Recommended Practice for Ultrasonic Evaluation of Pipe Imperfections

API RECOMMENDED PRACTICE 5UE
SECOND EDITION, JUNE 2005

ADDENDUM 1, APRIL 2009

REAFFIRMED, MAY 2015

AMERICAN PETROLEUM INSTITUTE

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Upstream Segment

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Recommended Practice for Ultrasonic Evaluation of Pipe Imperfections

1 Scope

1.1 This recommended practice describes procedures which may be used to "prove-up" the depth or size of imperfections. Included in this practice are the recommended procedures for ultrasonic prove-up inspection of new pipe using the Amplitude Comparison Technique and the Amplitude-Distance Differential Technique for evaluation of 1) surface breaking imperfections in the body of pipe and 2) surface breaking and subsurface imperfections in the weld area of electric resistance, electric induction or laser welded pipe and 3) surface breaking and subsurface imperfections in the weld area of arc welded pipe. For the purpose of this document, pipe is defined as including casing, plain-end casing liners, tubing, plain-end drill pipe, line pipe, coiled line pipe, pup joints, coupling stock, and connector material.

1.2 Prove-up inspection is a method to evaluate the radial depth of imperfections detected by automated inspection equipment or other nondestructive testing (NDT) technique(s) to determine acceptance criteria compliance with the appropriate API specification.

1.3 The recommended prove-up practices established within this document are intended as a guide, and nothing in this guide should be interpreted to prohibit the agency or owner from supplementing the guide with other techniques or extending existing techniques.

1.4 This RP covers evaluation, a description of inspection methods, calibration and standardization procedures, and inspection personnel requirements for prove-up.

1.5 Appendix A of this document is provided as an overview to inform the user of the basis for the techniques outlined in this RP.

1.6 Appendix B of this document provides a procedure for determining if imperfections are surface breaking and a formula for calculating the sound path distance for a circumferential or axial scan of a curved surface and a sample look-up table.

1.7 Appendix C of this document is provided as an overview to inform the user of the specifics for the evaluation of welds with filler metal.

09 **1.8** Appendix D of this document provides a procedure for sizing planar non-surface breaking imperfections from the pipe's outside surface.

2 References

2.1 This recommended practice includes by reference, either in total or in part, the latest editions of the following API and industry standards, unless a specific edition is listed:

API

RP 5A5	*Field Inspection of New Casing, Tubing, and Plain-end Drill Pipe*
Spec 5CT	*Casing and Tubing*
Spec 5D	*Drill Pipe*
Spec 5L	*Line Pipe*
RP 5L8	*Field Inspection of New Line Pipe*
Std 5T1	*Imperfection Terminology*

ASNT[1]

SNT-TC-1A	*Personnel Qualification and Certification in Nondestructive Testing*

ASTM[2]

E 317	*Standard Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-echo Testing Systems Without the Use of Electronic Measurement Instruments*
E 1065	*Standard Guide for Evaluating Characteristics of Ultrasonic Search Units*

3 Definitions

The following terms are used frequently in the nondestructive testing of pipe:

3.1 A-scan: A method of data presentation utilizing a horizontal time-base that indicates distance or time and a vertical deflection from the base line that indicates amplitude.

3.2 active peak memory: The capability of an instrument to retain an A-scan presentation while allowing instrument controls to be functionally active.

3.3 agency: An entity contracted to inspect new pipe using the methods and criteria specified.

3.4 Amplitude Comparison Technique (ACT): An ultrasonic prove-up method comparing the reflected signals from a reference indicator of known radial depth and an imperfection.

3.5 Amplitude Distance Differential Technique (ADDT): An ultrasonic prove-up method comparing both the

[1]American Society for Nondestructive Testing, Inc., 1711 Arlington Lane, P.O. Box 28518, Columbus, Ohio 43228-0518.
[2]American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428-2959.

distance and amplitude at 50% peak amplitude levels from a reference indicator of known radial depth and an imperfection.

3.6 angle beam: An inspection method in which the angle of incidence or refraction is other than perpendicular to the surface of the test object being inspected. This includes the use of shear waves and longitudinal (compression) waves.

3.7 angle beam block: A specified type of reference standard used for the angle beam method.

3.8 angle of incidence: The included angle between the beam axis of the incident wave and a line perpendicular to the surface at the point of incidence.

3.9 angle of refraction: The included angle between the beam axis of a refracted wave and a line perpendicular to the refraction interface.

3.10 API: Abbreviation for American Petroleum Institute, headquartered in Washington, D.C.

3.11 artificial discontinuity: See reference indicator.

3.12 ASNT: Abbreviation for American Society for Nondestructive Testing, headquartered in Columbus, Ohio.

3.13 ASTM: Abbreviation for American Society for Testing and Materials, headquartered in West Conshohocken, Pennsylvania.

3.14 axial scanning: Scanning for imperfections with a transverse orientation. The transducer is aligned with the longitudinal axis of the pipe.

3.15 calibration: The comparison of an instrument with, or the adjustment to, known reference(s) often traceable to the National Institute of Standards and Technology (NIST).

3.16 certification: A written declaration stating compliance with stated criteria.

3.17 circumferential scanning: Scanning for imperfections with a longitudinal orientation. The transducer is aligned perpendicular with the longitudinal axis of the pipe.

3.18 couplant: A material (usually a liquid) used between an ultrasonic transducer and the test specimen to conduct ultrasonic energy between them.

3.19 Differential Time of Flight: ($T_2 - T_1$), time difference from the leading edge of signal envelope to the trailing edge of the signal envelope.

3.20 digital readout: Numeric display of ultrasonic data.

3.21 disposition: The action taken in conformance with the applicable API Specification with regard to an imperfection in a length of new pipe.

3.22 distance standardization: The adjustment of the A-scan display to accurately reflect known distances to specific positions on the time-base.

3.23 evaluation: The process of determining the severity of an imperfection, which leads to determining whether the pipe is acceptable or rejectable under the appropriate specification.

