Advanced ultrasonic system for improved efficiency in pipelines inspection

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Keywords

Pipeline, inspection, ultrasonic testing, integrated system, TOFD technique, phased array technique, real time inspection

Introduction - System overview

Radiographic testing has been the primary inspection method used for the weld inspection in pipelines. However, the radiographic testing has several limitations whenever is intended to apply acceptance criteria codes based on fracture mechanics, since the information regarding the depth and height of the discontinuity is not provided.

Recently a new approach has been developed with the major advantage of being less conservative in comparison with the "standard" acceptance criteria codes based on the nature of the discontinuities. This leads to a smaller weld repair rate and therefore smaller costs in the overall project.

The revision of API 1104, made for the 19th edition, presents a methodology to use acceptance codes based on fracture mechanics, as described in appendix A5. For each project, an acceptance criteria is established based on the following information:

- Pipe outside diameter, OD;
- Pipe wall thickness, t;
- Qualified minimum CTOD (Crack Tip Opening Displacement);
- Maximum applied axial strain, a;
- Allowance for inspection error.

For the success of such methodology, the inspection shall be carefully planned, in order to allow the measure with accuracy of the discontinuities in terms of height and length.

The API 1104 defines some requirements to be fulfilled during the ultrasonic testing, like the type of sensitivity blocks to be used, the scanning sensitivity and the evaluation level. However, the code doesn't define rigid rules about how the inspection shall be performed. The responsibility to define the inspection strategy is from the NDT company which has to demonstrate the adequate performance of the testing procedure prior the beginning of the inspection.

In 1998, ASTM issued a standard practice E-1961 (ASTM E1961 - 06 Standard Practice for Mechanized Ultrasonic Testing of Girth Welds Using Zonal Discrimination with Focused Search Units) to establish some recommendations for the mechanized ultrasonic examination of pipe girth welds. This practice describes a methodology in which the weld volume is split in thin slices, each one with a height approximately equal to one filler pass height. Each zone will be inspected independently from the adjacent zone, in order to allow having a precise dimension of the discontinuity height.

Although this practice was originally developed for ultrasonic inspection using several monolytic focused probes, the same principle can be applied to the automated ultrasonic inspection system. In this context, this paper presents an automated and integrated ultrasonic inspection system combining Phased Array and TOFD (Time Of Flight Diffraction) techniques in order to use both capabilities to increase the POD (Probability Of Detection) and reduce the POF (Probability Of Failure).

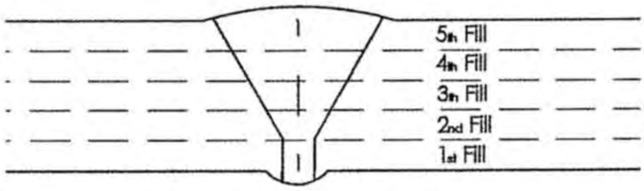

Figure 1. Weld zones

The Phased Array technique has strong capabilities of detection due to the several different beam configurations that can be implemented, according the Regions Of Interest (ROI) and defects morphology. Additionally to the Phased Array technique, TOFD technique (Time of Flight Diffraction) was also be incorporated into the system. Although TOFD is not recognized by API 1104, has great advantages like the ability to improve the indications sizing (length and height) as well to assist the NDT operator for the interpretation of the geometric features in the root region, like root concavity, excess of penetration, weld misalignment, that are very difficult or even impossible to assess using pulse eco techniques. As disadvantages TOFD has a presence of dead zones mainly in the OD surface, and a poor spatial resolution in depth from the OD surface up to the first third of the thickness. However the Phased Array module overcomes this disadvantage.

Most conventional ultrasonic inspections use monocrystal probes with divergent beams which mean that the beam is not focused. The ultrasonic field propagates along an acoustic axis with a single refracted angle. The divergence of this beam is the variable that will contribute to detection and sizing of misoriented defects.

