7.5.5 ULTRASONIC EXAMINATION USED IN LIEU OF RADIOGRAPHIC EXAMINATION

(19) 7.5.5.1 When used in lieu of the radiographic examination requirements of 7.5.3, automated or semi-automated ultrasonic examination shall be performed in accordance with a written procedure conforming to the requirements of Section V, Article 4, Mandatory Appendix VIII or Mandatory Appendix XI, as applicable, and the following additional requirements. For SAW welds in $2\frac{1}{4}$Cr–$1Mo–\frac{1}{4}$V vessels, additional ultrasonic examination is required and shall be in accordance with 7.5.4.1(c).

(a) The ultrasonic examination area shall include the volume of the weld, plus 50 mm (2 in.) on each side of the weld for material thickness greater than 200 mm (8 in.). For material thickness 200 mm (8 in.) or less, the ultrasonic examination area shall include the volume of the weld, plus the lesser of 25 mm (1 in.) or $t$ on each side of the weld. Alternatively, examination volume may be reduced to include the actual heat-affected zone (HAZ) plus 6 mm ($\frac{1}{4}$ in.) of base material beyond the heat-affected zone on each side of the weld, provided the following requirements are met:

(1) The extent of the weld HAZ is measured and documented during the weld qualification process; and

(2) The ultrasonic transducer positioning and scanning device is controlled using a reference mark (paint or low stress stamp adjacent to the weld) to ensure that the actual HAZ plus an additional 6 mm (0.25 in.) of base metal is examined.

(b) The initial straight beam material examination (Section V, Article 4, T-472) for reflectors that could interfere with the angle beam examination shall be performed:

(1) Manually,

(2) As part of a previous manufacturing process, or

(3) During the automated or semi-automated UT examination, provided detection of these reflectors is demonstrated.

(c) Personnel performing and evaluating UT examinations shall be qualified and certified in accordance with 7.3. Only UT Level II or or Level III personnel shall analyze the data or interpret the results. In addition, UT personnel shall meet the requirements of Section V, Article 4, Mandatory Appendix VIII, VIII-423 prior to performing production scans.

(d) Contractor qualification records of certified personnel shall be approved by the Certificate Holder and maintained by their employer.

(e) Qualification of the procedure shall be performed per Section V, Article 1, T-150(d), and Section V, Article 4, Mandatory Appendix VIII, VIII-421.2.

(f) Application of automated or semi-automated ultrasonic examinations shall be noted on the Manufacturer’s Data Report, as well as the extent of its use.

NOTE: Sectorial scans (S-scans) with phased arrays may be used for the examination of welds, provided they are qualified satisfactorily in accordance with (e). S-scans provide a fan beam from a single emission point, which covers part or all of the weld, depending on transducer size, joint geometry, and section thickness. While S-scans can demonstrate good detectability from side drilled holes, because they are omnidirectional reflectors, the beams can be mis-oriented for planar reflectors (e.g., lack of fusion and cracks). This is particularly true for thicker sections, and it is recommended that multiple linear passes with S-scans be utilized for components greater than 25 mm (1 in.) thick. An adequate number of flaws should be used in the demonstration block to ensure detectability for the entire weld volume.

7.5.5.2 Flaw Sizing. The dimensions of the flaw shall be determined by the rectangle that fully contains the area of the flaw, and the flaw shall be classified as either a surface or subsurface flaw (see Figures 7.11 through 7.15).

(a) The length, l, of the flaw shall be drawn parallel to the inside pressure-retaining surface of the component.

(b) The measured flaw through-wall dimension shall be drawn normal to the inside pressure-retaining surface and shall be defined as a for a surface flaw or $2a$ for a subsurface flaw.

(c) Subsurface flaw(s) close to a surface shall be considered surface flaw(s) if the distance between the flaw and the nearest surface is equal to or less than one-half the flaw through-wall dimension, as shown in Figures 7.11 through 7.15.

7.5.5.3 Flaw Evaluation and Acceptance Criteria. Flaws shall be evaluated for acceptance using the applicable criteria of Tables 7.8, 7.9, 7.10, or 7.11, and with the following additional requirements. Unacceptable flaws shall be repaired and the repaired welds shall be re-evaluated for acceptance.

(a) For surface connected flaws, the measured through-wall dimension, $a$, shall be compared to the value of $a$ as determined from the applicable flaw acceptance criteria table.

(b) For subsurface flaws, the measured through-wall dimension, $2a$, shall be compared to twice the value of $a$ as determined from the applicable flaw acceptance criteria table.

(c) Surface Flaws - Flaws identified as surface flaws during the UT examination may or may not be surface connected, as shown in Figures 7.11 through 7.15. Therefore, unless the UT data analysis confirms that the flaw is not surface connected, it shall be considered surface connected or a flaw open to the surface, and is unacceptable unless surface examination is performed. If the flaw is surface connected, the requirements above still apply. However, in no case shall the flaw length, l, exceed the acceptance criteria in this Division. Acceptance surface examination techniques are as follows:

(1) Magnetic particle examination (MT) in accordance with 7.5.6,
(2) Liquid penetrant examination (PT) in accordance with 7.5.7,
(3) Eddy Current examination (ET) in accordance with 7.5.8.

(d) Multiple Flaws

(1) Discontinuous flaws shall be considered a singular planar flaw if the distance between adjacent flaws is equal to or less than the dimension S as shown in Figure 7.12.

(2) Discontinuous flaws that are oriented primarily in parallel planes shall be considered a singular planar flaw if the distance between the adjacent planes is equal to or less than 13 mm (\( \frac{\sqrt{2}}{8} \) in.) (see Figure 7.13).

(3) Discontinuous flaws that are coplanar and nonaligned in the through-wall thickness direction of the component shall be considered a singular planar flaw if the distance between adjacent flaws is equal to or less than S as shown in Figure 7.14.

(4) Discontinuous flaws that are coplanar in the through-wall direction within two parallel planes 13 mm (\( \frac{\sqrt{2}}{8} \) in.) apart (i.e., normal to the pressure-retaining surface of the component) are unacceptable if the additive flaw depth dimension of the flaws exceeds those shown in Figure 7.15.

(e) Subsurface Flaws - the flaw length, l, shall not exceed 4t.

7.5.6 MAGNETIC PARTICLE EXAMINATION (MT)

7.5.6.1 All magnetic particle examinations shall be performed and documented in accordance with Section V, Article 7 except as specified below:

(a) A complete set of records, as described in Section V, Article 7, T-790, for each vessel or vessel part shall be retained by the Manufacturer until the Manufacturer's Data Report has been signed by the Inspector.

(b) Personnel performing and evaluating magnetic particle examinations required by this Division shall be qualified and certified in accordance with 7.5. Evaluation of magnetic particle examination shall only be performed by MT Level II or III personnel.

(c) Magnetic particle examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150.

(d) Indications will be revealed by retention of magnetic particles. All such indications are not necessarily imperfections, however, since excessive surface roughness, magnetic permeability variations (such as the edge of heat-affected zones), etc., may produce similar indications. An indication of an imperfection may be larger than the imperfection that causes it; however, the size of the indication is the basis for acceptance evaluation. Only indications which have any dimension greater than 1.5 mm (\( \frac{\sqrt{16}}{8} \) in.) shall be considered relevant.

(1) A linear indication is one having a length greater than three times the width.

(2) A rounded indication is one of circular or elliptical shape with a length equal to or less than three times its width.

(3) Any questionable or doubtful indications shall be reexamined to determine whether or not they are relevant.

7.5.6.2 Acceptance Criteria. The following acceptance standards shall apply unless other more restrictive standards are specified for specific material or applications within this Division. Unacceptable indications shall be removed or reduced to an indication of acceptable size. Whenever an indication is removed by chipping or grinding and subsequent repair by welding is not required, the excavated area shall be blended into the surrounding surface so as to avoid notches, crevices, or corners. Where welding is required after removal of indications, the repair shall be done in accordance with 6.2.7.

(a) All surfaces to be examined shall be free of:

(1) Relevant linear indications

(2) Relevant rounded indications greater than 5 mm (\( \frac{\sqrt{16}}{8} \) in.)

(3) Four or more relevant rounded indications in a line separated by 1.5 mm (\( \frac{\sqrt{16}}{8} \) in.) or less, edge-to-edge

(b) Crack like indications detected, irrespective of surface conditions, are unacceptable.

7.5.7 LIQUID PENETRANT EXAMINATION (PT)

7.5.7.1 All liquid penetrant examinations shall be performed and documented in accordance with Section V, Article 6 except as specified below:

(a) A complete set of records, as described in Section V, Article 6, T-691 and T-692, for each vessel or vessel part shall be retained by the Manufacturer until the Manufacturer's Data Report has been signed by the Inspector.

(b) Personnel performing and evaluating liquid penetrant examinations required by this Division shall be qualified and certified in accordance with 7.3. Evaluation of liquid penetrant examination shall only be performed by PT Level II or III personnel.

