Ultrasonic Phased Array Non-Destructive Testing and In-Service Inspection System for high integrity Polyethylene Pipe Welds with automated analysis software

N. Thorpe¹, M. Acebes¹, D. Wylie², M. Troughton², O. Gilmour², O. Roy³, G. Benoist³, R. Dweik⁴

¹ Tecnitest Ingenieros, Spain, comercial@tecnitest.com
² TWI, United Kingdom, Doug.Wylie@twi.co.uk
³ M2M, France, o.roy@m2m-ndt.com
⁴ Palad HY, Israel, ramid@palad.co.il

Abstract

The traditional way to ensure the quality of Butt-Fusion (BF) and Electrofusion (EF) welded joints in Polyethylene (PE) pipes during installation is by controlling the welding parameters used, together with a visual inspection and a hydrostatic pressure test. As part of the quality control process, these tests are complemented by destructive test on representative welded joints.

The main disadvantage for visual inspection is that only the outer surface of the pipeline can be examined. Although the hydrostatic pressure test normally tests every joint for gross flaws for the short-term integrity of the pipeline; there’s no guarantee in the long-term. In addition, destructive testing can only be carried out on representative welded joints, rather than the joints that will be in service, and only tests a small percentage of the circumference of the weld. For this reason, the integrity of the pipeline can’t be ensured.

On the contrary Non-destructive volumetric testing can provide a complete analysis of the whole welded joint, removing the requirement for destructive tests.

In this paper, the PolyTest™ technology is presented. This non-destructive inspection system Phased Array Ultrasonic Testing (PAUT) shows the weld joint integrity level of PE pipe systems commensurate to the safety critical function of the pipe component and furthermore opens up new uses for PE pipe in the energy industry that haven’t yet been possible due to the lack of a suitable commercially available inspection and testing transducers/sensors and data analysis software.

The overall concept is based on taking an existing proven PAUT – NDT technique and through a process of product engineering and signal processing/software algorithms enabling the rapid inspection of PE pipe BF and EF welds with automated data processing and automated defect recognition (ADR) such that the reliance on laborious, time-consuming and subjective manual inspection data evaluation is eliminated.
1. Introduction

Polyethylene (PE) pipes offer significant advantages over other materials for the transportation of fluids. They do not corrode and have a longer predicted service life leading to less frequent replacement, they are less expensive to install due to their light weight and flexibility, and they have significantly lower leakage rates due to having an all-welded system. However, their use in safety critical environments is being restricted by the lack of a proven, reliable non-destructive testing (NDT) method for the welded joints.

The current practice for assuring the quality of butt fusion (BF) and electrofusion (EF) joints in PE pipes during installation is by recording the welding parameters used, together with a visual inspection of the welded joint and a short-term hydrostatic pressure test, supplemented by the destructive testing of joints on a sample basis using a short-term test on specimens cut from the joint. However, visual inspection can only examine the external surface of the pipe joint; it cannot provide evidence of embedded flaws or cold welds. Also, previous work at TWI [1,2] has suggested that the hydrostatic pressure test will only cause BF and EF joints to fail if they contain gross defects. In addition, if a defect exists in a welded joint there is only a small chance that it will be included in a specimen that has been cut for mechanical testing. Finally, mechanically testing a joint and then replacing it with one of unknown quality does not ensure the integrity of the pipeline.

Volumetric NDT can provide a complete analysis of the whole joint and does not destroy perfectly good joints. It is therefore the only method that has the potential to ensure the integrity of the installed joints in a PE pipeline. However, in order to do this, the NDT technique must be proven to detect all possible types of flaws that reduce the integrity of the joint.

In recent years PAUT has been considered for assessing the integrity of both BF [3-7] and EF [8-10] joints. However, these have been limited to a narrow range of pipe sizes and/or have not included flaw acceptance criteria.

Taking this situation as a starting point, the results of the polytest project are presented in this paper. PolyTest™ is a field inspection system for volumetric non-destructive testing of electrofusion and butt fusion joints in polyethylene (PE) pipes. The equipment has been designed and optimised to provide:

- phased array ultrasonic probes, operating at the optimal frequencies
- a simple and flexible scanner to accommodate pipes with outside diameters from 90-900mm, with a maximum wall thickness of 72mm.
- membrane water wedges to reduce the electronic steering with the probe elements while still covering the weld fusion zone

The system enables detection of all types of flaw that can occur in PE pipe welds including planar flaws, particulate contamination and cold welds. TWI has carried out extensive performance testing to determine the acceptance criteria that should be applied, and has been used in the field as an advanced prototype on a variety of inspection projects.
Feedback from the operators from over five years of in-field use with the current version was collected and has formed the starting point for system improvements during the PolyTest project.

2. Development of phased array ultrasonic testing techniques for PE pipes

The BF and EF joint types require very different inspection techniques. The techniques used for both types of joints are shown in Figure 1.

