DESARROLLO Y VALIDACIÓN DE UN SISTEMA DE ENSAYO NO DESTRUCTIVO PARA INSPECCIÓN AUTOMATIZADA DE UNIONES SOLDADAS EN TUBERIAS DE PLASTICO. PROYECTO EUROPEO TESTPEP

DEVELOPMENT AND VALIDATION OF AN AUTOMATED NDE APPROACH FOR TESTING WELDED JOINTS IN PLASTIC PIPES EUROPEAN PROJECT TESTPEP.

***R. RODRÍGUEZ*[1], *M. TROUGHTON*[2]**

[1]*Asociación Española de Ensayos no Destructivos (AEND); Madrid. España*

r.rodriguez@aend.org

[2]*TWI; Granta Park, Great Abington, Cambridge. UK*

mike.troughton@twi.co.uk

Resumen

Las tuberías de plástico ofrecen avances significativos sobre otros materiales como acero, cobre y hormigón para el transporte de fluidos como gas natural, agua y líquidos corrosivos.

Actualmente, la mayor parte de las tuberías de distribución de gas y agua en Europa son de plástico, o se ha previsto su sustitución, en un futuro inmediato, por otras del mencionado material. Muchas de las fugas en esas tuberías de plástico tienen su origen en la fusión inadecuada de las uniones soldadas. El mejor método para atenuar el riesgo de fugas, y mantener la calidad de las uniones soldadas en las citadas tuberías, es inspeccionarlas previamente a su puesta en servicio. Sin embargo, no hay ningún método de END aceptado para el ensayo de tuberías de plástico. Esto ha restringido el uso de estos sistemas de tuberías para aplicaciones más exigentes, como es el caso de la industria nuclear, como consecuencia de la falta de confianza en su fiabilidad a largo plazo.

El principal objetivo del proyecto TestPEP, el cual es parte del Séptimo Programa Marco de la Comunidad Europea, es diseñar y construir un único instrumento que pueda ser usado para inspeccionar uniones de tubos realizadas a tope y por electofusión de tuberías de polietileno con diámetros hasta 1.000 mm. Se requerirá que el instrumento tenga suficiente memoria para almacenar los datos de una inspección y descargarlos en un ordenador. El prototipo del equipo diseñado y construido como parte del proyecto será evaluado en condiciones de laboratorio y de campo.

Palabras clave: *Ultrasonidos, soldadura, Phased Array, plásticos, tuberias*

Abstract

Plastic pipes offer significant advantages over other materials such steel, copper and concrete, for the transportation of fluids such as natural gas, water, and corrosive liquids.

Most new European gas and water supply distribution pipelines are now made of plastic or are planned to be upgraded to plastic over the next few years. Many of the leaks in these plastic pipelines arise from improperly fused welded joints. The best method of alleviating the risk of leaks and maintaining the quality of welded joints in plastics pipes is to inspect them prior to service. However, there is no accepted NDE method for the examination of plastic pipes. This has restricted the use of welded plastics pipe systems for more demanding service applications such as in the nuclear industry, because of a lack of confidence in the long-term reliability of these systems.

The main objective of the TestPEP project, which is part of the European Commission's Seventh Framework Programme, is to design and make a single instrument that can be used to inspect both butt fusion and electrofusion joints in polyethylene pipes of diameters up to 1,000 mm. The instrument will be required to have sufficient memory to store an inspection and download the data to a computer.

The prototype NDE equipment, designed and built as part of this project will be assessed under both laboratory and field conditions.

Keywords: *Ultrasonic, weld, Phased Array, plastic, pipeline*

1. ANTECEDENTES

Los tubos de plástico ofrecen ventajas significativas sobre otros materiales como acero, cobre y hormigón, para el transporte de líquidos como gas natural, agua y efluentes líquidos corrosivos. No se corroe; tiene una vida prolongada durante el servicio, con sustituciones menos frecuente; su instalación es menos costosa debido a su flexibilidad y poco peso; se producen menos fugas debido al proceso de soldadura. Sin embargo, su uso generalizado está siendo restringido por la falta de un método fiable de evaluación no destructiva (END) para las uniones soldadas, así como la falta de criterios de aceptación y rechazo. Las fugas en tuberías no sólo causan grandes gastos de reparación, sino que además pueden tener consecuencias desastrosas para el medio ambiente e incluso ocasionar la pérdida de vidas

Plastics pipes offer significant advantages over other materials such as cast iron, steel, copper and concrete, for the transportation of fluids such as natural gas, water, effluent and corrosive liquids. They do not corrode; 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 have significantly lower leakage rates due to having an all-welded system. However, their more widespread use in safety environments is being restricted by the lack of a reliable non-destructive evaluation (NDE) method for the welded joints, and no flaw acceptance criteria. Pipeline leakage does not only cause high repair costs but can also result in disastrous environmental consequences and even in loss of life

Although there are European standards for the volumetric inspection of plastic pipe welds there is a lack of commercially available systems for inspecting these welds. All large diameter steel pipes for the transportation of both natural gas and LPG are subject to volumetric inspection. The current best practise for inspection of these steel welds uses ultrasonic phased array NDE. From this evidence it is clear that the plastic pipe industry is out of step and lagging well behind the steel pipe industry. The main reason is because plastic is a difficult material to inspect due to its very specific acoustic properties of high attenuation and low ultrasonic velocity.

Several studies have been conducted to develop a reliable NDE method for welded plastic joints. The studies have focussed on the two main techniques for plastic pipe welding, electrofusion (EF) and butt fusion (BF). In recent years, phased array ultrasonic technology (PAUT) has been considered to assess the integrity of EF-joints (1, 2). However, these studies concentrated on specific pipe sizes with outer diameters (OD) of 125 and 250mm.

The main advantage with using a phased array probe on these joints is that the fusion zone in the pipe direction is covered by electronic scanning within the probe and mechanical scanning is only required in the circumferential direction. This solution provides huge advantages when it comes to inspection time and data interpretation.