3.24 frequency: Number of complete cycles of a wave motion per second of time. Unit of measure is called a hertz (Hz).

3.25 FSH: Abbreviation for full screen height.

3.26 gain: The controlled adjustment of the amplified, displayed signal response in dB units.

3.27 gate: An electronic device for monitoring signals in a selected segment of the trace on an A-scan display.

3.28 gate start: The position along the A-scan display where the gate begins. The displayed value may be expressed in inches or microseconds.

3.29 gate width: The length of the gate along the A-scan display as measured from the gate start. The displayed value may be expressed in inches or microseconds.

3.30 IIW block (International Institute of Welding): See angle beam block.

3.31 imperfection: A discontinuity or irregularity in the product. For exact definitions and illustrations of specific imperfections, see API Std 5T1.

3.32 indication: A response from nondestructive inspection that requires interpretation in order to determine its significance.

3.33 instrument delay control: An electronic circuit used to adjust the start of the time-base. May also be referred to as the zero control.

3.34 instrument material velocity control: An electronic circuit used to adjust the length of the time-base relative to the velocity of the material being inspected. May also be referred to as the range or calibrate control.

3.35 inspection: The process of examining pipe for possible defects or for deviation from established standards.

3.36 inspector: A person who is qualified and responsible for one or more of the inspections or tests specified in this document.

3.37 *k* **factor:** A derived factor for calculating depth when using the Amplitude Distance Differential Technique (ADDT).

3.38 longitudinal imperfection: An imperfection that has its principal direction or dimension approximately parallel to the longitudinal pipe axis.

3.39 marking: Assorted marks on tubular products, which includes inspection markings made with paint sticks and stencils, and ball-point paint tubes.

3.40 nondestructive testing (NDT): Inspection to detect defects or imperfections in materials, using techniques that do not damage or destroy the items being tested.

3.41 notch: See reference indicator.

3.42 oblique imperfection: An imperfection at an angle other than longitudinal or transverse to the axis of the pipe.

3.43 operator: The person present throughout the inspection or testing process who is responsible for the ultrasonic inspection unit, operates the controls, and observes the readout to detect imperfections.

3.44 owner: The entity who has ownership of the pipe at the time inspection is contracted, specifies and authorizes the type of inspection or testing to be conducted. The owner may be the purchaser.

3.45 parallax: Apparent displacement, or difference in the apparent position, of an object, caused by the actual change of the point of observation.

3.46 peak memory mode: An instrument capability that captures and stores the A-scan display.

3.47 pipe: Includes oil field casing, plain-end casing liners, tubing, plain-end drill pipe, line pipe, coiled line pipe, pup joints, coupling stock, and connector material.

3.48 plain-end: Pipe end without threads or tool joint.

3.49 planar: This term refers to an imperfection lying in one geometric plane that is normally parallel to, and within, the outer and inner surfaces.

3.50 prime pipe: Pipe meeting all of the specified inspection and testing requirements.

3.51 prove-up: The ultrasonic processes described within this RP for measuring and evaluating imperfections.

3.52 pulse: A short wave train of mechanical vibrations.

3.53 pulse-echo method: An ultrasonic test method that both generates ultrasonic pulses and receives the return echo.

3.54 quality program: A documented system to ensure quality.

3.55 recommended practice (RP): A standard to facilitate the broad availability of proven sound engineering and operating practices.

3.56 reference indicator: Real or artificial discontinuities in a reference standard that provide reproducible sensitivity levels for inspection equipment. Artificial indicators may be holes, notches, grooves, or slots.

3.57 reference standard: A pipe, or pipe section, containing one or more reference indicators used as a base for comparison or for inspection equipment standardization.

3.58 reflection: The return of sound waves from surfaces.

3.59 sensitivity: The size of the smallest imperfection detectable by a nondestructive test method with an acceptable signal-to-noise level.

3.60 shall: Used to indicate that a provision is mandatory.

3.61 should: Used to indicate that a provision is not mandatory but recommended as good practice.

3.62 signal: An electronic response of NDT equipment to an imperfection or defect.

3.63 signal envelope: The curve that encompasses successive return signals along the time-base on an A-scan display as an imperfection is scanned.

3.64 signal-to-noise ratio: The ratio of the signal from a significant imperfection or defect to signals generated from surface noise.

3.65 6 dB drop technique: An ultrasonic technique traditionally used as a means for the dimensional sizing of laminar imperfections in plate and for measuring the length of radial imperfections.

3.66 skip distance: In angle beam examination, the distance along the test surface, from sound entry point to the point at which the sound returns to the same surface. It can be considered the top surface distance of a complete vee path of sound in the test material.

3.67 skip position: The location on the A-scan display, along the time-base, relative to the skip distance for a given reflector.

3.68 sound path distance: The distance ultrasound travels from the entry point in the material to a given reflector.

3.69 standardization: The adjustment of instruments, to a known reference value.

3.70 standardization check: A check of the standardization adjustments to ensure that they remain correct.

3.71 time-base: The horizontal line on the A-scan display that represents time or distance.

3.72 transducer: Electroacoustical device for converting electrical energy into acoustical energy and vice versa.

3.73 transverse imperfection: An imperfection that has its principal direction or dimension approximately perpendicular to the longitudinal pipe axis.

3.74 ultrasonic beam: A vibrating pulse wave train traveling through the material.

3.75 wedge: A device used to direct ultrasonic energy into a test object at an acute angle.

3.76 weld with filler metal: A weld produced by submerged-arc welding, gas metal arc welding, or a combination thereof.

3.77 weld without filler metal: A weld produced by continuous welding, electric welding or laser welding.

4 Application

4.1 BASIS FOR INSPECTION

The basis for prove-up inspection is the applicable API Specification, or a supplemental specification or contract. The specifications or contract shall be the basis to determine the type and location of imperfection which must be detected by inspection, and the acceptance/rejection criteria for the imperfection.

4.2 APPLICABILITY OF INSPECTION

The techniques contained in this RP are applicable to pipe regardless of size and type.

