Defined Procedure

For

Advanced Ultrasonic Crack Sizing

API-UT-10

This Procedure Defines the Recommended Methods and Techniques for Ultrasonic Crack Sizing

1.0 PROCEDURE

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.

4.2.3.1 ID Creeping Waves
4.2.3.2 Tip Diffraction
4.2.3.3 Bi-Modal
4.2.3.4 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 degrees 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). (Technique 1)

5.2.2.2 The Tip Diffraction Method is used for shallow cracks, which are shallow to midwall from 10 to 40 % in height. (Technique 2)

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. (Technique 3)

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. (Technique 4)

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 preformed 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.

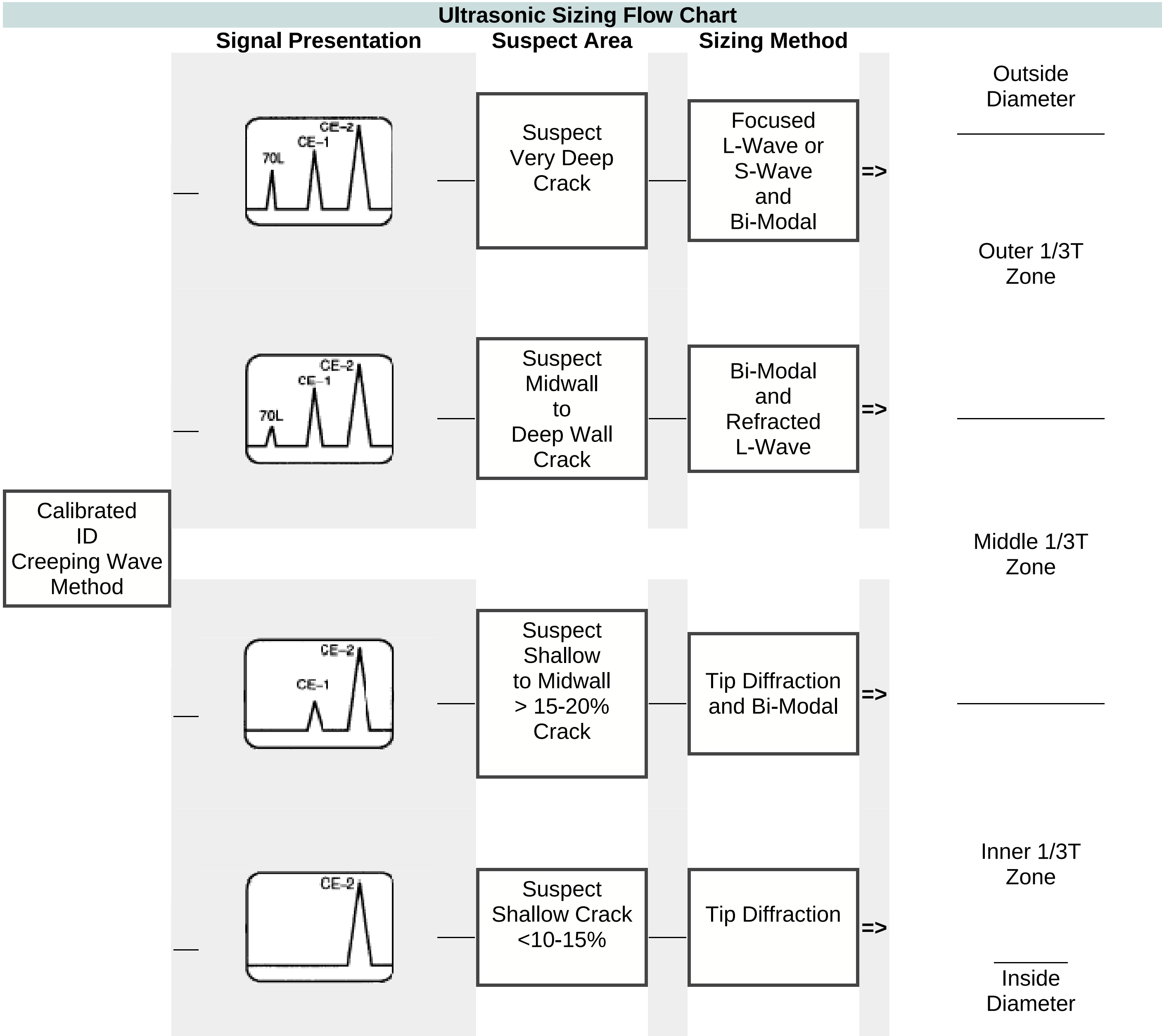


Figure 1 - ID Creeping Wave Flow Chart

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.

