Phased Array Ultrasonic Testing for Heavy Wall Austenitic Stainless Steel Welds

Yokesh G. Ravichandran, P. S. Sanath Thampi, Suresh Jakkula, G. Selvakumar, T. C. Karthikeyan, Pemmaraju Raghavendra

NDE Department, Heavy Engineering Division, Larsen and Toubro Limited

Hazira, Surat, India-394510

E-mail: yokesh.ravichandran@larsentoubro.com, sanath.thampi@larsentoubro.com, suresh.jakkula@larsentoubro.com, selva.kumar@larsentoubro.com, tc.karthikeyan@larsentoubro.com, pemmaraju.raghavendra@larsentoubro.com

Abstract

Fabrication of Heavy wall stainless steel (SS) vessels is still a challenge for the Heavy Fabrication Industries, because of the inherent limitations in the quality check methods employed for volumetric examinations such as Radiographic Examination (RE) and Ultrasonic Examination (UE). The anisotropic dendritic grain structures formed during welding acts as a hindrance for the volumetric NDE. Further, coarse dendritic grain structure plays a major role in scattering of ultrasonic sound waves and beam skewing, especially in Austenitic SS weld metal which have coarser grain boundaries compared to its base metal.

The pressure generated by conventional UE probes is high in the center of the beam and reduces as towards the edges. In addition sound waves will get easily scattered by the grain structure. Hence interpretation becomes very tough due to the noise produced by this scattering. This paper explains how Phased Array Ultrasonic Testing (PAUT), can be used for volumetric examination method in high thickness SS 304L welds overcoming the inherent properties of SS welds such as coarse grain dendritic structure, beam skewing etc. by using large number of crystals arranged in a similar manner as two arrays; one array will act as transmitter and the other as receiver, PAUT using a dual matrix array probe gives sound wave with uniform pressure in area of interest. Generating different angles in a single scan is also possible as other PAUT probe facilitates. A SS304L welded mockup block with holes and silts was made and the results obtained in regard to penetration power, sizing and locational accuracy are discussed in this paper.

Keywords: SS 304L welds, Austenitic, beam skewing, PAUT, Dual matrix array probe.
**Introduction on Inspection of austenitic steel welds**

SS 304L is one of the most preferred forms of stainless steel in fabrication of heavy walled vessels. It is low carbon variant of SS 304 with 0.03 % C, 18% Cr, 8% Ni, 0.75% Si and 2% Mn. SS304L does not have the problem of carbon precipitation when welded. The anisotropic dendritic grain structures formed during welding acts as a hindrance for volumetric NDE. Ultrasonic testing of austenitic stainless steel welds is often difficult because the ultrasonic beam is subjected to many perturbations: deviation, distortions and sometimes ghost echoes. The coarse dendritic grain structure plays a major role in scattering of ultrasonic sound waves and beam skewing. Thus two major problems are being faced during ultrasonic inspection of stainless steel welds: Defect detection is hampered by high attenuation and scattering by coarse grains, and defect location is made inaccurate by velocity variations and beam skewing caused by different grain structures. Hence high voltage is required for better penetration in the material. As a consequence interference and wedge echoes increases which compromises signal-to-noise ratio, limiting quality check methods employed for volumetric examinations of SS 304L welded components using ultrasonic examination.

Within the anisotropic weld metal the beams may deviate from the expected propagation directions. The extent of the beam deviation depends on wave mode (longitudinal or transverse) and propagation direction relative to the columnar grain axis. Studies have been conducted to show the variation in longitudinal wave velocity in stainless steel welds with orientation of columnar grain axis relative to propagation direction. In an anisotropic material the ray direction and the direction of energy travel is not perpendicular to the wave front, which results in skewing of beam off the transducer axis. Minimum skewing was observed for waves propagating at about 45° to columnar grain axis. Further research studies reached to the conclusion that the variation in apparent attenuation may be primarily due to the variation in beam width with propagation direction, with the smallest beam width observed in direction of maximum velocity.

For better penetration in these coarse grain materials, longitudinal waves (L-wave) are preferred. The drawback of using L-waves is that they will also generate shear wave (S-waves) when skipping from the back wall, therefore limiting their use for coverage of the upper part of the weld using the second leg.

**Dual Matrix Array probes**

Single crystal probe created shear wave components which resulted in confusion during data interpretation led to use of Transmit Receive Longitudinal (TRL) probe in acoustically noise material. TRL is basically a dual element probe with one emitter and one receiver separated by acoustic insulation. The squint and roof angles configuration allows focusing at one point in the part and creates a pseudo-focalization. This probe eliminate the interface echo, dead zones due to wedge echoes, reduces the backscattering signals and permit the use of higher gain.
As a TRL probe has a fixed refracted angle and pseudo-focal point, a typical inspection requires many of these probes to cover a range of different configurations. Dual matrix array probes (DMA) are evolution of this technology. A DMA probe combines the advantages of TRL probes with phased-array technology allowing electronic steering, skewing and focusing of acoustic beams. DMA phased array probes consists of two matrix arrays, the beam can be typically be swept from 45° to 87°, allowing inspection of upper part of the weld thus eliminating one of the limitation linked with using longitudinal probe for inspection of SS welds. Further pseudo-focal point can be adjusted for various depths, the beam size can be varied by selecting different aperture sizes and the beam can be skewed looking for oblique defects. Thus a DMA probe is more flexible than a TRL probe as it can adapt to different configurations electronically. With the use of phased array technology a record for the inspection carried can be maintained. Thus DMA phased array probe improves flaw detection and sizing of difficult to penetrate materials by combining the benefits of low frequency longitudinal focused beam S-scans and transmit-receive inspection technique.

