APPLICATION OF PHASED ARRAY TECHNIQUES TO THE REACTOR INTERNAL PUMP CASING WELD

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ABSTRACT
Integrity of the inconel weld joint connecting Reactor Internal Pump (RIP) casing to the Reactor Pressure Vessel (RPV) in Advanced Boiler Water Reactor (ABWR) is important for safety. The difficulty in examining is mainly caused by limited access space. The probes, scanner, and cabling has to be assembled within a high radiation dose rates working space of 18mm in height. In this research, a specific ultrasonic phased array probe and CIVA simulation were used to develop an efficient inspection technique. UT simulation on the RIP casing weld and mockup test result will be shown.

Keywords: ABWR, RIP, ultrasonic inspection, phased array, inconel weld

INTRODUCTION
Lungmen nuclear power plant in Taiwan is a twin-unit ABWR plant. Since the ASME (American Society of Mechanical Engineers) Boiler & Pressure Vessel Code Section XI (2007) required the RIP motor casing welds to perform visual examination only[1], the plant designer suggested to perform volumetric examination as well. Because the out side surface of the RIPs was not accessible for manual ultrasonic testing (UT), the owner decided to perform remote visual examination from out side and manual UT from inside of the RIPs during preservice inspection. After the plant startup, the inside surface of the RIPs become inaccessible, thus an automatic UT examination method from out side of motor casing need to be developed for checking the integrity of these welds during inservice. Figure 1 shows the RIP casing weld and the weld configuration.

The nickel based alloy weld, the so-called dissimilar metal weld (DMW), is 38mm thick with double sided inconel-82 buttering and 10mm thick stainless cladding. The gap between outside surface of RIP motor casing and RPV wall, where is the available space for examination, is only 18mm in width. The welds were fabricated by automatic machine welding. After fabrication, the welds were machined to provide a smooth outer surface for inspections[2]. That means the UT examination can be performed from either side of the weld. For the radiation dose rates are high during the plant inservice, it is necessary to perform examination efficiently in this area. However, inspecting the DMW by UT techniques is difficult because of the anisotropy nature of the weld metal microstructure[3]. To inspect a DMW, a qualified conventional UT procedure may require 5 different probes to scan from 6 direction. The procedure seems complex for scanner mechanism, probe movement and cable arrangement within merely 18mm in height. Furthermore, the system assembly/disassembly efficiency was important in this area. To develop a concise inspection system under these conditions, reducing the probes needed and simplifying the probes movement would be an effective solution.
Phased array ultrasonic testing (PAUT) techniques are very popular in this decade. For continuing improvement of the techniques, the probes are much compact and precisely controlled[4]. The analysis and simulation software are enhanced not only by the increased computer calculation speed but also the advanced functions supported. Using one PAUT probe to cover all the conventional UT angles needed for the DMW is now an achievable goal. In addition, with the advantage of electronic focusing ability, the PAUT technique helps to improve the detection rate of flaws, and with the advanced scan pattern, it helps to improve the inspection efficiency as well. This paper showed an experiment to examine the RIP motor casing weld specimen by using only one customized PAUT probe.

EXPERIMENT

EQUIPMENT
The equipment used in this experiment was Olympus Omniscan MX 32/128 PR phased array instrument with ZETEC Ultravision 1.1Q5 software, run on a personal computer connected to the instrument via Ethernet. The focal laws were developed by ZETEC Advanced PA Calculator 1.2R1. The beam simulation and scan calculation was calculated by CIVA 10 software.

MOCKUP
A 180 degree pipe weld specimen was used in this study. Figure 2 shows the test specimen weld configuration. All the weld configuration was the same as the RIP motor casing weld but the buttering. The thickness of RIP buttering was about 23mm on the upstream side and 10mm on the downstream side of the weld, but it was designed to be 23mm on both side of the weld in the specimen. There are three thermal fatigue cracks implanted in the weld metal or buttering. The dimension and orientation of the flaws were listed in Table 1. The position of all cracks were showed in Figure 3.
In this study, only one customized probe (8x3 elements per side, aperture size 28.0 x 13.8 mm) with integrated contour wedge was employed in this test. It is a special choice because in most of the applications used in examining the DMWs, at least two PAUT probes were employed. One is for circumferential cracks and the other is for axial cracks. But experience shows cracks in different orientations were frequently detected by each probe, therefore only one customized probe with integrated contour wedge was employed for simplicity.

When examining a DMW, a 1.5 MHz transmit-receive longitudinal (TRL) matrix array is commonly preferred for its balanced performance in resolution and penetration capability. The longitudinal wave probe with relatively low frequency was often used to penetrate the coarse grained or anisotropic material. While in this case, the dimension of the probe was seriously restricted by the space between RPV wall and RIP motor casing. That means, the probe should be less than 18mm in height. To meet this need, it was difficult for a 1.5 MHz matrix array to get suitable damping effect. So choosing a 2.0 MHz TRL matrix array was a trade-off between damping performance and frequency.