(c) Liquid penetrant examination shall be performed in accordance with a written procedure, certified by the Manufacturer to be in accordance with the requirements of Section V, Article 1, T-150.
7.5.5.4 Alternative Subsurface Flaw Evaluation and Acceptance Criteria

When $S \leq 0.4$ as shown in Figure 7.11A, a subsurface flaw near the surface may be classified as a surface flaw. When the requirements of 7.5.5.3 (a) through (e) are satisfied, and $0.4 < Y_a < 1.0$, subsurface flaws may be evaluated using the acceptance criteria given in Table 7.10A [or Figure 7.11D sketch (a) or sketch (b)] or Table 7.11A [or Figure 7.11D sketch (c)]. Unacceptable flaws shall be repaired, and the repaired areas shall be re-examined. When $Y_a > 1.0$, flaws shall be evaluated using the acceptance criteria of Table 7.8, 7.9, 7.10 or 7.11.

Table 7.9
Flaw Acceptance Criteria for Welds With Thicknesses Between 13 mm (½ in.) and Less Than 25 mm (1 in.)

<table>
<thead>
<tr>
<th>Flaw Type</th>
<th>$a/t$</th>
<th>$l$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Flaw</td>
<td>$\leq 0.087$</td>
<td>$\leq 6.4$ mm (¼ in.)</td>
</tr>
<tr>
<td>Subsurface Flaw</td>
<td>$\leq 0.143$</td>
<td>$\leq 6.4$ mm (¼ in.)</td>
</tr>
</tbody>
</table>

GENERAL NOTES:
(a) The parameter $t$ is the thickness of the weld excluding any allowable reinforcement, and the parameter $l$ is the length of the flaw. For a butt weld joining two members having different thickness at the weld, $t$ is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, then the thickness of the throat of the fillet weld shall be included in $t$.
(b) A subsurface indication shall be considered as a surface flaw if the separation ($S$ in Figure 7.11) of the indication from the nearest surface of the component is equal to or less than half the through dimension (2$d$ in Figure 7.11, sketch (b)) of the subsurface indication.
(c) The acceptance limits specified here are based upon workmanship considerations and are not necessarily intended for use in evaluating flaws identified after the vessel has gone into service.
(d) $a$ and $l$ are as defined in 7.5.5.2.

Table 7.10
Flaw Acceptance Criteria for Welds With Thicknesses Between 25 mm (1 in.) and Less Than or Equal to 300 mm (12 in.)

<table>
<thead>
<tr>
<th>Flaw Aspect Ratio, $a/l$</th>
<th>25 mm (1 in.)</th>
<th>64 mm (2 ½ in.)</th>
<th>100 mm (4 in.)</th>
<th>200 mm (8 in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$a/t$</td>
<td>$a/t$</td>
<td>$a/t$</td>
<td>$a/t$</td>
</tr>
<tr>
<td>0.00</td>
<td>0.031</td>
<td>0.034</td>
<td>0.019</td>
<td>0.020</td>
</tr>
<tr>
<td>0.05</td>
<td>0.033</td>
<td>0.035</td>
<td>0.020</td>
<td>0.022</td>
</tr>
<tr>
<td>0.10</td>
<td>0.036</td>
<td>0.043</td>
<td>0.022</td>
<td>0.025</td>
</tr>
<tr>
<td>0.15</td>
<td>0.041</td>
<td>0.054</td>
<td>0.025</td>
<td>0.029</td>
</tr>
<tr>
<td>0.20</td>
<td>0.047</td>
<td>0.066</td>
<td>0.028</td>
<td>0.034</td>
</tr>
<tr>
<td>0.25</td>
<td>0.055</td>
<td>0.078</td>
<td>0.033</td>
<td>0.040</td>
</tr>
<tr>
<td>0.30</td>
<td>0.064</td>
<td>0.090</td>
<td>0.038</td>
<td>0.047</td>
</tr>
<tr>
<td>0.35</td>
<td>0.074</td>
<td>0.103</td>
<td>0.044</td>
<td>0.054</td>
</tr>
<tr>
<td>0.40</td>
<td>0.083</td>
<td>0.116</td>
<td>0.050</td>
<td>0.061</td>
</tr>
<tr>
<td>0.45</td>
<td>0.085</td>
<td>0.129</td>
<td>0.051</td>
<td>0.069</td>
</tr>
<tr>
<td>0.50</td>
<td>0.087</td>
<td>0.143</td>
<td>0.052</td>
<td>0.076</td>
</tr>
</tbody>
</table>

GENERAL NOTES:
(a) The parameter $t$ is the thickness of the weld excluding any allowable reinforcement, and the parameter $l$ is the length of the flaw. For a butt weld joining two members having different thickness at the weld, $t$ is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, then the thickness of the throat of the fillet weld shall be included in $t$.
(b) A subsurface indication shall be considered as a surface flaw if the separation ($S$ in Figure 7.11) of the indication from the nearest surface of the component is equal to or less than half the through dimension (2$d$ in Figure 7.11, sketch (b)) of the subsurface indication.
(c) The acceptance limits specified here are based upon workmanship considerations and are not necessarily intended for use in evaluating flaws identified after the vessel has gone into service.
(d) For intermediate flaw aspect ratio $a/l$ and thickness $t$ (64 mm (2 ½ in.) $\leq t < 100$ mm (4 in.)), linear interpolation is permissible.
(e) If the acceptance criteria in this table results in a flaw length, $l$, less than 6.4 mm (0.25 in.), a value of 6.4 mm (0.25 in.) may be used.
(f) For materials exceeding 655 MPa (95 ksi) ultimate tensile strength, the use of this table is limited to a thickness of 200 mm (8 in.).

(g) For high alloy steels listed in Table 3-A.3, the use of this table is limited to a thickness of 200 mm (8 inch) unless the PWHT is performed and fracture toughness is at least 132 MPa-m$^{0.5}$ (120 ksi-in$^{0.5}$).
When the weld thickness, \( t > 400 \text{ mm (16 in.)} \), the acceptance criteria for a thickness of 400 mm (16 in.) of this table shall be applied.

When 300 mm (12 in.) \(< t \leq 400 \text{ mm (16 in.)} \), linear interpolation between the acceptance criteria for 300 mm (12 in.) in Table 7.10 and 400 mm (16 in.) in Table 7.11 is permitted.

For high alloy steels listed in Table 3-A.3, this table is not applicable unless the PWHT is performed and fracture toughness is at least 132 MPa-m\(^{0.5}\) (120 ksi-in\(^{0.5}\)).

**Table 7.11**

<table>
<thead>
<tr>
<th>Aspect Ratio, ( a/l )</th>
<th>Surface Flaw, ( a )</th>
<th>Subsurface Flaw, ( a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>5.8 mm (0.228 in.)</td>
<td>6.1 mm (0.240 in.)</td>
</tr>
<tr>
<td>0.05</td>
<td>6.1 mm (0.240 in.)</td>
<td>6.7 mm (0.264 in.)</td>
</tr>
<tr>
<td>0.10</td>
<td>6.7 mm (0.264 in.)</td>
<td>7.6 mm (0.300 in.)</td>
</tr>
<tr>
<td>0.15</td>
<td>7.6 mm (0.300 in.)</td>
<td>8.8 mm (0.346 in.)</td>
</tr>
<tr>
<td>0.20</td>
<td>8.5 mm (0.336 in.)</td>
<td>10.1 mm (0.396 in.)</td>
</tr>
<tr>
<td>0.25</td>
<td>10.1 mm (0.396 in.)</td>
<td>11.6 mm (0.456 in.)</td>
</tr>
<tr>
<td>0.30</td>
<td>11.6 mm (0.456 in.)</td>
<td>13.4 mm (0.528 in.)</td>
</tr>
<tr>
<td>0.35</td>
<td>13.4 mm (0.528 in.)</td>
<td>15.5 mm (0.612 in.)</td>
</tr>
<tr>
<td>0.40</td>
<td>15.2 mm (0.600 in.)</td>
<td>17.7 mm (0.696 in.)</td>
</tr>
<tr>
<td>0.45</td>
<td>15.5 mm (0.612 in.)</td>
<td>20.4 mm (0.804 in.)</td>
</tr>
<tr>
<td>0.50</td>
<td>15.8 mm (0.624 in.)</td>
<td>23.2 mm (0.912 in.)</td>
</tr>
</tbody>
</table>

**GENERAL NOTES:**

(a) The parameter \( t \) is the thickness of the weld excluding any allowable reinforcement, and the parameter \( l \) is the length of the flaw. For a butt weld joining two members having different thickness at the weld, \( t \) is the thinner of these two thicknesses. If a full penetration weld includes a fillet weld, then the thickness of the throat of the fillet weld shall be included in \( t \).