BF-joints have been examined using conventional ultrasonic transducers (3, 4, 5). However, due to the BF joint geometry a combination of several ultrasonic techniques is required to achieve sufficient coverage of the fusion zone. The techniques that have been employed include pulse-echo, tandem, creeping waves, and time of flight diffraction (TOFD).

In recent years, studies have been conducted to inspect BF joints using PAUT (6, 7). The main technique used was the pulse-echo, where a sector scan of the fusion zone is achieved by steering the beam at different angles.

Currently, the only commercial ultrasonic inspection systems for plastics pipes are in North America and South Korea (8, 9). The American system is limited to BF welds and uses conventional TOFD rather than phased array and, as a consequence it is not applicable to more complex weld configurations such as elbows, reducers and tees. The Korean system is limited to EF-joints and does not record data.

In addition to the ultrasonic techniques, other NDT techniques have been considered for the examination of plastic pipes, including thermography and microwave interferometry. However, the validity of these techniques has not been proven.

El proyecto TestPEP forma parte del 7º programa marco de la Unión Europea. El coordinador del proyecto es el TWI siendo los miembros actuales los que se muestran en la tabla 1

This project is part of the 7th framework programme of the European Union. The coordinator of this project is TWI and the current partners are listed in the table 1

Asociaciones industriales/Industry Associations	**Centros de investigación/Research Organisations**
European Federation for Welding, Joining and Cutting (Portugal) Asociación Española de Ensayos no Destructivos (Spain) Surface Mount and Related Technologies (UK) Pipeline Industries Guild (UK) Associazione Italiana Prove non Distructive (Italy)	TWI (UK) Hessel Ingenieurtechnik (Germany) Kaunas Technical University (Lithuania) Consorzio Catania Ricerche (Italy)
Fabricantes/Manufacturers	**Usuarios de END/End Users**
Vermon (France) Isotest Engineering (Italy) M2M (France)	E.ON Ruhrgas (Germany/Alemania) British Energy (UK/Reino Unido)

Plasflow (UK)	

Tabla 1. Composición del consorcio del proyecto

El proyecto TestPEP pretende el desarrollo de técnicas y equipos de ensayos no destructivos mediante ultrasonidos phased array para el examen volumétrico de uniones soldadas en tubos de plástico hasta 1 m de diámetro. Además, el proyecto desarrollará un sistema de inspección automatizada que será capaz de inspeccionar las uniones a tope de tubería con tubería y de tubería con accesorios en diversos materiales plásticos y diámetros entre 90 mm y 1.000 mm.

The TestPEP project will develop phased array ultrasonic NDE procedures, techniques and equipment for the volumetric examination of welded joints in plastics pipes of diameters up to 1m. In addition, the project will develop an automated inspection system that will be able to inspect pipe-to-pipe and pipe-to-fitting butt and socket joints in various plastic pipe materials and diameters between 90mm and 1000 mm.

Un objetivo fundamental del proyecto es desarrollar un sistema de inspección que sea resistente y fácil de utilizar. El concepto de este proyecto es disponer de un instrumento de caja negra con una simple conexión ethernet para descargar los datos registrados y proporcionar la necesaria solidez de la sonda de ultrasonido Phased Array, de tal modo que, a través de un análisis semiautomático, se obtenga cómo respuesta la aceptación/rechazo de las soldadura y el sistema pueda ser operado por el personal habitual de tendido de tuberías.

A crucial aim of the project is to develop an inspection system that is site-rugged and simple to operate. The concept in this project is to have a black box instrument with a simple ethernet connection to download the recorded data, and to provide the necessary robustness of the phased array probe. Another objective of the project is to analyse the data semi-automatically so that a red/green (yes/no) answer can be provided for the quality of the welds and the system can be operated by normal pipe laying technicians.

El desarrollo se hará para uniones soldadas que contienen discontinuidades conocidas. Se analizarán los datos para determinar los límites de detección para cada técnica. En paralelo, se establecerá la importancia de la cantidad y tamaño de defecto en relación con los requerimientos de servicio. Esto se logrará mediante pruebas mecánicas a largo plazo de las uniones que contienen discontinuidades conocidas y la comparación con los resultados obtenidos para soldaduras que no contienen discontinuidades.

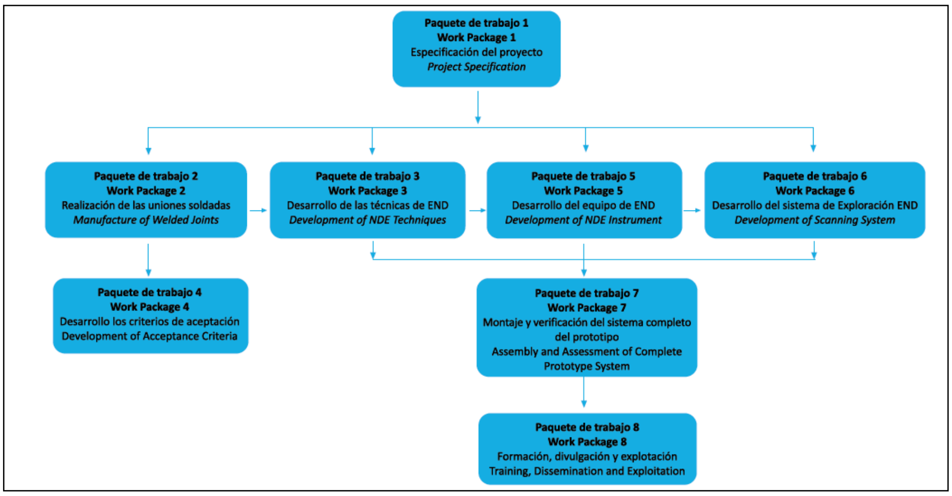
The development will be made by manufacturing welded joints containing known flaws. The NDE data will be analysed to determine the limits of flaw detection for each technique. In parallel, the significance of flaw size and quantity will be established in relation to service requirements. This will be achieved by long-term mechanical testing of joints containing known flaws, and comparison with results for welds containing no flaws.

