Ultrasonic Phased Array Inspection on PE Pipe Heat Fusion Joints and Electro-Fusion Joints

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Abstract:

Defects like impurity, gas holes and loose connection in heat fusion joint or electro-fusion joint of PE (polyethylene) material, have brought potential safety hazard. Therefore professional ultrasound inspectors have been working on how to test defects in heat fusion or electro-fusion joints. With conventional UT (ultrasound testing) method, there are problems like serious attenuation of ultrasound echo in PE material and flaws not display directly so that it is difficult to apply conventional UT method. To make use of Phased Array (PA) characteristics like multi-elements, focusing and imaging, disadvantages of conventional UT can be avoided, and good testing effects may be achieved. By making heat fusion and electro-fusion joints samples with different defects, obtaining heat fusion and electro-fusion joints with different specifications at site, using PA probes with different elements and frequencies and adjusting parameters of PA systems, various experiments have been done for analysis. In this paper, examples will prove ultrasound PA can inspect defects in heat fusion and electro-fusion joints. There is a phase transition line in heat fusion and electro-fusion joints. By measuring distance between the phase transition line and the fusion surface or un-welded pipe wall, connection quality can be determined.

Keywords: heat fusion joint; electro-fusion joint; phased array (PA); phase transition line

1. Introduction

PE fusion joint is the most vulnerable part on a PE pipe. Damage of fusion joint may result in PE pipe leakage or even accidents. In fusion welding, defects like impurity, gas holes and loose connection in heat fusion joint or electro-fusion joint of PE (polyethylene) material, will bring safety hazard to operation. Gas pipe is closely related to people’s life. Any leakage in gas may lead to significant impact. To achieve near-zero failure rate, in addition to pipe connection process control, NDT inspection is necessary.

The current management focus for PE pipe site connection is to control the connection process following the proper procedure. However, no mater how careful the process control is, without an effective inspection method, internal defects of joint connection might occur. Ultrasound testing, with its advantages like quick inspection speed, no radiation and low budget, is the common method for detecting internal defects.

PE pipe fusion joint defects include cracks, un-fusion along the fusion line, foreign objects, dislocation or gas holes of electro-fusion joint heating leads, and so on. Any crack is dangerous. As a result of insufficient heating time, un-fusion may occur between bad fusion interfaces. Bad fusion joints are unacceptable. Foreign objects like particles often exist in the fusion line. Even if the joints are connected under proper fusion process and procedures, bad weather or severe environment may cause defects. Inclusions such as sands, stones and leaves may result in leakage of pipe lines. Dislocation of heating wire on electro-fusion joint is caused by over heating time or over temperature. If the wire position is different from the intended position, dislocation of heating wire is also not acceptable. Gas holes are the common defects in electro-fusion joints. For gas holes on or near the fusion lines, if round or oval in shape, small enough in size and quantity, they can be considered as acceptable fusion deficiency. Good fusion lines and fusion lines with gas holes are shown as Fig. 1 and Fig. 2. We are looking for a technique that can detect flaws such as cracks, un-fusion along the fusion line, foreign objects, dislocation or gas holes of electro-fusion joint heating leads.

Fig.1 Good fusion line

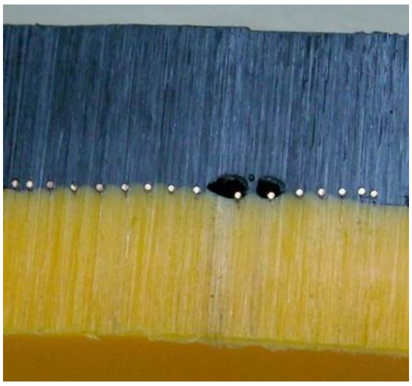

Fig. 2 Fusion line with gas holes

2. Acoustic Characteristics of Polythene (PE)

2.1 Material Difference

Different polythene materials with the same chemical composition of polythene may have quite different acoustic characteristics. Even for PE pipes of different brand, or PE pipes of the same brand but from different manufacture site or with different manufacture process parameters, the acoustic characteristics are not the same. For each lot of PE pipes, the operator should be familiar with the acoustic features, measure their parameters, prepare test blocks from such PE pipe. Test blocks from different PE pipes shall not be mixed up. Under the same test frequency and temperature, velocity of various PE pipes is different. See Fig. 3 for the typical sample velocity measurement.

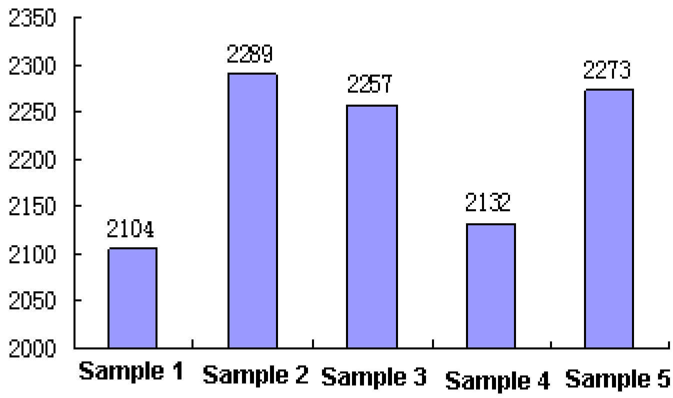

Fig.3 Typical sample velocity（m/s）

2.2 Severe Attenuation

Ultrasound attenuation is the phenomenon of power decrease with distance increase and S/N ratio decrease in ultrasound transmission, which includes diffusion attenuation, scattering attenuation and absorption attenuation. Because of different molecular structures, the attenuation rule of ultrasound in polythene is obviously different from that in metals, which is different from metal with small grains (e.g. low-carbon steel) or coarse grains (e.g. austenitic stainless steel and cast iron).

According to the ultrasound testing principle, if there is serious attenuation, the detected reflected longitudinal wave signals decrease and the inspection instrument can not get sufficient reflection echo; Or when the reflected longitudinal wave signals are close to grass wave signals, reflection wave and grass wave can not be correctly identified. Both cases may cause inspection failure.

Because ultrasound attenuation in polythene is severe, attenuation has become the most important issue in ultrasound inspection.

Ultrasonic attenuation coefficient in polyethylene is measured from the polythene hexahedron test block, as shown in Fig. 4. According to the test result, ultrasound attenuation coefficient in polythene is high, but, the attenuation coefficient at a lower frequency is a little lower than that at a higher frequency. Therefore it is easier to get a higher reflection by using a low-frequency probe.

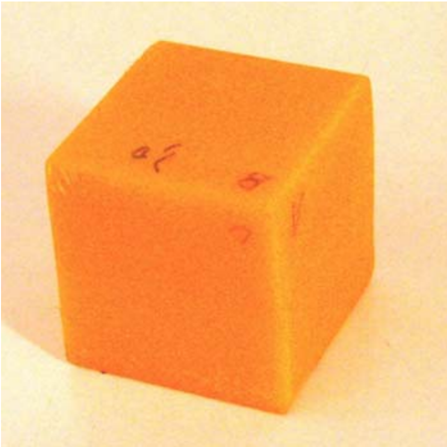

Fig.4 Polythene hexahedron test block

An ultrasound flaw detector can be used to calculate attenuation coefficient. Place a longitudinal wave normal probe of the same frequency as that of the flaw detector on the tested material surface. Use the height difference of multi bottom echoes beyond three times of near field for calculation. Ultrasound wave attenuation coefficient of polythene is usually one magnitude higher than that of steels. **Ultrasound flaw detector CTS-4020E, manufactured by Shantou Institute of Ultrasonic Instruments Co., Ltd. (SIUI)**, is used for testing steel and polythene with the same thickness. Triple waves are shown as Fig. 5. The left side is for the steel and the wave height decreases as the distance increases. Every decrease of 6dB is half an echo, which complies with the ideal diffusion attenuation rule of beams. There is almost no scattering attenuation and absorption attenuation. The right side is for the polythene and the wave height decreases obviously as the distance increases. The second echo height decreased by 23dB, and the scattering attenuation and absorption attenuation are serious. The signal is close to a grass wave signal and the third echo already disappears.