4.3 VARIABILITY OF RESULTS

Every inspection and measurement process is characterized by an inherent variability of results. The results of the nondestructive inspections included in this RP are dependent on the inherent variability of the techniques used and in part are attributable to the following factors:

4.3.1 Applicable API specifications permit options in the selection of the reference indicator.

4.3.2 Each manufacturer of nondestructive inspection equipment uses different mechanical and electronic designs.

4.3.3 Transducer frequency, diameter, focus, and angle beam wedge curvature.

4.3.4 Temperature.

4.3.5 Couplant.

4.3.6 Skill of inspector.

4.3.7 Surface condition variance between the reference standard and material to be inspected.

4.3.8 Configuration of the weld.

5 Certification of Nondestructive Testing Personnel

As a minimum, ASNT RP No. SNT-TC-1A (or equivalent) shall be the basis of certification for ultrasonic testing personnel. Ultrasonic inspections shall be conducted by Level I, II, or III certified inspectors. Inspection personnel shall be trained and skilled in the techniques covered in this document and familiar with the applicable API pipe specifications.

6 Prove-up Technique Descriptions

6.1 AMPLITUDE COMPARISON TECHNIQUE (ACT)

The ACT is based on the premise that the amount of sound reflected from a material imperfection is proportional to the surface area of the imperfection. The peak signal amplitude from an imperfection is compared to that of a reference indicator of known size or depth.

Note: Empirical data has proven, when applying the ACT to the sizing of radial imperfections in tubular products, accuracy may vary due to several factors, which may include the material entry surface condition and the shape, orientation, and surface roughness of the imperfection.

6.2 Amplitude Distance Differential Technique (ADDT)

The ADDT is based on the premise that the radial depth of an imperfection affects both the amplitude of the received echo signal and the differential time of flight of the transmitted ultrasonic wave as it passes over the imperfection.

ADDT relates to the loss of signal amplitude, relative to time (distance), as the ultrasonic beam is moved over the imperfection. The amount of time (distance) to incur a 50% drop in amplitude of the returned signal is related to the depth of the imperfection. A discussion of the ADDT method is included in A.1.

7 General Inspection Criteria

7.1 EQUIPMENT

7.1.1 Ultrasonic prove-up instrument.

7.1.2 Transducer and angle beam wedge with the appropriate angle of incidence depending on the pipe diameter, wall thickness, and the type of imperfection to be evaluated.

7.1.3 Reference standard.

7.2 INSTRUMENT AND TRANSDUCER EQUIPMENT CALIBRATION/CERTIFICATION

The instrument and transducer used to evaluate imperfections shall be verified in accordance with ASTM E 317 (instrument) and ASTM E 1065 (transducer) under the provisions of the manufacturer's or agency's documented quality program.

7.3 REFERENCE STANDARDS

A reference standard of the same specified diameter and thickness as the material being inspected shall be used. The material shall have ultrasonic velocity and attenuation properties that are similar to those of the pipe being inspected and be free of imperfections.

The surface condition of the reference standard and the area being evaluated shall be similar. This shall be achieved by taking the reference standard and the area being evaluated from the same lot or by conditioning (e.g., buffing) them to achieve a similar surface condition. The reference standard can be made from any convenient length or section of pipe.

7.3.1 Reference Indicators

All reference indicators shall be placed in an area of pipe where the wall thickness is within ± 0.005 in. of the specified wall thickness of the pipe to be inspected where practicable, or within ± 0.005 in. of the typical wall thickness of the pipe to be inspected.

a. Notch dimensions and tolerances.

1. The minimum length shall be two times the specified transducer width (or diameter).
2. The depth shall be as per the applicable specification with a tolerance of ± 10% of the specified notch depth or ± 0.002 in., whichever is greater. Notch depth shall be verified at a minimum of four points equally spaced where the notch is at full depth. All four points shall be within the above tolerances. The reported notch depth shall be the average of the four values.
3. The notch width shall not exceed 0.040 in.
4. The orientation of the notch shall be within 2 degrees of the specified notch orientation relative to the pipe axis.
5. The radial orientation shall be such that the ultrasonic variance is no more than 1 dB from opposing sides at the center of the notch's length. This is determined by the formula:

$$dB = 20 \log(A_1/A_2)$$

where

A_1 = amplitude from side 1,

A_2 = amplitude from side 2.

b. Through drilled hole dimension and tolerances.

1. The diameter shall be as per the specification and shall be based on the drill bit size in in.
2. The hole shall be drilled radially through the wall of the reference standard.
3. The radial orientation shall be such that the ultrasonic variance is no more than 1 dB from opposing sides of the drilled hole. This is determined by the formula:

$$dB = 20 \log(A_1/A_2)$$

where

A_1 = amplitude from side 1,

A_2 = amplitude from side 2.

7.3.2 Verification of Reference Indicators

Documentation of the reference standard shall contain data that verifies the conditions in 7.3.1 have been satisfied. Information recorded for each reference standard should include manufacturer, diameter, specified and actual wall thickness, dimensions of artificial reference indicators, and serial number.

7.3.3 Identification

All permanent reference standards shall be identified. Such identity shall be used to trace recorded information with regard to reference indicators.

7.4 TRANSDUCER, ANGLE BEAM WEDGE AND COUPLANT CRITERIA

7.4.1 The transducer frequency range used shall be based on wall thickness as defined below:

a. A 2.0 – 5.0 MHz frequency transducer for specified wall thicknesses 0.250 in. or greater.
b. A 3.5 MHz or higher frequency transducer for specified wall thicknesses less than 0.250 in.

7.4.2 Transducer width (or diameter) shall be $^1/_4$ to $^1/_2$ in.

7.4.3 Angle beam wedges shall be used to generate shear waves in the material to be inspected.

a. Angle beam wedges shall be either machine contoured or flat depending on the orientation of scanning and the pipe diameter. Angle beam wedges shall be machine contoured on pipe diameters less than $9^5/_8$ in. for longitudinal imperfections and on pipe diameters less than 5 in. for transverse imperfections. Flat angle beam wedges may be used for oblique imperfections.
b. When contoured, the sound exit point shall be centered on the radius, see Figure 7.4.3.b.