Appendices

The following Appendices will provide the calibration requirements for each of the Advanced Ultrasonic Crack Sizing Methods

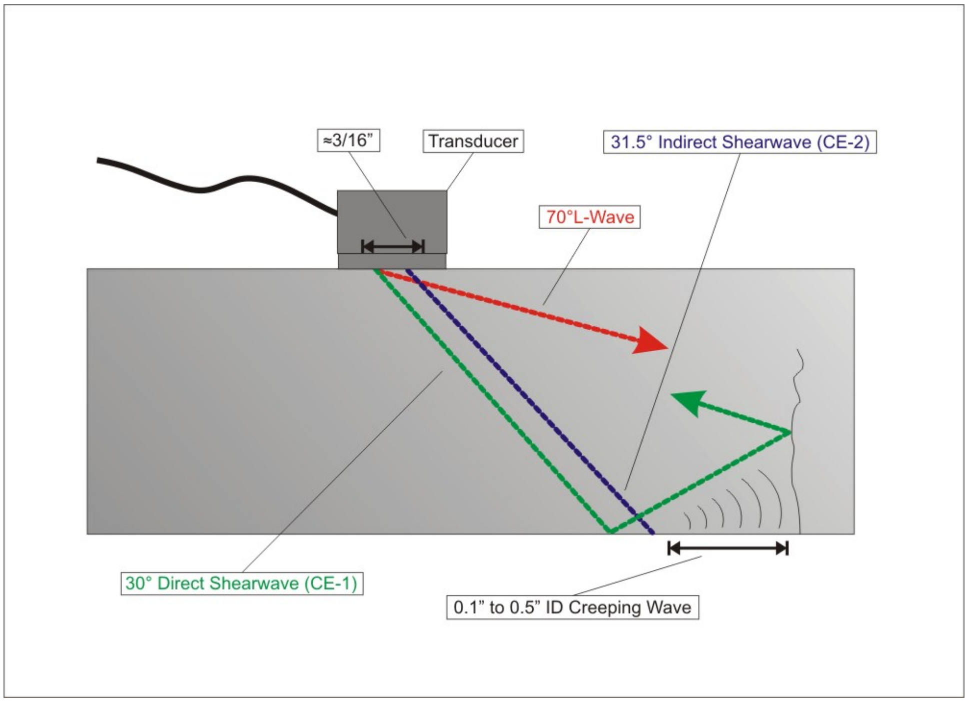
TECHNIQUE 1

ID Creeping Wave (IDCR) Method

1.0 Technique Description

1.1 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).

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.



2.0 Calibration

2.1 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.

2.2 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.

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

2.4 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.

3.0 Scanning/Evaluation

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.

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.

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.

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.

4.0 Limitations

4.1 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.

TECHNIQUE 2

Tip Diffraction Methods

1.0 Description

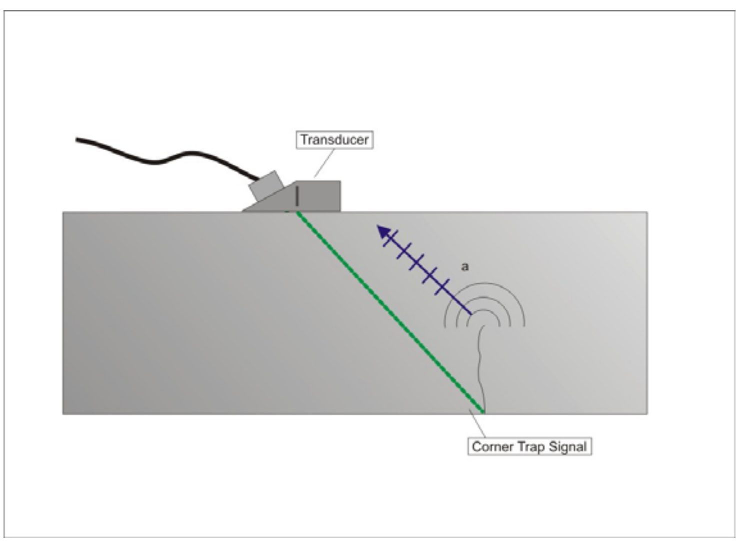
1.1 The Tip Diffraction Method is based upon the diffracted sound energy from the tip of a crack. A single or dual element, 1 MHz through 10 MHz, 45 degree to 60 degree shear or longitudinal wave search unit is used to ultrasonically measure the time-of-flight, (TOF) or sound path distance, (SP) from 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.

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

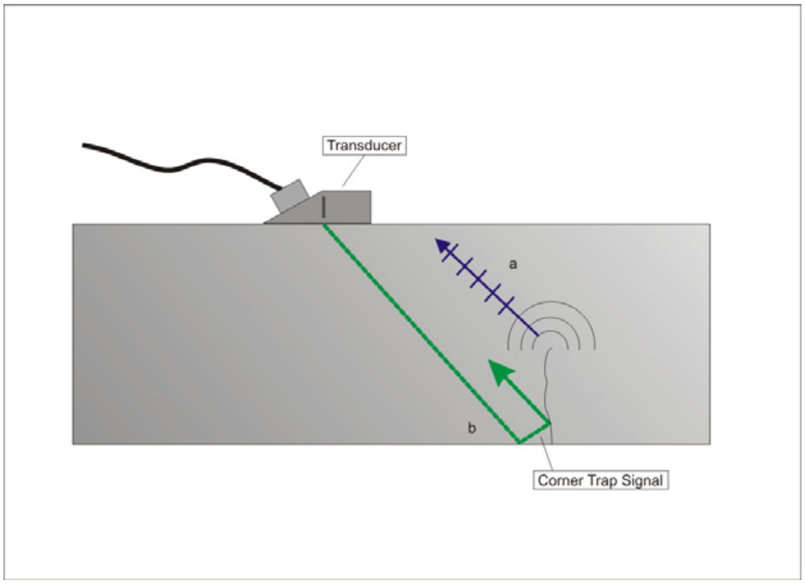
1.3 The half vee path technique is generally used for the Tip Diffraction method; however, the full vee path is applicable for qualitative sizing of deep cracks.

1.4 The two basic Tip Diffraction Techniques are:

1. Time of Flight (TOF), or, PATT (Pulse Arrival Time Technique), or AATT (Absolute Arrival Time Technique)



2. Delta Time of Flight (Δ TOF), or SPOT (Satellite Pulse Observation Sizing Technique, or RATT (Relative Arrival Time Technique).



2.0 <u>Calibration</u>

2.1 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%.

2.2 Time of Flight (TOF), PATT/AATT Technique

2.2.1 <u>As a ranging technique</u>, 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.

2.2.2 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.

2.2.3 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.

2.2.4 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.

2.3 Delta Time of Flight (Δ TOF), SPOT/RATT Technique

2.3.1 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.

2.3.2 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.

3.0 Scanning/Evaluation

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.

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.

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

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

3.6 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 <u>Calculations</u>

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 <u>Half-vee path technique</u>

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

$$d = (SPB - SPT) * \cos Ø$$

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 Ø	=	Cosine of the sound beam angle

5.0 <u>Limitations</u>

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.

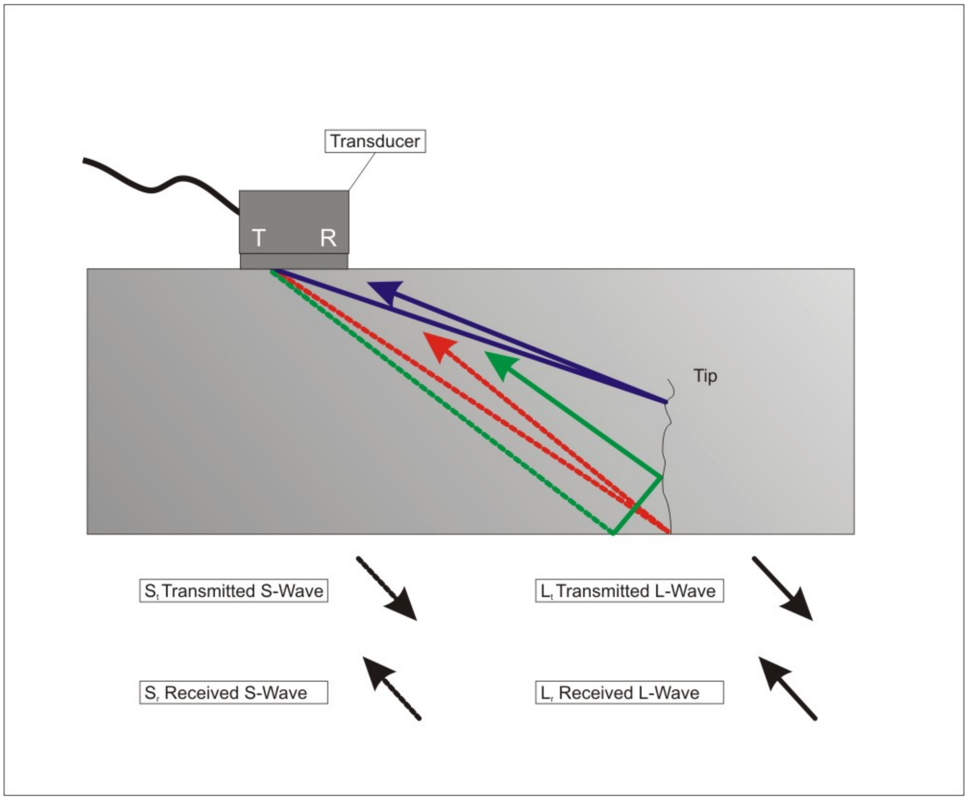
5.4 When using longitudinal waves, they shall be limited to use with the half-vee technique only.

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.

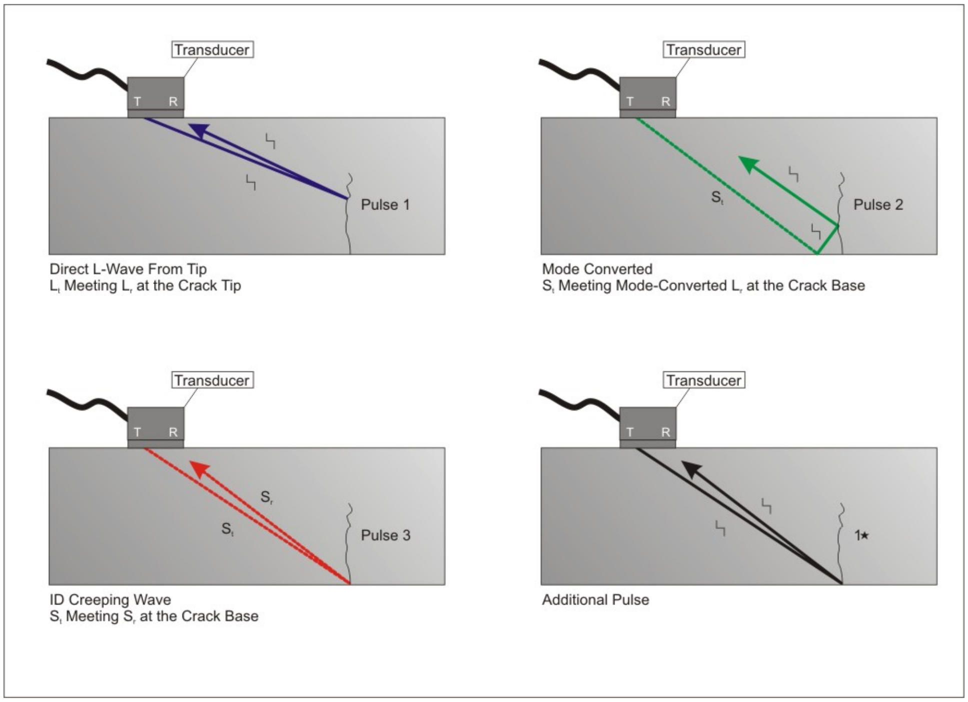
1.6 The Bi-modal Method is defined as follows. Three main signals are noted:

- 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 <u>Calibration</u>

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 <u>As a ranging technique,</u> 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.

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.

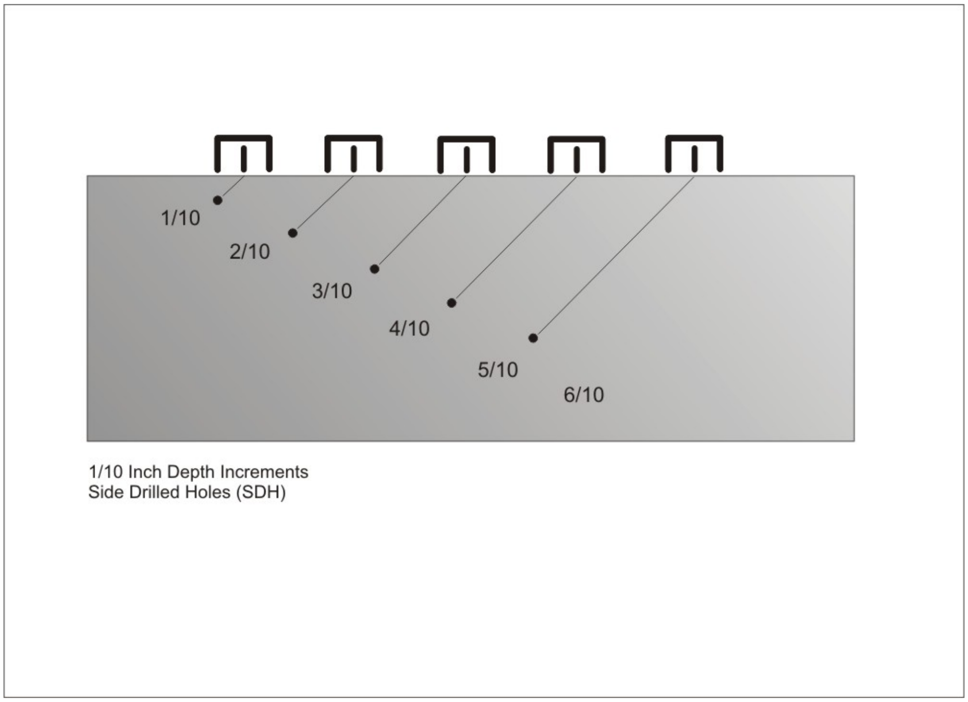
1.2 The HALT or HAST techniques are effective for sizing cracks in the outer 1/3 thickness of material, and is an effective method for determining if a crack has propagated near the OD surface of the component.

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 <u>Scanning/Evaluation</u>

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 <u>Calculations for Crack Sizing</u>

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.

Crack Height = T - RL

Where: T = the thickness of the pipe/component

RL = 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.