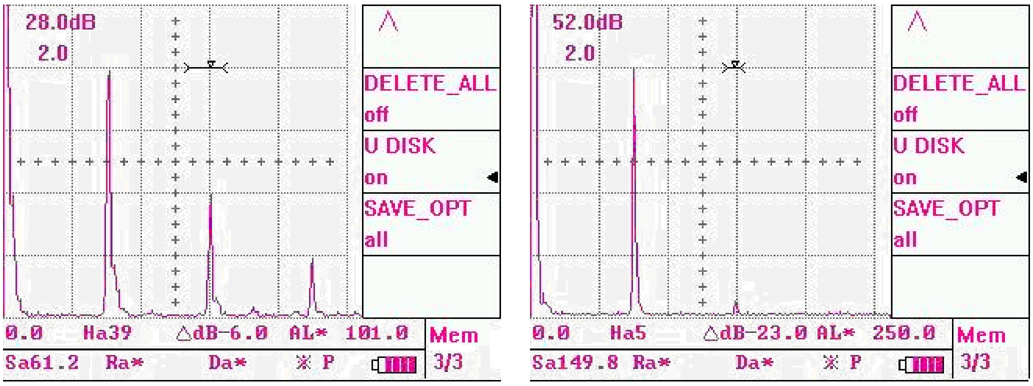

Fig.5 Attenuation of steel and polythene

2.3 Velocity changes rapidly as temperature changes

Polythene, the same as other common solid materials, has velocity decrease with temperature increase. Under certain heating conditions, specific heat capacity of polythene (PE) is about 2.3J/（g·℃） and specific heat capacity of steel is about 0.46J/（g·℃）. Although the specific heat capacity of polythene is higher than that of steel, the heat transfer coefficient of the former is far smaller than that of the latter. The heat transfer coefficient of polythene is about 0.35W/(m·℃) and the heat transfer coefficient of steel is about 75.4W/(m·℃). As a result, with the fast temperature rise of PE, the velocity rapidly decreases. Rule of change between velocity and temperature of polythene is shown in Fig. 6. **An ultrasonic thickness gauge CTS-49, manufactured by Shantou Institute of Ultrasonic Instruments Co., Ltd. (SIUI)**, is used for the test. With its velocity measurement function, when testing a section of polythene pipe, it is found that longitudinal velocity decreases from 2533 m/s to 2144m/s when the temperature rises from -5℃ to 58℃. In the testing, after the temperature of the test block changes, internal and external temperatures of the test block should be even. Due to the low heat transfer coefficient of polythene, the test would take a long time. To bath the test block in salty water would decrease heating and cooling time than in the air.

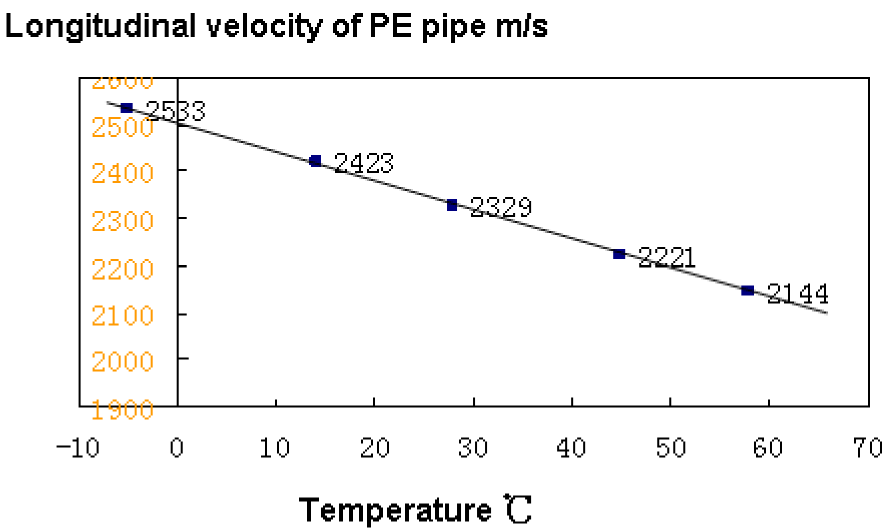

Fig.6 Velocity change with temperature

2.4 Anisotropy

Velocity of polythene pipe is anisotropic. A polythene hexahedron test block as in Fig. 4 was used for the testing, and the other test block was from another polythene pipeline as shown in Fig. 7. A-A is axial direction, B-B is radial direction, and C-C is circular direction.