Contoured angle beam wedges must have their radius machined based on the specified maximum pipe diameter. The wedge radius must be centered based on the beam index point of the wedge relative to the perpendicular axis of the pipe. The radius of the wedge equals $D_{max}/2$.

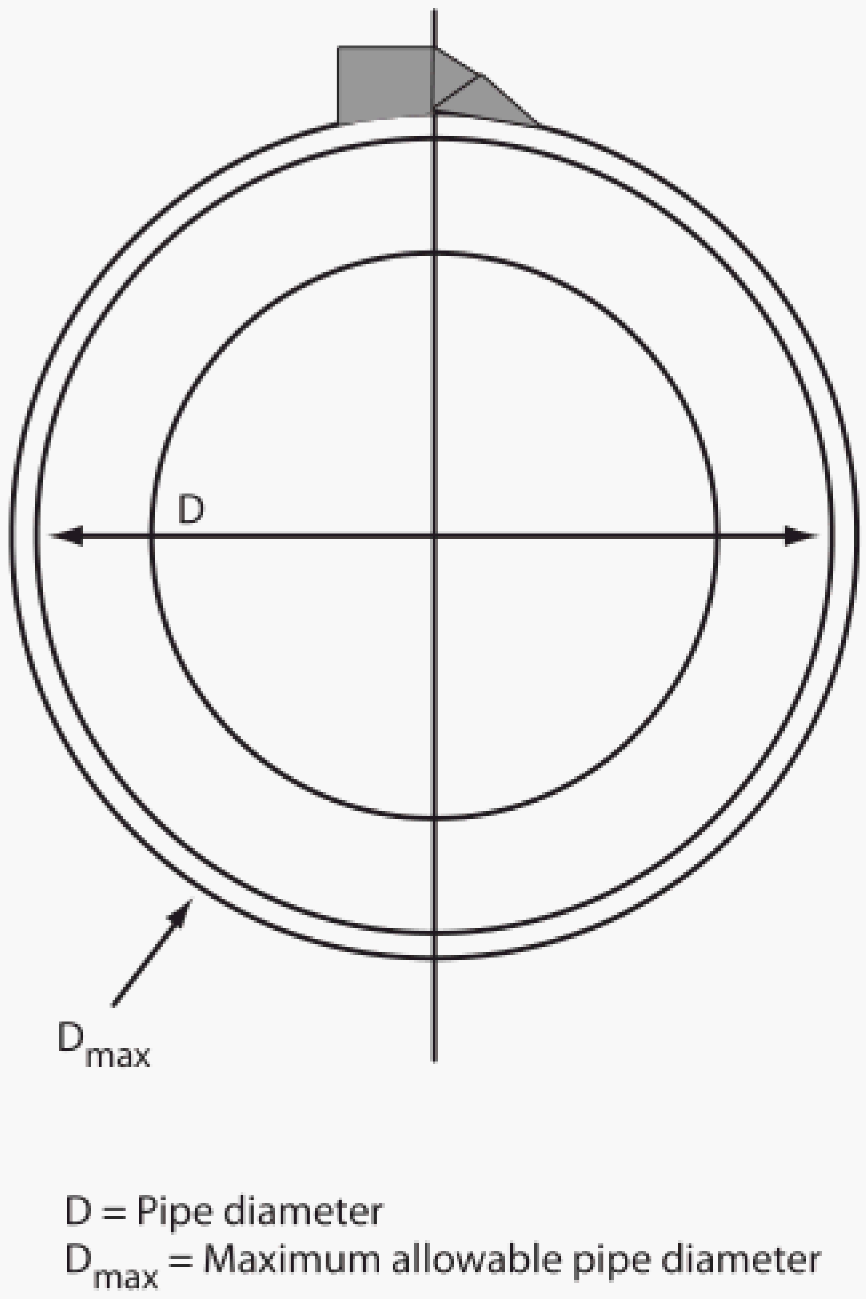


Figure 7.4.3.b

7.4.4 Suitable couplant shall be used to eliminate air between the transducer and the angle beam wedge, and between the wedge and the pipe surface. The same type of couplant that is used for standardization shall be used during imperfection evaluation.

7.5 INSTRUMENT CRITERIA

7.5.1 General

a. The ultrasonic instrumentation shall be the pulse-echo type with an A-scan display capable of operating at frequencies specified in 7.4.1.
b. Systems operated from line or external power sources should have voltage and frequency regulated to within manufacturer's specified requirements.

7.5.2 Optional

For the ADDT, the instrument should be of the digital type featuring active peak memory capabilities.

8 Standardization

8.1 GENERAL

8.1.1 When applicable, to eliminate parallax error during standardization and inspection, the A-scan display shall be viewed perpendicularly at all times.

8.1.2 The maximum amplitude shall be obtained from both sides at the center of the reference indicator in the reference standard with the higher amplitude being used as reference.

8.1.3 Non-linear reject control should be in the off position.

8.1.4 Selection of the reference indicator should be based upon the following:

a. The specified notch should be used for standardization if the imperfection length is one half the specified transducer width (or diameter) or greater.
b. The specified through drilled hole should be used for standardization if the imperfection length is less than one half the specified transducer width (or diameter) or in the case of subsurface weld line imperfections. This is critical when a surface breaking imperfection has a shallow entry angle relative to the pipe surface.