(b) A subsurface indication shall be considered as a surface flaw if the separation (\( S \) in Figure 7.11) of the indication from the nearest surface of the component is equal to or less than half the through dimension \( [2d \text{ in Figure 7.11, sketch (b)}] \) of the subsurface indication.

(c) The acceptance limits specified here are based upon workmanship considerations and are not necessarily intended for use in evaluating flaws identified after the vessel has gone into service.

(d) Linear interpolation is permissible for intermediate values of the flaw aspect ratio \( a/l \).

(e) This table is not applicable for materials exceeding 655 MPa (95 ksi) ultimate tensile strength, having a specified minimum ultimate tensile strength greater than 655 MPa (95 ksi).
Flaw Classification of

If \( S \leq d \), a subsurface flaw is categorized for evaluation as a surface flaw with depth \( a \) (=\(2d+S\)) and length \( \ell \).
Figure 7.11A Surface Flaw Acceptance Criteria

(a) For weld thickness 25 mm (1 in.) ≤ t < 64 mm (2 1/2 in.) and 100 mm (4 in.) ≤ t < 300 mm (12 in.)

(b) For weld thickness t ≥ 400 mm (16 in.)
Figure 7.11A Surface Flaw Acceptance Criteria (Cont'd)

(c) For weld thickness $t \geq 16$ in. (400 mm)
Figure 7.11B Subsurface Flaw Acceptance Criteria

GENERAL NOTE: This graph obtained from acceptance criteria for subsurface flaw for 25 mm (1 in.) ≤ t < 64 mm (2 1/2 in.) and 100 mm (4 in.) ≤ t ≤ 300 mm (12 in.) in Table 7.10

(a) For weld thickness 25 mm (1 in.) ≤ t < 64 mm (2 1/2 in.) and 100 mm (4 in.) ≤ t < 300 mm (12 in.)

(b) For weld thickness t ≥ 400 mm (16 in.)
Figure 7.11B Subsurface Flaw Acceptance Criteria (Cont'd)

GENERAL NOTE: This graph obtained from acceptance criteria for subsurface flaw for \( t \geq 16 \) in. in Table 7.11

(c) For weld thickness \( t \geq 16 \) in. (400 mm)
Figure 7.12
Multiple Planar Flaws Oriented in a Plane Normal to the Pressure-Retaining Surface

- $0.5d_1$ or $0.5d_2$
- $d_1$ or $d_2$
- $d_2$ or $d_3$
- $S = 2d_1$ or $2d_2$
- $S = 2d_2$ or $2d_3$
- $S = 2d_3$ or $2d_4$
- $S = 2d_4$ or $2d_5$
- $S = 2d_5$ or $2d_6$
- $d_1$ or $d_2$
- $d_2$ or $d_3$
- $S = 2d_3$ or $2d_4$
- $S = 2d_4$ or $2d_5$
- $S = 2d_5$ or $2d_6$
- $d_1$ or $0.5d_2$
- $d_2$ or $0.5d_3$
- $d_3$ or $0.5d_4$
- $d_4$ or $0.5d_5$
Figure 7.13
Surface and Subsurface Flaws

S < ½ in. (13 mm)
Figure 7.14
Nonaligned Coplanar Flaws in a Plane Normal to the Pressure-Retaining Surface

- $d_1$, $2d_2$, $2d_3$, $2d_4$ = depths of individual flaws
- $S = d_1$ or $2d_2$ (whichever is greater)
- $S = d_1$ or $2d_2$ (whichever is greater)
- $S = d_1$ or $2d_2$ (whichever is greater)
- $S = 0.4d_4$
- $S = 2d_4$ or $2d_5$ (whichever is greater)
- $S = 2d_4$ or $2d_5$ (whichever is greater)
- $S = 2d_4$ or $2d_5$ (whichever is greater)
GENERAL NOTE: The flaw depth dimensions ($a_s$, $a_e$) and ($a_1$, $a_2$) are the allowable flaw criteria for surface and subsurface flaws, respectively.
(3) This illustration indicates two surface flaws and one subsurface flaw.

\[(a_1 + a_3) \leq \frac{(a_s + a_e^*)}{2}\] within planes \(E - E'\) and \(F - F'\)

\[(a_1 + a_2 + a_3) \leq \frac{(a_s + a_e + a_s^*)}{3}\] within planes \(F - F'\) and \(G - G'\)

\[(a_2 + a_3) \leq \frac{(a_s^* + a_e)}{2}\] within planes \(G - G'\) and \(H - H'\)