![Figure 1](image)

The inspection technique for EF joints is a 0-degree linear scan, focusing on the fusion zone between the fitting and the pipe; see Figure 1(a). The most critical factors for the inspection of EF joints are the coverage and the resolution. The fusion zone is normally located below the heating wire and sufficient resolution for inspection between the turns of wire is required.

For the inspection of BF joints two different techniques are used; sector pulse-echo and creeping wave; see Figure 1(b). The techniques are complementary in terms of coverage. The sector pulse-echo technique uses all the elements in the probe array to create an aperture, sweeping the beam over a range of angles to cover most of the fusion zone, except for a few millimetres close to the outer surface. The creeping wave technique is designed to cover the region close to the outer surface, which is the part of the weld not covered by the sector pulse-echo technique [11].

3. Inspection System

The PAUT inspection system consists of a number of components: a phased array probe, which produces the ultrasonic signal and detects the reflected signals from any flaw in the joint; a probe wedge, which ensures that the ultrasound is transmitted from the probe into the PE pipe or fitting at the correct angle and with the minimal loss of energy; a probe holder, which ensures good contact between the probe wedge and the PE pipe/fitting around the whole circumference; a scanner, which carries the probe assembly around the pipe joint without any movement in the axial direction and records its circumferential position; and a flaw detector, which sends electrical signals to the probe elements and analyses the returning signals.

In this project, the design of each of these components has been optimized specifically for inspecting PE pipes.
4. Requirements

4.1 The PolyTest™ Scanner - Complete System Requirements

The PolyTest™ scanner system is supplied with a chain link scanning mechanism containing a probe carriage with positional encoding, holding a phased array UT probe housed in a water filled membrane wedge.

Three different probe/wedge combinations are available for inspection of butt fusion and electrofusion pipe welds covering a range of pipe diameters and wall thickness. An optional fourth probe/wedge is available on request for thick section electrofusion joints.

- The scanner system shall be robust and capable of operating reliably under normal site conditions in different sectors
- The scanner system shall be IP67 Rated
- The scanner system shall be easily attached/removed from the pipe and weld by one operator
- The scanner system shall be capable of producing encoded phased array UT data on any commercially available PAUT equipment
- All parts shall be capable of replacement without the need of specialist tools and under normal site or workshop conditions
- Where possible, parts should not be sourced from other NDT scanner or equipment suppliers, where withdrawal of a critical component could prevent operation or reduce capability of the system

4.2 Validation Samples

The butt fusion (BF) and electrofusion (EF) welded samples to be made in the project are required for a number of different reasons:

- To determine the probability of detection (POD) of planar lack of fusion flaws;
- To validate the automatic defect recognition (ADR) procedures;
- To validate defect sizing capabilities of the system;
- For the training course and examination for the inspection personnel.

Each welded joint should contain a number of lack of fusion flaws of different size and each flaw should be positioned randomly around the joint. To simulate lack of fusion flaws in a consistent and reproducible way, thin (40μm) aluminium discs were used.

For the BF joints, the overall pipe wall thickness range of interest in the project is between 10 and 72mm. It was agreed that three wall thickness ranges would be investigated: 10-15mm; 25-35mm;>50mm.

The chosen pipe sizes that cover these ranges were:

1. 110mm diameter SDR11 (wall thickness 10.0mm);
2. 315mm diameter SDR11 (wall thickness 28.6mm);
3. 630mm diameter SDR11 (wall thickness 57.2mm).
For the EF joints, the overall pipe diameter range of interest in the project is between 90 and 800mm. It was agreed that EF fittings from three different manufacturers and three pipe size ranges for each EF fitting manufacturer would be investigated: 90-125mm; 180-315mm; 450-800mm.

The chosen pipe sizes that cover these ranges were: 110mm SDR11; 225mm SDR11; 630mm SDR11.

It was also agreed that, for the BF joints, the smallest flaw should have a diameter of 1mm and the largest flaw should have a diameter of 8mm or 50% of the pipe wall thickness, whichever is smaller. For the EF joints, the lack of fusion flaws should be between 2 and 50mm in diameter and, in addition, pipe under-penetration should be investigated, where the amount of under-penetration is between 0 and 20% into the fusion zone.

Figure 2 Pipes for the project provided by Palad HY Industries.

5. Instrument, PAUT, Scanner, Software Integration

One of the key activities is the introduction of automatic defect recognition (ADR) in to a bespoke PolyTest operating system on the Gekko phased array controller.

M2M have developed a bespoke software package for installation on the Gekko array controller that will utilize an image driven method of selecting the required parameters for inspection of any given butt fusion (BF) or electrofusion (EF) weld joint in HDPE piping utilizing the PolyTest phased array ultrasonic testing system. This uses bespoke phased array probes fitted to water membrane probes, both of which are designed specifically for the PolyTest system.

