Enhancing reliability for CRA Clad piping weld joints utilizing advanced Phased Array Ultrasonic inspection

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Abstract

Corrosion resistant alloy pipe materials are more popular for the transport of hot and corrosive gases and fluids. For the Offshore Gas projects, the offshore platforms and producing facilities produce Sour gas which is being transported through these Pipelines. The use of clad corrosion resistant alloy (CRA) pipes for the transport of hot and corrosive fluids is desirable as they offer the corrosion resistance of solid CRA materials, whilst the use of a high strength substrate significantly reduces material costs and pipeline weight. However due to highly attenuating weld joints and the dissimilar metal welding offers challenge in flaw assessment and inspection methods.

This paper explains how the advanced Phased Array Ultrasonic Inspection is best suitable for CRA clad Piping weld joints having material of construction as API5L Gr X65 with Inconel 625 weld overlay. The real challenge is to identify and size the indications situated at root areas with adequate signal to Noise ratio to achieve due to noise indications coming from base metal and Inconel weld overlay interface. This advanced Phased Array Ultrasonic Inspection system utilizes DMA (Dual Matrix Array) Probes with special wedges which have significantly improved Probability of Detection (PoD), Signal to noise ratio and widen the weld area coverage. Dual Matrix Array probe utilizes transmit/receive arrangement of elements ensuring uniform sound pressure in the area of interest. The conventional RT has inherent limitations including safety hazards. A comparison with conventional RT and advanced Phased Array UT is carried out to understand the limitations of conventional method and advantages of advanced Phased Array UT inspection technique. Actual weld mock up/Validation blocks were prepared with artificial defects in weld and HAZ areas to assess the technique capabilities in detection and sizing of such defects. Advanced Phased Array Ultrasonic inspection was successfully demonstrated on validation pieces and more safe and reliable inspection was carried out.

Keywords: CRA, Phased Array, DMA, Dissimilar metals, Mock up/Validation blocks.

1. Introduction to CRA Pipes:

According to DNV-OS-F101 [7] a clad pipe is defined as “a pipe with internal (corrosion resistant) liner where the bond between (line pipe) backing steel and cladding material is metallurgical”. Base material of clad pipe is usually high-strength-low-alloy (HSLA) steel, such as X52, X60 and X65 which has superior mechanical properties. This combination is cost effective solution against solid SS piping. Figure 1 shows offshore platform and circumferential weld overlay on the inner surface of CS pipe.

Figure 1, Offshore Platform and circumferential weld overlay inside CS Pipe.
Corrosion Resistant Alloys (CRAs) are typically used to protect the base material from corrosion due to corrosive fluids, Wet H2S/Sour service, high temperatures and pressures including partial pressure of Co2 and H2s. The typical clad pipe girth welding is being done using CRA filler throughout the complete joint using GTAW and/or SMAW welding processes. Figure 2 shows typical cross section of CRA clad weld joint.

Figure 2, Typical Cross section of CRA Clad weld joint

2. Challenges in inspection of CRA Clad piping joint

Because material, velocity, grain structure, and other properties of the CRA material differ from the base material, these types dissimilar weld joints raise new challenges in the inspection of the same. The Non Destructive Testing of such welds to assure weld quality/integrity at the point of fabrication and during services is complicated by their inhomogeneity and anisotropy. Both radiography and conventional ultrasonic inspection techniques have limited capability for the detection of flaws at the dissimilar materials interface.

Past experimental studies have shown that longitudinal wave is generally best suited for the inspection of austenitic stainless steel welds due to more sound energies and less attenuation. Transverse waves due to their nature are more sensitive to scattering and highly attenuated due to coarse grain structure which resulted into seldom use of them for inspection of austenitic materials. To reduce the effect of scattering, low frequency ultrasonic transducers with longitudinal wave are used for inspection of coarse grained materials. At grain boundaries longitudinal waves experience reflection; refraction, mode conversion and beam skewing. Beam skewing can lead to depth errors and confusion between actual indications and indications due to interferences. Inspection in second leg is almost impossible because of the clad layer and highly attenuating weld joint. Coarse grain material and dissimilar metal weld joint makes penetration difficult for transverse waves or even conventional longitudinal waves. Defects situated at root area are much more difficult to find due to issues with SNR ratio, standing echoes and reflections from root areas. Challenge increases when single side access is available for Pipe# Elbow type of joints. In such case, scanning to be done from single side and defects to be captured from weld and HAZ areas including opposite side of the probe scanning surface. (Refer figure 3)
Latest ASME Code is addressing this issue by adding in clause no T-451 of Article 4 as “Additional items, which are required, are weld mock-ups with reference reflectors in the weld deposit and single or dual element angle beam longitudinal wave transducers.” Hence welded mock up block with reference reflectors are mandatory to ensure detectability, sizing of indications and weld volume coverage. Signal to Noise ratio is an important indicator of the quality of the technique for the inspection of austenitic welds, as it quantifies reliability of detection and characterization of small flaws.

