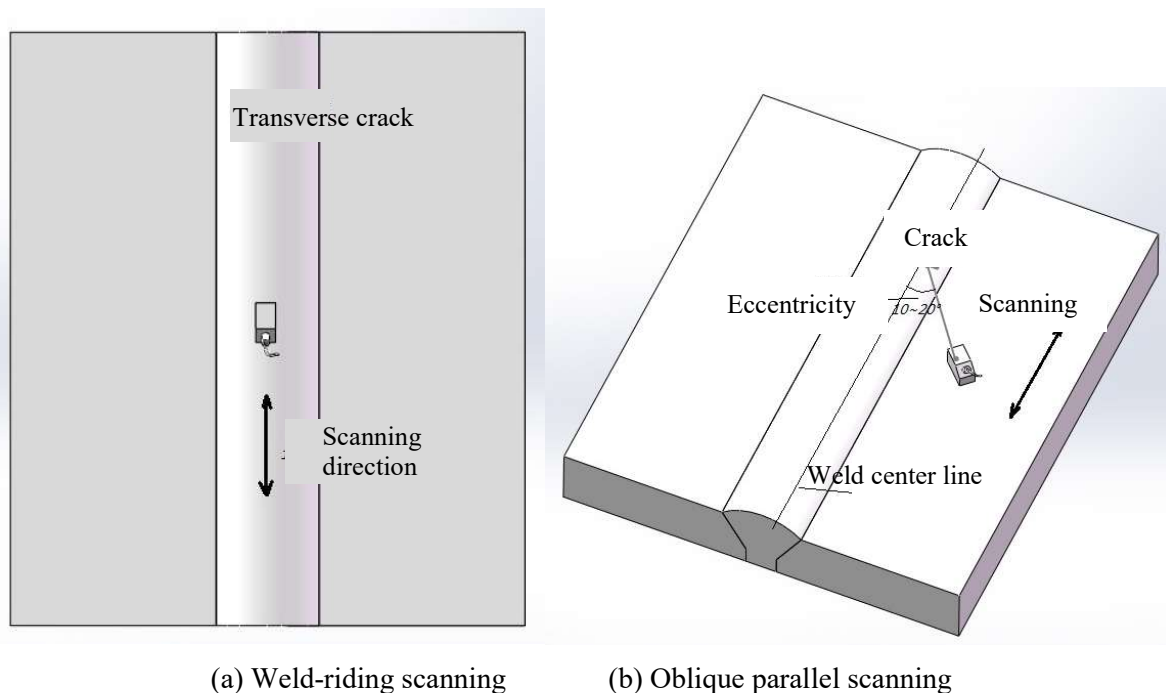


Fig. 1 Conventional ultrasonic testing method for transverse cracks in welds

2.2. Dual probe cross-weld detection method

Dual probe cross-weld detection is a method that uses a set of probes with the same parameters, one as the emission probe, and the other as the receiving probe, which is placed on both sides of the weld to be inspected. As shown in Fig. 2. This method can receive reflected echoes from transverse cracks, so the detection sensitivity is high. It is suitable for detecting the transverse crack in the bottom of the weld. The defect locates at the intersection point at which the two probe points when the highest wave occurs. The indicated length of the defect can be obtained by simultaneous scanning of the probes in the direction perpendicular to the weld seam. It's called the endpoint length measurement method[4].

