Application Research on Ultrasonic Phased Array Technology in Weld Seam Inspection

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Abstract. Welding seams are prone to safety accidents and failures during actual operation, which has an adverse effect on the economic benefits of the enterprise. When using traditional ultrasonic inspection methods to inspect the pipe butt welds, the staff needs to use the inspection probe to move as needed, which makes the inspection process difficult to operate and is greatly affected by human factors. The beam of conventional ultrasound cannot be deflected and focused. It is difficult to detect parts with complex geometric shapes and large anisotropic welds. Ultrasonic phased array is a new type of non-destructive testing method, which makes up for the limitations of conventional ultrasonic testing, and has great advantages compared with conventional ultrasound. Therefore, in order to reduce the misjudgment of defects caused by humans, this paper studies the application method of ultrasonic phased array technology in weld inspection, discusses the principles and characteristics of ultrasonic phased array inspection technology in nondestructive testing, and the defects were tested. The test results show that the phased array technology can effectively detect weld defects.

1. Introduction

In industrial production, non-destructive testing plays an indispensable role in defect detection and performance evaluation. Ultrasonic testing, as a non-destructive testing method, has the advantages of no pollution, convenience and no harm to human body compared with other methods advantage. Ultrasonic testing has developed more ultrasonic nondestructive testing methods with the development of technology, such as ultrasonic guided wave testing, laser ultrasonic testing and other new methods. Therefore, it has gradually expanded the application field of ultrasonic testing. And with the development of various welding processes, more and more welding joints have emerged in the market, and at the same time, various methods for welding joint detection have also appeared.

Due to its flexible beam deflection, high sensitivity and detection speed, ultrasonic phased array quickly became a research hotspot and received more and more attention. The phased array was first used in the medical field. The concept came from the phased array radar. With the development of modern electronic information and signal processing technology, the phased array technology is becoming more and more mature. Ultrasonic phased array technology is a fast, efficient and flexible detection technology. Ultrasonic phased array technology uses electronic technology to control the excitation delay time of each array element to form a circumferential scan. The electronic scanning method has obvious advantages in speed, can easily control the direction and shape of the sound beam, and can flexibly set the focus point. Ultrasonic phased array technology does have the advantages of fast, efficient and flexible in the welding seam inspection, which is of great significance to the online inspection of the pipe.
2. Ultrasonic Phased Array Detection Principle

2.1. Working Principle of Ultrasonic Phased Array Probe

The traditional ultrasonic single crystal probe uses high-frequency mechanical oscillation as the source of ultrasonic acoustic emission. Its working principle is shown in Fig. 1. When a voltage is applied vertically to the surface of the wafer, the deformation of the wafer returns to the original after a few microseconds. At this time, a pulse of mechanical energy is generated, including ultrasound. The probe wafer receives the reflected ultrasonic wave, and the ultrasonic wave acts on the wafer to convert the wave signal into an electrical signal. Perform signal processing on electrical signals to produce defective echo signals. Therefore, the single crystal piezoelectric array element can be used to receive ultrasonic pulses that are sent one by one.

![Fig. 1 Working Principle of Piezoelectric Wafer](image)

The linear array of probes is shown in Fig. 2, where \( e \) is the width of the array unit, \( n \) is the number of arrays, and the width of the array is \( W \), and the spacing between the center of the elements is \( p \), and the gap between the elements is \( g \). The ultrasonic phased array can deflect the sound beam in the direction of the active aperture \( A \), but not in the width \( W \) direction.

During the inspection process, the selection of the ultrasonic phased array probe is the same as conventional ultrasound. The wafer parameters have a greater impact on the inspection results. For example, when the wafer width \( e \) is reduced, the deflection ability of the ultrasonic beam is enhanced, and the size of the probe housing can be reduced, but the processing difficulty is increased accordingly. With a large number of active chips, the probe has a wider ultrasonic physical sound field, covering more areas.
2.2. **Principle of Ultrasonic Phased Array Detection**

Ultrasound belongs to a kind of mechanical vibration wave, it is generated by the piezoelectric effect of piezoelectric chip to generate piezoelectric effect. The typical frequency of ultrasound is from 0.1MHz to 50MHz, and the frequency of most industrial applications is from 0.5MHz to 15MHz. The traditional ultrasonic inspection uses a single crystal probe. The ultrasonic field propagates through the direction of the acoustic axis with a one-way reflection angle. The deflection of the angle is only through the tilt of the wafer in the probe, so as to facilitate the detection of small cracks with uncertain orientation. It is assumed that the single crystal wafer is cut into many identical arrays, and its width is much smaller than its length. Therefore, each array can be used as a separate cylindrical wave source. The wave sources of the array interact with each other during the propagation process to form a new wave front to realize the propagation of the ultrasonic beam. The wave sources of these arrays synchronize the phase and amplitude through delay control, so as to achieve the deflection of the ultrasonic beam and the focus of the beam in this way.