In the case of Phased Array technique, it is assumed that the monoblock is cut in many identical elements, each with a width much smaller than its length. Each small crystal may be considered a line source of cylindrical waves and according

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Huygens principle a new wavefront of the new acoustic block will constructively interfere, generating an overall wavefront. The small wavefronts can be time-delayed and synchronized for phase and amplitude, in such a way as to create an ultrasonic focused and/or driven beam with steering capability. The main feature of phased array ultrasonic technology is the computer controlled excitation, in terms of amplitude and delay, of individual elements in a multielement probe. The excitation of the different piezocomposite elements can generate an ultrasonic focused beam with the possibility of electronic modifying the beam parameters such as angle, focal distance, and focal spot size through software.

The sweeping beam is focused and can detect in specular mode the misoriented cracks. These cracks may be located randomly away from the beam axis. A single crystal probe, with limited movement and beam angle, has a high probability of missing misoriented cracks, or cracks located away from the beam axis, Figure 2. [1]

To generate a beam in phase and with a constructive interference, the various active probe elements are pulsed at

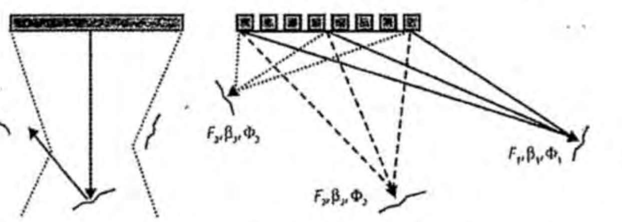

Figure 2. Detection of misoriented cracks by monocrystal (left) and multielement probes (right). The beam is divergent and unidirectional for the monocrystal probe, while it is focused and multiangled for the phased array probe. Cracks of most orientations can be detected by the phased array probe [1]

slightly different times. The echo signals received at each transducer element are time-shifted before being summed together. The resulting sum is an A-scan that emphasizes the response from the desired focal point and attenuates various other echoes from other points in the material. [1]

The beam focusing principle for normal and angled incidences is presented in Fig. 3.

Regarding the second advanced ultrasonic technique used in the system presented in this paper, Time Of Flight

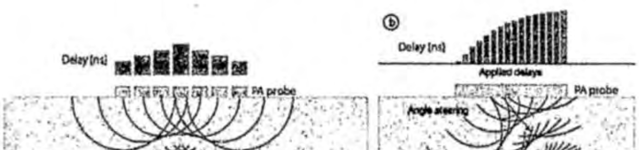

Figure 3. Beam focusing principle for (left) normal and (right) angled incidences [1]

Difraction (TOFD), the most significant distinction between this technique and the other UT methods is that it monitors the forward-scattered diffracted energies, relatively low amplitude signals, only from the tips of defects rather than reflected ultrasonic energies. Two wide beam angle probes are used in transmitter-receiver mode and the distance of the probes is calculated according to the wall thickness. Broad beam probes are used so that the entire crack area is covered by the width of the ultrasound beam and, consequently, the entire volume is inspected using a single scan pass along the inspection line. At the tips of the flaw the acoustic beam is diffracted and in some situations reflected and the diffracted signal is redirected to a receiver probe. At some generated time and due to the beam aperture, the lateral wave propagates along the surface, the back wall echo reflects the bottom surface of the test object and reach to the receiver. The other two signals, upper flaw tip diffracted signal and lower flaw tip diffracted signal appear due to the presence of a discontinuity, Figure 4.