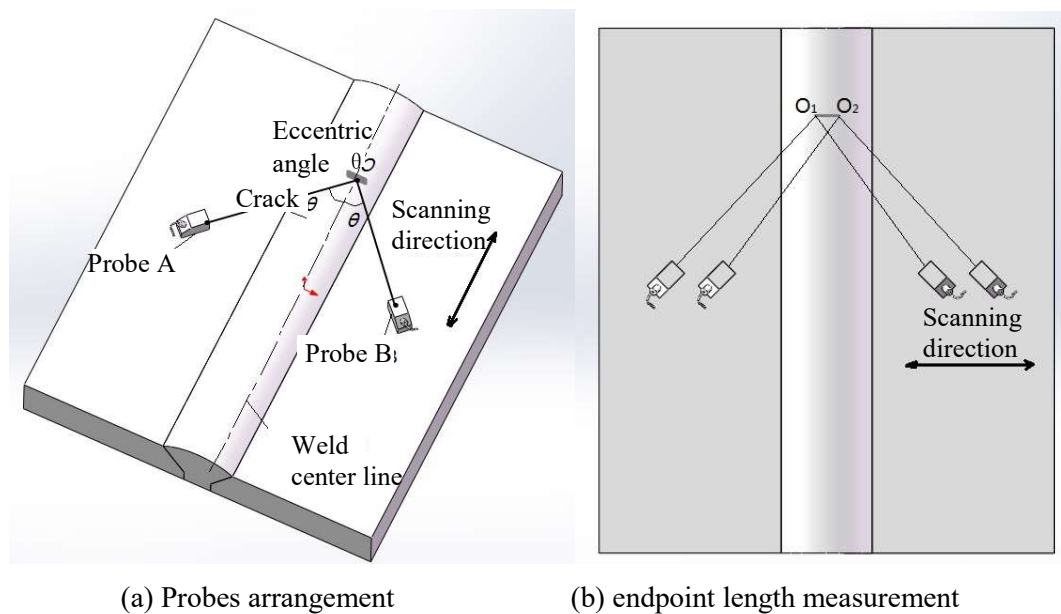


Fig. 2 Schematic diagram of dual probe scanning

3. Simulation research on detection of transverse crack in weld seam by dual probe

CIVA is a software platform developed by the French Atomic Energy Commission for ultrasonic testing simulation. It can simulate the sound field of ultrasonic wave and the interaction of acoustic wave with the defect and test piece boundary, and obtain many results such as A scanning and D scanning imaging. Researchers can easily analyze the results, and CIVA helps technicians explain the actual results. In this paper, the simulation test is carried out based on plate analog blocks, in order to indicate the results of actual test and provide supports for subsequent experimental research.

3.1. Establishment of weld and transverse crack defect model

In order to make the results of simulation research practical and instructive, a detection model is established according to the actual test blocks. In order to avoid the influence of complex shapes, steel plates with two groups of artificial grooves of different sizes are fabricated to simulate the real workpiece containing vertical cracks. The designing thickness of the test block is 11mm, and the crack defects are simulated as EDM grooves. The defects are located at the bottom of the weld and the width of the weld is 10mm. One group of the cutting grooves' length are 4mm, their height are 2mm, 1mm and 0.5mm, and the other group of cutting grooves' length are 2mm, the height of them are 2mm, 1mm and 0.5mm respectively. The defects of different series are comparable, which is convenient for further study. The shape and size of the test block and the location and size of each defect are shown in Fig. 3 and Tab. 1.

Tab. 1 Defect parameter table

Crack number	Crack size/mm×mm	Crack depth/mm
F1	4×2	9
F2	4×1	10
F3	4×0.5	10.5
F5	2×2	9
F6	2×1	10
F7	2×0.5	10.5