Stainless steel welded block of thickness 50& 120 mm with holes and notches was used for study. CADD drawing of the mock up block made is shown in Figure 3. Holes and notches made on block are mentioned in table in 1.

Details of 50 mm block:

Thickness of the Block: 50mm

Material: Austenitic stainless steel Gr SA 304 L

Welding Process: GTAW+SMAW
Slits made using: EDM

**Details of 120 mm thick block:**

Thickness of the Block: 120mm

Material: Austenitic stainless steel Gr SA 304 L

Welding Process: GTAW+SAW

Reflectors used: Side Drilled Holes (SDH)

*Figure 3 CADD Drawings of Mockup Block*

*Figure 4 Details of slits placed in the weld (a) 2mm(W) X 8mm (H) Slit at the WEP fusion zone (b) 1mm(W)X 3mm(H) Slit at the weld center.*
Figure 5 Slits made in mock up block

Table 1 List of Artificial Defects Made In Block

<table>
<thead>
<tr>
<th>DEFECT TYPE</th>
<th>LOCATION FROM TOP SURFACE, mm</th>
<th>DIMENSION, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOLE, H1</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>HOLE, H2</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>HOLE, H3</td>
<td>28</td>
<td>3</td>
</tr>
<tr>
<td>HOLE, H4</td>
<td>43</td>
<td>3</td>
</tr>
<tr>
<td>SLIT, N1</td>
<td>0</td>
<td>25x2x1</td>
</tr>
<tr>
<td>SLIT, N2</td>
<td>0</td>
<td>12x2x3</td>
</tr>
<tr>
<td>SLIT, N3</td>
<td>11</td>
<td>16x2x8</td>
</tr>
<tr>
<td>SLIT, N4</td>
<td>17</td>
<td>16x2x8</td>
</tr>
<tr>
<td>SLIT, N5</td>
<td>22</td>
<td>16x2x8</td>
</tr>
<tr>
<td>SLIT, N6</td>
<td>37.5</td>
<td>16x2x8</td>
</tr>
<tr>
<td>SLIT, N7</td>
<td>00</td>
<td>12x2x3</td>
</tr>
<tr>
<td>SLIT, N8</td>
<td>00</td>
<td>25x2x1</td>
</tr>
</tbody>
</table>
Setup and scan plan:

The block was scanned using Olympus Dual matrix array probe. Probes specification and settings used for inspection are mention in Table 2. A special software Set-Up builder developed by Olympus was used for preparing the scan plan and generating focal laws. Sensitivity and wedge delay calibration was performed using the side drill hole present in V1 block. TCG curve was plotted using the holes made in the mock up.

Since main objective was to study the penetration of ultrasonic wave with less beam skewing and attenuation in weld, scanning surface was not considered as a main parameter for the study. The block was scanned from both root and face side of weld. The induced EDM slits were detected from these two surfaces.

Two important capabilities of the longitudinal wave was studied – Penetration and Sensitivity.

Penetration capability of longitudinal ultrasonic wave:

<table>
<thead>
<tr>
<th>Table 2 Probe Parameters and UT Settings Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Elements</td>
</tr>
<tr>
<td>Pulsar Voltage</td>
</tr>
<tr>
<td>Aperture</td>
</tr>
<tr>
<td>Start Angle</td>
</tr>
<tr>
<td>Stop Angle</td>
</tr>
<tr>
<td>Resolution</td>
</tr>
</tbody>
</table>
Penetration power of the ultrasonic longitudinal wave, generated by DMA probe, was studied by catching the slit from face side. The important fact is that the slit has to be detected by the wave that is passing through the weld. So the probe was positioned on the surface opposite to that of slit. The slit was detected by the wave that passed through weld metal with signal-to-noise ratio of 6.9. Figure 6 shows the arrangement of probe and the respective response. The slit was detected at an angle of 62°. The slit was placed exactly parallel to the 37° WEP face and hence this angle of detection shows that the reflection is from the length face of slit. Sizing and location of the slit was found to be same as in Table 1 from 6 dB analysis and machine read outs respectively. This helps in understanding the penetrating capability of longitudinal wave while using DMA probe.

Figure 6 Probe position and response from slit N4

Figure 7N4 Slit detected by DMA probe
Sensitivity – The minimum detectable size:

The sensitivity of the longitudinal wave generated by DMA probe was studied by catching the slit N10 from the root face. This slit which was having a dimension of 1mm width and 3 mm height was detected by the wave passing through weld material. This shows that the size is not a factor which decreases POD, it is the penetrability of the sound wave crossing this coarse grain structure.

Heavy wall austenitic stainless steel inspection with DMA probe:

The feasibility of this probe in case of inspecting higher thickness of SS weld was studied using a 120mm thick – Tee joint block. Since the weld was with SAW weld process and the thickness
being high, the grain structure was expected to be very coarse grain with large size, as heat
dissipation in SAW weld decreases as thickness is increases. Ultrasonic wave was allowed pass
through the weld material. It was noted that the longitudinal sound wave generated by this probe is
passing the heavy coarse grain structure and catching the SDH, shown Figure 10, which is at a depth
of 74 mm in fusion zone between base material and the weld.

Figure 10 SDH in Tee joint
Conclusions

With the help of DMA probe combined with phased array technology the slit that was made in the weld was captured by ultrasonic wave that penetrated through the weld. The effect of beam skewing and attenuation in SS welds was found to have very less effect when tested with DMA probe. The ability of DMA probe to sweep from 45° to 70° helped in inspection of complete weld volume using first leg reducing the number of scans. A drawback while using DMA probe for inspection of austenitic steel weld is that weld should be accessible from both sides as inspection and data interpretation is carried using first leg only. The probe has the capability to sweep from 38° to 70° so the weld must be flushed and made in level with base metal to detect the surface and near surface indications.

References