El prototipo del equipo diseñado y construido como parte de este proyecto se evaluará en condiciones de laboratorio y de campo.

The prototype NDE equipment, designed and built as part of this project will be assessed under both laboratory and field conditions

2. ESTRUCTURA DEL PROYECTO

El proyecto se estructura en 8 paquetes de trabajo según se muestra en la figura 3.
The project structure has 8 work packages as shown in figure 1



Paquete de Trabajo 1 Especificación del proyecto. Las asociaciones Industriales que forman parte del consorcio han realizado estudios entre sus miembros a fin de definir los materiales plásticos (p. e. PE, PP, PVC, PVDF y ABS), rango de tamaños de los tubos y tipos de juntas (p.e. fusión a "a tope", electrofusión, tubo-a tubo, tubo-a-accesorio) que son de más interés para las compañías europeas involucradas en la industria de los tubos de plástico.

3

Asimismo, se han investigado los principales tipos de discontinuidades que pueden aparecer durante la soldadura de tubos de plástico en campo.

The Industry Associations in the consortium have conducted survey among their members in order to define the plastics materials (e.g. PE, PP, PVC, PVDF and ABS), pipe size ranges and joint types (e.g. butt fusion, electrofusion, pipe-to-pipe, pipe-to-fitting) that are of most interest to European companies involved in the plastics pipes industry.
Also, the main types of discontinuities that may appear during the welding of plastic pipes in field have been investigated.

También es esencial que el sistema de END TestPEP desarrollado (equipo, palpadores "phased array", técnicas y software de proceso de datos) esté directamente relacionado con las necesidades del mercado. Por esta razón, las asociaciones industriales deberán realizar estudios entre sus miembros a fin de desarrollar una especificación funcional para los sistemas de END.

It is also essential that the developed TestPEP NDE system (equipment, phased array transducers, techniques and data processing software) is directly relevant to the market needs. The Industry Associations have therefore also surveyed their members in order to develop a functional specification for the NDE system.

Con las 72 respuestas obtenidas desde 10 países diferentes se establece que:

- En el 82 % de los casos el material utilizado es polietileno (PE)
- Un 72% de las tuberías está comprendido entre 110 mm a 1000 mm.
- El tipo de soldadura empleada es por electrofusión en un41% y a tope en un 42%.
- El tipo de uniones entre tuberías y accesorios (codos, reducciones uniones en T) es diversa, bien sean estos fabricados o moldeados.

With the responses obtained from 10 different countries provides that:

- In 82% of the cases the used material is polyethylene (PE)
- 72% Of the pipes is comprised from 110 mm to 1000 mm.
- The type of used welding is by electrofusion is 41% and by butt fusion is 42%.
- The type of joints between pipes and fittings (reductions, T joints, elbows) is diverse, and the fittings are both fabricated and molded.

Como discontinuidades típicas se encuentran:

Falta de penetración 19%	Soldadura fría 25%	Partículas gruesas 14%
Discontinuidades planas 19%	Partículas finas 20%	

As typical discontinuities are:

Lack of penetration 19 %	Cold welding 25 %	Coarse particles14%
19% Flat discontinuities	20% Fine particles	

Basándose en la información proporcionada, se han elegido dos tipos de tubo de poleitileno (PE 80 y PE 100) con uniones soldadas por electrofusión y a tope para ser examinados dentro del ámbito del proyecto, y serán evaluados hasta cinco tamaños de tubo y cinco tipos de discontinuidades

Based on the information provided, two types of tube PE have been chosen (PE 80 and PE 100), welded by electrofusion and by butt fusion, to be examined in the project, and for each material up to five pipe sizes and five flaw types will be assessed.

Las dos técnicas principales utilizadas para soldar tubos de plástico son la soldadura a tope por fusión y la electrofusión.

The two main techniques for welding plastics pipes are butt fusion welding and electrofusion welding

Soldadura a tope.
En la soldadura a tope por fusión (Figura 1), los extremos de los tubos, que han sido cortados a escuadra y alisados, son empujados contra una placa calefactora de metal hasta que funden, en ese momento se retira la placa y los tubos son empujados uno contra otro dejándolos enfriar hasta que forman la unión soldada.

In butt fusion welding (Figure 2) the pipe ends, which have been cut square and flat, are pushed against a heated metal plate until they melt; the plate is then removed and the pipes are pushed together and allowed to cool, forming a weld.

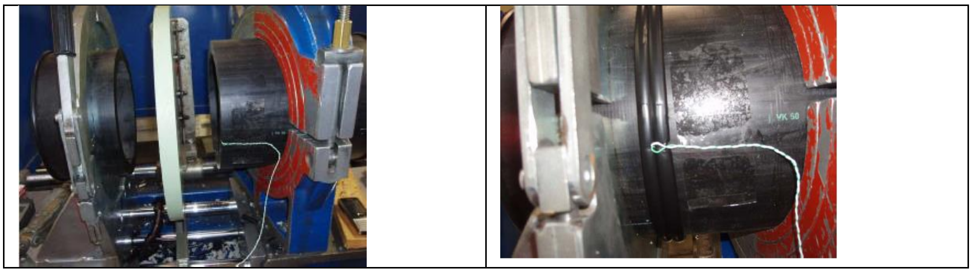


Figura 2 Soldadura de tubos a tope (PLASFLOW)

Electrofusión

En la soldadura por electofusión los extremos de los tubos son empujados en el interior de ambos lados del accesorio EF, el cual contiene una bobina calefactora en su interior (Figura 2). Se hace pasar corriente a través de la bobina, que calienta el interior del accesorio y el exterior de los tubos hasta la fusión, `produciendo la soldadura.

In electrofusion welding the pipe ends are pushed into either end of the EF fitting, which contains a coil of heating wire in the inside (Figure 3). Current is passed through the coil, which heats up and melts the inside of the fitting and the outside of the pipes, producing a weld.