These bespoke probe and wedge parameters are pre-loaded into the PolyTest version of the software, along with the range of BF and EF weld configurations that will enable fast setup and good inspection repeatability.

A large quantity of data is acquired from phase array ultrasonic inspections. This data is stored in a three-dimensional array, the length of which is determined by the number of samples in the signal, the number of scans performed and the number of measurement points around the circumference of the pipe. Defect detection in such large data sets is
not a straightforward task, despite the computational power available on modern computers.
The objectives are to:
1. Develop ADR algorithms for EF and BF joints
2. Integrate these algorithms into the Gekko Platform Development Kit (PDK) software
3. Validate both EF and BF algorithms on multiple data sets.

Before arriving at final versions for the EF and BF ADR algorithms, these algorithms need to be extensively tested on pipes with different diameters and wall thicknesses.

6. Development of the inspection system

6.1. Chain Link System
- The scanner length shall be easily adjusted without the need for tools, to accommodate a range of pipe diameters.
- The scanner shall provide a means of moving it around the pipe without discomfort or undue effort from the operator.
- The chain tension shall be adjustable to ensure scanner tracks around the pipe without axial drift.
- The scanner should provide a means of maintaining a constant chain tension to accommodate pipe ovality and repeated fitting across a range of pipe diameters.

6.2. Probe Carriage
- The probe shall be capable of easy adjustment in the pipe axial length
- The probe shall be held onto the scan surface in all orientations without operator input
- The probe mounts shall provide a quick means to replace the probe wedge body, with either no or minimal requirement for tools, under normal field conditions
- The carriage shall include the positional encoder and provide means to maintain its force on the scan surface in all orientations under normal field conditions
- The carriage shall permit vertical movement of the wedge to fit all thickness of EF collar (within the scope of the system)
- Shall maintain the probe alignment to the pipe axis throughout the scan

Figure 3 Upgraded CAD model with BF wedge and prototype in use on EF joint
6.3. Phased Array Probes

- Probes shall be supplied meeting the specifications of the PolyTest™ system
- Probes shall be supplied meeting the requirements of ISO/18563-1:2015, Non-destructive testing – Characterization and verification of ultrasonic phased array equipment – Part 1: Instruments.
- Probe connection shall be appropriate to the Phased Array acquisition unit specified in for the combined system

6.3.1. Butt fusion probe
The BF probe has 32 elements to generate a focussed beam across a selected angular range. There were initially two probes; 2.25MHz and 4.0MHz, to cover the thin (<20.0mm) and thick (>20.0mm) pipe wall thickness ranges. They were different sizes and thus necessitated separate angled wedges.

The new probe design simplifies the probe package design and has a requirement to house both frequency array options in the same probe package, to enable the wedge to be designed to accommodate either frequency probe.

![Figure 4 New 4.0MHz and 2.25MHz, 32 element PolyTest bespoke probes](image)

6.3.2. Electrofusion probe
The EF probe has 128 elements to generate a focussed beam along the length of the array, which is intended to be wide enough to enable coverage of the full fusion zone width without axial probe movement.

As with the BF probes, there are two frequencies; 3.5MHz and 5.0MHz, with the original probes having different dimensions and additionally different shapes, again necessitating different wedge designs.

As with the BF probes, they follow the same probe package design simplification with the advantage of a single wedge and simplified fitting for all EF fitting sizes.

![Figure 5. New 5.0MHz and 3.5MHz, 128 element PolyTest bespoke probes](image)
6.3.3. Membrane Wedges
Weight and parts reduction objectives lead to the decision to design a single wedge capable of accommodating both high and low frequency probes for each weld type and thus wedge type, thereby reducing the number of wedges by 50%. Both wedge types had to be compatible with the mounting system, taking weight reduction into consideration and having built in anechoic features for dispersal of internally reflected ultrasonic energy from the water/membrane interface. ‘V’ features enable the sound to be absorbed at the surface, so that they do not make it back to the probe face and generate unwanted probe/wedge noise which can generate standing signals that interfere with data analysis and interpretation.

![Figure 6. Butt Fusion wedge](image)

7. Conclusions

There is an estimated 11.5 billion metres of polyethylene (PE) and plastic industrial piping globally, carrying essential and in many cases potentially hazardous and safety-critical fluids.

There are an estimated 700 million PE (or closely similar equivalent plastic) welds worldwide, mainly concentrated in the energy, gas, water, mining and process plant industry sectors. The need for a commercially available system for the inspection of welds in PE/plastic piping is clear.

The PolyTest project consortium brings together all the necessary expertise to develop the already successful PolyTest system and realise its true potential as an invaluable inspection tool for all industries using PE/plastic piping.

Essential to its success are compliance with standards, reliability and sufficient robustness for use in all industrial environments, a consistent approach through well-developed and validated procedures, high-quality training of PE/plastic pipe inspection personnel and through-life product support.

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References