8.2 SHEAR WAVE STANDARDIZATION

8.2.1 Amplitude Comparison Technique (ACT)

a. Verify that the angle of refraction is appropriate for the product to be evaluated using an angle beam block, IIW block, or other capable method.
b. Angle beam wedges with noticeable uneven wear at the bottom surface shall not be used.
c. The instrument horizontal time-base or the digital readout shall be standardized for metal travel distance using a typical angle beam distance standardization block or other capable method. In order to enhance the accuracy of the horizontal distance measurement, the smallest range of the A-scan display should be used, but shall encompass the area of evaluation.
d. Select the reference standard with the proper reference indicators as per 7.3.
e. When distance standardization is performed on the flat surface of a reference block and evaluation is performed using a contoured angle beam wedge, the zero or delay control must be adjusted to compensate for the differences in the couplant/wedge transit time. This adjustment is made using the known sound path distance to the internal reference indicator at the $^1/_2$ skip position. The sound path distance may be determined using the formulas in B.3.
f. Locate the ID reference indicator and peak the signal at the $^1/_2$ skip position (A_{max}).

For instances where the interface signal and the reference signal are not separate, use the $1^1/_2$ skip position and perform in accordance with item e above, using the $1^1/_2$ skip distance.

Adjust the gain so that the signal is at 80% of full screen height (FSH) and note the reference gain value and location of the signal along the time-base.

g. When applicable, locate the OD reference indicator and peak the signal at the 1 skip position (A_{max}).

Adjust the gain so that the signal is at 80% of FSH and note the reference gain value and location of the signal along the time-base.

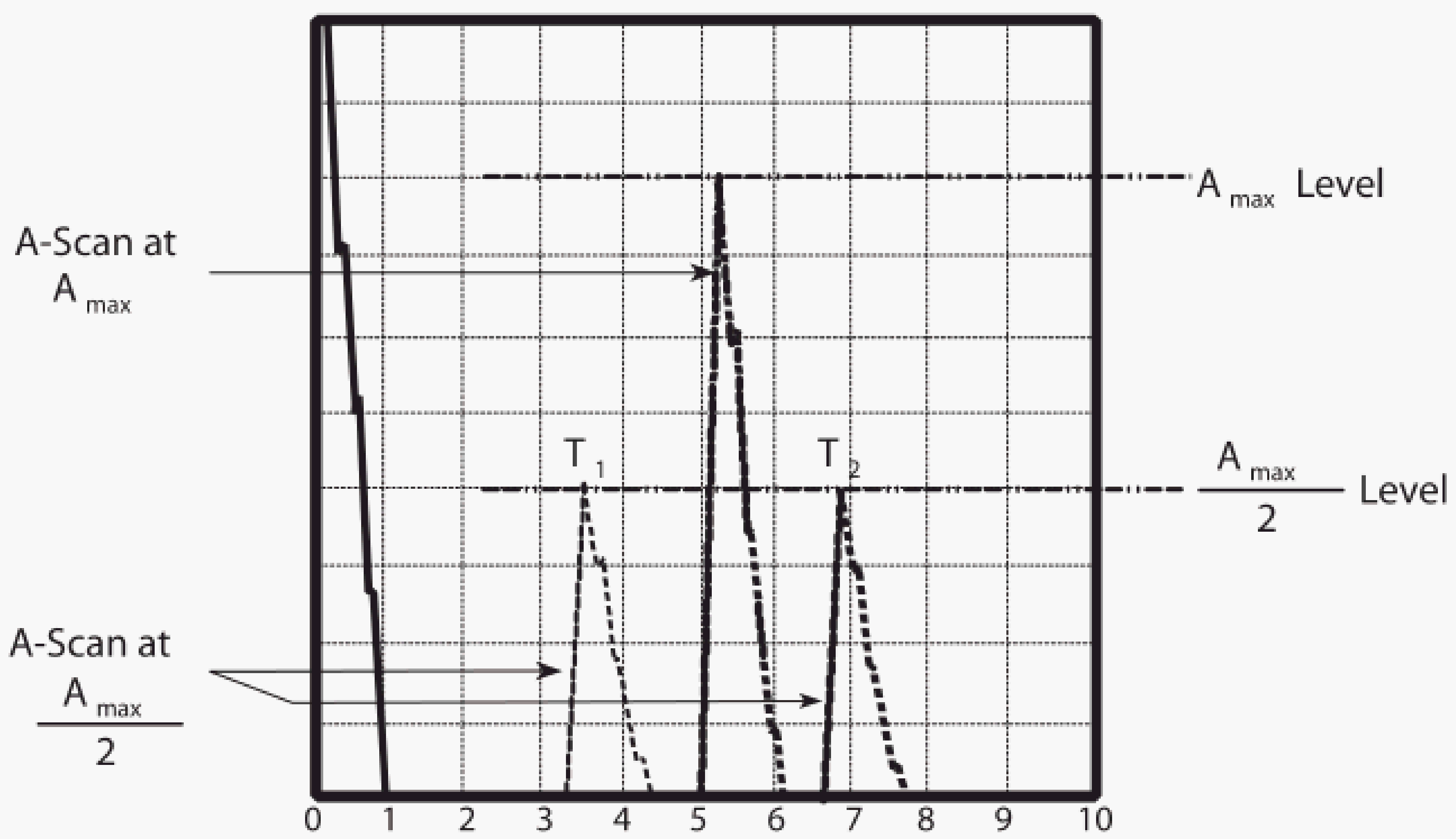


Figure 8.2.2.a

8.2.2 Amplitude Distance Differential Technique (ADDT)

Note: 8.2.1 must be completed prior to standardizing in accordance with 8.2.2.

a. From the A_{max} position, move the transducer forward until the signal drops to $^1/_2$ of A_{max}, and note the distance to this signal (T_1). Move the transducer back through the signal peak until the amplitude again drops to $^1/_2$ of A_{max}, and note the distance to this signal (T_2) (see Figure 8.2.2.a).

b. The calculated imperfection depth is the product of A_{max}, ($T_2 - T_1$) and the k factor.

Calculate the k factor using the formula:

$$k = d_r / A_{max}(T_2 - T_1)$$

where

k = a derived factor for calculating depth,

d_r = depth of reference indicator,

A_{max} = peak signal amplitude,

T_1 = time or distance to signal leading peak at $^1/_2$ amplitude,

T_2 = time or distance to signal trailing peak at $^1/_2$ amplitude.

c. To complete standardization, obtain values for A_{max}, (T_1) and (T_2) by repeating 8.2.2.a. Calculate the depth (d_c) using the k factor derived in 8.2.2.b with the following formula:

$$d_c = A_{max}(T_2 - T_1)k$$

Standardization is acceptable when the calculated depth from at least two consecutive readings are within ± 0.002 in. of the actual notch depth.