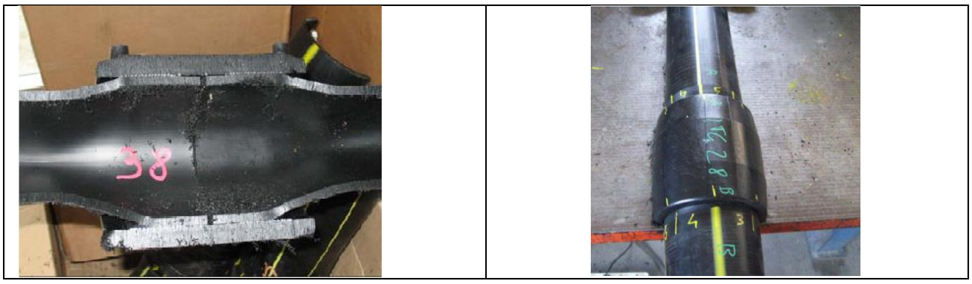


Figura 3 Soldadura por electrofusión (ISOTEST)

The ultrasonic phased array NDE techniques will be developed in Work Package 3 for the detection of defects in the joint types and plastic pipe materials defined in Work Package 1. This will include the technical and functional specifications of phased array probe design and the technical specification of the ultrasonic instrument and manipulator. In addition, this task will develop the spatial data analysis algorithms required for the EF welds. The material properties of the chosen plastics will be defined as well as the methods to overcome the very slow acoustic velocity and highly attenuative nature of these materials. These two factors will be incorporated into the ultrasonic probe specification.

Material properties

The acoustic properties of PE, frequency dependent velocity and attenuation of longitudinal waves, need to be determined for development of the NDT techniques, configuration of the NDT equipment, detecting and measuring wall thickness and flaws, and for the modeling that is used during the inspection technique development.

The ultrasonic properties will need to be determined for different grades of PE to be able to develop and calibrate the inspection techniques. However, at this stage, ultrasonic properties have only been measured for one grade of PE pipe.

Eight samples with parallel surfaces were manufactured from a pipe. The thickness of the samples ranged from 2.5-20.0mm. The measurements were conducted using an immersion pulse-echo technique using ultrasonic transducers with centre frequencies of 1-5MHz. The result did not indicate any significant frequency dependency and the mean value of the ultrasonic velocity was 2240m/s, with a variation of ±10m/s.

Results showed that the variation of the estimated velocities is highly dependent on the accuracy of the thickness measurement and a variation of 10µm (0.4%) gives a change of 9m/s. The eight samples were also used to determine the attenuation in the material. The results showed an attenuation increasing by 0.3dB/mm with a frequency increase of 1MHz, starting at 0.2dB/mm at 1MHz.

Paquete de trabajo 2. Realización de las uniones soldadas.

Se deberán realizar una serie de uniones soldadas conteniendo las diferentes discontinuidades definidas en el Paquete de trabajo 1, con los materiales, tipos de junta y tamaños de tubería, también definidos en el mencionado paquete de trabajo, habida cuenta que tanto para la validación de los END, como para los criterios de aceptación, es necesario conocer el tamaño exacto de cada discontinuidad y/o la cantidad discontinuidades, muchas de las cuales pueden ser simulaciones idealizadas de discontinuidades reales que pueden encontrarse "en campo". Basados en la experiencia previa, los tipos de discontinuidades serán, probablemente, discontinuidades planas, simulando huellas de dedos, aceite, grasa y gotitas de lluvia, partículas finas, polvo en suspensión en el aire, partículas gruesas, arena y suciedad, soldaduras con aporte de calor reducido, que pueden tener lugar en campo si no se siguen los procedimientos correctos, y específicamente para las soldaduras “shocket”, penetración incompleta del tubo en el accesorio, que puede ocurrir cuando en campo no se utilizan abrazaderas de montaje (“pipe clamps”).

A range of welded joints containing the various flaws defined in Work Package 1 have been made in the materials, joint types and pipe sizes also defined in Work Package 1. Since, for both the NDE assessment and the acceptance criteria, it is necessary to know the exact size and/or quantity of each flaw, most of the flaws chosen were idealised simulations of actual flaws that may be encountered in the field. Based on previous experience, the flaw types are likely to be planar flaws, simulating fingerprints, oil, grease and rain droplets; fine particulates, simulating airborne dust; course particulates, simulating sand and dirt; welds with reduced heat input, which can occur in the field if the correct procedures are not followed; and specifically for socket joints, incomplete penetration of the pipe into the fitting, which can occur in the field if pipe clamps are not used.

For the development of the techniques on BF joints, flat bottom holes (FBHs) and slots in unwelded pipes were used. The FBHs were machined at the pipe ends and the slots were machined in the middle of the pipe. The sizes of the test samples are shown in Table 2.

BF pipe	100 mm SDR 11	220 mm SDR11	355 mmSDR11	450 mm SDR17	710 mm SDR 17
EF fitting	100 mm SDR 11	220 mm SDR11	355 mmSDR11	450 mm SDR17	710 mm SDR 17

Tabla 2 Tamaños de tuberías utilizadas para el desarrollo de las técnicas

The slots were used to evaluate the creeping wave and TOFD techniques. The FBHs were used to evaluate the sector pulse-echo and tandem techniques. The arrangement of the FBHs and slots for 225mm OD pipes are shown in Figure 4.