The biggest feature of the ultrasonic phased array is that it can control a single array in the polycrystalline array probe through electronic delay. The ultrasonic sound beam with focusing parameters is generated by the excitation of the piezoelectric wafer unit, and the focusing parameters include angle, focusing distance, and size of the focusing point, etc. This scanning sound beam can detect cracks in a special orientation. However, for a single wafer probe in conventional ultrasound, the change in the probe position and the area covered by the sound beam limit the detection of defects away from the axis of the sound beam. Therefore, it has a high missed detection rate.
As shown in Fig. 3, the transmitting unit of the ultrasonic phased array receives the transmission signal of the electronic circuit, the phased array unit receives the trigger signal, and sends the pulse signal to the ultrasonic phased array probe. The probe emits an ultrasonic beam, and the ultrasonic phased array emits a certain time difference or phase difference between the channels of the array elements. Through the triggering of pulse excitation, the excitation pulses of different channels must have time differences. Through the triggering of pulse excitation, the excitation pulses of different channels must have time differences. When there is a defect in the inspected workpiece, the probe receives the reflected echo from the defect and converts the sound signal into an electrical signal to form an ultrasonic defect signal.

2.3. Transmission and Reception of Ultrasonic Phased Array Signals

Phased array transmission mainly uses the physical properties of the wave phase. The ultrasonic pulse transmission time is controlled by a delay electronic circuit. Each wafer in the probe emits ultrasound waves, and these ultrasound waves interact. Unlike traditional ultrasonic probes, phased array probes are composed of several independent wafers arranged in a certain order. In the 17th century, Christian Huygens proposed that the generation of waves can be seen as the sum of a series of point sources interacting together to reconstruct a new wave front, and the deflection and focusing shape of the sound beam angle can be achieved. Under normal circumstances, the sensitivity of the phased array probe is increased by increasing the activation aperture of the phased array probe. In order to obtain a better beam deflection effect, the phase law array system's built-in focus law calculator performs specific delay control on each array element to obtain the desired beam shape.

According to the used wedge, probe parameters, workpiece geometry, etc., a series of wave fronts are transmitted to the test specimen through the phased array operating system. These wave fronts interfere with each other to form a new wave front. When encountering internal defects and geometric discontinuities in the workpiece, reflection echoes are formed due to the effect of acoustic resistance.

The ultrasonic phased array uses multiple groups of array elements to receive the reflected echo, and adds a different delay time for each array element during focusing. Therefore, when receiving the signal, it is necessary to add a reverse delay, because the phased array is to control the direction of the array element by controlling the phase delay of the array element. Therefore, the reception of the phased array also realizes the control of its receiving direction through phase delay. Finally, the delay of the returned echo signal is superimposed to obtain the echo reflection in the target direction, so that the signal arrives at the same time and is converted into an electrical signal to form a defect signal.
3. Test Plan Design
Ultrasonic phased array technology has the advantages of high speed, high sensitivity, no ionizing radiation hazard and recordable results of conventional radiographic inspection. It has been widely used in small and uniform welded carbon steel materials. The most representative application is the application in the process pipeline of the deep-sea oil and gas platform. The test plan is designed and verified in this paper.

The experimental material is Q345E, and two types of welding test plates with inclusions and pores are made respectively. The air holes are welded with peeled light welding wire, which causes gas to enter the weld seam, and the gas fails to escape in time when the weld metal is solidified to generate air holes. In multi-layer multi-pass welding, the wire pack or clustered inclusions are formed by the method without removing the coating. The welding experiment board is shown in Fig. 4 and its size is 350mm × 300mm × 16mm. During the detection, a phased array longitudinal wave straight probe with zero degree incidence is used. During the detection process, in order to avoid scratches on the surface of the probe, it is installed on a zero degree wedge with a thickness of 30 mm. The longitudinal wave velocity is 5930 m/s, the equipment calibration adopts CSK-IIIASK ship type test block and rectangular test block, the detection coupling agent adopts washing liquid, and the detection method is manual fixed-point scanning.

4. Analysis of Test Results
The single-point vertical scanning method is used. During the scanning process, 16 groups of wafers are excited each time, and the step is 1, and the device probe has a total of 64 wafers. Therefore, after one scan is completed, 49 sets of A-scan signal maps will be obtained. The detection equipment is an ultrasonic phased array system. The B-scan and A-scan diagrams of the two types of defects are shown in Fig. 5. Figure 5 shows the A-scan signals and the corresponding B-scan diagrams of the two types of defects. The relative position and size of the defect can be visually observed from the B-scan diagram. The pores are prefabricated in the middle of the weld, and the inclusion defects are deeper. The amplitude of the A-scan of the two types of defects is greatly different. The pores and inclusion defects have a large scattering and absorption attenuation effect on ultrasound. The amplitude change is relatively large.

During the inspection, the characteristic parameters of the acoustic impedance of different defects and the degree of scattering of the ultrasonic echo signals by the defects are different. The heights of the ultrasonic reflected echoes are different. The appearance characteristics of the defects in the B-scan diagram are also slightly different. The B-scans of stomata and inclusions differ greatly. When detecting pores, it is difficult to detect because the pore size is small. Therefore, the background noise is higher.
than that of the inclusion when the gain value is increased in the detection process. In the process of defect prefabrication, for different defects, there are some common characteristics, such as the size and orientation of defects. Therefore, in the research process, only qualitative analysis is carried out on defects, not quantitative analysis, and the specific impact of defect size and location on the results is ignored.

**Fig. 5** A scan of different defects and corresponding B scan

5. **Conclusion**

In summary, in the nondestructive testing technology, the ultrasonic phased array inspection technology plays an important role in China's industrial inspection. Using ultrasonic phased array to detect welded test panels with prefabricated natural defects can accurately detect different defects. The development of non-destructive testing technology is a long and complicated process of exploration. With the continuous progress of science and technology and economic society, ultrasonic phased array technology can be more widely applied to various industries. Non-destructive testing technology will also become more innovative, environmentally friendly and efficient.

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