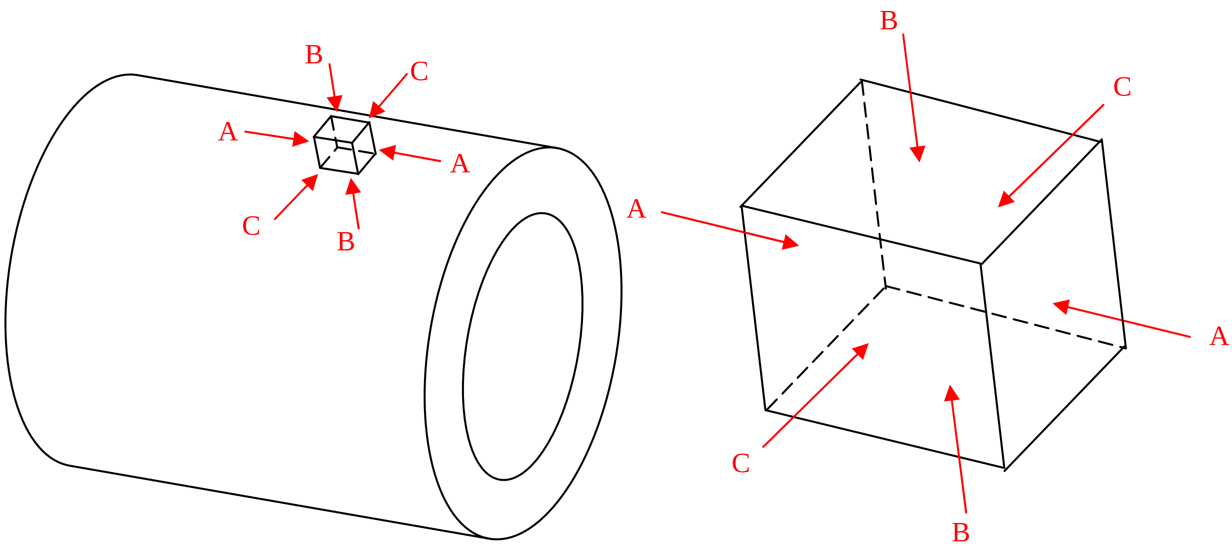

Fig. 7 Sample of polythene pipe

Use the same test block under the same temperature （9℃）, and velocity was measured in each direction, and the measurement result was shown in Fig. 8. Velocity of each direction is different, which shows anisotropy. Velocity of this test block from high to low under 9℃ is in circular direction, axial direction and radial direction.

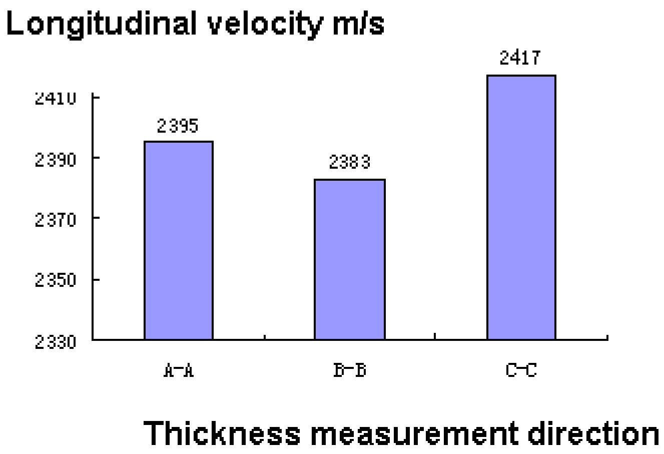

Fig.8 Velocity of different directions

3. Conventional Ultrasound Testing Method

On how to accurately detect flaws in heat fusion or electro-fusion joints of PE material, the ultrasound professionals have been working on it. The attenuation coefficient of longitudinal wave in PE pipe is obviously lower than that of transverse wave. So when compared with transverse wave, longitudinal wave is more suitable. Longitudinal angle probes can be used for ultrasound testing of PE pipe joints.

The material from PE pipe was used for making an angled wedge, so as to achieve longitudinal wave angle probe inspection on PE pipe, as shown in Fig. 9. The material is the same for angle probe wedge, test block and PE pipe. The advantage is that when probe angle wedge has the same material as the tested PE pipe, velocity of angle wedge is the same as that of PE pipe, and the refraction wave is longitudinal wave only, as shown in Fig. 10. By using a ladder arc, reflection wave of different sound path can be found. But there is only one longitudinal wave reflection for every ladder, and its velocity value is the same as the measurement value of the normal probe in Fig. 3. At the same time, it is noticed that: no transverse wave reflection is available, which is useful for flaw identification.

Fig. 9 Probe with angled wedge and test block made from PE

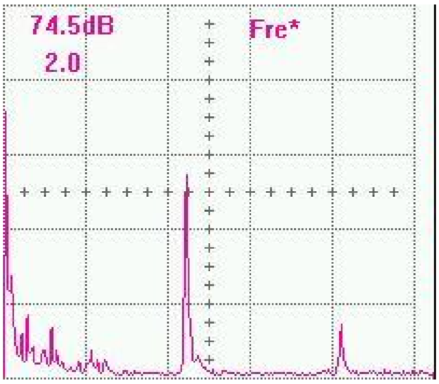

Fig. 10 Adjusting scan speed with a ladder arc

However, because of problems like serious attenuation of ultrasound in PE material and non-intuitive display of flaws, the use of conventional ultrasound inspection method is not applicable in practical inspection.