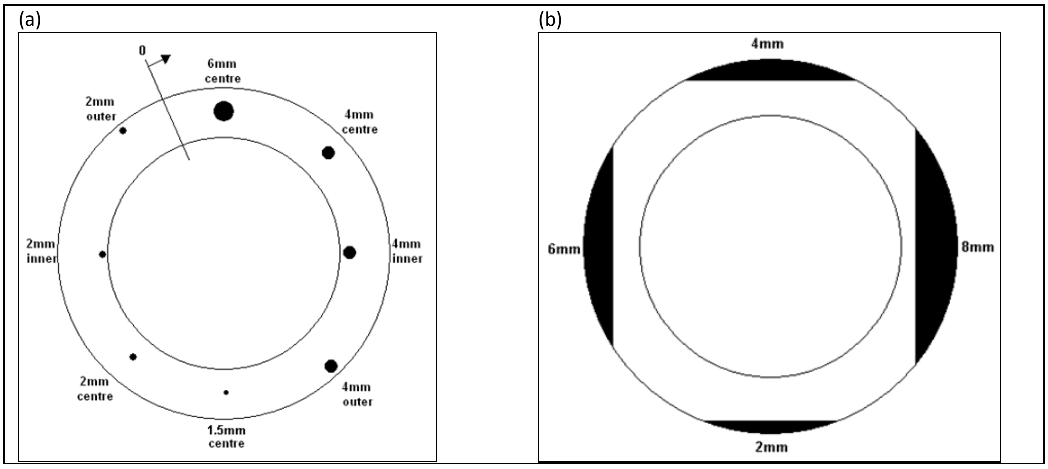


Figura 4. (a) Arrangement of FBHs in the pipe end. (b) Arrangement of slots in the pipe.

In order to develop the PAUT technique for the EF joints initial inspection trials were carried out using unwelded fittings. It was proposed that if sufficient resolution was achieved in detecting the wires, the fusion zone located just below the wires could be inspected.

Paquete de Trabajo 3. Desarrollo de las técnicas de END.

Las técnicas de END mediante ultrasonidos “Phased Array” serán desarrolladas para la detección de discontinidades en los tipos de juntas y materiales de los tubos de plástico definidos en el Paquete de Trabajo 1, esto incluirá las especificaciones técnicas y funcionales del palpador “Phased Array”, diseño y especificación técnica del equipo y del manipulador. Esta tarea debe incluir el desarrollo de los algoritmos para el análisis de los datos requerido para las soldaduras efectuadas mediante EF. Deberán ser definidas las propiedades de los materiales plásticos seleccionados, así como, los métodos para superar la muy baja velocidad de propagación de los ultrasonidos y naturaleza altamente atenuante de esos materiales. Estos dos factores serán incorporados en la especificación del palpador.

Se diseñarán y fabricarán suelas especiales para los palpadores de ultrasonidos, Para las soldaduras por fusión, las suelas necesitan ser fabricadas a partir de materiales de muy baja velocidad de propagación de los ultrasonidos; las soldaduras por EF requerirán cuñas especializadas para acoplar con agua. La capacidad de los sistemas de END optimizados será determinada utilizando las soldaduras de tubos producidas en el Paquete de Trabajo 2. Subsiguiente a la optimización, se generaran procedimientos del plan general de inspección.

Specialist ultrasonic probe shoes have been designed and manufactured. For butt fusion welds, the probe shoes will need to be manufactured from very low velocity ultrasonic materials; EF welds will require specialised water wedges. The capability of the optimised NDE system will be determined using the welded pipe joints produced in Work Package 2. Following optimisation, outline inspection procedures will be generated.

3.1 Palpadores

For the evaluation of the inspection technique on EF-joints two different 1D linear 128 element probes were used; a 5MHz probe; and a 7MHz probe. Since no steering is required the pitch can be large without reducing the performance of the probe. The demand on the probe is low since no steering and only focussing at the fusion zone is required.

The BF-joints have a smaller fusion area and high angles are required to fully cover the fusion zone. The probes can then be physically smaller, enabling the usage of a smaller pitch and increasing the steering capabilities. Angled beams are required to inspect BF-joints and since the steering capability is limited with these probes, angled wedges were used to minimize the steering by the transducer elements. For the evaluation of the inspection techniques on BF joints two pairs of identical 1D linear 32 element probes were used; a pair of 2MHz probes; and a pair of 4MHz probes. By using these probes on the plastic pipes, the pitch p, will be larger than half the wavelength, $p > \lambda/2$.

3.2 Cuñas

To perform the inspection on plastic pipes, novel water wedge prototypes have been designed and manufactured. The advantages of using a water wedge are low attenuation and a velocity ratio enabling the steering of angled beams to the fusion zone. The main challenges with a water wedge are possible air bubbles and maintaining the water between the elements and the PE material.

When designing and manufacturing the wedges, the aim was to make them as physically small as possible, but still allowing for the desired range of angles to be transmitted into the material. The probes for EF-joints required 0° water wedges, and the probes for BF-joints required angled water wedges. The refracted angles for all the techniques and pipe sizes were between 55-90 degrees. By the application of Snells law, the incident angles for these two extreme refracted angles can then be calculated as 32.8 degrees and 41.5 degrees respectively. By constructing the water wedge with an angle of 35 degrees, the array only needs to steer the beam to a maximum of 6.5 degrees.

Photos of both types of wedges with the probe mounted on them are shown in Figure 5. The figure also shows the sealing skirt that is used to effectively keep the water in the probe wedge. The sealing material is flexible and the sealing skirt can be customised to specific shapes of the outer surface of EF-fittings.

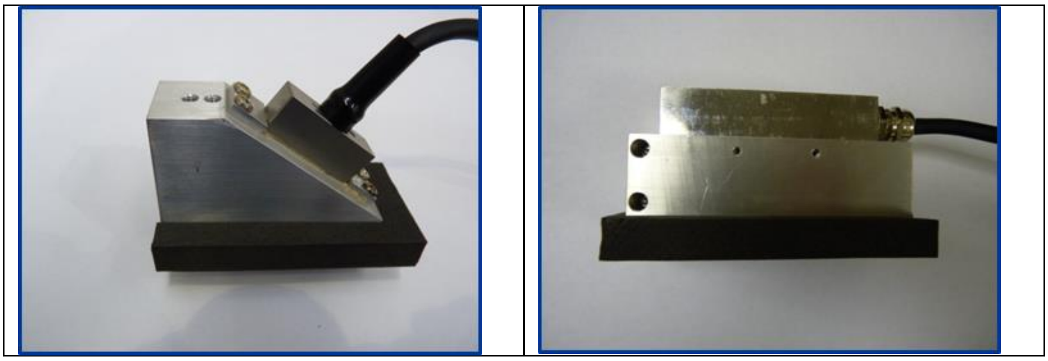


Figura 5. Diferentes tipos de cuñas

3.3 Desarrollo de técnicas de inspección

EF-joints

For the EF-joints a 0-degree water wedge was used with a water column between the transducer and the pipe fitting surface. A normal focusing linear scan was used, focused on the fusion area between the fitting and the pipe, see Figure 6.