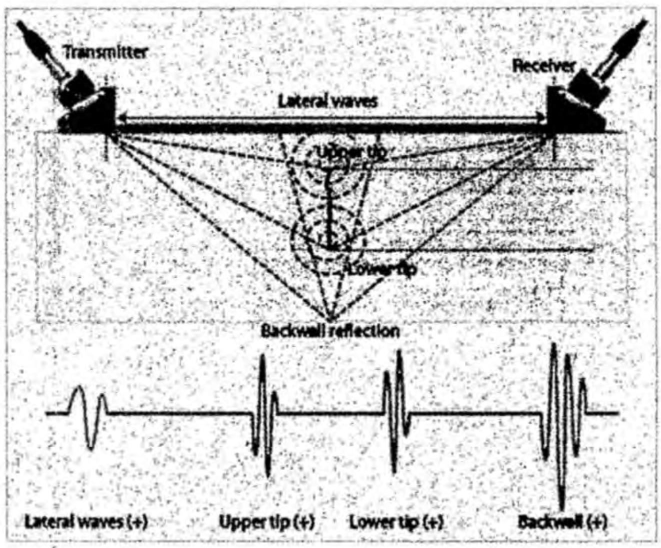

Figure 4. TOFD principle [1]

Because the technique relies on detection of the forward scattered diffracted signals originating at the flaw edges, precise measurement of flaw size, location, and orientation is possible.

During the system development, the different techniques were numerically modelled in order to optimise the acoustic beam configuration and its response to the several type of defects along the complete welding volume in a single inspection step. For this purpose, a commercial ultrasonic modelling software, CIVA 9.1, was used and the different modelling stages and algorithms are presented in Fig. 5.

System development and implementation

The development of the inspection system includes the moving and fixing devices, the automated scanner, the probe pan holder, the numerical modelling to optimise the beam configuration and its response to the different type of defects, the system setup and calibration and the validation trials. The Fig. 6 presents an overall image of the inspection system.

The system is composed by the inspection scanner (1), the fixing and moving rail (2) and the inspection probes and related probe pan holders (3). Additionally, the integrated system includes a central processing unit of 128 full parallel channels architecture to process the information of all the inspection probes and beam configurations.

In terms of probes the system includes:

- 2 Phased Array linear probes with 32 elements, 0.5 mm pitch and 5MHz.