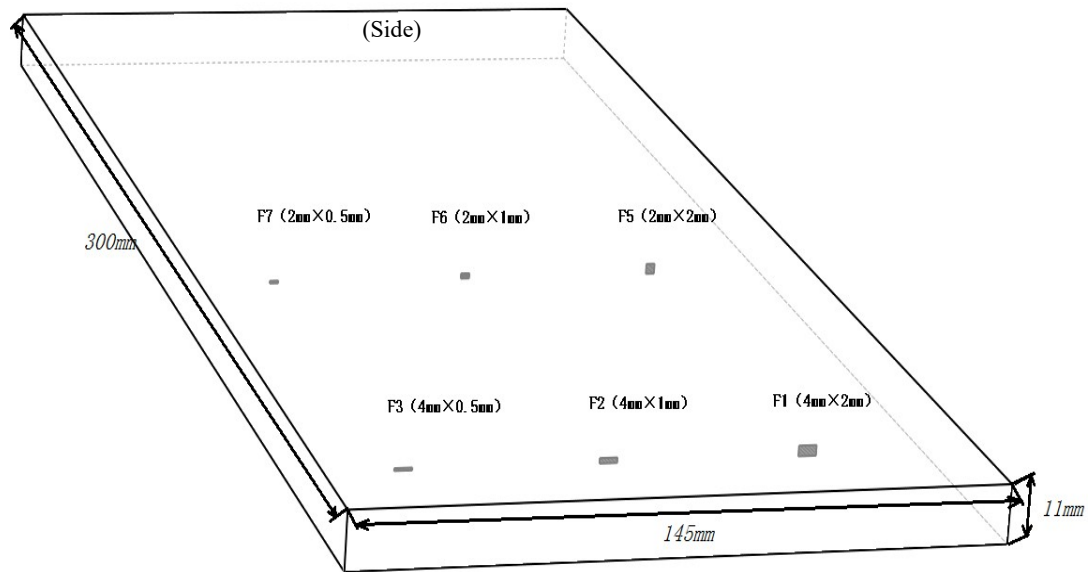


Fig. 3 Sketch picture of artificial defect block

3.2. Test parameter settings

The chip size of the probe is $6\text{mm} \times 6\text{mm}$, the beam refraction angle is 68.2° (corresponding to the K2.5 probe), the modulated pulse signal is a 5MHz frequency Hanning signal. Set the detection mode as dual probe scanning, one probe at each side of the weld. The probe direction and weld center line form an angle of 45° (i.e. two probe direction are perpendicular to each other and are symmetric about the weld center line). The scanning progresses along the parallel and vertical directions of the weld seam respectively, and the scanning steps were all 1mm. The layout and scanning method of the probes are shown in Fig. 4.

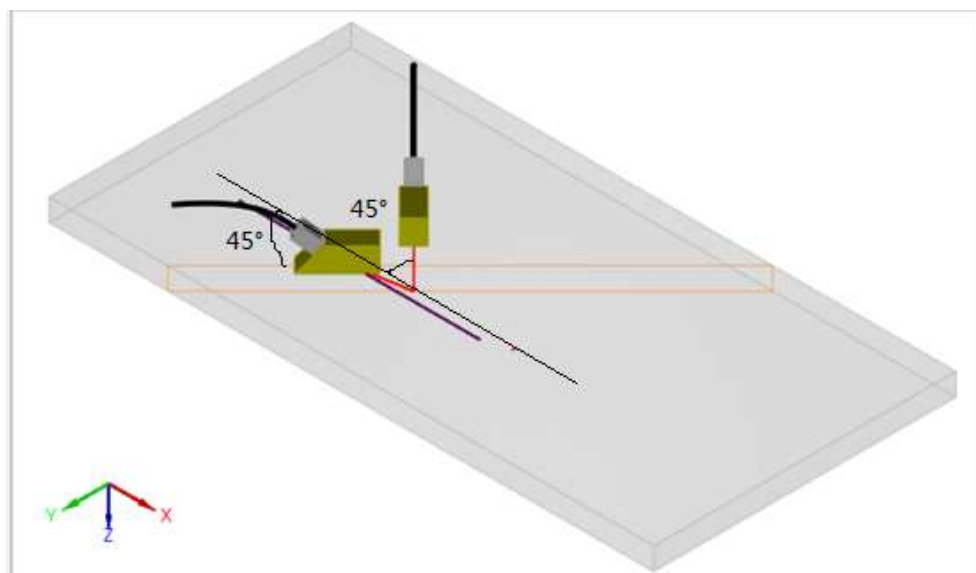
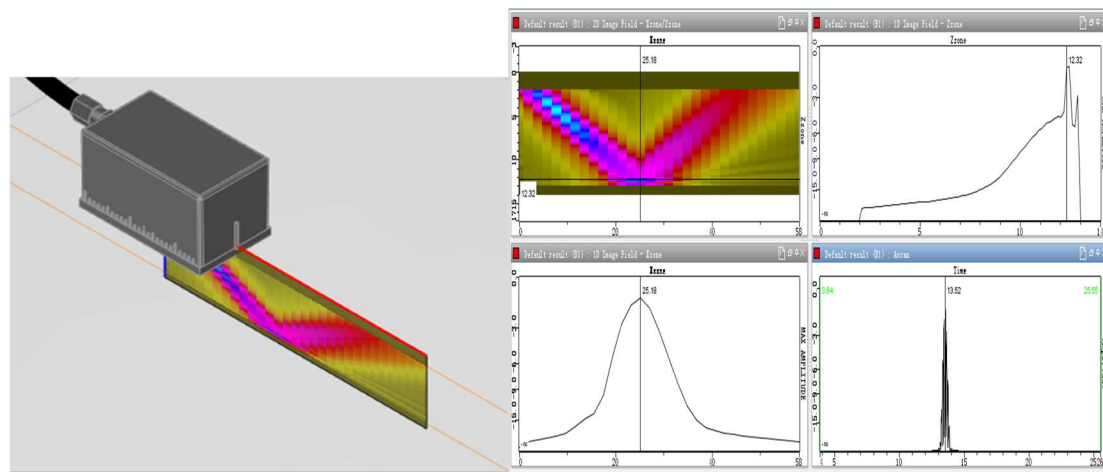