8.3 STANDARDIZATION CHECKS

All pipe inspected between an unacceptable check and the most recent acceptable check shall be reinspected or rejected. Standardization checks shall be performed as follows:

8.3.1 At the beginning of each inspection shift.

8.3.2 At least once every 25 areas measured or inspected in a continuous operation.

8.3.3 After any power interruption or change in power supply (battery to charger).

8.3.4 Whenever there is a change of operator (inspector).

8.3.5 Prior to equipment shutdown during a job.

8.3.6 Prior to resuming operation after an equipment repair.

8.3.7 Whenever the transducer, cable, angle beam wedge or type of couplant is changed.

9 Inspection Procedures

9.1 GENERAL

If the imperfection is not accessible for mechanical measurement, then ultrasonic methods shall be used.

9.2 PROCEDURE

9.2.1 General

a. Standardize the shear wave unit as explained in Section 8.

b. Clean the surface of the pipe and apply a uniform amount of couplant to the area of the pipe to be inspected.

c. When scanning to locate imperfections, add a minimum of four dB to the reference gain.

d. The scanning direction should be perpendicular to the suspected imperfection orientation. The scanning speed should not exceed 5 in. per second. There should be an overlap between scans.

9.2.2 Surface or Subsurface Determination

a. When an imperfection is located, determine if the imperfection is surface breaking or subsurface using an acceptable technique.

b. Techniques for making this determination should be based on the procedure located in Appendix B, 18.6.3 in API RP 5A5, 16.5.2.1 in API RP 5L8 or other accepted methods.

9.2.3 Evaluation Using Compression Wave Ultrasonics

a. If the imperfection is determined to be surface breaking in 9.2.2, the imperfection may be classified using the remaining wall value in accordance with 18.6.1.f in API RP 5A5 for API Spec 5CT and Spec 5D product, as applicable. If the remaining wall value is less than the minimum wall thickness as defined in the applicable specification, the imperfection shall be classified as a defect.

b. For surface breaking linear imperfections, the radial depth of the imperfection may be used to classify the imperfection by subtracting the remaining wall thickness (determined in 9.2.3.a) from the average wall thickness surrounding the imperfection. If the radial depth exceeds the depth tolerance as defined in the applicable specification, the imperfection shall be classified as a defect.

9.2.4 Imperfection Length Determination

The 6 dB drop technique should be used for locating the ends of the imperfection, when specified. The length of the imperfection is determined by measuring the distance between the ends per Appendix A (A.1).

9.2.5 Evaluation Using ACT

a. For internal imperfections determined to be surface breaking in accordance with 9.2.2, the ACT may be applied.

b. When an imperfection is located, that area shall be scanned rotating the transducer around the suspect area until peak amplitude is achieved for evaluation.

c. Change the direction of the sound beam and observe the change in the displayed echo. (The echo from a smooth imperfecton is narrower than the echo from a rough imperfection. There is a greater loss of amplitude when the sound beam is moved around a linear imperfection than for a rounded imperfection.)

d. Move the transducer back and forth, causing the beam to move up and down the imperfection depth. Watch the horizontal movement of the echoes left to right and vice versa along the A-scan display. (Greater movement of the echo indicates greater depth into the wall, assuming the depth in the radial direction. Horizontal movement that exceeds that of the reference indicator, even at low amplitude, indicates a imperfection that should be evaluated using ADDT or other capable method.)

e. Return to position of peak signal amplitude.

f. Adjust the gain so that the peak signal amplitude is at 80% of FSH and note the change in dB from the reference gain value. A gain value less than the reference gain value indicates an amplitude greater than reference amplitude.

Note: The ADDT may be preferred in borderline situations. An example of a borderline situation is a shear wave indication with ACT results within 3 dB of the reference gain value. This is particularly true in the case of imperfections with irregular shapes or orientations other than perpendicular to the pipe surface.

9.2.6 Evaluation Using ADDT

a. The assumption is made that the axis of the beam is aligned with the edge of the imperfection when the amplitude of the imperfection reflection is half of its peak amplitude. At this point, half of the ultrasonic energy is being reflected back to transducer, while the other half continues through the material.

b. Identify the edges of the imperfection by manipulating the transducer back and forth across the imperfection.

c. The depth of imperfection is calculated using the formula:

$$d_i = k(T_2 - T_1)\,A$$

where

d_i = imperfection depth,

k = a derived factor for calculating depth,

$T_2 - T_1$ = differential time from leading edge of walk envelope to trailing edge of walk envelope,

A = amplitude.

9.2.7 Evaluating welds with filler metal

See Appendix C for guidelines to evaluate welds with filler metal.

10 Acceptance Criteria and Disposition

The applicable API specification, supplemental specification, or contract shall constitute the basis for acceptance and disposition of the pipe inspected in accordance with this RP.

11 Records

11.1 Records shall be maintained that include at least the following:

11.1.1 Pipe identification.

11.1.2 Prove-up technique as identified in this RP.

11.1.3 Prove-up reference standard dimensions and traceability.

11.1.4 Prove-up results.

11.1.5 Pipe disposition.

APPENDIX A

A.1 Amplitude Distance Differential Technique

The ADDT employs a combination of amplitude comparison and 6 dB drop techniques to determine the radial depth of an imperfection. The technique is based on the premise that the radial depth of a imperfection affects both the amplitude of the received echo signal and the differential time of flight of the transmitted ultrasonic wave as it passes over the imperfection.