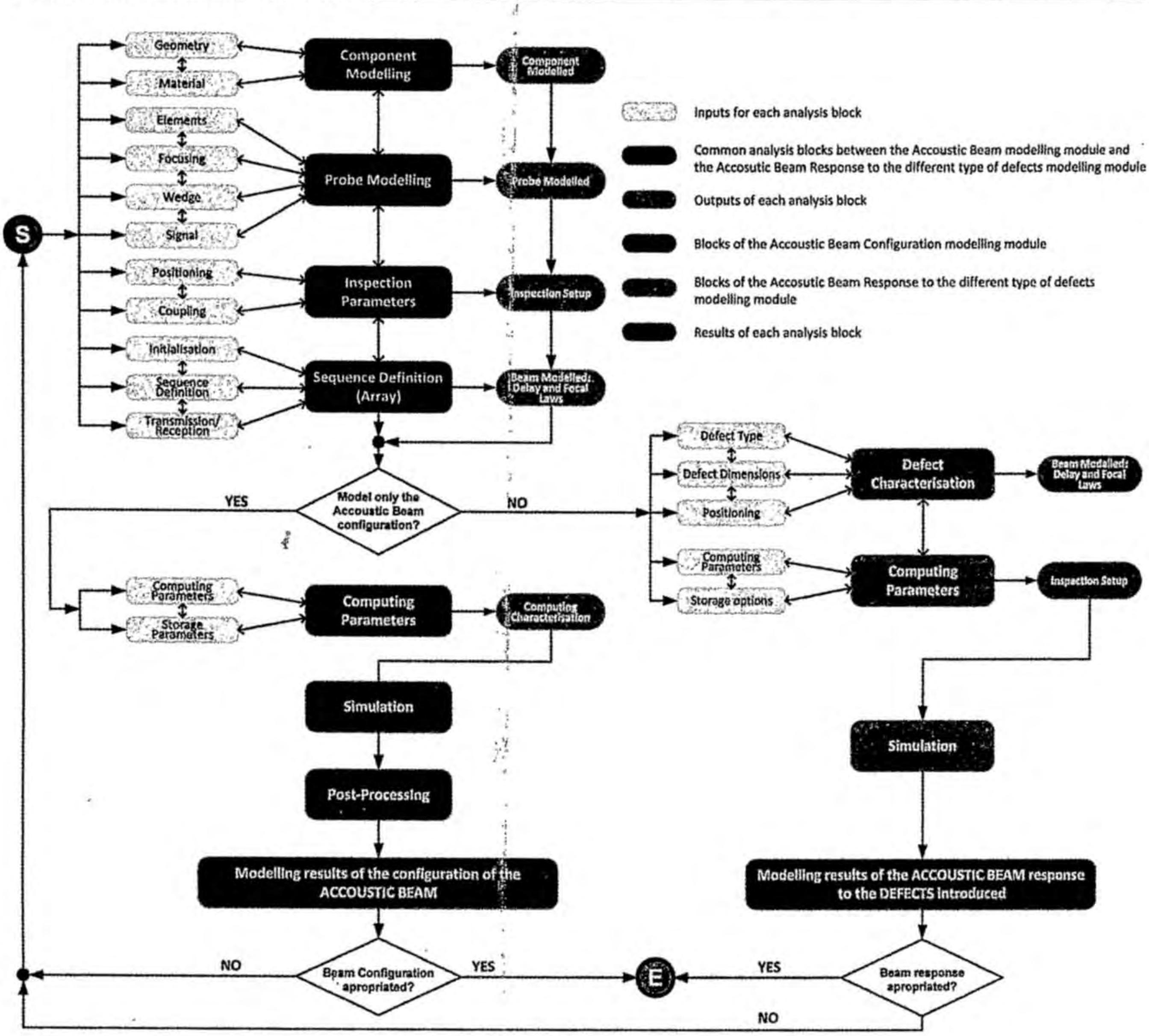

Figure 5. CIVA modeling steps

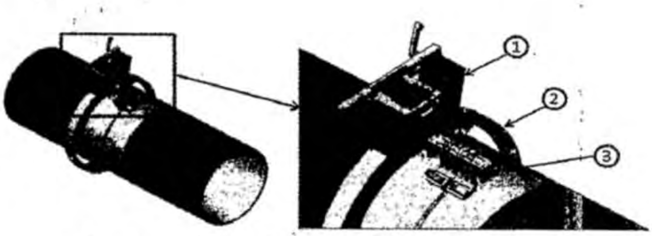

Figure 6. Overview of the inspection system

- 2 TOFD probes of 10 MHz with angle of 70? and crystal diameter of 3 mm.

This probe configuration can be adapted according the inspection requirements due to the modularity capability of the system.

The Fig. 8 illustrates the inspection system after the development, implementation and construction phases

Concerning the modelling stage, in each zone a focal point was associated with a specific angle and focal distance, Fig. 9, illustrates one typical configuration for a V bevel weld with a thickness of 9.5mm. In this case the weld volume was split in 5 regions.

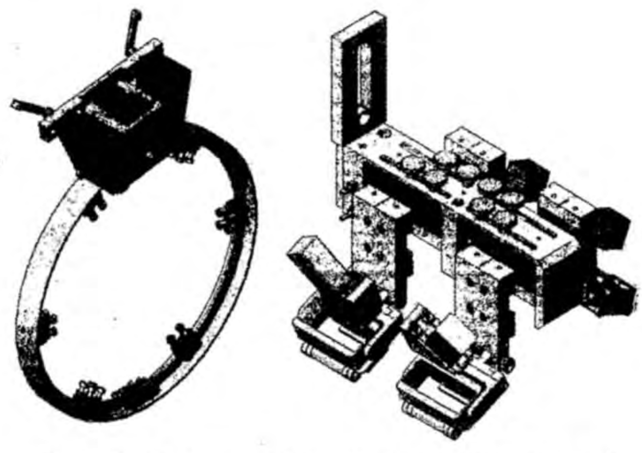

Figure 7. Moving and fixing devices (left), probes and holders (right)