Fig. 4 Dual probe scanning model

3.3. Analysis of simulation test results

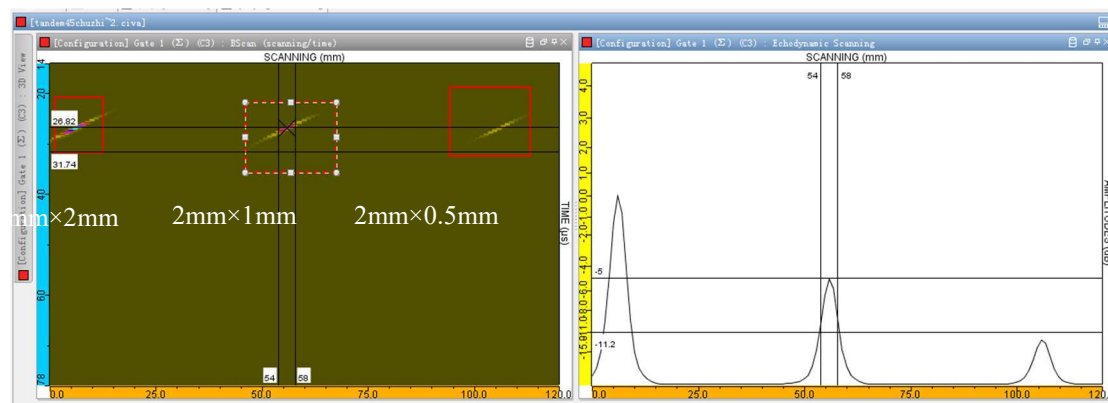
In accordance with the method described above, a detection model is set up and the probe parameters are set to calculate the sound field of the probe transmitting acoustic beam. The results obtained are shown in Fig. 5.



(a) Schematic diagram of probe ultrasonic field (b) Probe ultrasonic field parameter diagram

Fig. 5 Figures of probe beam simulation

According to the method mentioned in 3.2, the probe layout and scanning parameters are set up, and the model is simulated and tested. The scanning results are shown in Fig. 6.



(a) Double probe scanning image (B scan)

(b) Dynamic envelope image

Fig. 6 The simulation results of dual probe scanning

According to the result of the simulation test, the result can be obtained as shown in Tab. 2.

Tab. 2 Data table of dual probe scanning simulation

Crack	Gain(dB)	Indicated length/error(mm)
2mm×2mm	0	3.0/1.0
2mm×1mm	-5	3.0/1.0
2mm×0.5mm	-12.5	2.0/0.0

As shown in Fig. 6 and Tab. 2, the echo signal of the crack is clear, and the scanning image has obvious contour. The imaging of the crack signal is characterized by a clear slant line. The gain of 1mm-high crack echo is only 5dB higher than that of 2mm-height crack. It is proved that the method has high sensitivity to detect small size cracks. The indicated length of the crack calculated by the image has high precision, and the maximum error is only 1mm. The phenomenon appears that the indicated length is larger than the true length. It proves that the results of endpoint measurement tend to be larger than actual length. The simulation model is ideal, and the solution of simulation ignores the influences of factors such as surface characteristics and coupling and dispersion of acoustic waves, etc. Therefore, the results of simulation test are much better than that of the actual detection, and can only be used as a reference for actual detection.

4. Experimental research on dual probe cross-weld inspection

4.1. Design of plate analogue block

The design of test block refer to Section 3.1.

4.2. Selection of probes and instruments

A group of probes is provided, whose nominal frequency is 5MHz, and the size of the wafer is 6mm×6mm, all of which are transverse wave angular probes. The K values of the probes are K1, K2.5 and K3. In the progress of actual testing, we found that the detection effect of K2.5 probe group is better than the other two groups. Therefore, a group of probes with a K value of 2.5 is selected.

The testing instrument must have two channels, which can collect signals from two probes. At the same time, it shall process ultrasonic signals and generate images.

4.3. Analysis of test results

The test block is detected in accordance with the method described above, and the results are shown in Tab. 3 and Fig. 7.

Tab. 3 Dual probe cross-weld inspection data sheet

Crack	Eccentricity angle						
	20°	25°	30°	35°	40°	45°	60°
2mm×2mm	27.9	31.8	37.5	37.6	35.6	28	37.2
2mm×1mm	33	35.2	39.2	39.5	36.7	33.6	38.1
2mm×0.5mm	43.7	45	48	49.8	45.6	39.8	41.4

Unit: dB

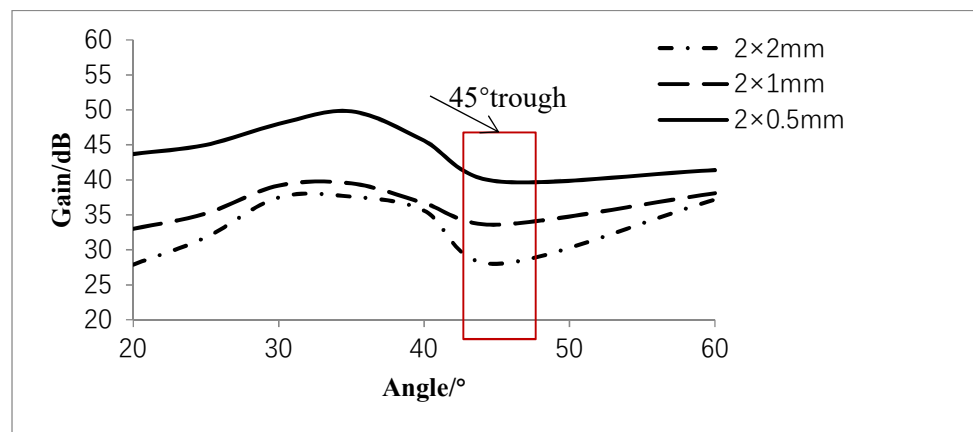


Fig. 7 dual probe of different eccentricity angle

According to the results shown in Figure 7 and table 3, the detection sensitivity of dual probe scanning with different eccentricity angles is nonlinear. With the increase of eccentricity, the detection sensitivity decreases at first, then increases rapidly, and finally decreases slowly. In the range of 0 ~20 degrees, the scanning of dual probe is restricted by the structure of the weld joint and the probes themselves. In the range of 20 ~35 degrees, the detection sensitivity decreases as the angle of eccentricity increases. This is because sound waves are reflected two times on the surface of the crack and the bottom to reach the receiving probe. However, the total reflectance of twice reflection is larger in the range of 35 ~55 degrees[5]. Therefore, when the eccentricity angle is near 45 degrees, the detection sensitivity is relatively high. The 45 degrees "trough" in Fig. 7 indicates the high detection sensitivity range. The detection sensitivity decreases again with the eccentricity angle exceeds 45 degrees away. Therefore, according to the above results, 40 degrees ~50 degrees is the best eccentricity angle range for dual probe scanning.

In accordance with the above results, the $2\text{mm} \times 2\text{mm}$ and $2\text{mm} \times 1\text{mm}$ cracks on the artificial defect block were scanned using a dual probe with an angle of 45 degrees. The resulting scanning image are shown as follows.