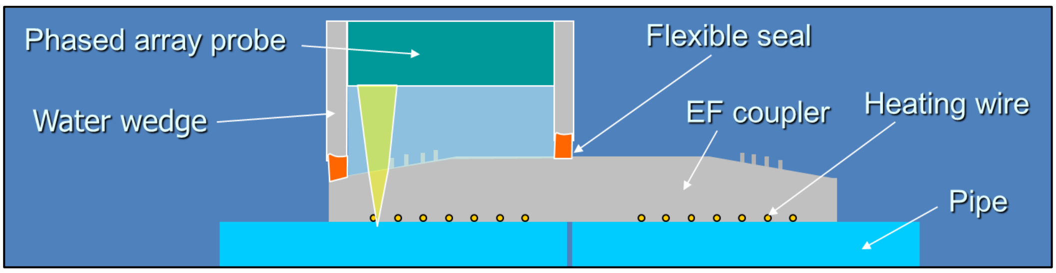


Figura 6. Esquema de inspección de soldaduras por electrofusión

The main limiting factors that prevent full coverage of EF-joints are the several connectors, inscriptions and labelling around the fitting surface.

As can be seen in Figure 6, the heating wires are located just above the fusion area and sufficient resolution to be able to see both the wires and between the wires is required. The most critical factors for the inspection of EF-joints are the coverage and the resolution. The resolution is generally dependent on the frequency, higher frequencies give higher resolution. However, PE is a highly attenuating material and attenuation increases exponentially with frequency. Thus, the frequency needs to be reduced for larger pipes to be able to get sufficient propagation of sound. Fortunately, in the fittings for larger diameter pipes, the wire diameter and the wire spacing are also larger so the resolution is still sufficient. For smaller pipes both the wire diameter and the spacing between two adjacent wires get smaller, and a probe with a higher frequency is required to be able to inspect.

Taking the limitations of coverage and resolution mentioned above into consideration it is necessary to use probes with different frequencies; higher frequency for smaller pipes and lower frequency for larger pipes. The pipes are divided into different categories depending on fitting thickness/pipe diameter/wall thickness. This means that probes with different frequencies need to be manufactured for each category. The coverage can then be optimized by choosing optimal aperture sizes for each probe, e.g. a larger pitch for the larger pipes. (6)

BF-joints

Four techniques have been investigated for inspecting BF joints: tandem; sector pulse-echo; creeping wave, and TOFD as shown in Figure 7 and described below.

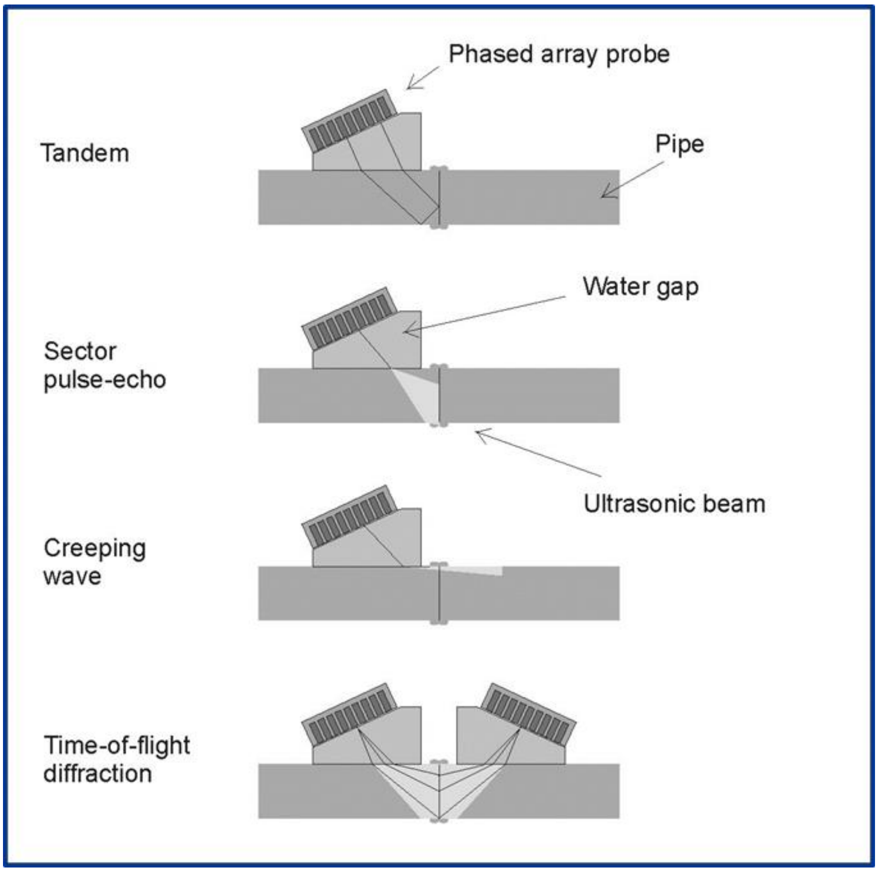


Figura 7. Esquema de diferentes técnicas de inspección de soldaduras a tope

Tandem

The tandem technique focuses on an area closer to the inner surface of the weld; it covers approximately two thirds of the fusion face towards the inner surface of the weld. It shows good performance on planar flaws within the weld. The tandem technique is challenging to implement due to a long propagation distance inside the highly attenuating material combined with several internal reflections which will decrease the signal-to-noise ratio.