The 6 dB drop technique is traditionally used as a means for the dimensional sizing of laminar imperfections in plate and for measuring the length of radial imperfections. When sizing a lamination (Figure A.1), the maximum amplitude is noted when the transducer is in position A. The transducer is then advanced until the peak signal amplitude decreases by 50%, position B, where the center of the transducer is positioned directly over the edge of the imperfection. The surface of the material is marked at the center of the transducer and the process is repeated in the opposite direction, and in the other dimension, thus mapping the size and location of the imperfection. This is a relatively simple but accurate technique for sizing imperfections. This technique is only accurate, however, when the imperfection dimension being measured is greater than the effective width of the ultrasonic beam.

When applying ADDT, a derived factor for calculating depth known as the *k* factor must be applied to compensate for combined test variables including, but not limited to, beam angle, effective beam width, pipe diameter and wall thickness, and imperfection position.

The ADDT can be performed using any basic ultrasonic imperfection detector, but is simpler, more accurate and much less time consuming when using a digital instrument featuring active peak memory capability.

Standardization must be performed using a reference indicator such as a notch of known depth or a through drilled hole. When using a notch, the actual notch depth is used as the basis for standardization, while the material wall thickness is the basis for standardization when using a through drilled hole. The following paragraphs explain typical standardization and imperfection measurement processes for both ultrasonic instruments, with and without active peak memory capability.

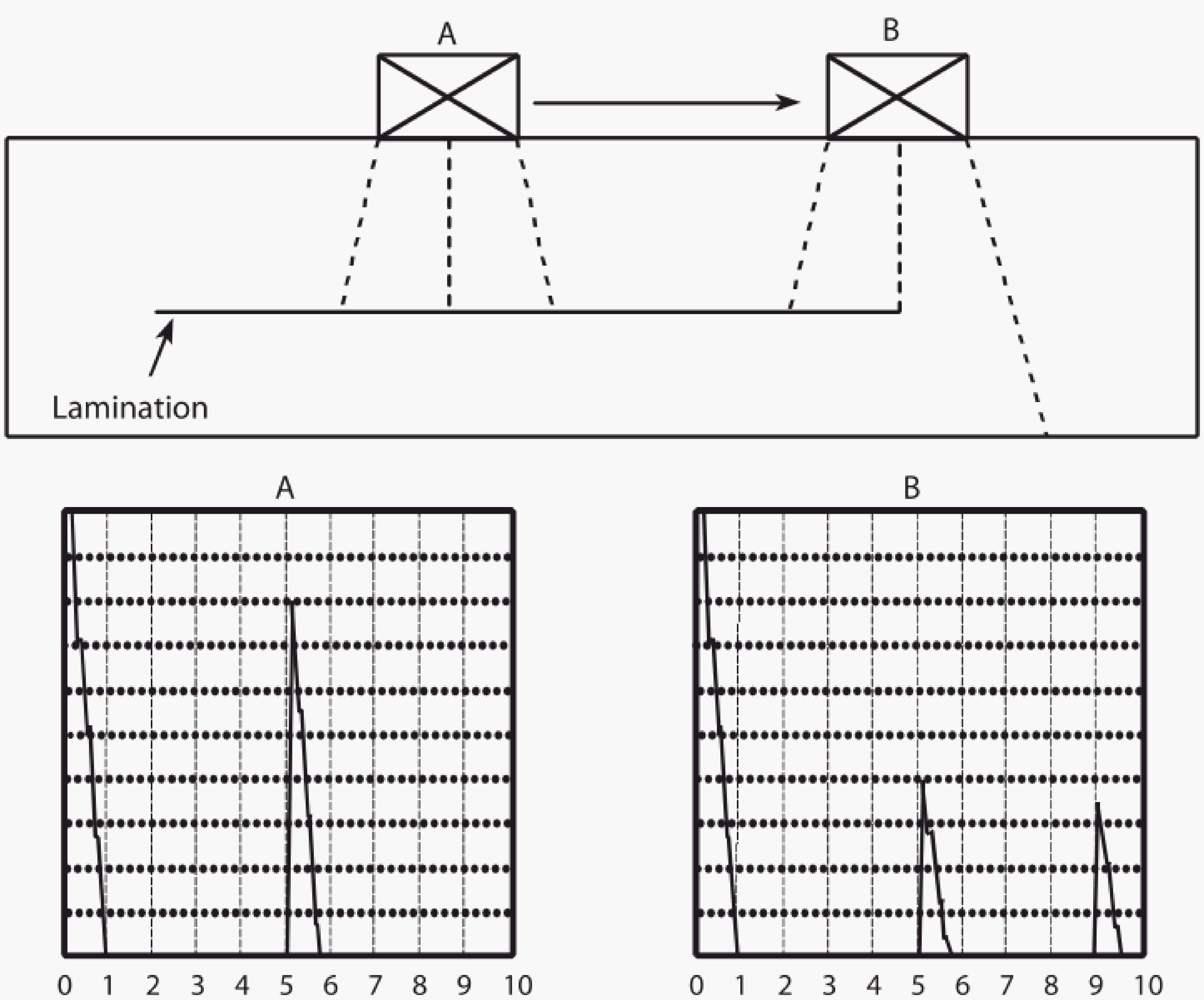


Figure A.1

A.2 Ultrasonic Instruments without Active Peak Memory Capability

The instrument horizontal time-base or digital readout must first be standardized for metal travel distance using an Angle Beam block, IIW block or other capable method. To maximize resolution, the range of the A-scan display should be minimal, but sufficient to encompass the complete signal envelope.

When a contoured angle beam wedge is used during standardization on the (curved) reference standard an adjustment to the zero or delay control must be made while the angle beam wedge is on the pipe surface to compensate for the difference in couplant thickness.