4. Characteristic of Phased Array

Using the characteristics of phased array like multiple elements, focusing and imaging may avoid the disadvantages of conventional ultrasound and obtain good inspection results.

During ultrasound phased array inspection, each ultrasound transducer elements is activated and ultrasound beams are formed by phase delay. Ultrasound phased array inspection can detect those parts not easily detected by other probes, and dynamic focusing can be realized by one angle after another to produce two-dimensional scan images. Therefore ultrasound phased array is not only widely used for NDT research on steel butt welding, but for PE pipe electro-fusion joint inspection.

Ultrasound phased array inspection system can use electronic scan method to produce ultrasound focus, which means that the focus point position of the scanning can be controlled real-time. By changing focal depth and angle for continuous scanning, electronic scan results calculated by the phased array instrument can obtain two-dimension images. Its horizontal scan range indicates the sound beam coverage area, the vertical scale shows relative depth, and the reflection echo amplitude is shown in different gray scales or colors. From the inspection results of ultrasound phased array system, positions of flaws and heating wire coiled in every joint in the PE pipe can be differentiated. Electronic energy in the ultrasound transducer unit is converted to sound energy. Frequency of the transducer when testing PE is lower than testing metal, and the frequency shall be selected according to the thickness of the PE pipe. Generally speaking, higher frequency can provide higher sensitivity and better resolution for the near-surface, but the effective tested thickness is limited. While lower frequency provides effective testing in a bigger thickness range, which is better for testing on a rough or in-continuous surface.

5. Phased Array Inspection for Electro-fusion Joints

Ultrasound phased array inspection can achieve real-time two-dimensional image display of PE pipe electro-fusion joints section. The horizontal scale shows the sound beam coverage area and vertical scale shows the relative thickness between the PE pipe electro-fusion joint and transducer. The ultrasound from the probe will produce reflection wave when it reaches a reflection object and the strength of the reflection signals is indicated by different colors, which is the indication of the position, size and type of the reflection object. Ultrasound phased array can also detect the flaws between the wires or below the wires. When flaws are between the wires or below the wires, test the hidden part between the points of two wires.

By making electro-joint samples with different flaws, and acquiring electro-joints with different specifications from manufacture sites, the **Phased Array Ultrasound Flaw Detector CTS-602, manufactured by Shantou Institute of Ultrasonic Instruments Co., Ltd. (SIUI)**, was used with phased array probes with different frequencies and elements and parameters well adjusted when performing experiments for anatomical verification.

Flaws such as gas hole, cracks, un-fusion, foreign objects and heating wire dislocation, can be detected by ultrasound phased array. A good fusion joint is shown as Fig. 11. The ultrasound image clearly indicates the wire signs, and the spots with colors show the heating wire of the fusion interface. Ultrasound phased array of the heating wire dislocation is shown as in Fig. 12 and the ultrasound image displays the heating wire dislocated by over-heating.

