Guidance for the Development of Ultrasonic Examiner Qualification Programs

API PUBLICATION 587
FIRST EDITION DRAFT 1
1.0 **Scope**

The availability of high quality and accurate Ultrasonic Testing (UT) data is often the cornerstone for fitness-for-service (FFS) or risk-based inspection (RBI) decisions. As a result, API has implemented several QUTE (Qualification of Ultrasonic Examiners) certification programs to assist in defining the minimum criteria for assessing the performance of UT technicians. Examinations for these programs are administered differently than other Individual Certification Programs (ICP) certifications in that they are based on hands-on performance demonstration tests.

This publication covers the requirements for the development of owner/user ultrasonic examiner qualification programs which are consistent with the American Petroleum Institute (API) performance demonstration programs for both detection and characterization, and crack height sizing weld defects. The performance demonstration programs covered in this publication includes:

a) Qualification of Ultrasonic Examiners – Detection and Characterization (QUTE/DC)
b) Qualification of Ultrasonic Examiners – Crack Sizing (QUTE/CS)
c) Qualification of Ultrasonic Examiners – Phased Array Detection and Characterization (QUTE/DC-PA)

The purpose of this publication is to provide owner/users with guidelines for developing robust in-house programs to identify qualified ultrasonic examiners for inspection of pressure equipment and piping that are equivalent with existing API qualification programs.

2.0 **Normative References**

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

- API 510, *Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair, and Alteration*
- API 570, *Piping Inspection Code*
- API RP 577. *Welding Processes, Inspection, and Metallurgy*

3.0 **Terms, Definitions, Acronyms and Abbreviations**

3.1 **Terms and Definitions**

For the purposes of this document, the following definitions apply.

3.1.1 **Bi-modal method**

An ultrasonic technique used that uses dual element search units to produce both shear and longitudinal waves to determine the height of a crack.

3.1.2 **grading unit**
This is a 3-inch length of a weld which may contain a weld defect on either side of the weld in the QUTE/DC and QUTE/DC-PA performance demonstration specimens.

3.1.3 high-angle longitudinal wave method (HALT)  
(NEED DEFINITION)

3.1.4 ID creeping wave method  
(NEED DEFINITION)

3.1.4 owner/user  
An owner or user of pressure vessels or piping who exercises control over the operation, engineering, inspection, repair, alteration, maintenance, pressure testing, and rerating of those pressure vessels and piping systems.

3.1.5 QUTE/CS  
This is a performance demonstration (PD) qualification program for evaluating the capability of ultrasonic examiners for crack height sizing examinations. (Note: This program was previously designated as the API QUSE program).

3.1.6 QUTE/DC  
This is a performance demonstration (PD) qualification program for evaluating the capability of ultrasonic examiners for detecting and characterizing weld discontinuities. (Note: This program was previously designated as the API QUTE program).

3.1.7 QUTE/DC-PA  
This is a performance demonstration (PD) qualification program for evaluating the capability of ultrasonic examiners for detecting and characterizing weld discontinuities using phased array ultrasonic equipment.

3.1.8 test administrator  
The individual designated by the owner/user to directly responsible for performance demonstration test administration. (Note: The owner/user may also designate this individual to be responsible for overall security of the performance demonstration program.)

3.1.8 tip diffraction method  
An ultrasonic technique used to determine the length and height of a crack when the sound energy from the transducer diffracts off the base of a crack or planar reflector. (Note: This method is used for sizing shallow cracks ranging from approximately 5-35% through wall.)

3.2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>∆TOF</td>
<td>delta time of flight</td>
</tr>
<tr>
<td>AATT</td>
<td>absolute arrival time technique</td>
</tr>
<tr>
<td>HALT</td>
<td>high angle refracted longitudinal wave technique</td>
</tr>
<tr>
<td>HAST</td>
<td>high angle refracted shear wave technique</td>
</tr>
<tr>
<td>IDCRR</td>
<td>ID creeping wave method</td>
</tr>
<tr>
<td>M-RATT</td>
<td>(need description)</td>
</tr>
</tbody>
</table>
4.0 Specimens for Performance Demonstration Tests

The specimens utilized for the API ultrasonic examiner qualification programs represent simplified weld geometries that are commonly encountered in piping throughout the refining, production and chemical process industries. Specimens for the detection and characterization (i.e. QUTE/DC and QUTE/DC-PA) and the crack height sizing performance demonstration (QUTE/CS) tests need to be manufactured according to the requirements outlined below. Photographs of each test sets are shown in Figure 1.

![Figure 1](image)

Figure 1  Photograph of performance demonstration test sets for detection and characterization (left) and crack sizing (right)

4.1 Sample Identification

Every specimen used in any of the performance demonstration programs (i.e. QUTE/DC, QUTE/DC-PA, and QUTE/CS) shall be given a permanent unique identification/serial number which shall be vibro-etched on the back surface of the specimen. Candidate viewing of unmasked specimens during or after the performance demonstration test is prohibited.

To the degree practicable, care should be taken to ensure that no single test is significantly more difficult to examine that any other test set. The determination of the difficulty of the test sets shall be assessed by the owner/user during the test set validation activities.

4.2 Detection and Characterization Test Set Specimen Design
An owner/user developing a performance demonstration shall have a minimum of two complete test sets. An individual test set for the detection and characterization (i.e. QUTE/DC and QUTE/DC-PA) performance demonstration test shall include:

a) One carbon steel (P1) 1/2-inch (12 mm) thick plate with a single ‘V’ weld prep
b) One carbon steel (P1) 1-inch (25 mm) thick plate with a single or double ‘V’ weld prep
c) One carbon steel (P1) 8 in. (200 mm) NPS pipe with a ½-inch (12 mm) thick pipe wall with a single ‘V’ weld prep
d) One-half segment 12 in. (300 mm) NPS pipe with a ½-inch (12 mm) thick pipe wall with a single ‘V’ weld prep

4.2.1 **Figure 2** shows a cross sectional views for each of the detection and characterization specimens.

![Cross Sectional View of Detection and Characterization Test Set](image)

4.2.2 Specimen weld crowns and root geometry's shall be in the "as-welded" condition and may be offset from specimen centerline.

4.2.3 Specimens may contain ID or OD mismatch.

4.2.4 Specimens shall not contain counter bore geometry.
4.2.5 Each specimen shall have sufficient volume to minimize spurious reflections that may interfere with the interpretation process.

4.2.6 Detection and Characterization Defect Types

The types of weld defects that are included in these performance demonstration test programs are typical of those that can be encountered during inspections of new and/or post construction piping or vessels. Table 1 identifies the potential weld discontinuities that may be included in each test specimen. The number of flaws in each test specimen may vary for each test set, or the test specimen may be unflawed along the entire length.

<table>
<thead>
<tr>
<th>Defect Type</th>
<th>1/2&quot; Plate</th>
<th>1&quot; Plate</th>
<th>8&quot; Pipe Weld</th>
<th>12&quot; Pipe Weld</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside surface connected crack (ID Crack)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Outside surface connected crack (OD Crack)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Incomplete penetration in a Double ‘V’ weld (IP)</td>
<td>-</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lack of root penetration (LOP)</td>
<td>X</td>
<td>-</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Lack of side wall fusion (LOF)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Porosity</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Slag inclusion</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Table 1 Defect Types for QUTE/DC and QUTE/DC-PA Test Specimens

4.3 Crack Height Sizing Test Set Specimen Design

An owner/user developing a performance demonstration shall have a minimum of two complete test sets. An individual test set for the crack height sizing (i.e. QUTE/CS) performance demonstration test shall include:

- Eight (8) carbon steel (P1) 3/8-inch (9.5 mm) thick crack bar samples with a single ‘V’ weld prep.
- Eight (8) carbon steel (P1) 1-inch (25 mm) thick crack bar samples with a single ‘V’ weld prep.
- The crack sizing bars shall be approximately 2-inches (50 mm) wide and 10-inches (250 mm) in length.
- The weld shall be centered near the middle of the 10-inch (259 mm) length.

4.3.1 Figure 3 shows a cross sectional views for each of the detection and characterization specimens.
4.3.2 Specimens may be ground flush or may be in the as-welded condition.

4.3.3 All cracks shall be ID connected cracks at or near the weld root.

4.3.4 Crack height sizing of any embedded cracks (if present) are not required.

4.3.5 Each specimen shall have sufficient volume to minimize spurious reflections that may interfere with the interpretation process.

4.3.6 The crack test sample will be an actual with root geometry.

4.3.7 Specimens will NOT contain counterbore geometry.

4.3.8 The weld joint geometry or preparation will be a 30 degree weld prep bevel.

4.3.9 The ID of the crack sizing specimen will be masked.

4.4 Alternate Specimen Designs

In order to address specific site applications, the owner/user may choose to conduct performance demonstration tests on specimen designs different than those shown in Figures 2 and 3. The owner/user should consider developing similar protocols to meet specific application needs.

4.5 Test Set Validation
Whether purchased or manufactured by the owner/user, each specimen in a test set shall be given a validation assessment to determine the types of defects present and their locations prior to utilization in a performance demonstration test program. The purposes of this validation assessment are:

   a) To test and validate that each flaw can be correctly assessed by ultrasonic shear wave examination.
   b) To disqualify flaws which have not been properly manufactured to produce an unambiguous test signal, and
   c) To establish the ultrasonic ground truth for the performance demonstration specimens.

4.5.1 These validation assessments shall be conducted by a minimum of three experienced personnel using ultrasonic equipment and procedures typical and available for use during candidate testing. The results from these examinations should be averaged, and serve as the ground truth which candidates will be graded against.

4.5.1.1 Radiography may also be used to help define defect location and length.

4.5.2 Results from these validation assessments shall be documented and shall be stored in a secure location by the owner/user in order to maintain the integrity of each performance demonstration testing program.

5.0 **Security**

A key ingredient for an effective owner/user performance demonstration test program is the ability of the owner/user to maintain the security of test specimens, test specimen ground truth, and candidate results. In this regard, the owner/user shall designate an individual to be responsible for maintaining the security of the ultrasonic examiner qualification programs at the site where performance demonstration tests will be conducted. The owner/user shall also designate an individual to be responsible for test administration at the test site. The individual responsible for security of the ultrasonic examiner qualification programs may also serve as the test administrator.

5.1 **Pre- and Post-Test**

In order to limit access to the performance demonstration specimens, the owner/user shall store all performance demonstration specimens in a secured location before and after any performance demonstration test. In addition, the owner/user shall also establish detailed security procedures for use when specimens are shipped from one site to an alternate site.

5.1.1 All performance demonstration specimens shall be secured in their designated storage/shipping container while the specimens are not in use. Theses storage/shipping containers shall be under lock and key prior to and after performance demonstration tests. Test sets that are not in use during a performance demonstration test shall remain in a secure environment until they are required for use by a candidate. The individual responsible for the ultrasonic examiner qualification programs at the test site shall maintain control of the key for all locked storage containers.
5.1.2 When specimens are shipped from one location to an alternate site, the individual designated by the owner/user as being responsible for the ultrasonic examiner qualification programs at the originating test site shall prepare shipping instructions which identifies a specific individual at the alternate site to receive the shipment, and to be responsible for maintaining the security of the test specimens. The owner/user shall verify that the shipment has been received by the individual identified in the shipping instructions.

5.1.2.1 When specimens are shipped from one site to an alternate site, the owner/user shall document in sufficient detail the type of test specimens being shipped, authorization, and means of shipment and date.

5.1.2.2 Upon arrival at the alternate site, all performance demonstration specimens shall be secured in their designated storage/shipping container while the specimens are not in use.

5.2 During the Test

The test administrator shall communicate the following rules which will be enforced during the performance demonstration test:

- Cell phones shall be turned off and turned in to the test administrator.
- One candidate per table.
- Steel samples are to remain on their tables.
- Any marks on specimens shall be removed when a candidate has finished examination of the sample set.
- If a sample set is shared between two (2) candidates, any marks on the specimens shall be removed before transferring to another candidate.
- No talking between test candidates.
- Taped ID numbers on specimens are not permitted to be disturbed by the candidate.
- All exam forms, plotting graphs and scratch paper used in the exam are to be reproduced onto yellow paper. Only yellow paper will be allowed during the exam.
- Only one person is allowed to leave the room at a time.
- Upon completing the exams, give the folder with completed paperwork to the proctor. The proctor will verify all information is complete prior to your leaving the room.

6.0 Test Administration

After a performance demonstration test is scheduled, the owner/user has a number of tasks to perform prior to, during, and after the performance demonstration.

6.1 Pre-Test Preparation

Prior to any performance test, the owner/user shall contact candidates scheduled to take the test and communicate to them regarding the test date/location, the equipment/supplies permitted at the test location, and the examination rules. In addition, the owner/user shall prepare the appropriate test sets for the performance demonstration test.
The owner/user shall also inform all candidates that **no one will be admitted to a performance demonstration test without a valid driver’s license or other government-issued proof of identification.**

6.1 Prior to the test, the owner/user or the test administrator shall inform the candidates that they shall bring the following equipment and supplies to the performance test include:

- Ultrasonic instruments
- UT cables
- Transducers/search units
- Calibration Standards (IIW, Rompas, and DSC blocks)
- Ultrasonic couplant

The candidate shall also be informed whether the owner/user or test candidate must provide the ASME B & PV Code, Section V, calibration blocks.

6.1.1 The owner/user or the test administrator shall also inform the candidates that they may bring the following items to the performance test:

- Plotting Devices (protractors, rulers, etc.)
- A calculator
- Ultrasonic procedures for detection, characterization, and sizing of defects and cracks. (Note: The candidate has the option of using the API ultrasonic procedures shown in Annex B.)

6.1.2 Prior to conducting the test, the test administrator shall undertake the following steps:

a) The identification/serial number on the specimen shall be covered by opaque tape with a random number ID written on it.

b) No other markings shall be visible on the sample other than the random number written on the opaque tape.

c) Specimens used in the QUTE/CS performance demonstration test shall have the bottom of the specimen covered with opaque tape to obscure the weld root area.

d) Each candidate shall complete and submit the appropriate Equipment Inventory Form (see Annex A) to the test administrator.

e) The test administrator shall verify that only equipment listed on a candidate’s Equipment Inventory Form is brought into the test site.

f) The test administrator shall store all non-inventoried equipment in an area outside of the test site.

h) The test administrator shall have a folder for each candidate which contains the following:

- One (1) copy of an **Equipment Inventory Form** (either Fig. A.1 or Fig. A.2)
- Four (4) copies of a **Calibration Form** (either Fig. A.3 or Fig. A.4)
For the QUTE/DC or QUTE/DC-PA test, four (4) Weld Indication Report. Specifically, one (1) Double Vee Weld Indication Report Form and three (3) Single Vee Weld Indication Report Forms.

For the QUTE/CS test, one (1) copy of Crack Height Sizing Report Form.

Several (e.g. 6-12) sheets of plain, colored paper. (Note: No other scratch paper is allowed in the test location.)

No other paperwork shall be permitted in the test location.

6.1.3 Prior to conducting the test, the test administrator shall give a candidate orientation which describes the following:

- Name and background of the test administrator
- Lab safety and sample handling precautions
- Evacuation routes
- Location of bathrooms
- Schedule for the performance demonstration test
- Expectation for candidate conduct during the performance demonstration test

6.1.4 Prior to the test, the owner/user or the test administrator shall inform the candidates whether they need to provide their own lunch and beverages during the test, or whether these will be provided by the owner/user.

6.2 During the Test

All performance demonstration tests are scheduled to be completed during a single eight (8) hour workday. A one (1) hour in-room lunch break will be available at the candidate's option. A security plan will be enforced during testing (including lunch and bathroom breaks) to prevent test sample compromise.

6.2.1 The time schedule identified below is provided for reference. Actual test specimen evaluation times can be affected as a result of candidate readiness. It is strongly recommended that candidate's become familiar with the qualification protocol, specifically the data reporting forms and examination procedure to increase efficiency. The scheduled test schedule time limits may be modified by the test administrator on a case by case basis to accommodate special circumstances that allow sufficient time for specimen evaluation.

**Example of the Test Schedule**

<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 AM</td>
<td>9 AM  Candidate orientation</td>
</tr>
<tr>
<td>9 AM</td>
<td>10 AM Equipment Inventories and Calibration's</td>
</tr>
<tr>
<td>10 AM</td>
<td>12 PM Specimen Evaluation</td>
</tr>
<tr>
<td>12 PM</td>
<td>1 PM  Lunch Break/In-Room (optional)</td>
</tr>
<tr>
<td>1 PM</td>
<td>4 PM  Specimen Evaluation</td>
</tr>
<tr>
<td>4 PM</td>
<td>5 PM  Post demonstration paperwork and reporting</td>
</tr>
</tbody>
</table>
6.2.2 There is no time limit for a single specimen. However, if a sample set is shared between two candidates, the test administrator shall establish an equitable time limit each candidate has for a given specimen.

6.2.3 All paperwork must be completed and turned into the monitor by end of day. Time extensions will not be authorized. Candidates that fail to complete the examination in the allotted time will be considered unsuccessful.

6.2.3.1 The candidate may reexamine any specimen they have already finished, provided they are within the time limits of the test and sample security requirements are not compromised.

6.2.3.2 No reexamination shall be allowed once the time limits have been reached and the specimen data from the candidate has been turned in for grading.

6.2.3.3 To ensure accurate grading, the test administrator may request that a candidate reexamine a specimen when errors such as sample mis-orientation, identification, recording errors, etc. are made by the candidate.

6.3 Post-Test Administration – Grading

The grading of an API detection and characterization qualification test shall be performed in accordance with the grading guidelines set forth in this section. A Weld Indication Report Sheet (i.e. either Fig. A.5 or Fig. A.6) or a Crack Height Sizing Report Form (i.e. Fig. A.7) shall be completed for each specimen. These forms have been designed to properly identify indications, characterize flaws within those provided in the procedure table, their start and stop locations, flaw lengths and flaw positions, or crack height size. The candidate is responsible to ensure that all required fields listed below are legibly filled out in their entirety:

<table>
<thead>
<tr>
<th>QUTE/DC &amp; QUTE/DC-PA Tests</th>
<th>QUTE/CS Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name and Social Security number</td>
<td>Name and Social Security number</td>
</tr>
<tr>
<td>Specimen ID</td>
<td>Scheduled Test Date</td>
</tr>
<tr>
<td>Flaw table</td>
<td>Specimen ID</td>
</tr>
<tr>
<td>Plan view</td>
<td>Nominal Thickness</td>
</tr>
<tr>
<td>Cross-sectional view</td>
<td>Crack Height Estimate</td>
</tr>
</tbody>
</table>

6.3.1 Detection and Characterization Specimens (QUTE/DC and QUTE/DC-PA Tests)

Each of the detection and characterization test specimens are divided into grading units with each grading unit being at least 3 in. (75 mm) of weld length. Each grading unit shall be assessed as being flawed or unflawed. The segment of weld length used in one grading unit shall not be used in another grading unit.

6.3.1.1 Candidate performance shall be evaluated in the following four areas as determined from the Weld Inspection Report Forms:

6.3.1.2 Flaw Detection:

The detection portion of the test is applied to initially evaluate a candidate’s data report. If the candidate does not detect an intended flaw, no further evaluation is required. The indication
report form identifies flaw start and stop positions with statistical information and a plan view drawing. Sufficient flaw length and/or start and stop information must be provided in order for the monitor to determine if the candidate actually detected the flaw.

Specifically:

- The reported flaw must provide overlap with the actual flaw position.
- The reported flaw end-points shall be reported within 1.0” of the actual flaw end-points.
- Reported flaw lengths shall be a minimum of 50% of the truth length for surface connected flaws and 25% of the truth length for volumetric flaws.
- Gross over sizing of flaws shall be penalized in accordance with the false call criteria.

6.3.1.3 Flaw Characterization:
Reported flaws must be identified by flaw type on the indication report form. Credit shall be given for flaw characterization if the flaw type reported is in the same group as the flaw truth.

<table>
<thead>
<tr>
<th>Flaw Characterization Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
</tr>
<tr>
<td>Inside Surface Connected Flaws</td>
</tr>
<tr>
<td>Inside Surface Connected Crack</td>
</tr>
<tr>
<td>Lack of Root Penetration</td>
</tr>
<tr>
<td>Group 2</td>
</tr>
<tr>
<td>Outside Surface Connected Flaws</td>
</tr>
<tr>
<td>Outside Surface Connected Crack</td>
</tr>
<tr>
<td>Group 3</td>
</tr>
<tr>
<td>Volumetric Flaws</td>
</tr>
<tr>
<td>Lack Of Fusion</td>
</tr>
<tr>
<td>Slag</td>
</tr>
<tr>
<td>Porosity</td>
</tr>
<tr>
<td>Embedded Centerline Crack</td>
</tr>
</tbody>
</table>

6.3.1.4 Flaw Positioning:
Reported flaws must be positioned correctly with respect to the weld centerline (i.e. upstream/downstream). Indication positioning with respect to the weld centerline is provided on the indication report form as a cross sectional drawing.

The following tolerances shall be applied to the reported flaw positioning:

- Volumetric flaws shall be reported within or near to, the weld volume on the cross sectional plot.
- Inside surface connected flaws need only be reported on the correct side of weld centerline for the 1.0” thick plate. For all other components, credit shall be given if the flaw is reported as connected to the inside surface.
- Outside surface connected flaws shall be reported on the correct side of weld centerline for all components.

6.3.1.5 Flaw Discrimination (False Calls):
A false call is defined as a flaw being reported in an unflawed grading unit. The maximum number of false called grading units allowed per test set shall be 2. For flaws, which have an end-point(s) ≤ 1.0” from an adjacent unflawed grading unit, no false call shall be given if the reported end-point is ≤ 1.0” from the actual flaw end-point. Single reported flaws that cross multiple unflawed grading units shall be considered as multiple false calls (1 for each grading unit entered) with the following exceptions:
a) The reported flaw length is \( \leq 3.0" \), and/or
b) The condition that caused the false call (excessive root, ID mismatch, etc.) has been identified as a highly probable false call area during sample fingerprinting and documented in the grading book and database.

Additionally, the candidate’s **Weld Indication Report Form** must properly position this indication in the same location (start/stop) and volumetric position (inside or outside surface connected, mid-wall, etc.) as noted in the grading book and database.

This situation is isolated to a single reported instance during the evaluation of a test set.

6.3.1.6 Grading criteria are shown below in **Table 2**.

<table>
<thead>
<tr>
<th>Flaw Detection Errors *</th>
<th>Flaw Characterization Errors * (Max)</th>
<th>Flaw Positioning Errors (Max)</th>
<th>False Call Errors (Max)</th>
<th>Total Allowance of Error (Max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Notes:

a) Grading shall be weighted based upon flaw detection errors (e.g., if 2 flaw detection errors occur, the maximum total allowance of error is 3)

b) The maximum number of flaw detection error's is 2.

c) Flaw detection errors shall be included in the count for total allowance of MGM

d) Grading shall be done in the following sequential order: 1) Detection, 2) Characterization, 3) Positioning, and 4) False calls.

e) Candidates shall only be penalized a single time for each reporting error. For example, if a single reported flaw that is not characterized correctly, no additional penalty shall be applied if it is also not positioned correctly.

6.3.2 **Crack Height Sizing Specimens (QUTE/CS Test)**

The grading of an API sizing qualification test shall be performed in accordance with the grading guidelines set forth in this section. Special care must be taken when grading, due to the various grading criteria that shall be applied to determine a candidate’s success or failure of the qualification.

6.3.2.1 It is the responsibility of the test administrator to ensure that the techniques prescribed in the examination procedure are being utilized. Adequate surveillance must be provided in order to ensure procedure compliance and candidate capabilities. Where the candidate has obviously not followed the procedure, it shall be noted on their grading records.
6.3.2.2 Grading criteria for the crack height performance demonstration test shall be based on the Root Mean Square (RMS) evaluation method, see Eq. (1) below. A candidate shall a $X_{\text{RMS}}$ value of 12.5% or less based on the examination of 10 samples.

$$X_{\text{RMS}} = \sqrt{\frac{1}{10} \left( x_1^2 + x_2^2 + \cdots + x_{10}^2 \right)}$$  \hspace{1cm} (1)

where

- $X_{\text{RMS}}$ = root mean square value for the candidate
- $x_1$ thru $x_{10}$ = measured crack height for each specimen
Appendix A
Sample Forms for Use During Performance Demonstration Tests

Figure A.1: Equipment Inventory Form

<table>
<thead>
<tr>
<th>Search Unit #</th>
<th>Mfg. / MODEL</th>
<th>FREQ.</th>
<th>SIZE</th>
<th>ANGLE (S)</th>
<th>S/N</th>
<th>INSTRUMENTS</th>
<th>CABLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>KBA / MSWQC</td>
<td>5.0</td>
<td>0.25&quot;</td>
<td>45/60/70</td>
<td>123456</td>
<td>Staveley</td>
<td>RG-174</td>
</tr>
<tr>
<td>2</td>
<td>Mega / MST</td>
<td>2.25</td>
<td>0.375&quot;</td>
<td>45/60</td>
<td>654321</td>
<td>KBA</td>
<td>RG-174</td>
</tr>
</tbody>
</table>

Revision 3; 09/01/14
**PHASED ARRAY EQUIPMENT INVENTORY FORM**

<table>
<thead>
<tr>
<th>Candidate’s Name:</th>
<th>SSN:</th>
<th>Owner/User Location:</th>
<th>Scheduled Test Date:</th>
</tr>
</thead>
</table>

**PHASED ARRAY PROBE PARAMETERS**

<table>
<thead>
<tr>
<th>Phased Array Probe</th>
<th>Mfg. / MODEL</th>
<th>FREQ.</th>
<th>Pitch</th>
<th>ANGLE(s) Used</th>
<th>S/N</th>
<th>MANUFACTURER</th>
<th>MODEL</th>
<th>Software Version</th>
<th>Pulsers Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>5L16</td>
<td>ONDT/A-1</td>
<td>5.0</td>
<td>.6 mm</td>
<td>45 - 70 Degrees</td>
<td>123456</td>
<td>Olympus</td>
<td>OmniScan MxM</td>
<td>2.0/R19</td>
<td>16/64</td>
</tr>
<tr>
<td>5L64</td>
<td>ONDT/A-2</td>
<td>5.0</td>
<td>.6mm</td>
<td>45 to 65 Degree</td>
<td>654321</td>
<td>GE</td>
<td>Phasor-XS</td>
<td>1.3</td>
<td>16/16</td>
</tr>
</tbody>
</table>

*Revision 1; 09/01/14*
Figure A.3: Angle Beam Calibration Form

<table>
<thead>
<tr>
<th>Angle Beam Calibration Data Sheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candidate's Name:</td>
</tr>
<tr>
<td>Test Set #:</td>
</tr>
<tr>
<td>Sample ID:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Instrument Manufacturer:</th>
<th>Model No.:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Search Unit Information</th>
<th>Search Unit Information</th>
<th>Search Unit Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Model</td>
<td>Model</td>
</tr>
<tr>
<td>Size</td>
<td>Size</td>
<td>Size</td>
</tr>
<tr>
<td>Freq.</td>
<td>Freq.</td>
<td>Freq.</td>
</tr>
<tr>
<td>Shape</td>
<td>Shape</td>
<td>Shape</td>
</tr>
<tr>
<td>Exit Point</td>
<td>Exit Point</td>
<td>Exit Point</td>
</tr>
<tr>
<td>Config. (circle one)</td>
<td>Single D-SBS Tandem</td>
<td>Config. (circle one)</td>
</tr>
<tr>
<td>Mode (circle one)</td>
<td>Shr. RL Bi-Modal</td>
<td>Mode (circle one)</td>
</tr>
<tr>
<td>Wedge (circle one)</td>
<td>Integral Non-Inegral</td>
<td>Wedge (circle one)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Instrument Setting</th>
<th>Instrument Setting</th>
<th>Instrument Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range:</td>
<td>Range:</td>
<td>Range:</td>
</tr>
<tr>
<td>Delay:</td>
<td>Delay:</td>
<td>Delay:</td>
</tr>
<tr>
<td>Velocity:</td>
<td>Velocity:</td>
<td>Velocity:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calibration Information</th>
<th>Calibration Information</th>
<th>Calibration Information</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Reference Sensitivity:</th>
<th>(dB)</th>
<th>Reference Sensitivity:</th>
<th>(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exam Sensitivity:</td>
<td>(dB)</td>
<td>Exam Sensitivity:</td>
<td>(dB)</td>
</tr>
<tr>
<td>Col. Type: (circle one)</td>
<td>MP Depth</td>
<td>Col. Type: (circle one)</td>
<td>MP Depth</td>
</tr>
<tr>
<td>Col. Type: (circle one)</td>
<td>MP Depth</td>
<td>Col. Type: (circle one)</td>
<td>MP Depth</td>
</tr>
</tbody>
</table>
Figure A.4: Phased Array Calibration Form

Phased Array Calibration Data Sheet

<table>
<thead>
<tr>
<th>Candidate's Name:</th>
<th>SSN:</th>
<th>Owner/User Location:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Set #:</td>
<td>Reference Block:</td>
<td>API ID #:</td>
</tr>
<tr>
<td>Sample ID:</td>
<td>ASME Cal. Std.:</td>
<td></td>
</tr>
</tbody>
</table>

Instrument Manufacturer:  
Model No.:  

<table>
<thead>
<tr>
<th>Search Unit Information</th>
<th>Mfg.</th>
<th>Model</th>
<th>Elements</th>
<th>Freq.</th>
<th>Pitch</th>
<th>Exit Point Verification</th>
<th>Ph. Array Angles Min/Max</th>
<th>Config (circle one)</th>
<th>S-Scan</th>
<th>Mode (circle one)</th>
<th>Shear. Longitudinal</th>
<th>Wedge Model #:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mfg.</td>
<td>Model</td>
<td>Elements</td>
<td>Freq.</td>
<td>Pitch</td>
<td>Exit Point Verification</td>
<td>Ph. Array Angles Min/Max</td>
<td>Config (circle one)</td>
<td>S-Scan</td>
<td>Mode (circle one)</td>
<td>Shear. Longitudinal</td>
<td>Wedge Model #:</td>
</tr>
</tbody>
</table>

Instrument Setting  
Range:  
Delay:  
Velocity:  
Focus Depth:  
Wedge Delay:  
Sensitivity:  
Encoded/Non-Encoded:  
DAC/TCG Calibration Information  

<table>
<thead>
<tr>
<th>Reference Sensitivity: (dB)</th>
<th>Exam Sensitivity: (dB)</th>
<th>Reference Sensitivity: (dB)</th>
<th>Exam Sensitivity: (dB)</th>
<th>Reference Sensitivity: (dB)</th>
<th>Exam Sensitivity: (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cal. Type: (circle one) MP</td>
<td>Depth</td>
<td>Cal. Type: (circle one) MP</td>
<td>Depth</td>
<td>Cal. Type: (circle one) MP</td>
<td>Depth</td>
</tr>
</tbody>
</table>
Figure A.5: Single Vee Weld Indication Report Form

<table>
<thead>
<tr>
<th>Flaw Table: Enter ID shown on current sample</th>
<th>% of DAC</th>
<th>Flaw Start</th>
<th>Flaw Stop</th>
<th>Total Length</th>
<th>Flaw Location (Upst/CL/Dnst)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candidate’s Name:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSN:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Owner/User Location:</td>
<td>Test Date:</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Plan View:** Sketch in Flaw Location and Number Each Indication

**Cross-Sectional View:** Sketch in Flaw Location and Number Each Indication

For Grading Purposes Only

<table>
<thead>
<tr>
<th>Detection</th>
<th>Miss Char.</th>
<th>Miss Position</th>
<th>False Calls</th>
<th>Grading Notes:</th>
</tr>
</thead>
<tbody>
<tr>
<td>___ of ___</td>
<td>___</td>
<td>___</td>
<td>___</td>
<td>___</td>
</tr>
</tbody>
</table>
Figure A.6: Double Vee Weld Indication Report Form

<table>
<thead>
<tr>
<th>Flaw Table: Enter ID shown on current sample:</th>
<th>1” Plate:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Candidate’s Name:</td>
<td>SSN:</td>
</tr>
<tr>
<td>Owner/User Location:</td>
<td>Test Date:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Indication #</th>
<th>Search Unit #</th>
<th>Flaw Type*</th>
<th>% of DAC</th>
<th>Flaw Start</th>
<th>Flaw Stop</th>
<th>Total Length</th>
<th>Flaw Location (Upst/CL/Dnst)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

*ID Crack    OD Crack    Embedded Center Line Crack (CL Crack)    Lack of Fusion    Porosity    Slag

**Plan View:** Sketch in Flaw Location and Number Each Indication

<table>
<thead>
<tr>
<th>Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld C/L</td>
</tr>
<tr>
<td>Upstream</td>
</tr>
</tbody>
</table>

| 0 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 |

**Cross-Sectional View:** Sketch in Flaw Location and Number Each Indication

For Grading Purposes Only

<table>
<thead>
<tr>
<th>Detection</th>
<th>Miss Char.</th>
<th>Miss Position</th>
<th>False Calls</th>
<th>Grading Notes:</th>
</tr>
</thead>
<tbody>
<tr>
<td>___ of ___</td>
<td>_____</td>
<td>_____</td>
<td>_____</td>
<td></td>
</tr>
</tbody>
</table>
Figure A.7: Crack Height Sizing Report Form

### Crack Height Sizing Report Sheet

<table>
<thead>
<tr>
<th>Sample ID Number</th>
<th>Nominal Thickness</th>
<th>UT Crack Sizing Methods</th>
<th>List Other Technique</th>
<th>Reported UT Height</th>
<th>Actual Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ID Creeping Estimate</td>
<td>Tip Diffraction Estimate</td>
<td>Bi-Modal Estimate</td>
<td>HALT Estimate</td>
</tr>
<tr>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>For Grading Purposes Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graded by:</td>
</tr>
</tbody>
</table>
Appendix B
API Ultrasonic Examination Procedures

B.1 Each candidate shall perform examinations to a written ultrasonic examination procedure. The candidate can use his own company's procedure, or he can use any of the ultrasonic procedures developed by the API which are shown below.

B.2 API-UT-1: Generic Procedure for the Ultrasonic Examination of Ferritic Welds

NOTE: This procedure defines the minimum mandatory requirements for the API Qualification of Ultrasonic Examiners.

1.0 SCOPE
1.1 This procedure is applicable only to ultrasonic examinations conducted for the American Petroleum Institute (API) Qualification of Ultrasonic Examiners Certification Program.
1.2 This procedure applies to the manual, contact ultrasonic examination of the material product forms and component designs identified in Figure 1.
1.3 The objective of examinations performed in accordance with this procedure is to accurately detect, characterize, and length size discontinuities within the specified examination volume from the outside surface.

2.0 REFERENCE
2.1 American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section V

3.0 PERSONNEL REQUIREMENTS
3.1 Personnel performing this qualification should be, as a minimum, certifiable to UT Level II or III in accordance with their employer’s written practice.

4.0 EQUIPMENT
4.1 Ultrasonic Instruments
4.1.1 Any ultrasonic instrument may be used provided that it satisfies the requirements of this procedure.
4.2 Search Units
4.2.1 Any search unit may be used provided that it satisfies the requirements of this procedure.
4.2.2 Search unit frequency should be between 2.25 and 5.0 MHz.
4.2.3 Search unit wedges designed to produce nominal inspection angles of 45°, 60°, or 70° (±3°) in ferritic material should be used.
4.2.4 Any search unit size may be used provided that adequate contact can be maintained.
4.3 Cabling
4.3.1 Any convenient type and length of cable may be used.
4.4 Couplant
4.4.1 Any couplant material may be used.
4.5 Calibration Blocks
4.5.1 ASME B & PV Code, Section V, Calibration blocks shall be provided.
5.0 EXAMINATION AREA REQUIREMENTS
5.1 Examination Volume
5.1.1 The examination volume shall consist of the entire weld volume and base material for a distance of 1/4 inch from each weld toe shown below. This volume applies to all configurations.

6.0 CALIBRATION
6.1 General Information
6.1.1 Calibration should be performed and recorded prior to the start of any examination or series of examinations.
6.2 Time Base Calibration
6.2.1 A linear time base (screen range) representing either metal path or material depth should be obtained.
6.3 Primary Reference Sensitivity and DAC
6.3.1 The primary reference sensitivity level and associated distance amplitude correction curve (DAC) should be established using the inside and outside surface notches in the following manner:

   a.) Maximize the signal response from the ID notch at ½ V-Path and set the response at ~ 80% FSH, establishing a flat line DAC at 80% for ½ V-Path examinations. For examinations beyond ½ V-Path continue the DAC curve as defined in step b.
   b.) Without changing the gain control established in step a, determine and mark the maximum signal response obtainable from the OD notch at a full V-Path and the ID notch at one and one half (1 ½) V-Paths as applicable. Construct the DAC curve from these points.

7.0 EXAMINATION
7.1 Examination Sensitivity (Scan Gain)
7.1.1 The examination sensitivity (scan gain) should be a minimum of twice (+ 6 dB) the primary reference level.

8.0 INDICATION EVALUATION
8.1 General Information
8.1.1 All suspected flaw indications shall be plotted on a cross sectional drawing of the weld in order to accurately identify the specific origin of the reflectors.
8.2 Flaw Indications
8.2.1 All actual flaw indications e.g., slag, LOP, LOF, cracks, etc., exceeding 20% of the primary reference level shall be reported.
9.0 RECORDING AND REPORTING OF EXAM RESULTS

9.1 General Information
9.1.1 Component reference information (datum 0 position, direction of flow) used for indication reporting shall be identified on the examination sample.

9.1.2 Exam results shall be reported on the API indication report sheet.

9.2 Non-Relevant Indications
9.2.1 Reporting of non-relevant indications is not required.

9.3 Flaw Indications
9.3.1 Flaw indications 20% of DAC or greater shall be reported.

9.3.2 The following information shall be recorded on the applicable indication report sheets for each reported flaw:

a) The flaw length dimension (L1 and L2)

b) The flaw location in relationship to the weld centerline (e.g., upstream, downstream, centerline)

c) The flaw location in relationship to the weld volume (e.g., inside surface connected, outside surface connected, embedded)

d) Recording amplitude (% of DAC)

e) Flaw type

Figure 1
Demonstration Sample Design
(Typical)
B.3 API-UT-2: Defined Procedure for the Ultrasonic Examination of Ferritic Welds

Note: This procedure defines the recommended techniques for the API Qualification of Ultrasonic Examiners.

1.0 SCOPE
1.1 This procedure is applicable only to ultrasonic examinations conducted for the American Petroleum Institute (API) Qualification of Ultrasonic Examiners Certification Program.
1.2 This procedure applies to the manual, contact ultrasonic examination of the material product forms and component designs identified in Figure 1. Examinations shall be performed using the pulse echo examination technique.
1.3 The objective of examinations performed in accordance with this procedure is to accurately detect, characterize, and length size discontinuities within the specified examination volume from the outside surface. Expected flaw mechanisms for each of these components are identified in Table 1 of Section 9.0.
1.4 Dual side access shall be available for all samples. Examinations shall always be performed from both sides of the weld.
1.5 The weld crown condition shall be "as-welded".

2.0 REFERENCE
2.1 American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section V

3.0 PERSONNEL REQUIREMENTS
3.1 Personnel performing this qualification should be, as a minimum, certifiable to UT Level II or III in accordance with their employer’s written practice.

4.0 EQUIPMENT
4.1 Ultrasonic Instruments
4.1.1 Any ultrasonic instrument may be used provided that it satisfies the requirements of this procedure. Ultrasonic instruments should be equipped with a calibrated dB gain or attenuation control stepped in increments of 2dB or less.
4.2 Search Units
4.2.1 Search unit parameters are identified in Section 6.
4.3 Cabling
4.3.1 Any convenient type and length of cable may be used.
4.4 Couplant
4.4.1 Any couplant material may be used.
4.5 Calibration and Reference Blocks
4.5.1 Calibration blocks shall be provided for each component identified in Figure 1. Calibration block design is in accordance with ASME B & PV Code, Section V.
4.5.2 Reference blocks (i.e. IIW, DSC, Rompas, etc.) should be used for establishing linear screen ranges and determining refracted angle and exit point information. Reference blocks should be made of ferritic material.

5.0 EXAMINATION AREA REQUIREMENTS
5.1 Examination Volume
5.1.1 The examination volume shall consist of the entire weld volume and base material for a distance of 1/4 inch from each weld toe shown below. This volume applies to all configurations.

5.2 Surface Condition Requirements
5.2.1 The examination surface shall be free of irregularities, loose material, or coatings, which interfere with the ultrasonic wave transmission.

6.0 TECHNIQUE SELECTION
6.1 General Information
6.1.1 This section defines the requirements for search unit mode of propagation, frequency, element shape/size, and examination angle(s).
6.1.2 Weld contour and thickness information should be acquired and reviewed prior to the examination to ensure that the examination angles and screen ranges selected will provide adequate coverage of the examination volume.
6.2 Search Unit Mode Propagation
6.2.1 Examinations shall be performed using shear wave search units.
6.3 Search Unit Frequency
6.3.1 Search unit nominal center frequency should be 5.0 MHz. Other frequencies may be used at the discretion of the examiner.
6.4 Search Unit Element Size
6.4.1 The search unit element size (and associated “footprint”) should be small enough to allow for adequate contact and coupling to each examination surface.
6.4.2 Shear wave search unit element size (maximum) should be selected from the table below:

<table>
<thead>
<tr>
<th>Component</th>
<th>Maximum Element Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>8” Nominal Pipe</td>
<td>0.25”</td>
</tr>
<tr>
<td>12” Nominal Pipe</td>
<td>0.375”</td>
</tr>
<tr>
<td>¼” Thick Plate</td>
<td>0.25”</td>
</tr>
<tr>
<td>1” Thick Plate</td>
<td>0.375”</td>
</tr>
</tbody>
</table>

6.4.3 If the maximum search unit size is utilized, the search unit wedge may require conditioning to allow for increased access in areas limited by the weld crown width. Wedge conditioning is defined as reducing the wedge front to exit point dimension. Calibrations shall be performed after completion of all wedge conditioning.

6.5 Search Unit Angle(s)
6.5.1 Search unit wedges designed to produce nominal inspection angles of 45°, 60°, or 70° in ferritic material should be used.
The search unit angles selected for each component should be chosen based upon the configuration of the component and expected flaw mechanism. Variables such as weld design, weld crown width, and material thickness should be evaluated prior to selecting the inspection angle(s).

CALIBRATION

General Information

Weld profile and thickness data should be available for review prior to calibration.

Calibration should be performed and recorded prior to the start of any examination or series of examinations. Calibration should include the complete ultrasonic examination system.

Instrument Settings

The settings of the ultrasonic instrument (pulser and receiver settings) should be optimized during calibration in order to maximize the systems resolution capabilities.

Search Unit Exit Point and Beam Angle Measurements

Actual search unit exit points and beam angles should be determined prior to calibration using a ferritic reference standard. The following process is provided for reference.

a) Exit Point Measurement Position - the search unit perpendicular to the radius of the reference block and maximize the signal response. The exit point is the location where the side of the wedge/search unit coincides with the reference line on the calibration standard.

b) Beam Angle Measurement Position - the search unit perpendicular to the applicable beam angle measurement reflector in the standard reference block and maximize the signal response. The actual refracted angle is the point where the measured exit point intersects with the angle gradients scribed on the reference block.

Time Base Calibration

A linear time base (screen range) representing either metal path or material depth should be established. The time base should be calibrated using a ferritic reference block with known reflector distances.

Time Base (Range) Size

The time base size selected should be sufficient to provide adequate coverage of the required examination volume (Figure 1) from each side of the weld with sufficient allowance for material thickness and/or sound path variation. The maximum time base size should not be excessive to the extent that resolution capabilities are compromised. Recommended time base sizes are identified as:

<table>
<thead>
<tr>
<th>Examination Angle</th>
<th>Time Base Size</th>
<th>Calibration Reflector(s) (DAC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45°</td>
<td>Full V-Path (+~25%)</td>
<td>ID/OD Notch</td>
</tr>
<tr>
<td>60°</td>
<td>Full V-Path (+~25%)</td>
<td>ID/OD Notch</td>
</tr>
<tr>
<td>70°</td>
<td>1/2 V-Path (+~25%)</td>
<td>ID Notch</td>
</tr>
</tbody>
</table>

Recommended calibration reflector positioning for ½ V-Path calibrations would properly position the ID notch response at approximately 7 screen divisions. Recommended calibration reflector positioning for Full V-Path examinations would properly position the ID and OD notch responses at approximately 4 and 8 screen divisions.
7.5.3 During examination, the time base size may be adjusted for indication discrimination and characterization. Final recording of indications and indication plotting should be done utilizing the time base settings established during calibration.

7.6 Primary Reference Sensitivity and DAC

7.6.1 The primary reference sensitivity level and associated distance amplitude correction curve (DAC) should be established using the inside and outside surface notches in the following manner:

a.) Maximize the signal response from the ID notch at ½ V-Path and set the response at ~ 80% FSH, establishing a flat line DAC at 80% for ½ V-Path examinations. For examinations beyond ½ V-Path continue the DAC curve as defined in step b.

b.) Without changing the gain control established in step a, determine and mark the maximum signal response obtainable from the OD notch at a full V-Path. Construct the DAC curve from these points.

8.0 EXAMINATION

8.1 Scan Direction

8.1.1 For the examination of reflectors oriented parallel with the weld, the sound beam should be directed essentially perpendicular to the weld axis from two directions.

8.2 Scan Pattern

8.2.1 The probe movement should consist of a raster type scanning sequence providing adequate beam overlap in the indexing direction. This scanning pattern may be supplemented as needed with localized lateral scanning and probe oscillation to provide information important to indication characterization.

8.2.2 For Full V-Path examinations the scan length should be sufficient to allow for full evaluation of the OD surface of the component.

8.3 Technique Application

8.3.1 The 70° search unit at ½ V-Path calibration is intended to provide 2 direction coverage of the lower ½ of the inspection volume. This probe may also be utilized to confirm indications in the upper ½ of the inspection volume if coverage is obtainable.

8.3.2 The 45° and/or 60° search units at full V-Path calibration are intended to provide 2 direction coverage of the upper ½ of the inspection volume. These probes may also be utilized to confirm indications in the lower ½ of the inspection volume if coverage is obtainable.

8.3.3 Characterization and positioning of suspect indications should be done with the search unit angle(s) that provides the greatest response from the indications.

8.4 Examination Sensitivity (Scan Gain)

8.4.1 The examination sensitivity (scan gain) should be a minimum of twice (+ 6 dB) the primary reference level. Scan sensitivity should be increased beyond the + 6dB level as geometric responses allow.

8.4.2 Scan sensitivity may require adjustment during the examination to compensate for changes in material type, thickness, surface condition, or to evaluate suspect indications.

8.5 Scan Speed

8.5.1 Scan speed should not exceed 3.0" per second.

9.0 INDICATION EVALUATION

9.1 General Information
9.1.1 All suspected flaw indications, regardless of amplitude, should be investigated to the extent necessary to provide accurate characterization, identity, and location.

9.1.2 All suspected flaw indications should be plotted on a cross sectional drawing of the weld in order to accurately identify the specific origin of the reflectors.

9.2 Indication Classification
9.2.1 Non-relevant indications (Geometric/Metallurgical)
9.2.1.1 All indications produced by reflectors within the volume to be examined that can be attributed to the geometry of the weld configuration (Inside surface mismatch, root geometry, weld cap responses, metallurgical responses, etc.) shall be considered as non-relevant indications.

9.2.2 Flaw Indications
9.2.1.1 All indications which are produced by reflectors within the exam volume, that cannot be clearly attributed to the geometry of the weld configuration (Inside surface mismatch, root geometry, weld cap responses, metallurgical responses, etc.) should be considered as flaw indications. The minimum reporting threshold for flaw indications is identified in Section 10.

9.2.1.2 Table 1 identifies the flaw mechanisms that potentially exist in the qualification specimens. Specific test specimens and test sets are not required to contain all of the flaws identified within this table.

Table 1
Potential Flaw Mechanisms

<table>
<thead>
<tr>
<th>Inside surface connected crack (ID crack)</th>
<th>8” Pipe</th>
<th>12” Pipe</th>
<th>½” Plate</th>
<th>1” Plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside surface connected crack (OD crack)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Embedded Center Line Cracking</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Lack of root penetration (LOP)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Lack of side wall fusion (LOF)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Porosity</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Slag inclusion</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

9.3 Indication Discrimination
9.3.1 Flaw Indications
9.3.1.1 All suspected flaw indications should be evaluated taking into account the following typical indication characteristics. These characteristics should not be considered as mandatory criteria for reporting indications as flaws, but are listed as significant points of interest for the examiner to consider during the exam.

   a) Inside Surface Connected Crack (ID Crack)
   b) Outside Surface Connected Crack (OD Crack)

   • Unique, significant, and sharp amplitude response with defined start and stop positions
- Unique and significant signal travel or “walk”
- Multiple points of reflection (flaw base, flaw tip, faceting, etc.)
- Similar response from opposite scan direction
- Plots correctly to expected ID or OD crack location from both directions (correct sound path, surface distance, and flaw positioning from both directions)

c) Embedded Center Line Cracking (CL Crack)

- Unique, significant, and sharp amplitude response with defined start and stop positions
- Unique and significant signal travel or “walk”
- Similar response from opposite direction (comparable amplitude, surface position, signal responses from each scan direction)
- Does not connect to either the inside or outside surfaces
- Plots correctly to centerline area of weld volume from both directions (similar and correct sound path, surface distance, and flaw positioning from both directions)

d) Lack of Root Penetration (LOP)

- Unique and significant amplitude response with defined start and stop positions
- Unique and significant signal travel or “walk”
- Similar response from opposite scan direction
- Plots correctly near the centerline of weld from both directions (comparable and correct sound path, surface distance, and signal response from both directions)
- Through wall dimension supported by component design

e) Lack of Side Wall Fusion (LOF)

- Unique and significant amplitude response with defined start and stop positions
- Unique and significant signal travel or “walk”
- Indication may provide unique upper and lower tip responses from favorable angles and scan directions
- Response from opposite scan direction may be significantly reduced in amplitude or observable from a much different sound path and surface distance position
- Plots correctly near the fusion line of weld

f) Porosity

- Multiple less significant signal responses or signal clusters varying randomly in amplitude and position
- Plots correctly to weld volume
• Start and stop positions “blend in” with background responses

g) Slag Inclusion

• Unique signal responses which plot correctly to weld volume
• Amplitude responses dependent upon the size, shape, and orientation of inclusion
• Typically detectable using several examination angles from both sides of the weld

9.4 Length Sizing
9.4.1 Length sizing should generally be performed using the search unit(s) that provides the most significant signal responses.
9.4.2 Length sizing should be performed in a manner similar to the technique identified below. Multiple search unit angles should be evaluated in order to properly discriminate flaw responses from surrounding metallurgical and geometrical responses.

a) Optimize the signal response from the flaw indication.
b) Scan the indication area with specific focus on the flaw signal responses, (e.g., signal shape, walk, orientation, effect of skew, etc). Adjust the system gain as needed to optimize the flaw response.
c) Scan an adjacent unflawed area in close proximity to the flaw area with specific focus on the surrounding geometrical responses (weld noise, root, weld cap response, etc.).
d) Scan along the length of the flaw in each direction until the signal response has diminished into the background noise.

10.0 RECORDING AND REPORTING OF EXAM RESULTS
10.1 General Information
10.1.1 Component reference information (datum 0 position, direction of flow) used for indication reporting shall be identified on the examination sample.
10.1.2 Exam results shall be reported on the API indication report sheet.
10.2 Non-Relevant Indications
10.2.1 Reporting of non-relevant indications is not required.
10.3 Flaw Indications
10.3.1 Flaw indications 20% of DAC or greater shall be reported.
10.3.2 The following information shall be recorded on the applicable indication report sheets for each reported flaw:

a) The flaw length dimension (L₁ and L₂)
b) The flaw location in relationship to the weld centerline (e.g., upstream, downstream, centerline)
c) The flaw location in relationship to the weld volume (e.g., inside surface connected, outside surface connected, embedded)
d) Flaw type (See Table 1)
e) Flaw amplitude response as either a % of DAC or as a dB level compared to reduced sensitivity.
Figure 1
Demonstration Sample Design
(Typical)
B.4 API-UT-10: Defined Procedure for Advanced Ultrasonic Crack Sizing of Ferritic Welds

NOTE: This procedure defines the recommended methods and techniques for the API Qualification of Ultrasonic Examiners.

1.0 SCOPE
1.1 This procedure is applicable only to ultrasonic examinations conducted for American Petroleum Institute (API) Qualification of Ultrasonic Examiners Certification Program.
1.2 The following procedure addresses equipment and sizing evaluation techniques for crack height sizing examinations.
1.3 This procedure provides guidelines and techniques for ultrasonic sizing of planar cracks which originate at the opposite side of the scanning surface or the inside diameter (ID).
1.4 This procedure is applicable to carbon steel material thicknesses from 0.375 inches to 1.0 inches.
1.5 The Advanced Ultrasonic Crack Sizing Procedure outlines the requirements for contact methods, using refracted longitudinal wave and shear wave techniques for carbon steel materials.
1.6 Other methods and techniques may be used when an appropriate sizing calibration block is utilized.
1.7 Special longitudinal and/or shear wave search units, and special ultrasonic sizing calibration blocks are used for the sizing examinations.
1.8 These sizing techniques are applicable to manual examinations only.

2.0 REFERENCES
2.1 American Society for Nondestructive Testing (ASNT), SNT-TC-1A
2.2 American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section V
2.3 ASTM Crack Sizing Standard ASTM E-2192

3.0 PERSONNEL REQUIREMENTS
3.1 Personnel performing the sizing examination should be, as a minimum, certified to UT Level II or III in accordance with their employer’s written practice.

4.0 EQUIPMENT
4.1 Ultrasonic Instruments
4.1.1 Any ultrasonic instrument may be used provided that it satisfies the requirements of this procedure. Ultrasonic instruments should be equipped with a calibrated dB gain or attenuation control stepped in increments of 2db or less.
4.2 Search Units
4.2.1 Search units shall be in the frequency range of 1.0 to 10.0 MHz
4.2.2 Search units may be of the single or dual element type, which may produce shear and/or longitudinal waves as they apply to the appropriate crack sizing technique.
4.2.3 Search units to be used in crack sizing shall be of the type to produce the appropriate wave physics associated with the following crack sizing methods described in this procedure.
   a) ID Creeping Waves
b) Tip Diffraction

c) Bi-Modal

d) Focused Refracted L-Waves or focused Shear Waves

4.2.4 Other search units and techniques may be used provided that the methods and techniques are outlined in a procedure.

4.3 Cabling

4.3.1 Any convenient type and length of cable may be used.

4.4 Couplant

4.4.1 Any couplant material may be used.

4.5 Calibration and Reference Blocks

4.5.1 Special Crack Sizing Calibration Blocks shall be used to establish specific calibrations for the sizing methods identified in this procedure.

4.5.2 Sizing calibration blocks shall contain notches and/or side drilled holes (SDH) reflectors at specific known depths for calibration of the applicable sizing method.

4.5.3 The sizing calibration blocks shall be fabricated from the carbon steel materials.

4.5.4 Normally, a flat plate with notches from 20% to 80% through-wall in 20 % steps is used to calibrate the screen range in depth. Other blocks thicknesses in the range of the material being examined may be used.

4.5.5 Special blocks may be used for calibration of other sizing methods.

4.5.6 Reference blocks (i.e. IIW, DSC, Rompas, etc.) may be used for establishing linear screen ranges and determining refracted angle and exit point information. Calibration blocks should be made of carbon steel material.

5.0 CALIBRATION

5.1 The temperature of the calibration block material shall be within 25°F of the component to be examined.

5.2 System Calibration

5.2.1 System calibration shall include the complete examination system. Any changes in search unit, shoes, couplant or instrument shall be cause for recalibration.

5.2.2 The crack sizing techniques utilized in accordance with this procedure are as follows:

5.2.2.1 The ID Creeping Wave (IDCR) Method, or 30-70-70 mode conversion technique is used as a precursor to determine approximate height of the crack, e.g., shallow (Inner 1/3 t), midwall (Middle 1/3 t), or deep (Outer 1/3 t). See Appendix E (Technique 1) for a description of the crack sizing method.

5.2.2.2 The Tip Diffraction Method is used for shallow cracks, which are shallow to midwall from 10 to 40 % in height. See Appendix E (Technique 2) for a description of the crack sizing method.

5.2.2.3 The Bi-Modal Method is used for cracks which are in the midwall range in the area of 30% to 70% in height. See Appendix E (Technique 3) for a description of the crack sizing method.

5.2.2.4 The Focused Refracted Longitudinal Wave and Focused Shear Wave Methods are used for cracks are very deep, (greater than 40 or 50 % in height), and penetrate to the outside surface. See Appendix E (Technique 4) for a description of the crack sizing method

Note: The crack height ranges are presented as a guide and are indicative of the material thickness and the specific sizing method usually for a 1 inch thick component.
5.3 Calibration for screen range may be accomplished by either direct sound path or actual depth. Specific calibrations may be performed as outlined in the Appendices (Page 8) for the appropriate sizing technique.

