Phased Array Ultrasonic Inspection on PE Pipe
Heat Fusion & 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. 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. In this paper, examples will prove 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 joints may result in PE pipe leakage or even accidents.

Management focus:
Control the connection process
Ultrasound testing
• Quick inspection speed
• No radiation
• Low budget
1. Introduction
PE pipe fusion joint defects:
• Cracks
• Un-fusion along the fusion line
• Foreign objects
• Dislocation of electro-fusion joint heating leads
• Gas holes

Fig.1 Good fusion line        Fig. 2 Fusion line with gas holes
2. Acoustic Characteristics of Polythene (PE)

2.1 Material Difference

2.2 Severe Attenuation

2.3 Velocity changes rapidly as temperature changes

2.4 Anisotropy
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. Under the same test frequency and temperature, velocity of various PE pipes is different.

Fig.3 Typical sample velocity (m/s)
2. Acoustic Characteristics of Polythene (PE)

2.2 Severe Attenuation

Ultrasonic attenuation coefficient in polyethylene is measured from the polythene hexahedron test block, as shown in Fig. 4. According to the test result, it is easier to get a higher reflection by using a low-frequency probe.

Fig.4 Polythene cubed test block
2. Acoustic Characteristics of Polythene (PE)

2.2 Severe Attenuation

Attenuation coefficient calculation:
An ultrasound flaw detector
Longitudinal wave normal probe
Use the height difference of multi bottom echoes beyond three times of near field for calculation.
Usually one magnitude higher than steels.
2. Acoustic Characteristics of Polythene (PE)
2.2 Severe Attenuation

Ultrasonic flaw detector: CTS-4020E by SIUI
Test material: steel & polythene (same thickness)

Steel: 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.

Polythene: 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. Acoustic Characteristics of Polythene (PE)

2.3 Velocity changes rapidly as temperature changes

Ultrasonic Thickness Gauge: CTS-49 by SIUI

Test material: A section of polythene pipe

Result: Temperature from -5°C to 58°C
Velocity from 2533 m/s to 2144 m/s

![Fig. 6 Velocity change with temperature](image-url)
2. Acoustic Characteristics of Polythene (PE)
2.4 Anisotropy
Velocity of polythene pipe is anisotropic.
Test block: Polythene hexahedron
A-A: Axial direction
B-B: Radial direction
C-C: Circular direction

Fig. 7 Sample of polythene pipe
2. Acoustic Characteristics of Polythene (PE)

2.4 Anisotropy

Measured velocity: same test block, same temperature (9°C)

Result: Velocity of each direction is different, which shows anisotropy.

Velocity high-low: circular direction, axial direction, radial direction.

Fig. 8 Velocity of different directions
3. Conventional Ultrasound Testing Method
For PE pipe joints: Longitudinal angle probes
The attenuation coefficient of longitudinal wave is lower.
Angled wedge: from PE pipe
Same material for angle probe wedge, test block and PE pipe.

Fig. 9 Probe with angled wedge and test block made from PE
3. Conventional Ultrasound Testing Method

Advantage: same velocity, 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 ladde.

No transverse wave reflection is available, which is useful for flaw identification.

Fig. 10 Adjusting scan speed with a ladder arc
3. Conventional Ultrasound Testing Method

Due to 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

Emitting
- Acquisition unit
- Phased array unit
- Trigger
- Pulses
- Probes
- Incident wave front
  - Flaw

Receiving
- Acquisition unit
- Phased array unit
- Echo signals
- Reflected wave front
  - Flaw
4. Characteristic of Phased Array
4. Characteristic of Phased Array

B Scan—Linear Scan
• Also called electronic scan or E scan
• Using a select window with a fixed size
• Scanning at a constant angle
• Along the phased array probe length
5. Phased Array Inspection for Electro-fusion Joints

Test equipment: PAUT by SIUI

Horizontal: the sound beam coverage area
Vertical: the relative thickness between the PE pipe electro-fusion joint and transducer.

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.
5. Phased Array Inspection for Electro-fusion Joints

The ultrasound image clearly indicates the wire signs, and the spots with colors show the heating wire of the fusion interface.

Fig. 11 Ultrasound phased array inspection for good fusion joint
5. Phased Array Inspection for Electro-fusion Joints

The ultrasound image displays the heating wire dislocated by over-heating.

Fig. 12 Ultrasound phased array inspection for heating wire dislocation
5. Phased Array Inspection for Electro-fusion Joints

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.

Fig. 13 Ultrasound phased array inspection for gas holes
5. Phased Array Inspection for Electro-fusion Joints
Electro-joints phase transition line can be identified properly. 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
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.

Fig. 15 Ultrasound phased array inspection for good heat fusion joint
6. Phased Array Inspection for Heat Fusion Joints
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. 16 Ultrasound phased array inspection for bad fusion on heat fusion joint face
7. Key Points of PE Pipe Phased Array Inspection

- PAUT inspection
- The appropriate probe
- Test block
- Adjust parameter
- Phase transition line
- Pipes fully cool down
- Clean surface

Fig. 17 Probes and Test block for PE pipe phased array inspection
8. Conclusion

Ultrasound phased array inspection can inspect fusion area in many positions. 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.
Municipal water and waste water pipelines
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