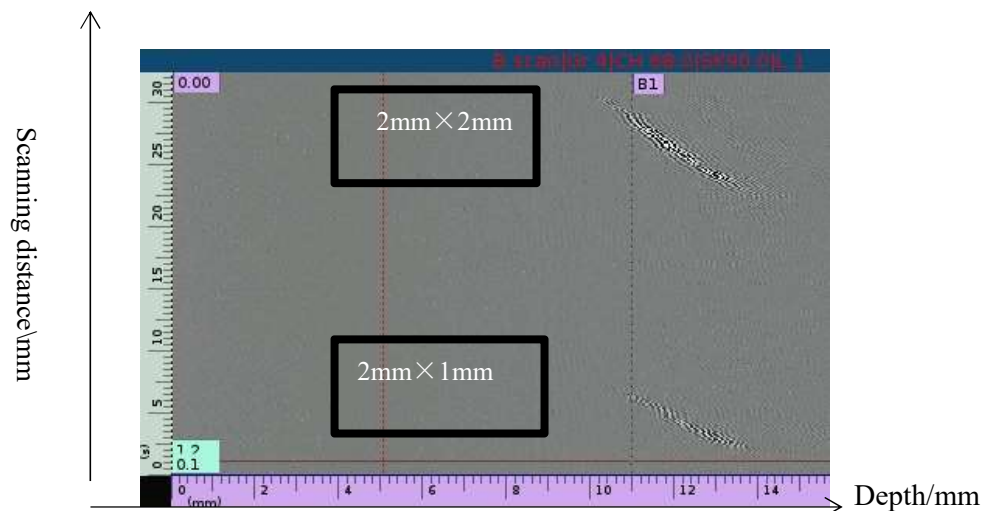


Fig. 8 45 degree angle eccentric double probe scanning imaging

Compared with the imaging results shown in Fig. 6 and Fig. 8, the coincidence between the actual scanning and the simulated detection image is very high. It further confirms the feasibility and reliability of the dual probe scanning method. At the same time, it is found that the crack imaging in the actual scanning is slightly behind the bottom wave. And there is a slight error between inspection results and the real situation, so further research is needed.

According to the endpoint length measurement, the indicated length of the crack is measured, and the result is shown in Tab. 4.

Tab. 4 Dual probe test scanning data sheet

Crack	Gain(dB)	Indicated length/error(mm)
$2\text{mm} \times 2\text{mm}$	28	4.0/2.0
$2\text{mm} \times 1\text{mm}$	33.6	3.3/1.3
$2\text{mm} \times 0.5\text{mm}$	39.8	2.8/0.8

Comparing results in Tab. 3 with results in Tab. 2, normalize the gain data to obtain the results shown in Fig. 9.

As can be seen from Fig. 9, the experiment results are in good agreement with the simulation results. Through simulation and testing, it is found that the change of the gain level with the crack size is basically the same. This rule is helpful to the quantitative evaluation of the transverse cracks in the actual test. The length of the crack indicated deviates a little from actual value. The results of both simulation and test tend to go large, but the results of simulation are more accurate. This is because the width of the sound beam is greater than the theoretical value in the actual test[6].

5. Conclusion

In this paper, through the simulation and experimental study of the detection of transverse cracks in welds, we can draw the following conclusions:

- (1) Dual probe scanning method has the advantages of high sensitivity to oblique parallel scanning method, and compare with weld-riding scanning the merit of not treating weld reinforcement has great advantages. It would shorten the testing cycle, improve the detection efficiency and has high application value in engineering;
- (2) By simulation, it is found that the 1mm crack is only 5dB lower than the 2mm crack, which proves that the dual probe scanning method has high detection sensitivity;
- (3) It is found that the optimum eccentricity angle of dual probe scanning method is 40~50 degrees;
- (4) The test results of dual probe scanning method are in good agreement with the simulation results, and verify the feasibility and reliability of dual probe scanning method.

References

- [1] Wang Xue, Li Xiqiang, Yang Chao, Ge Zhaoxiang, Yang Xianbiao, Ren Yuan. Analysis of early failure of T23 water cooling wall in ultra supercritical tower furnace [J]. China electric power, 2014, 47 (12): 21~27.
- [2] Chen Yonggan, Zhang Tao. Study on ultrasonic method for detecting transverse cracks in water cooled wall [J]. Anhui electric power. 1999, 4: 48~51.
- [3] GB/T 11345-2013 nondestructive testing of welds, ultrasonic testing techniques, inspection grades and evaluation [S], 2013.
- [4] Lu Baoxue. Study on marine T fillet weld transverse crack ultrasonic testing[J]. Welding machine. 2014, 44 (11): 147~150.
- [5] Krautkramer, Josef. Ultrasonic testing of materials /-3rd ed[M]. Springer-Verlag, 1983:41~42.
- [6] Li Jiawei, Chen Jimao. Nondestructive testing Handbook [M]. Beijing: Mechanical Industry Press, 2002: 200~201.