After the equipment setup, was necessary to adjust the sensitivity. The ASTM E-1961 proposes one calibration block that is also in accordance with the requirements of API 1104. Figure 10 illustrate an example of such block for a thickness of 9.5mm:

This calibration block was 2 ID notches, 2 OD notches and 6 flat bottom holes with diameter of 2mm. The flat bottom holes are oriented perpendicularly to the weld fusion line. Each one of these reflectors will be used to adjust the sensitivity of the corresponding filler zone in order to get a response from the reflector of 80% FSH-Full Screen Height.

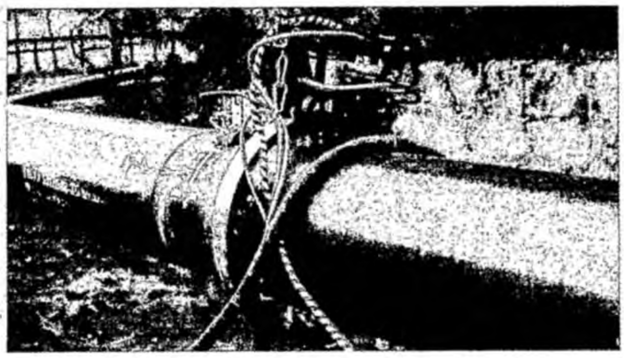

Figure 8. Inspection System integrated

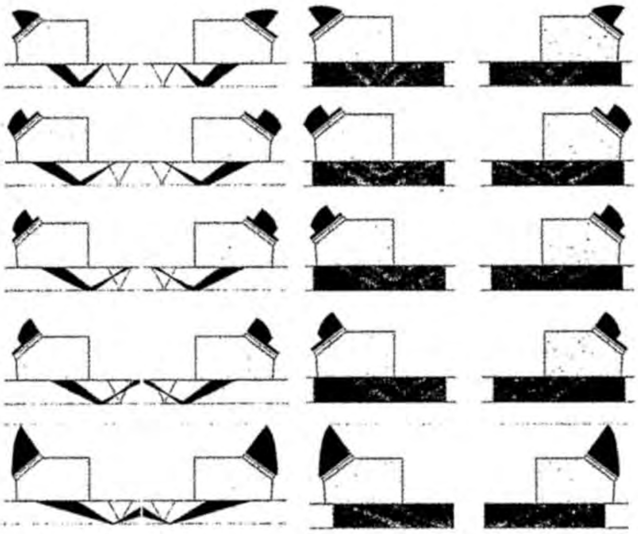

Figure 9. Acoustic pressure and beam configuration distribution associated to each filler zones

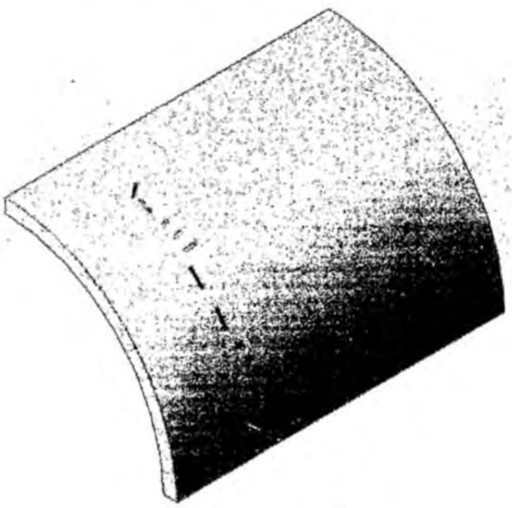

Figure 10. Calibration block

The Graphical User Interface (GUI) of the system was also developed, including the configuration and acquisition steps, and is presented in Fig.11 and Fig. 12 respectively.