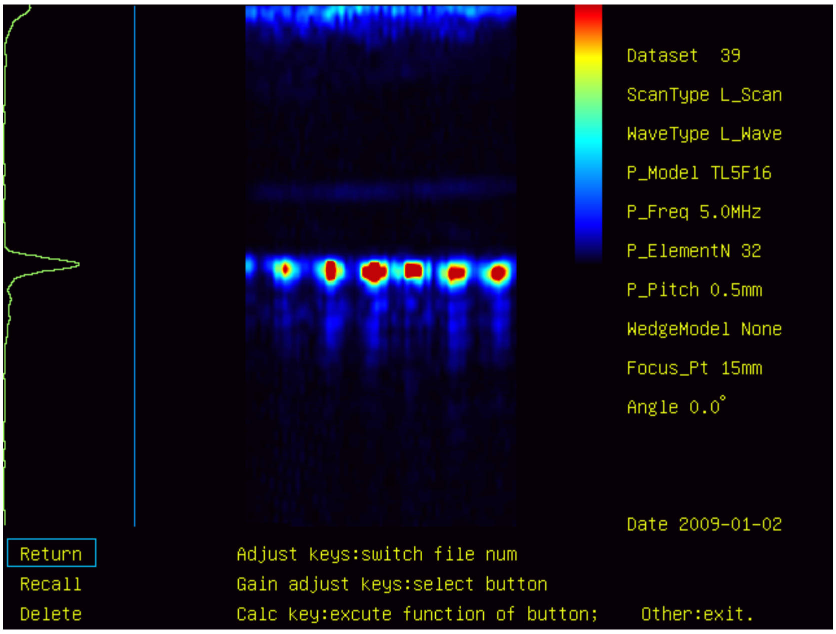

Fig. 11 Ultrasound phased array inspection for good fusion joint

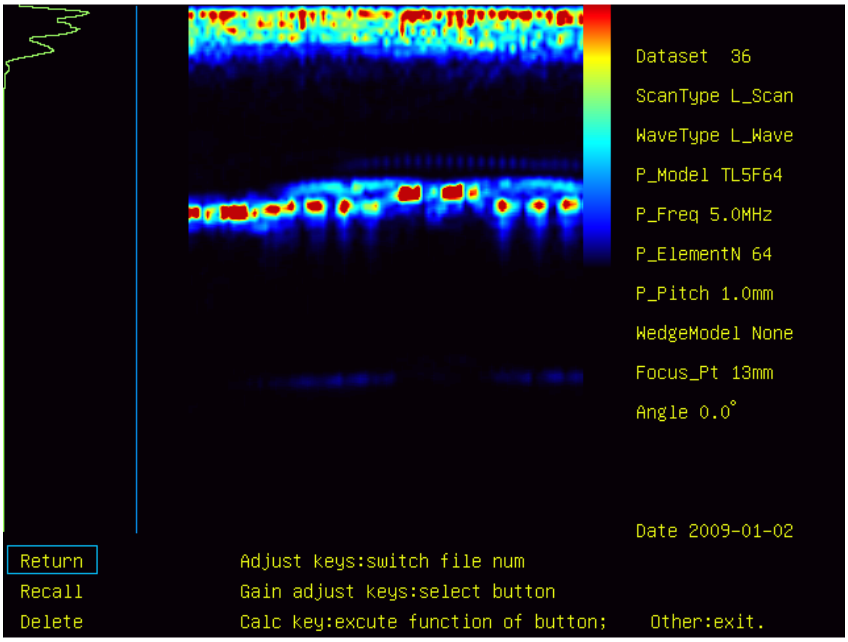

Fig. 12 Ultrasound phased array inspection for heating wire dislocation

If a colored fusion line is displayed along the wire arrangement direction and below the wire, such linear display shows unfused connection. If the color image is above the wire and close to the wire position, it is usually a gas hole. Gas holes indicated in ultrasound phased array inspection is shown as Fig. 13.

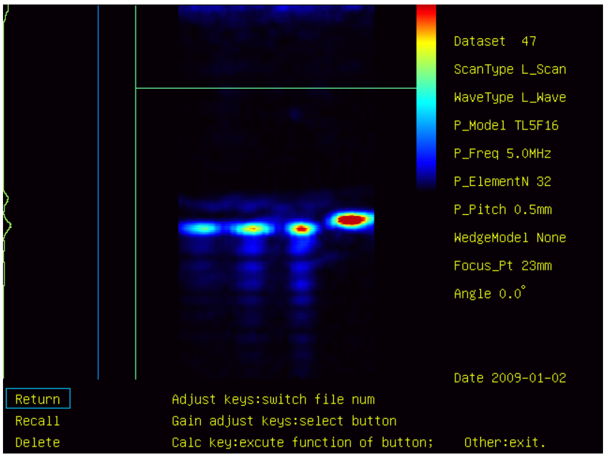

Fig. 13 Ultrasound phased array inspection for gas holes

The Phased Array Ultrasound Flaw Detector CTS-602, manufactured by Shantou Institute of Ultrasonic Instruments Co., Ltd. (SIUI) was used for inspection, and electro-joints phase transition line can be identified properly, as shown in Fig. 14. Quality of electro-fusion joints can be determined from the phase transition line.