3. Solution for CRA Clad piping weld joint inspection

In order to improve the inspection of austenitic welds, longitudinal waves with transmit and receive configuration, focused beam, and signal processing method are key parameters to overcome the limitations. Conventional probes are having fixed focus and hence required many probes to cover full weld volume. Advanced Phased Array UT utilizes Dual Matrix Array (DMA) Probes which offers full weld volume coverage, deep penetration in coarse grain material, flexible focusing thus improving sizing and SNR ratio combining advantages of TRL probes. Dual Matrix Array probe utilizes transmit/receive arrangement of elements ensuring uniform sound pressure in the area of interest. DMA probe constructed from two matrix array as shown figure 4. This provides capability to focus electronically at different depths as well as allows to perform skew angles to verify any oblique flaws. DMA probe configuration is 7X4 elements utilizing 28 elements for the transmitter and 28 elements for the receiver with an aperture of 19 x 12 mm. (See figure 4)
4. Validation of CRA Clad piping weld joint using DMA probes

Successful validations were carried out from 12” OD to 60” OD pipe with thickness range from 12.5mm (+ 3 mm clad) to 53.77 mm (+ 3mm clad) was carried out for CRA clad piping weld joints. Since inspection in second leg is not feasible, weld cap was flush ground to ensure detectability and sizing of flaws. Sample validation details are as follows:

4.1 Important Parameters:
Material MOC: API5L Grade X 65 (base material) + INCONEL 625 Clad.
Thickness: 53.77 + 3 mm Clad
Outer Diameter: 12 Inch
WEP/Joint type: Single V to Compound (Pipe # Fitting)
Probe/Wedge details: 2.25M7x4-19X12-A17 / SA17-DN55L0-IHC-AOD12.75 DMA
Surface: Flush Ground.
Angular Range: 35-70(Group 1), 35-70 deg (Group 2) & 65-87 deg (Group 3)
Angular increment: 1 Deg.

4.2 Calibration Block:
Welded Calibration block was used with same material/product form, welding parameter, cladding and WEP to simulate actual job configuration with set of SDH on weld fusion zone as well as at the centre of the weld ensuring exact sensitivity setting without any transfer correction. In addition to top and bottom notches, creepwave notches (at depths 1mm, 2mm and 4mm) are added to ensure detection of surface flaws.

Figure 5, Calibration Block

4.3 Validation block
Validation block was made with same material/product form, welding parameters, cladding and WEP as per actual job. The same was made in line with ASME B 31.3 Code Case 181 and ASME Section V article 4 appendixes IX requirements with additional flaws in weld volume and HAZ area to ensure full weld volume coverage with adequate sensitivity. EDM
notches were made to simulate Lack of fusion at weld fusion line, Lack of penetration at root area, toe cracks near HAZ area and transverse cracks in weld volume as shown in figure-6.

Figure -6, Validation Block

4.4 Scan Plan
Weld was divided into three zones i.e. Top, Middle and Bottom. Scan Plan was designed to ensure complete weld coverage with adequate focus at each zone. Due to elbow at opposite side, only one probe was kept to ensure middle (weld volume) and bottom (root) zone flaws (Sector scan 35 to 70 deg). A dedicated sector scan i.e. 65 to 87 Deg was kept from both sides for the surface flaws.
4.5 Validation block images-Critical Sample Flaws

4.5.1 Flaw-1-Surface Flaw at Weld HAZ area-OD surface
Flaw-1 was captured with 65 to 87 deg sector scan focusing at top/OD surface Area. Height and length Sizing also shown in the below image.

Figure 8, Flaw-1 PAUT image
4.5.2 Flaw-4-Surface Flaw at Root area-ID Surface
Flaw-4 captured with 35 to 70 deg sector scan focusing at root/ID Surface area. Height and length Sizing also shown in the below image. Signal of flaw 4 is Very clear even though the presence of root indication and interface echoes.

Figure 9, Flaw-4 PAUT image
4.5.3 Flaw-11-Sub-Surface Flaw at Weld side wall

Flaw-11 captured with 35 to 70 deg sector scan focusing at weld volume and from both side of the weld. However to achieve better signal to Noise ratio, the same was captured with probe placing same side of the flaw and on the weld cap area. Height and length Sizing also shown in the below image.

Figure 10, Flaw 11-PAUT image
4.3 Comparison with Radiography:

It was observed that surface flaws (except ID surface flaws are clearly captured with radiography however few sub-surface flaws are difficult to identify. Flaw no 12 was not at all found in radiography. 100% detection was achieved with PAUT whereas 91.6% detection was achieved with radiography. Accurate height sizing was achieved in PAUT thus Fracture mechanics based acceptance criteria can be applied whereas radiography does not give height sizing and thus workmanship based acceptance criteria is applicable. At offshore structure/platforms these piping weld joints are located at height and sometimes radiography is not at all feasible due to geometry and sizes of the joints. For these joints, double wall technique calls for Cobalt RT as the thickness increases to 114 mm. Cobalt RT is banned at many places due to its safety hazards. In case of Cobalt RT, complete evacuation of site area is mandatory resulting into man-hour losses and safety hazards. Refer below figure 11 showing image of RT film. Table -1 shows detailed comparison chart between actual planned indications, PAUT and RT.

Figure-11 Showing surface flaws (Flaw 1,2 & 3) detection in radiography film image.

Figure 12 showing sub surface flaws (Flaw 9, 10 & 11) detection in radiography film Image.
4 Way Forward:
PAUT with DMA probe can be utilized in conjunction with Total Focusing Matrix and Full Matrix Capture techniques to further enhance the sizing capabilities thus improving quality of inspection.

5 Conclusion:
PAUT with DMA probe and specific setup, root indications which are difficult to identify due to clad interface echoes and root geometry indications, can also be successfully detected and sized with adequate SNR ratio. Weld with complex geometries like Pipe# Fittings can be successfully inspected using DMA probe with full weld volume and HAZ coverage. 100% detection was achieved with the DMA probe against 91.6% detection in radiography. 14dB SNR ratio was achieved against conventional PAUT does not have even detection of indications due to highly attenuating Inconel 625 weld. Hence advanced PAUT inspection with DMA probe is the best solution for CRA clad piping weld joints. The only drawback visible with this technique is to flush ground the weld cap to ensure 100% detection and adequate sizing of indications.

6 References: