SEMI-AUTOMATED PHASED ARRAY UT IN LIEU OF RADIOGRAPHY FOR SMALL DIAMETER, REDUCED WALL THICKNESS PIPE WELD JOINTS

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ABSTRACT

The growing demand for power in the global scenario has put pressure on the Power Sector to expand the production capacity and capability to cater to the need. Major share holders for these demands are the Thermal and Nuclear Sectors. These sectors add additional pressure on power plant manufacturers to augment facilities through introduction of innovative productive ways and smarter ways of working in all spheres of activities. The present requirement implies increased production rate to cater to the demand. Radiography is the most widely accepted technology for inspecting welds; however, the production of good and acceptable welds is difficult due to inherent problems associated with radiography. This paper discusses the advantages of utilizing Phased Array techniques in lieu of radiography for smaller diameter, reduced wall thickness pipe to pipe welds that are used in Thermal Power Plants for better production with on-time reliability.

Keywords: PAUT, Radiography, Tomo view, productivity

INTRODUCTION

Phased array ultrasonic testing with imaging capabilities is becoming popular in the NDT industry for its well-known advantages. The proper choice of PAUT probe arrays coupled with better instrumentation for data acquisition, storage and retrieval at a later stage helps in increasing production when compared with radiography with its limitations. The demand to cater for the increased capacity of power requirement pushes NDT technologies to develop faster and more reliable production. Thermal Power sectors utilize smaller diameter, reduced wall thickness pipe welds for their high pressure, high temperature utilities such as boilers and associated steam circuits. The “state of the art” new technologies with supercritical thermal power plants warrants for a quick construction of new power plants which can be installed and commissioned to cater to the demand. In this scenario, increased productivity is the need of the hour, which is aimed with phased array ultrasonic testing for replacement of radiography for thin wall welds. This paper discusses the semi-automated PAUT approach for smaller diameter pipe welds with reduced wall thickness.

ADVANTAGES OF AUT OVER RADIOGRAPHY

Thermal Power Plants use ASME Section VIII, Division 1&2 guide lines for their construction needs for high pressure and high temperature circuits (1). Structural integrity of high pressure, high temperature parts are subjected to one surface and one volumetric NDT methodology for welded construction. While visual, liquid penetrant and magnetic particle tests are used for surface anomalies, radiography and ultrasonic tests are used for volumetric approaches. Low carbon and low alloy ferritic steel play a title role for integration of various components. The possession of high mechanical strength and weldability of these steels leads to a better utilization in designing various components of the power plant industry. Smaller diameter, reduced wall thickness pipe weld joints (21.3mm to 114.3mm) are mostly used in water wall tubes, and high pressure high temperature steam circuits in thermal power plants. Present day NDT methodology utilizing radiography is the main method with a “double wall double image” (DWDI) technique to check the integrity of these welded joints. PAUT with semi/fully automated approaches provides the following advantages: (i) Permanent record of all collected data (ii) Various signal processing options (iii) Easy comparison of results (iv) Re-analysis of raw data at any time (v) Variety of visual displays available (vi) Integrated data acquisition and probe manipulation control (vii) Multiple channel data can be viewed and compared with an overlay (viii) Auditing possibilities.

Phased array technology enables the generation of an ultrasonic beam where parameters such as angle, focal distance and focal point size are controlled through software. The phased array technology offers the following benefits: (i) Software control of beam angle, focal distance and spot size. (ii) Multiple angle inspection with a single small electronically controlled multi-element probe (iii) Greater flexibility for the inspection of complex geometry (iv) High speed scans with no moving parts.
PAUT APPROACH TO THE PROBLEM

Semi-automated PAUT is used to solve the weld inspection for pipe ranges from 21.3 mm (0.84" OD) outside diameter to 114.3 mm (4" OD) with wall thicknesses as per schedule 40, schedule 80 and schedule XS varieties as specified by pipe manufacturers. In order to validate PAUT with semi-automated data acquisition, three carbon steel pipes of 44.5 mm outer diameter and 5 mm wall thickness with a “single Vee” configuration were welded as shown in Fig. 1. For the PAUT approach the studies were carried out using ultrasonic phased array flaw detector model Omni Scan model MX2 of Olympus manufacture, Canada (16:64 System) with multi group option for phased array (see Figure 2).

Natural weld defects such as (i) toe crack (6 mm) and lack of incomplete penetration (9 mm) were introduced in Pipe-1, (ii) root crack (6 mm) and lack of side wall fusion (10 mm) were introduced in Pipe-2 and (iii) an individual porosity (3 mm) and cluster porosities (7 mm) were introduced in Pipe-3. The three pipe samples were subjected to radiography and the results were analyzed. Both X-ray and gamma ray radiography were carried out to identify the location of the above mentioned defects.

TRANSDUCERS & WEDGES

PAUT solution was attempted with a low profile ultrasonic phased array probe of 7.5 MHz (7.5CCEV35-A15) of Olympus manufacture, with optimized elevation focusing, which improves the detection of small defects in thin wall pipes [5]. Two probes are used on both sides of the weld for optimum results to detect any mis-oriented defects from both side of the weld with high POD. The probes are integrated with a couplant supply mechanism for automated couplant supply. Specially designed custom made wedges are coupled to the phased array probe that fits each pipe diameter covered by the scanner. The wedge ID surface is contoured to the pipe outside diameter and fitted to the probe for various diameters ranging from 21.3 mm - 114.3 mm (0.84"-4.5").

FOCUSED ARRAYS

Michael Moles et al in their paper [5] have established the results showed that lateral (or horizontal) oversizing could become a major problem for smaller diameter pipes, as beam spread was more critical. Modeling showed that only two curvatures were required to cover essentially all small pipe diameters, independent of wall thickness. The larger radius curved array was manufactured and tested on known reflectors, and compared with a standard flat (unfocused) array on pipes of 70 and 38 mm diameter and curved arrays showed a better sizing accuracy.

MECHANICS

The PAUT solution was carried out with the Olympus small manual scanner (COBRA) which is capable of inspecting standard pipes as small as 0.84 in. OD (21.3 mm OD) to 4.5 in. OD (114.3 mm OD). The spring loaded design enables holding onto carbon steel and stainless steel pipes of different diameters.
The scanner is characterized by a smooth rolling encoded movement (32 steps/mm) enabling precise data acquisition (Fig. 3). The scanner holds two low profile phased array probes and wedges as mentioned above for a complete inspection of the weld in one pass. For pipe to component inspections, the scanner can be quickly configured to make one sided inspections with only one probe. The compact design of the scanner enables inspecting with a clearance around 12.7mm between the pipes for a full circumferential weld. COBRA’s capabilities have been documented elsewhere [5-6]. More details about the scanner is elaborated in Olympus web site [8].

**COUPLANT SUPPLY MECHANISM**

AUT uses water as a couplant due to continuous feed of water during data acquisition. The COBRA Scanner is equipped with a water irrigation system coupled to the two probes independently with a manual water spray kit for field use and portability.

**RESULTS**

The three pipes were subjected to both radiography and PAUT. The radiographic image and PAUT analysis could be clearly identifiable. PAUT Results: The data captured from both probes were merged with Olympus’s advanced ultrasonic data analysis software “Tomo View” with the weld overlay. The results are tabulated below for all the six defects. The zero reference was marked on the pipe and results were analyzed independently. Semi-automated data acquisition clearly shows the position and size of the defects which is in correlation with radiography. A total scan length of 150mm was kept for data acquisition and scanning was carried out from the end marked zero on the pipes. The results are summarized in the Table 1 below:

**Table 1: PAUT RESULTS**

<table>
<thead>
<tr>
<th>Description of the defect</th>
<th>Length (6dB Sizing)</th>
<th>Position from start (0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toe Crack</td>
<td>6 mm</td>
<td>22-28mm</td>
</tr>
<tr>
<td>Incomplete Penetration</td>
<td>9mm</td>
<td>129-138mm</td>
</tr>
<tr>
<td>Root Crack</td>
<td>6mm</td>
<td>18-24mm</td>
</tr>
<tr>
<td>Lack of Fusion</td>
<td>10mm</td>
<td>72-82mm</td>
</tr>
<tr>
<td>Porosity</td>
<td>3mm</td>
<td>64-67mm</td>
</tr>
<tr>
<td>Cluster porosities</td>
<td>7mm</td>
<td>120-127mm</td>
</tr>
</tbody>
</table>

Fig. 4: Radiographic image of Pipe sample-1 (a) Toe-crack detection by PAUT (b) Incomplete penetration detection by PAUT
Fig. 5 : Radiographic image of Pipe sample-2 (a) Root crack detection by PAUT (b) Lack of side wall fusion detection by PAUT

Fig. 6 : Radiographic image of Pipe sample-3 (a) Individual pore detection by PAUT (b) Cluster porosities detection by PAUT
Pipe no: 2: Two weld defects have been introduced into this pipe. These defects are (i) Root crack (ii) Lack of side wall fusion. Radiographic image shown below has identified both the defects and the PAUT results are shown in Figure 5a &5b:

Pipe no: 3: Two weld defects were introduced into this pipe. These defects are (i) isolated porosity (ii) Cluster of porosities. Radiographic image shown below. PAUT (see Figure 6a & 6b) has identified both the defects:

**DISCUSSIONS**

**CODE GUIDELINES**

ASME Section VIII, Division 1& 2 (1) guidelines are also followed for boiler power plant constructions. While radiography is dealt with in appendix 4, ultrasonic testing is dealt with in appendix 12. With the prove out of the potential capabilities of phased array ultrasonic testing through various code cases, this technology has been brought into ASME Section V, Article 4, 2010 Edition [4] for welds. Encoded data with a resolution of 0.5mm and with a beam swept angle resolution of 0.5° clearly identified the weld defects with a better accuracy.

The arrival of ASME Code Cases B31.31-179 & B31.3-181 [2,3] has permitted AUT of small diameter pipe girth welds. ASME B31.1 CC 179 is a workmanship-based Code Case. ASME B31.3 does permit manual ultrasonic inspection of pipe welds, but has the limitations listed above (slow, operator-dependent, no auditable results). As it is Fracture Mechanics-based, B31.3 Code Case 181 needs accurate defect sizing and dimensioning. This is difficult requirement for thin pipes. For small diameter pipes, the ultrasound beam naturally spreads (defocuses) on entry in the horizontal direction. This will lead to defect oversizing, and hence higher repair rates. Irrespective the welding methodology the main advantage of PAUT approach is the time factor involved in lieu of RT. While Radiography warrants additional UT for assessing the depth for repairs and corrective actions, PAUT eliminates this with both side access over the weld providing the length, depth and orientation which is superior to Radiography. The reduced time in inspecting a weld (within five minutes) leads to a better production rates. As regulatory board for operation of power plants suggests only 20% radiography of these joints, the integrity of 80% can be better utilized with this technology for fitness for purpose applications for defect detectability and with an increased production rate.

**CONCLUSIONS**

Radiography and PAUT of three pipe welds were carried out and analyzed by both techniques. Both the techniques have validated the weld defects. The encoded scan resolution of 0.5mm data acquisition of the entire length of the weld with a beam sweep resolution of 0.5° have demonstrated the capabilities of phased array ultrasonic technology in lieu of radiography. PAUT has more advantages in detecting weld discontinuities than radiography and provides a three dimensional view i.e. length, height, orientation and depth which has a cutting edge over radiography. The high speed inspection, accessibility to the welds and quicker analysis leads to firm decisions of acceptance/reject of the welds with immediate results. On the contrary use of radiography limits the productivity of these welds by isolation and condoning the area. Present day Engineering Critical Assessments (ECA) and Risk Based Inspections (RBI) warrant adoption of single volumetric NDT methodology during fabrication and in-service inspection approaches. The study encourages in utilization of PAUT is the alternate choice for smaller diameter, reduced wall thickness pipe weld joints in lieu of Radiography. The data acquisition during production forms the basis for in-service inspection on installed components for easier accessibility and monitoring for degradation if any due to service. One methodology proves to be adequate for fitness for purpose applications till the design life of weld/components.

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