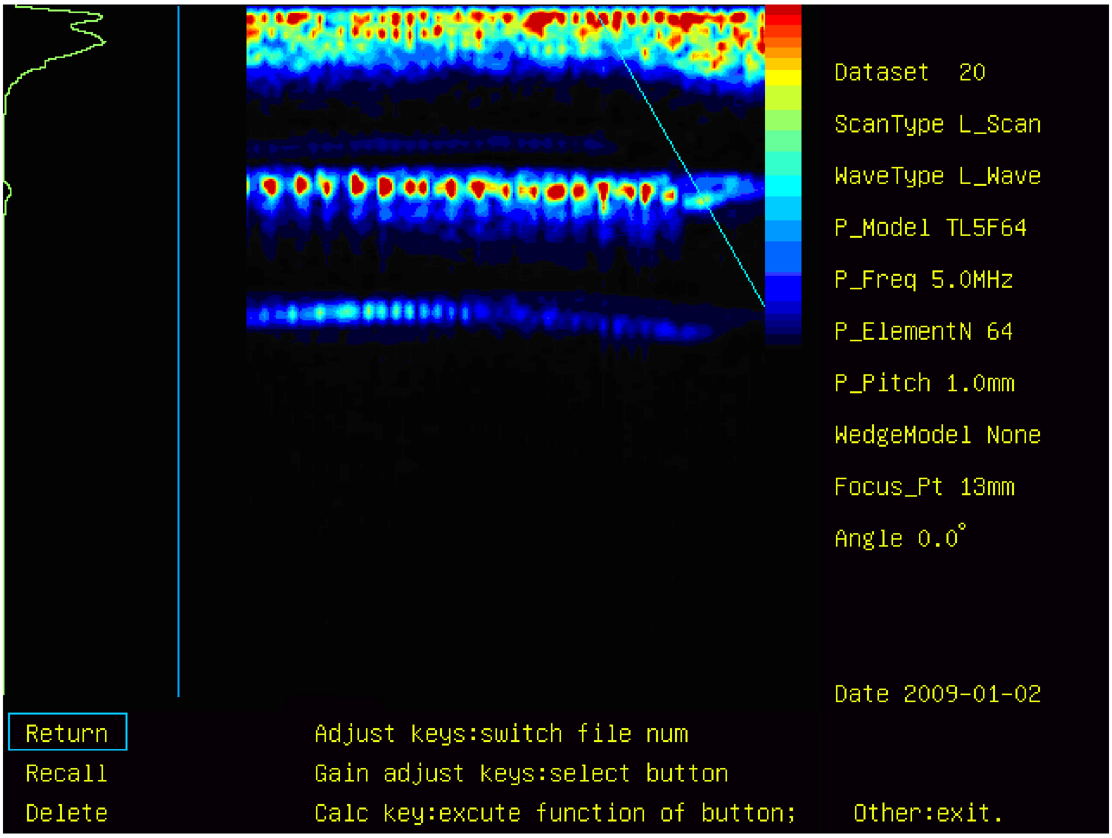

Fig. 14 Electro-fusion joints phase transition line

6. Phased Array Inspection for Heat Fusion Joints

Ultrasound phased array inspection can realize real-time two-dimensional image display of PE pipe heat fusion joints section. The heat fusion joint section shall be acquired and enable the transducer parallel to the fusion surface. Likewise, the horizontal scale shows the sound beam coverage area and the vertical scale shows the relative thickness between the PE pipe heat fusion joint and the transducer. The ultrasound from the probe will produce reflection wave when it reaches the fusion surface. With the reflection signals, the position, size and type of the reflection object can be confirmed. Similarly the phase transition line can be produced when ultrasound reaches the phase transition interface.

By making heat fusion joint samples with different flaws, and acquiring heat fusion joints with different specifications from manufacture sites, the **Phased Array Ultrasound Flaw Detector CTS-602, manufactured by Shantou Institute of Ultrasonic Instruments Co., Ltd. (SIUI)**, was used with phased array probes with different frequencies and elements and parameters well adjusted when performing experiments for anatomical verification.

Flaws such as cracks, un-fusion and foreign objects, can be detected by ultrasound phased array. A good fusion joint is shown as Fig. 15. From the phase transition line, fusion quality of the heat fusion joint can be determined. The ultrasound image clearly displays three lines, the middle of which is the fusion surface line and the other two lines on both sides are the phased transition lines. Ultrasound phased array of bad fusion of the fusion face is shown as Fig. 16. The ultrasound image displays the unfused fusion face due to insufficient heating temperature, and the signals of the fusion face line become extremely strong.

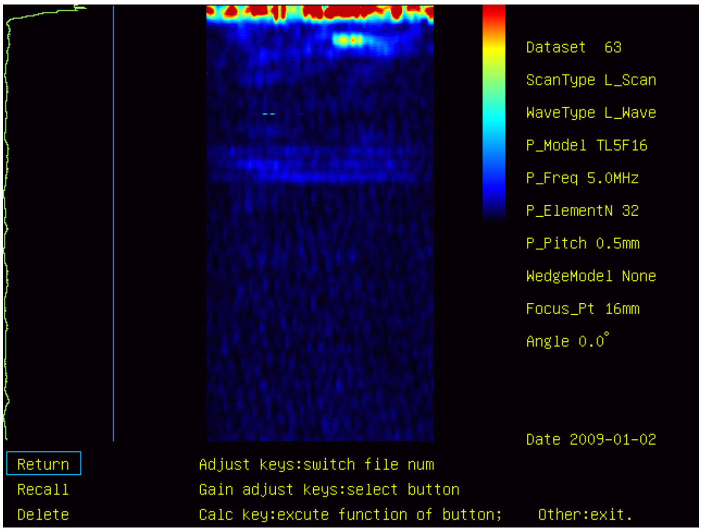

Fig. 15 Ultrasound phased array inspection for good heat fusion joint

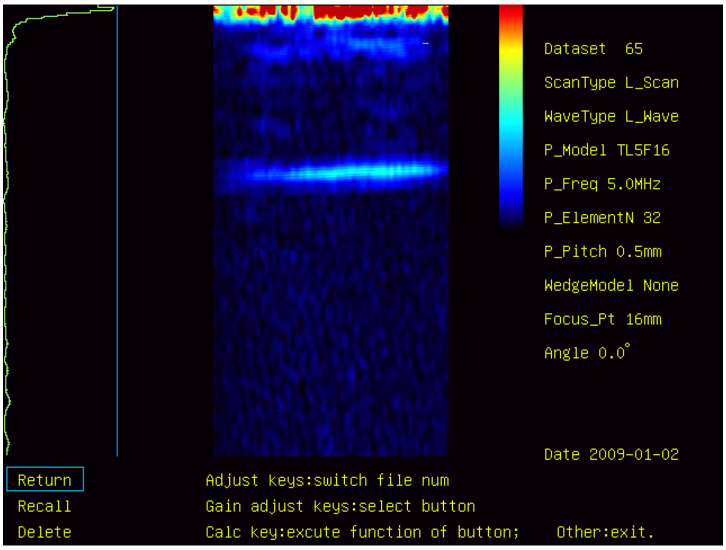

Fig. 16 Ultrasound phased array inspection for bad fusion on heat fusion joint face

7. Key Points of PE Pipe Phased Array Inspection

Ultrasound phased array can detect flaws in heat fusion joints or electro-fusion joints. Phased transition lines exist in both heat fusion joints and electro-fusion joints. By measuring the distance between the phased transition line and the heat fusion interface or the unfused pipe wall, connection quality can be determined.

The timing for ultrasound phased array inspection should be after joint cooling. After the joints are fused, the PE pipe gradually cools down. The best timing for inspection is when the pipes fully cool down.

The surface of the fusion pipe and the detected pipe should be clean. Observe carefully before fusion, and remove pollution like water, grass, dirt, dust, rain, ice or snow. Ensure that the condition of the test surface will not affect the inspection.

The appropriate probe for the ultrasound phased array inspection system shall be selected according to the actual situation, and the selected transducer shall match the pipe thickness.

For calibrating scan sensitivity, a test block is required. The test block should be made from material with the same or similar acoustic property of the detected PE pipe. The shape of the test block is shown as Fig. 17, with several side drilled holes at different depth.

Fig. 17 Test block for PE pipe ultrasound phased array inspection

Before inspection, side drilled holes should be selected with depth similar to the PE pipe thickness. Select the probe and adjust parameters like gain based on the inspection result, so as to obtain suitable image resolution and sensitivity of the side drilled hole and confirm that the requirements are met within the inspection range.

The resolving power of ultrasound phased array is determined by the minimum distance between two distinguishable signs of two side drilled holes. When the resolution on the thickness direction and the horizontal direction of the test block is confirmed, the system resolving power can be determined.

The radial direction of ultrasound phased array inspection range shall include the fusion area and the heat affected zone. The axial direction shall at least cover the nominal length range of the fusion. The nominal length refers to the fusion length after the wire is heated.

Coupling gel is required between the probe and the pipe, and it shall be applied to all over the test position surface. The selection of coupling gel should not be harmful to the product or the inspection process, and the same coupling gel shall be used for test block experiments and inspection. In ultrasound phased array inspection, sufficient area of the coupling gel shall be maintained between the probe and the pipe, and the force holding the probe be kept uniform to maintain the same thickness of the coupling gel.

8. Conclusion

Ultrasound phased array inspection can inspect fusion area in many positions. In ultrasound phased array inspection, the probe shall have good coupling with the pipe on the outer surface of the PE pipe wire. However, such position of many pipes have uneven surface, letter mark or steps.

Therefore a normal (straight-beam) probe does not couple properly with the PE pipe, which is not easy for inspection. The phased array focus position shall be adjusted to keep the probe away from such regions but test on the parts with good coupling. By making proper selection such as the inspection position, the scan direction and the probe, ultrasound phased array is for scanning areas difficult to be tested, and finish inspection on PE pipe electro-fusion and heat fusion joints.

9. Reference

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