The data result is presented in a strip chart representation. Each Phased Array channel, associated to one focal point, will be displayed in an echodynamic view that represents the circumferential position of the indication versus the maximum amplitude recorded (red line) and the transit time (green line) within the gate. Additionally Phased Array channels for

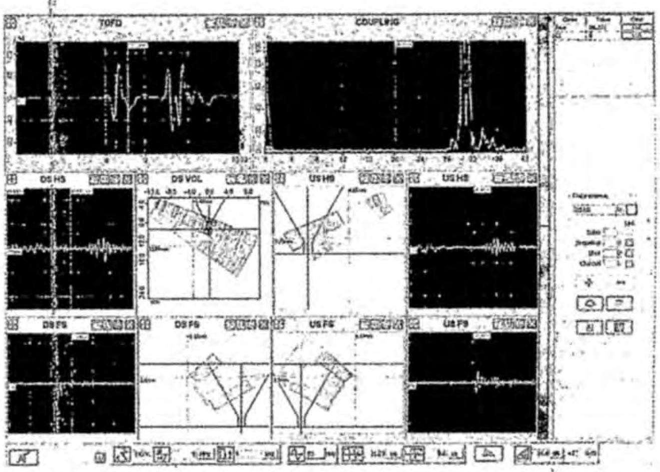

Figure 11. Graphical User Interface (GUI) - System Configuration

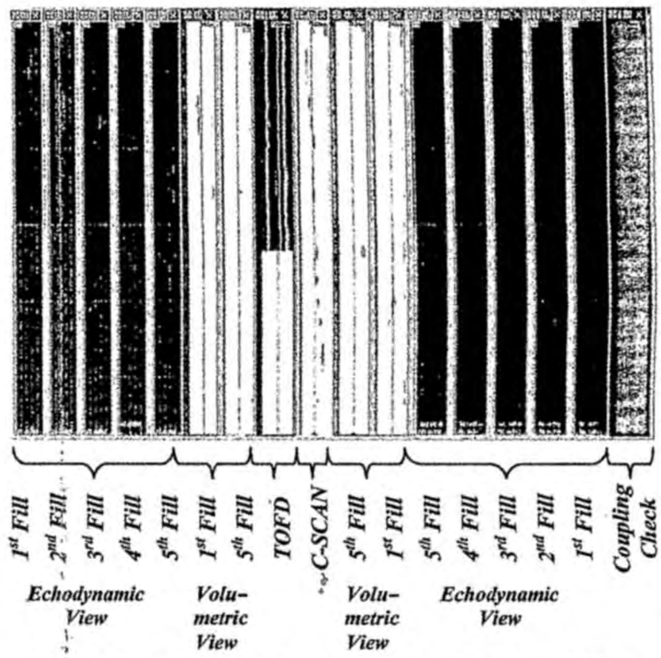

Figure 12. Graphical User Interface (GUI) - Acquisition

volumetric detection as well TOFD signals will be displayed in a B-Scan view. This representation displays the circumferential position of the indication versus the signal amplitudes of all recorded signals within the gate codified by a colour or greyscale palette. The Phased Array volumetric channels are very useful to interpret the nature of the signals (planar vs. volumetric). Additionally a C-Scan view will be available to locate axially the discontinuities and a Coupling check to monitor the proper acoustic coupling of the Phased Array probes.

Results

After the system setup and calibration the validation trials were performed. For this purpose a pipe sample of 20" and 9.5 mm of thickness was used. This sample was also inspected trough radiography with a Se75 source and a C5 film in panoramic exposition, and the both results were compared. The Fig.13 shows an example of these results related to a crack (left side) and a lack of fusion (right side)

The Tab. 1 shows the results comparison mentioned previously.