In conventional ultrasonic inspection, the tandem technique is implemented using a transmitter and a receiver probe, one in front of the other. However, when using a single phased array probe, a self-tandem technique can be achieved using one part of the array as the transmitter and one part as the receiver.

When using a single phased array probe, a self-tandem technique can be achieved using one half of the array as the transmitter and one half as the receiver. The image is created by sending the sound using an electronic sweep over the elements in the transmitting part and in a similar manner receiving with a sweep in the receiving part. A property of the self-tandem technique is that one half (transmitter or receiver) is reversed in order to accurately receive the transmitted sound.

A 32 element probe was employed. The last 16 elements (17 to 32) were used for the transmitter and first 16 elements (1 to 16) were used for the receiver. The transmitter is set to transmit with start on element 17 and sweep upwards to element 32 and the receiver was set to start on element 16 and sweep downwards to element 1. The standoff between the front of the probe/wedge and the weld centreline and the thickness of the pipe wall determine the appropriate angle to be used for the self-tandem technique. The coverage of the self-tandem technique is restricted by the angle and the number of beams used.

Sector pulse-echo

The sector pulse-echo technique covers most of the weld fusion zone, except for the upper ¼ of the weld close to the outer surface. The technique uses all the elements in the array to create an aperture, sweeping the beam from the lower angle to the higher angle.

The transmitted beams were focussed at the inner surface distance and Dynamic Depth Focussing (DDF) was used when receiving the beams.

This technique benefits from having both direct pulse echo signals and tandem signals reflecting from the inner wall before reflecting from a defect at the weld centreline and back to the array. This increases the detected signals from the defects, but careful interpretation of all detected signals must be undertaken.

Creeping waves

Creeping waves are compression waves propagating immediately beneath the inspection surface, to detect surface-breaking and near-surface defects. As creeping waves propagate, mode conversions at the surface cause secondary shear waves to be emitted.

However, shear waves do not travel any significant distance in PE and are effectively cancelled out. This continuous transfer of energy results in high attenuation of the waves and inspection is only effective over a relatively short range.

Creating creeping waves or near creeping waves with a phased array probe are achieved using a sector scan between the angles of 78 degrees and 90 degrees in a similar manner to the sector pulse-echo technique and therefore covers the upper part of the weld that the sector pulse-echo and the tandem technique cannot see.

Time-of-flight diffraction (TOFD)

The TOFD technique aims to cover the entire weld fusion zone although there is a possibility that a couple of millimeters close to the outer surface will be missed, depending on how the technique is implemented. The conventional technique utilizes forward diffraction from the flaw tips and is sensitive to flaws perpendicular to the pipe surface.

The main advantage is that good signal amplitude is achieved at each location due to the focusing. The main limitation is that the mechanical setup is highly important to be able to receive the transmitted sound. This setup provides a compromise between instrument demands, software development and inspection results.

Using the steering and focussing capabilities of phased array ultrasonic testing, several different configurations can be considered.

1) Imitating conventional TOFD. The aperture is used to transmit one beam with beam spread and the sound is received in the same way. The limitation is that it produces weak signal amplitude, as the focussing capabilities of the phased arrays are not used.

2) Pitch-catch with two sector scans. With this technique, the transmitter uses a large aperture to transmit focused beams at the weld centreline. Angles that cover the entire pipe through wall thickness are used. The receiver is set up in the same way. The main advantage is that good signal amplitude is achieved at each location due to the focussing. The main limitation is that the mechanical setup is highly important to be able to receive the transmitted sound. The transducers have to be positioned carefully at the same distance from the weld centreline.

3) A combination of conventional TOFD and sector scan. This technique transmits one beam with beam spread like technique 1. The sound is then received with focused beams using a large aperture like technique 2. The advantages with this technique are that the mechanical setup is less important and that it has high flexibility. The main limitations are that the technique is demanding for the instrument to perform and that the received signal must be weighted according to the transmitted sound, which has to be carefully implemented.

The configuration evaluated at this stage of the project is the second technique (Pitch-catch with two sector scans). It provides a compromise between instrument demands, software development and inspection results.

Paquete de Trabajo 4. Desarrollo los criterios de aceptación.

Las soldaduras inspeccionadas en el Paquete de Trabajo 3 serán ensayadas mecánicamente usando probetas, y

sometiendo a un tubo completo a un ensayo de rotura por deformación progresiva (bajo carga constante). Los resultados de estos ensayos serán analizados para cada uno de los diferentes tipos de discontinuidades y comparados con los resultados de los ensayos de soldaduras conteniendo discontinuidades no planificadas. El tamaño real de las discontinuidades en las juntas, frente al de las discontinuidades insertadas en las juntas antes de su soldadura, será determinado seccionando una serie de probetas de ensayo. Los niveles reales de la contaminación por partículas serán determinados usando técnicas de análisis superficial en las interfases de la soldadura. Se generarán gráficos de “tamaño de discontinuidades/nivel de contaminación por partículas” con respecto al “tiempo transcurrido hasta la rotura”, a fin de calcular los tamaños/niveles críticos que reducen la integridad de la soldadura a largo plazo, para cada material, tamaño de tubo y tipo de junta. Esta información será comparada con las discontinuidades detectadas utilizando el prototipo del equipo de END que permita la aceptación o rechazo de la soldadura inspeccionada.

In Work Package 4 the welds inspected in Work Package 3 will be mechanically tested using both specimen and whole pipe creep rupture tests. The results from these tests will be analysed for each of the different flaw types and compared with the results from tests on welds containing no deliberate flaws. The actual size of the flaws in the joints, as opposed to the size of the flaw inserted into the joint before welding, will be determined by sectioning a set of test samples. The actual particulate contamination levels will be determined using surface analysis techniques on the weld interfaces. Graphs of flaw size/particulate contamination level against time-to-failure will be generated in order to calculate the critical sizes/levels of defects for each pipe material, pipe size and joint type that reduce the long-term integrity of the weld. This information will be compared with the flaws detected using the prototype NDE equipment to enable the inspected weld to be accepted or rejected.