5.4 Other sizing techniques or variations of the aforementioned techniques may be used in accordance with this procedure.

5.5 The sizing method and search unit shall be selected from the appropriate techniques, based upon the zone of investigation.

5.6 Whenever practical, the through wall crack height should be verified by more than one sizing technique.

5.7 In addition, whenever practical, sizing should be performed from both sides of the crack.

6.0 EXAMINATION

6.1 Scanning Requirements

6.1.1 The area designated by the API Test Administrator shall be investigated with the appropriate sizing technique. The sizing examination shall be performed along the length of the crack to determine the **maximum crack height**. The deepest crack depth or through wall height dimension shall be recorded on the API Crack Sizing Report Form.

6.1.2 In addition, the remaining ligament of good metal above the crack shall be recorded on the API Crack Sizing Depth Reporting Form.

6.1.3 Weld crown configuration may restrict search unit movement for proper crack sizing using the specific technique. Select the appropriate crack sizing technique to accommodate this limitation.

7.0 SIZING EVALUATION AND RECORDING CRITERIA

7.1 Sizing Application

7.1.1 The Sizing Flow Chart (Figure 1) may be used to categorize the suspected crack into the appropriate zone or material volume.
7.1.2 Each sizing technique has certain advantages, disadvantages and limitations. **No one sizing technique is best for sizing cracks of any through-wall depths in all material types or thicknesses.**

7.1.3 It is important to understand the use and application of each sizing technique and the associated wave physics so that accurate crack height sizing is achieved.

7.2 Recording

7.2.1 Clearly document the height of each crack on the designated API Crack Sizing Reporting Form, Figure 1. The maximum through wall depth along the length of the crack in decimal inches from the ID shall be recorded for each of the cracks to be sized.

6.0 **Description of Advanced Ultrasonic Crack Sizing Methods**
The following provides a description of the advanced shear wave and focused refracted wave ultrasonic crack sizing methods discussed in API-UT-10 in Appendix D. Calibration requirements for each method are also discussed as well as the limitations of each method.

E.8.1 **TECHNIQUE 1: ID CREEPING WAVE (IDCR) METHOD**

E.8.1.1 Technique Description
The ID Creeping Wave Technique uses a single or dual element search unit which transmits a 70 degree refracted longitudinal wave, a 30 degree direct shear wave (CE-1 or 30-70-70), and a 31.5 degree indirect shear wave (CE-2 or ID Creeping Wave).

E.8.1.2 This technique is effective for estimation of crack depths from 10% to 90% through wall. The ID Creeping Wave (IDCR) is used as a precursor sizing technique to provide a qualitative or non-quantitative sizing depth measurement.

E.8.1.2 Calibration
Using a carbon steel calibration block of similar thickness as the component to be examined with ID notches from 20% to 80% depths, adjust the CE-1 and CE-2 signals to 4 and 5 horizontal screen divisions on the CRT, respectively. Adjust the amplitude of CE-2 to approximately 80 to 100% Full Screen Height (FSH). Add 6 to 8 dB. This is the scanning and evaluation gain setting. Gain may be increased or decreased as appropriate to maintain a baseline noise level of approximately 5% FSH.
If during calibration, the CE 1 signal is not observed when the CE 2 signal is peaked, then increase the gain to set the CE 1 signal to approximately 10 percent FSH. This will be the scanning and evaluation gain setting.

For each of the notches, record the amplitude and presence of the 70L, CE -1, and CE – 2 signals, when CE -2 is peaked. Then, record the Echo Dynamics (ED) movement of CE-1, in screen divisions and the peaked 70 L signal in screen divisions.

Calibration blocks or reference blocks of other dimensions and designs may be used as long as they provide equivalent information as described in paragraphs 2.1, 2.2, and 2.3.

E.8.1.3 Scanning/Evaluation
E.8.1.3.1 Move the IDCR search unit over the area of interest and observe the CRT to identify the 70 L, CE -1, and CE - 2 signals.
E.8.1.3.2 The absence of a CE -2 signal may indicate the suspected crack is actually mid wall defect such as porosity, or slag, or a geometric reflection, like a mismatch.
E.8.1.3.3 When the CE2 signal is peaked, record the amplitude of the CE - 1 and 70 L signals, as appropriate. Record the echo dynamics movement of the CE - 1 signal. Record the peaked amplitude signal of the 70 L in screen divisions. Compare the absence or presence, the amplitude, echo dynamics, and the peaked 70 L wave signals to those signals obtained from the calibration block examination using the IDCR technique.
E.8.1.3.4 In general, the following may be observed:

a) The presence of a CE -2 signal and the absence of a CE - 1 signal is a good indication that the crack is shallow (e.g., less than 10 or 15 % through-wall height.)
b) When a CE1 signal is observed in conjunction with the CE - 2 signal, then the crack is estimated to be shallow to midwall (e.g., greater than 15 % to 20 % through-wall height.)
c) When a broad echo dynamic CE - 1 signal is observed, a 70L signal will generally be detected to the left of the CE - 1 signal. This should indicate a midwall to deep crack.

Note: These nominal crack height estimation values are indicative of the search unit design and frequency, calibration block thickness and material type.

E.8.1.4 Limitations
The IDCR Wave Method is a qualitative sizing technique which allows the examiner to classify ID connected cracks as shallow, midwall, or deep. Finite crack height analysis is best obtained by one of the other crack sizing methods, e.g., Tip Diffraction, Bi-Modal, Focused Refracted Longitudinal or Focused Shear Waves.

E.8.2 TECHNIQUE 2: TIP DIFFRACTION METHOD

E.8.2.1 Description
The Tip Diffraction Method is based upon the diffracted sound energy from the tip of a crack. A single or dual element, 1 MHz through 10 MHz, 45 degree to 60 degree shear
or longitudinal wave search unit is used to ultrasonically measure the time-of-flight, (TOF) or sound path distance, (SP) from the crack tip, or the time or sound path separation of the tip signal and relatively larger response at the crack opening at the ID. Generally, 3 to 5 MHz search units, which produce shear waves, are used for sensitivity and resolution.

The Tip Diffraction Method is most effective for sizing ID connected cracks which are approximately 5 to 40% in through wall height.

The ½ V-Path technique is generally used for the Tip Diffraction method; however, the full V-Path is applicable for qualitative sizing of deep cracks.

The two basic Tip Diffraction Techniques are:

a) Time of Flight (TOF), or, PATT (Pulse Arrival Time Technique), or AATT (Absolute Arrival Time Technique)
b) Delta Time of Flight (Δ TOF), or SPOT (Satellite Pulse Observation Sizing Technique, or RATT (Relative Arrival Time Technique).

E8.2.2 Calibration
Obtain a calibration block of known thickness and similar material specification as the component to be examined (0.375 or 1 inch thick) with the required ID notches, e.g., 20%, 40%, 60%, and 80%.

E.8.2.2.1 Time of Flight (TOF), PATT/AATT Technique
E.8.2.2.1.1 As a ranging technique, adjust the ID signal from the edge of the calibration block using the delay or zero offset control to 5 horizontal screen divisions. Adjust the OD signal from the edge of the calibration block using the range or sweep control to 10 horizontal screen divisions.

E.8.2.2.1.2 Position the search to obtain the base or corner trap signal from the 80% ID notch. Move the search unit forward to obtain the 80% notch tip signal. Using the delay or zero offset control, adjust the peaked tip signal to 1 horizontal screen divisions.

E.8.2.2.1.3 Position the search unit to obtain the base signal from the 20% ID notch. Move the search unit forward to obtain the peaked 20% notch tip signal. Using the range or sweep control, adjust the notch tip signal to 4 horizontal screen divisions.

E.8.2.2.1.4 Position the search unit to obtain signals from the 40% and 60% notches to verify their respective positions at 3 divisions for the 40% and at 2 divisions for the 60% notches.

E.8.2.2.2 Delta Time of Flight (Δ TOF), SPOT/RATT Technique
E.8.2.2.2.1 With the PATT/AATT calibration complete, record the separation in screen divisions of the notch tip and the base signal for each of the applicable ID notches, e.g., 20%, 40%, 60%. Due to search unit beam spread limitations, the notch tip signal and the base signal may not be readily detectable at the same time for the deeper, (60 to 80%) notches. As such, only record the separation for the applicable notch depths.
E.8.2.2.2 The SPOT/RATT technique does not require peaking of the signals.

**Note:** In lieu of the aforementioned calibration techniques, other screen ranges, using appropriate reference blocks, (e.g., Rompas, DSC, and IIW Blocks) are acceptable for the required zone of examination. This will vary with technique, material type and thickness, search unit frequency and size, and more specifically the area of interest.

E.8.2.2.3 Scanning/Evaluation

E.8.2.2.3.1 Position the search unit to obtain the maximum amplitude from the crack base signal at the ID of the component for the one-half vee technique.

E.8.2.2.3.2 For the TOF or PATT/AATT technique, move the search unit forward between the crack base signal to obtain the maximum amplitude (peaked) and record the depth of the crack from the calibrated CRT screen.

E.8.2.2.3.3 When using the half-vee technique for very deep cracks, the crack tip signal may not be readily discernible due to near field effects.

E.8.2.2.3.4 Scanning sensitivity shall be established at a level that maintains a noise level of 10% to 15% of FSH during scanning.

E.8.2.2.3.5 For the ΔTOF or SPOT/RATT technique, record the separation in screen divisions for the crack tip signal and the crack base signal. Compare this sizing estimate result with the TOF/ PATT/AATT sizing estimate.