SOUND FIELD SIMULATION AND SCAN PLAN
To maximize the efficiency of the examination, the probe was expected to performed sectorial scan (S-Scan) 35 to 70 degree in 1 degree increment; skew angle -15 to +15 degree in 15 degree increment. After the probe specification was designated, a simulation for the expected focal laws was done by the CIVA 10 software. Figure 4 showed the radiated beams (Longitudinal waves) at 35, 60 and 70 degrees for focused beams formed with all transmitting element. All beams were focusing at the inner surface of specimen (38mm in depth). The simulation results revealed that the probe was not able to focus at the desired depth for angle higher than 60 degree. In order to perform a full coverage inspection of the area of interest conservatively, these angle were excluded while calculating the coverage of the scan plan.

Figure 5 showed the required exam volume for a dissimilar metal pipe weld according to the ASME
Boiler & Pressure Vessel Code Section XI FIG. IWB-2500-8. The area of interest includes 1/3 thick of the weld from the inside surface out to about 6mm from a line drawn from the toe of the outside surface weld crown.

Figure 4: Sound field simulation of the customized probe
(a) longitudinal waves at 35 degree;
(b) longitudinal waves at 60 degree;
(c) longitudinal waves at 70 degree

Figure 5: ASME Section XI FIG. IWB-2500-8

According to the code, the thickness of the buttering does not affect the area of interest, whereas some field practice requires the examination coverage to include 1/3 thick of the weld from the inside surface out to about 6mm from a line drawn from the outer exterior edge of the buttering. In this paper, the examination adopted the later definition for conservation, so the thickness of the buttering do affect the
size of exam volume. For the RIP motor casing weld specimen used, the exam volume was increased significantly because it’s double sided buttering and the thickness of a single buttering is up to about 24mm. By assuming a focused S-Scan 35 to 60 degree, the scan plan was calculated to meet the full coverage requirement of the specimen. Figure 6 showed the resulting scan plan of the specimen from one side of the weld. There were 5 line scan each side, so it took 10 line scan in total.

![Figure 6: The scan plan of the specimen](image)

DATA ACQUISITION
Although the angles higher than 60 degree were excluded from the full coverage calculation for conservation, it was necessary to include these higher angles for through wall depth sizing of deep cracks. The final focal laws setting were S-Scan 35 to 70 degree in 1 degree increment; skew angle -15 to +15 degree in 15 degree increment. Data were acquired at 50MHz with 8 bit format. Only one encoded manual probe holder were employed.

RESULTS
After merging all the inspection data, the examination result with CAD weld configuration overlay was shown in Figure 7. Two cracks were identified on the upstream side and one was identified in the downstream side. The length and depth sizing of all cracks were performed by further evaluating through the raw data. The sizing evaluation and error calculation results of all cracks were listed in the Table 2.

Figure 7(c) showed the crack 1 was an axial crack and positioned in the stainless cladding area of the RPV nozzle. In all the raw data, crack 1 was not able to distinguish the corner echo from stainless cladding noise, it was thus not possible to perform length sizing of the crack.

The ASME Boiler and Pressure Vessel Code Section XI, Appendix VIII, requires that the acceptable length sizing root mean square (RMS) is within 19.1 mm (0.75 in.) and depth sizing is within 3.2 mm (0.125 in.). In the examination, the maximum error of length sizing is 8.5mm, which is good enough for the requirement. On the contrary, the maximum error of the depth sizing is 11.3mm, which is fairly unacceptable.
CONCLUSION
In this research, a customized PAUT probe was successfully developed to perform examination from outside of RIP motor casing welds. A RIP motor casing weld mockup with 3 implanted thermal fatigue cracks was used in the examination. The result showed good detection ability and acceptable length sizing accuracy for circumferential cracks. Axial cracks can be detected but without fair performance in length sizing. The depth sizing results were unreliable whether the crack was axial or circumferential orientated. The strong noises were noted in the examination result, it could be difficult to distinguish corner echoes from cladding noises when the cracks were positioned in the cladding area. The test result will be helpful while developing future scanner for this type of welds.

REFERENCES
4) J M Davis and M Moles, Resolving capabilities of phased array sectorial scans (S-scans) on diffracted tip signals, Insight Vol 48 No 4, April 2006.

Table 2 Test results (unit: mm)

<table>
<thead>
<tr>
<th>Crack</th>
<th>UP/DOWN</th>
<th>Orientation</th>
<th>Length</th>
<th>Height</th>
<th>Err of Length</th>
<th>Err of Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 UP</td>
<td>AXIAL</td>
<td>N/A</td>
<td>26.6</td>
<td>N/A</td>
<td>11.3</td>
<td></td>
</tr>
<tr>
<td>2 UP</td>
<td>CIRC</td>
<td>16.6</td>
<td>21.4</td>
<td>8.5</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>3 DOWN</td>
<td>CIRC</td>
<td>37.8</td>
<td>21.5</td>
<td>4.9</td>
<td>7.0</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7: Specimen test result
(a) Volume Corrected C-Scan;
(b) Volume Corrected B-Scan;
(c) Volume Corrected D-Scan