Paquete de Trabajo 5.Desarrollo del equipo.

El prototipo del sistema de adquisición de datos y análisis END mediante ultrasonidos Phased-Array será desarrollado. Se emprenderá el diseño progresivo del control electrónico del haz y del procesado de los datos. Esto requerirá la implementación en el equipo de los algoritmos desarrollados en el Paquete de Trabajo 3. Se llevaran a cabo esfuerzos importantes de miniaturización del equipo y se procurará la inclusión de conexión wireless.

The prototype ultrasonic phased array NDE data acquisition and analysis systems are being developed in Work Package 5, including extensive design of the ultrasonic beam control electronics and the data processing within the instrument. This requires the implementation within the instrument of the algorithms developed in Work Package 3. Significant effort has been implemented to miniaturization and including wireless connection. A model of the prototype instrument is shown in Figure 8.

- Integrated UT device and remote user interface on separate PC/monitor
- Compact box with IP67 protection for full immersion (<0.5m)
- SSD memory for data storage (100GB)
- Two removable batteries allowing up to 6 hours operation
- Weight: 4kg
- Size: 320 x 240 x 100mm

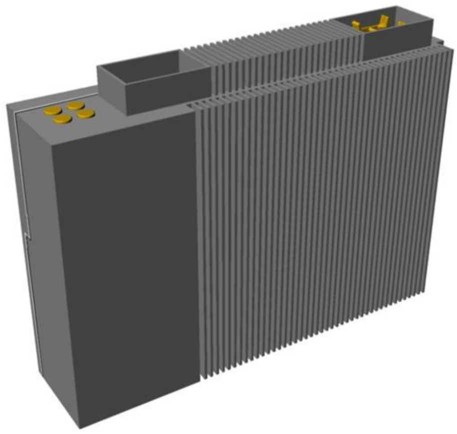


Figura 8 Miniaturización del equipo

Paquete de Trabajo 6.Desarrollo del sistema de exploración.

Se diseñará, desarrollará y fabricará un prototipo de posicionador flexible y adaptable a un rango amplio de tamaño de tubos y geometría de juntas, para explorar con el(los) palpador(es) de ultrasonidos Phased-Array, que permita una desplazamiento completo de 360º alrededor de la unión mientras proporciona datos detallados de su posicionado.

In Work Package 6 a flexible prototype system for scanning the ultrasonic phased array probe(s) over the surface of the welded joints, allowing full 360° rotation around the joint whilst providing detailed positional data, and accommodating a wide range of pipe sizes and joint geometries, has been designed, developed and manufactured (see Figure 9). The system comprises a main plate that is held in position around the pipe by several links and an adjustment mechanism. This flexible system should allow the scanner to inspect pipes with an OD from 90mm to 1m. The main plate contains the encoder and also the support for the probe holders. The two different joint configurations require different probe holders.

(a) **(b)**

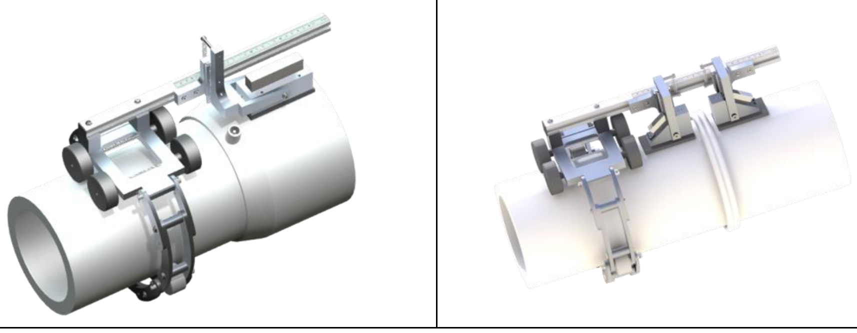


Figura 9 Sistema de exploración
(a) porta palpadores para EF (b)porta palpadores para BF

Paquete de Trabajo 7. Montaje y verificación del prototipo.
El sistema completo de END, incluyendo el equipo, palpador(es) y sistema de exploración, será montado y verificado en campo por el usuario final que forma parte del proyecto, así como por miembros de las asociaciones industriales que estén interesados, para evaluar la sensibilidad, reproducibilidad y facilidad de uso del sistema. Este Paquete de Trabajo incluirá la validación el sistema para el rango de soldaduras especificado en el Paquete de Trabajo 1. Se realizaran una serie de soldaduras de tuberías, para la validación, en las que la localización y número de discontinuidades permanecerán ocultas para el operador de END.

In Work Package 7 the complete NDE system, including instrument, probe(s) and scanning system, will be assembled and assessed in the field by the end users in the project, as well as by interested members of the Industry Associations, to evaluate the sensitivity, reproducibility and ease-of-use of the system. This work package will include the validation of the system for the range of welds specified in Work Package 1. For the validation a series of pipe welds will be produced, where the location and number of flaws will remain blind to the NDE operator.

Paquete de Trabajo 8. Formación divulgación y explotación.
El conocimiento generado durante en el transcurso del proyecto será difundido, tanto a los responsables de las pequeñas y medianas empresas que vayan a proveer los nuevos servicios de inspección, como a los usuarios finales. Esto se llevará a cabo vía “página web” del proyecto, temarios y directrices para la formación, campañas de concienciación, jornadas técnicas, publicaciones, comunicados y conferencias.

The knowledge generated during the course of the project will be disseminated both to SMEs responsible for providing the new inspection service and to end users. This will be done via the project website, training guidelines, awareness campaigns, workshops, publication, newsletters and conferences.

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