4.0 Calculations

4.1 For those sizing examinations where a sizing calibration block is not available, a suitable screen range calibration may be performed, e.g., 2.5 inches, 5.0 inches, etc.

4.2 The following formulas may be used to calculate the crack depth as opposed to the aforementioned techniques where the crack depth is read directly from the CRT screen.

4.2.1 Half-vee path technique

a) When the CRT sweep readings have been converted to sound path values:

\[ d = (SPB - SPT) \times \cos \varphi \]

Where:

- \( d \) = crack depth from the component ID
- \( SPB \) = sound path to the base of the crack @ maximum amplitude
- \( SPT \) = sound path to the crack tip @ peak amplitude
- \( \cos \varphi \) = Cosine of the sound beam angle

5.0 Limitations

5.1 Crack tip signals from very shallow cracks, .050 inches or less from the ID may be difficult to size due to resolution of the search unit. In other words, the resolving capabilities of the search unit may limit the separation of the crack tip signal and the crack base signal.

5.2 As such, varying the frequency, damping, and size of the search unit may improve the sizing accuracy for very shallow cracks or cracks in very thin material, e.g., less than 0.300 inches.

5.3 When using the half-vee path technique, crack tip signals from very deep cracks, may be lost in the near field noise. The examiner must consider near field effects when
examining very deep cracks. Generally, the full vee path technique is used as a qualitative sizing estimate only.

5.4 When using longitudinal waves, they shall be limited to use with the half-vee technique only.

E.3 TECHNIQUE 3: BI-MODAL METHOD

1.0 Description
1.1 The Bi-Modal Method uses a dual element search unit, either side-by-side or tandem orientation, producing a pulse train of longitudinal and shear waves. Sizing estimates are obtained by reflecting a refracted longitudinal wave from the crack tip, mode converting a direct shear wave from the crack face, and mode converting an indirect shear wave to produce an ID Creeping Wave, which reflects from the crack base.

1.2 The two basic crack sizing techniques for the Bi-Modal Method are:
1) Time of Flight (TOF), Tau or M-AATT, which is the peaked Pulse 1 signal, set to specific screen ranges.
2) Delta Time of Flight (Δ TOF), Sigma or M-RATT, which is the screen division of separation between the Pulse 1 and Pulse 2 signals.
1.3 The Bi-Modal techniques are very effective for sizing ID connected planar cracks in the material thickness range of 0.3” to 1.5 inches. Due to the pseudo-focusing effect of the incident angles of the transmit and receive crystals, the Bi-Modal technique is most effective for sizing ID connected mid-wall cracks, generally 30 to 70 % through wall.

1.4 Search units designs are as specified by the manufacturer. Examples of acceptable search units include: ADEPT 60, SLIC 40, and Sigma Bi-Modal. Other search units for the Bi-Modal Method may be used as demonstrated by an acceptable Bi-Modal calibration on the sizing calibration block.

1.5 Generally, the frequency of the Bi-Modal Search is approximately 3 to 3.5 MHz. Other frequencies may be used.

1.6 The Bi-modal Method is defined as follows. Three main signals are noted:

- Pulse 1 is the reflected longitudinal wave from the crack tip.
- Pulse 2 is the direct shear wave which mode converts to a longitudinal wave and then reflects a longitudinal wave from the face of the crack (similar to CE-1 with the ID Creeping Wave Method)
- Pulse 3 is an indirect shear wave which mode converts to an ID Creeping Wave at the ID surface of the component (similar to the CE-2 signal with the ID Creeping Wave Method).
- A fourth signal is noted as a satellite pulse signal of Pulse 1. Sometimes called 1 star. Generally, this signal is not used for calibration.

2.0 Calibration
Time of Flight (TOF), Tau / M-AATT Calibration

2.1.1  Determine the thickness of the component to be sized and obtain a calibration block of the similar material and nominal thickness with notches in a range of at least 20% to 80% through-wall depth.

2.1.2  Place the search unit on the edge of the sizing calibration block. Identify the three basic signals, or "Pulse Train", Pulse 1, Pulse 2, and Pulse 3. Also, note the 1 star signal.

2.1.3  As a ranging technique, adjust the range control to separate Pulse 2 and Pulse 3 to approximately 2 major divisions.

2.1.4  Place the Bi-modal search unit to obtain the Pulse 1, 2, and 3 signals from the 80% notch. Peak the Pulse 1 signal. Using the delay or zero offset control; adjust this Pulse 1 signal to 1 horizontal screen divisions.

2.1.5  Place the Bi-Modal search unit to obtain the Pulse 1 signal from the 20% notch. Using the range or sweep control, adjust the Pulse 1 signal from the 20 % notch to 4 screen divisions.

2.1.6  Repeat steps 2.1.4 and 2.1.5 until a linear screen range is obtained such that the 80% Pulse 1 signal is at 1 screen division and the 20 % Pulse 1 signal is at 4 screen divisions. The 60% and the 40 % Pulse 1 signals should be at 2 and 3 divisions respectively.

2.2  Delta Time of Flight (Δ TOF), Sigma / M-RATT

2.2.1  With the (TOF), Tau / M-AATT technique calibration complete, record the horizontal screen divisions of separation between the Pulse 1 and Pulse 2 signals for each of the notches, e.g., 80%, 60%, 40%, and 20%.

2.3  With the TOF/Tau and Δ TOF/Sigma calibrations complete, record the screen divisions of separation for the Pulse 2 and Pulse 3 signals.

2.4  If during the crack sizing evaluation, the separation of the Pulse 2 and Pulse 3 signals change from that observed during calibration, then the Delta Time of Flight or Sigma depth sizing estimate maybe incorrect due to a crack that is oriented other than perpendicular to the ID surface, or there has been a change in thickness.

2.5  As such, the Pulse 1 signal sizing estimate is the most accurate depth estimate.

3.0  Scanning/Evaluation

3.1  Scan the area of interest. First observed the Pulse 3 signal to verify the crack is ID connected. Then observe the Pulse 1 signal. Peak the Pulse 1 signal to obtain a sizing TOF/Tau depth estimate.

3.2  Once the TOF/Tau sizing depth estimate is obtained, then measure the screen divisions of separation between the Pulse 1 and Pulse 2 signals. This is ΔTOF/Sigma depth estimate. Compare the separation of Pulse 1 and Pulse 2 of the crack to the separation estimates from the notches to determine the crack height estimate.

3.3  Adjust the instrument gain such that the average noise level is about 10% to 15 % full screen height (FSH).

3.4  If possible, repeat the sizing examination from the weld side to verify the signals obtained from the base material side of the weld.

3.5  Scan along the length of the crack to determine the deepest sizing estimate.

4.0  Limitations

4.1  The ultrasonic instrument should have a RF displays to aid the sizing examiner to resolve the crack tip signal. The crack tip signal may have a low signal-to- noise ratio. The RF display may help the sizing examiner to detect the crack tip signal.
4.2 The Bi-Modal techniques are somewhat difficult. The sizing examiner must be thoroughly trained in the applications of the TOF/Tau and ΔTOF/Sigma techniques.

4.3 The Bi-Modal Method may detect multiple crack tip signals. The sizing examiner must be aware that the highest amplitude signal does not always indicate the deepest point of the crack.

4.4 If Pulses 2 and 3 are difficult to interpret, then the Delta Time of Flight or Sigma measurement may produce false sizing estimates.

4.5 The crack depth must be estimated on the basis of the Time of Flight or Tau measurements when both Pulse 2 and Pulse 3 are absent.

4.6 The Pulse 1 signal for TOF/Tau may be difficult to detect since oriented cracks may not produce Pulses 2 and 3.

E.4 TECHNIQUE 4: FOCUSED REFRACTED LONGITUDINAL (HALT) WAVE AND FOCUSED SHEAR WAVE (HAST) METHODS

1.0 Description
1.1 This technique employs a dual element, focused, refracted longitudinal wave or shear wave search unit to detect, locate and measure the Time of Flight or sound path of the crack tip signal.

1.2 The HALT or HAST techniques are effective for sizing cracks in the outer 1/3 thickness of material, and is an effective method for determining if a crack has propagated near the OD surface of the component.

2.0 Calibration
2.1 The UT screen presentation shall be adjusted to represent actual depth or remaining ligament from the OD surface of material.

2.2 The depth calibration is performed by utilizing a calibration block with holes or notches that provide a calibrated CRT for the desired depth range.

2.3 For example, a .100" reflector from the OD surface of the calibration block will appear at sweep division 1 and a .500" reflector from the OD will appear at a sweep division 5.
2.4 The desired search unit should be selected based upon refracted angle, frequency, and focal depth.

2.5 Other calibration methods utilizing sound path or depth calibrations may be used.

3.0 Scanning/Evaluation

3.1 Move the search unit over the area to be examined perpendicular to the suspected crack axis and observe the CRT for signals.

3.2 If a response is obtained, record the first signal (closest in time) at its peaked amplitude.

4.0 Calculations for Crack Sizing

4.1 The depth of the crack tip from the OD surface of the pipe, (Remaining Ligament, RL) shall be subtracted from the wall thickness of the material at the crack location to determine the height of the crack.

\[
\text{Crack Height} = T - RL
\]

Where:

\[
T = \text{the thickness of the pipe/component}
\]

\[
RL = \text{the remaining ligament from the OD surface to crack tip}
\]

5.0 Limitations

5.1 With the refracted longitudinal wave search unit, an associated shear wave is present which may produce confusing signals or other mode-converted signals.

5.2 Focal depth is a very important consideration for accurate crack sizing. This is controlled by the roof angle of the search unit.

5.3 Sizing in the less intense area of the beam spread may produce inaccuracies in crack depth estimates.

5.4 Generally, the useful focal range is from .5 to 1.5 times the actual focal depth of a refracted L-Wave or Shear Wave transducer.
Bibliography