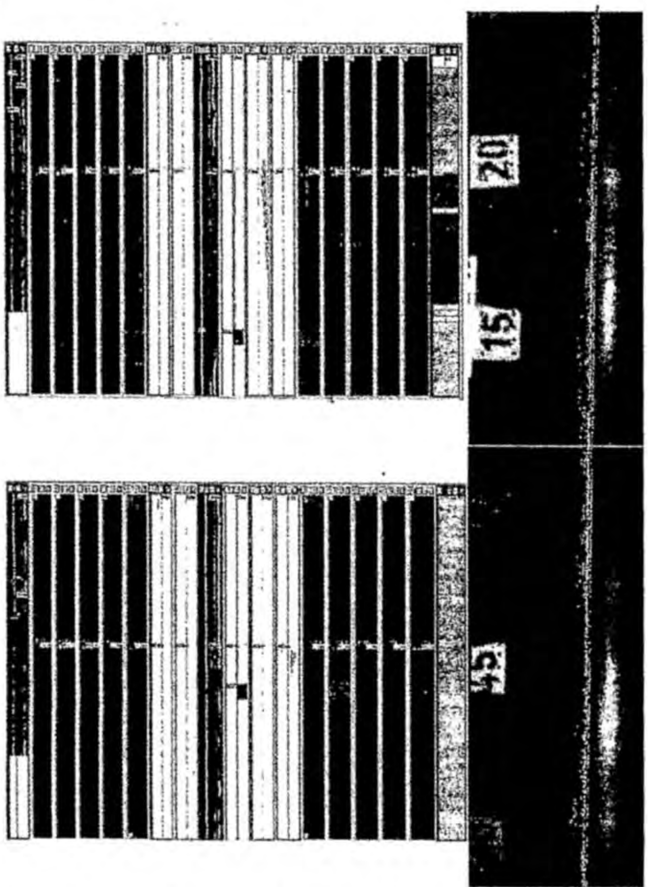

Figure 13. Results of the integrated ultrasonic system and Rγ

Table 1: Results of the validation tests between radiography (Se75) and the ultrasonic system

Defect n°	Type	Dimension Rγ [mm]	Dimension AUT [mm]	Real Dimension [mm]
1	Root Crack	67	90	93
2	Lack of Fusion	21	28	30
3	Lack of Fusion	N.D	25	25
4	Root concavity	100	104	105
5	Porosity	25	20[1]	25
6	Lack of Fusion	64	53	54

[1] Detected by the TOFD module

As can be observed in Tab.1 the results obtained with the Automated Ultrasonic system (AUT) in terms of inspection capabilities were considerable better than those obtained with the conventional systems based in the radiography.

Regarding the porosity, the TOFD module is able to detect this type of defect. As the API does not consider this technique to evaluate the defects, at this stage this module is used as complementary information to the Phased Array. In any case, the TOFD module has an important added value in the integrated system, because its information can be used to validate the welding process.

The system was also tested in field in a gas pipeline of 12". The inspection results of 250 welding joints were simultaneously compared with radiography (Crawler) using a Se75 source.

After this set of validation trials, the conclusions are that the AUT system has higher levels of accuracy in the defects dimensioning. A very important aspect concerning the system developed is that, based on API 1105 (appendix A5) which presents and describe a methodology to use acceptance codes based on fracture mechanics, the use of Phased Array system allow the definition of the acceptance criteria based on this methodology. The use of this methodology will maximise the inspection efficiency, reducing the repairing rates and consequently reducing the associated costs.

After the validation trials an inspection system is available with the following capabilities:

- Flexible and modular architecture to inspect pipes from 8" of OD and wall thickness above 6 mm. This architecture allows the selection of the set of probes more appropriated for the desired application.
- High levels of productivity and the inspection can be performed simultaneously with the welding process.
- Real time inspection system.
- Information storage capabilities allowing futures monitoring tasks.
- Absence of radiation and radiography consumables. This is particular important when safety restrictions are considered.
- Higher levels of POD than the conventional radiographic procedures. This characteristic is important in the detection of planar defects, which are the more critical.
- Less probes than the alternative conventional ultrasound systems. The use of Phased Array allow to reduce the number of probes and increase the inspection capabilities, according the principles presented previously.

The Fig.14 shows the system operating in real environmental conditions.

Conclusions

An automated ultrasonic system (AUT) combining Phased Array and TOFD techniques in a single inspection architecture was designed. The system was developed and tested in real conditions and compared with the traditional radiography methods. The results obtained show that the AUT system has higher inspection accuracy than the traditional methods, has real time inspection capabilities, information storage capabilities, high levels of productivity and avoids the risks associated with the use of ionising radiation.

Additionally the modular and flexible architecture allows the application of the system in a wide range of outside diameters and wall thicknesses, trough the modelling and setup of the most appropriated acoustic beam configurations.

The presented system also allows, according the API 1105 (appendix A5), the use of acceptance codes based on fracture mechanics leading to the optimisation of the repairing levels and of the inspection costs.

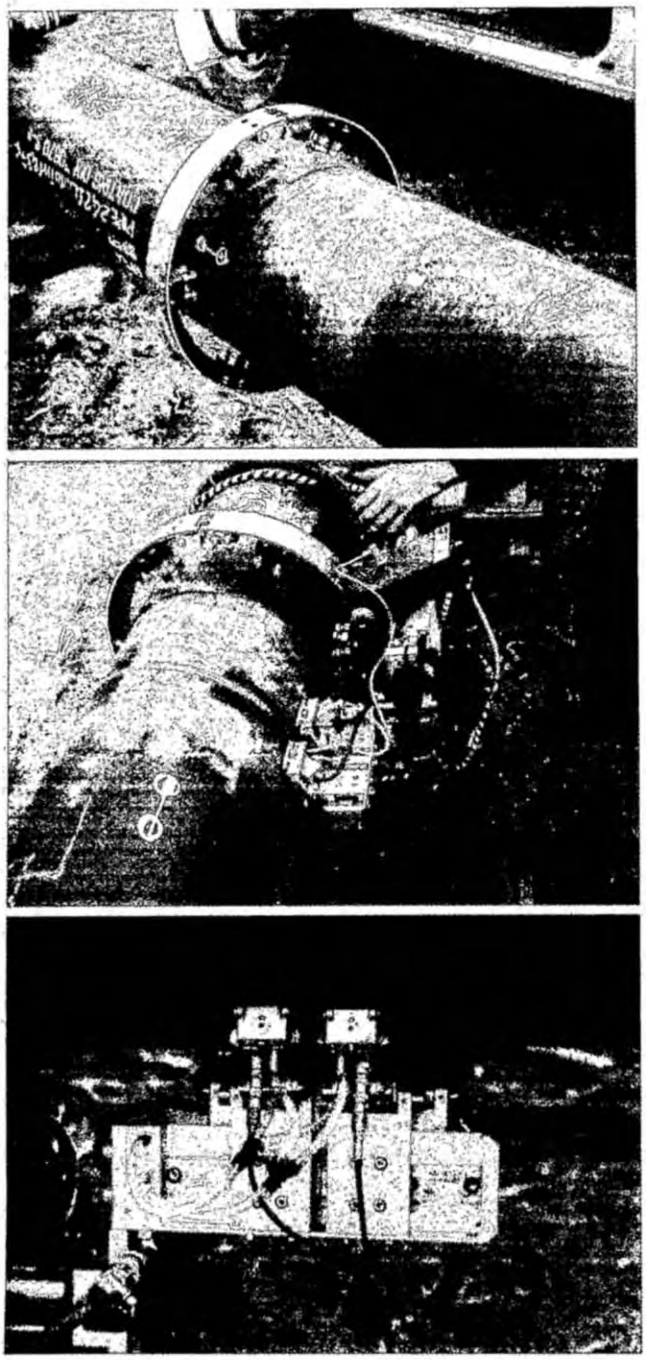

Figure 14. Gas pipe inspection using the integrated inspection system

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