As shown in Figure A.2.a, with the reference signal at peak amplitude, the gain is adjusted to achieve 80% FSH (A_{max} = 0.80). The transducer is then moved forward until the signal drops to $^1/2$ of A_{max}, and the distance to this signal (T_1) is noted. The transducer is then moved back through the signal peak until the amplitude again drops to $^1/2$ of A_{max}, and the distance to this signal (T_2) is noted. As shown in Figure A.2.b, when using a through drilled hole or wall thickness end, the same procedure is used for the ID reflector to record T_1 at $^1/2$ of A_{max}. T_2 is recorded by scanning the OD reflector with the same gain and using $^1/2$ A_{max} of the ID envelope as the reference level. The calculated imperfection depth is the product of A_{max}, (T_2 - T_1) and the k factor. The k factor is derived using the formula:

$$k = d_r / A_{max}(T_2 - T_1)$$

where

k = k factor, a derived factor for calculating depth,

d_r = depth of reference indicator,

A_{max} = peak signal amplitude,

T_1 = time or distance to signal leading peak at $^1/2$ amplitude,

T_2 = time or distance to signal trailing peak at $^1/2$ amplitude.

The establishment of the reference gain value and the k factor constitutes standardization of the instrument to the material being inspected and the specific transducer being utilized. The gain value used to establish standardization must remain constant during imperfection depth measurement.

When measuring the radial depth of an imperfection, the A_{max}, T_1 and T_2 are determined by maximizing the imperfection signal and manipulating the transducer forward and back in the same manner as was used during standardization.

The depth of an imperfection is calculated using the formula:

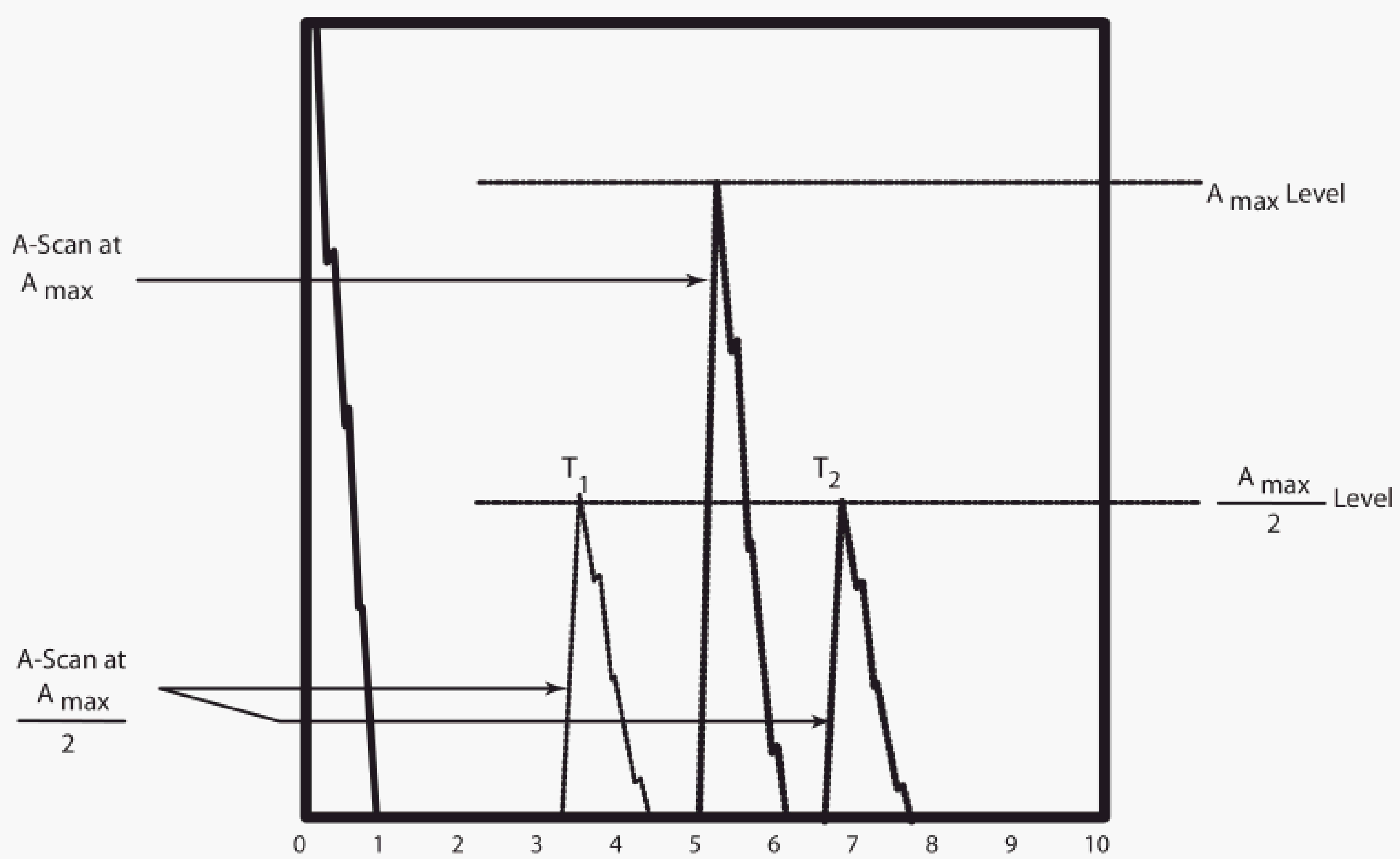


Figure A.2.a

$$d_i = A_{max}(T_2 - T_1)k$$

where

d_i = imperfection depth,

A_{max} = peak signal amplitude,

T_1 = time or distance to signal leading peak at $^1/_2$ amplitude,

T_2 = time or distance to signal trailing peak at $^1/_2$ amplitude,

k = k factor, a derived factor for calculating depth.

A.2.1 Standardization Example

Determine the k factor where:

d_r = 0.032 in.,

A_{max} = 80% FSH,

T_1 = 0.675 in.,

T_2 = 0.740 in.

k = 0.032 / 0.80 (0.740 – 0.675)

k = 0.032 / 0.80 × 0.065

k = 0.032 / 0.052

k = 0.615 or 0.62

A.2.2 Imperfection Measurement Example

A_{max} = 84% FSH

T_1 = 0.588"

T_2 = 0.655"

k = 0.62

d_i = 0.84(0.655 – 0.588)0.62

d_i = 0.84 × 0.067 × 0.62

d_i = 0.056 × 0.62

d_i = 0.035

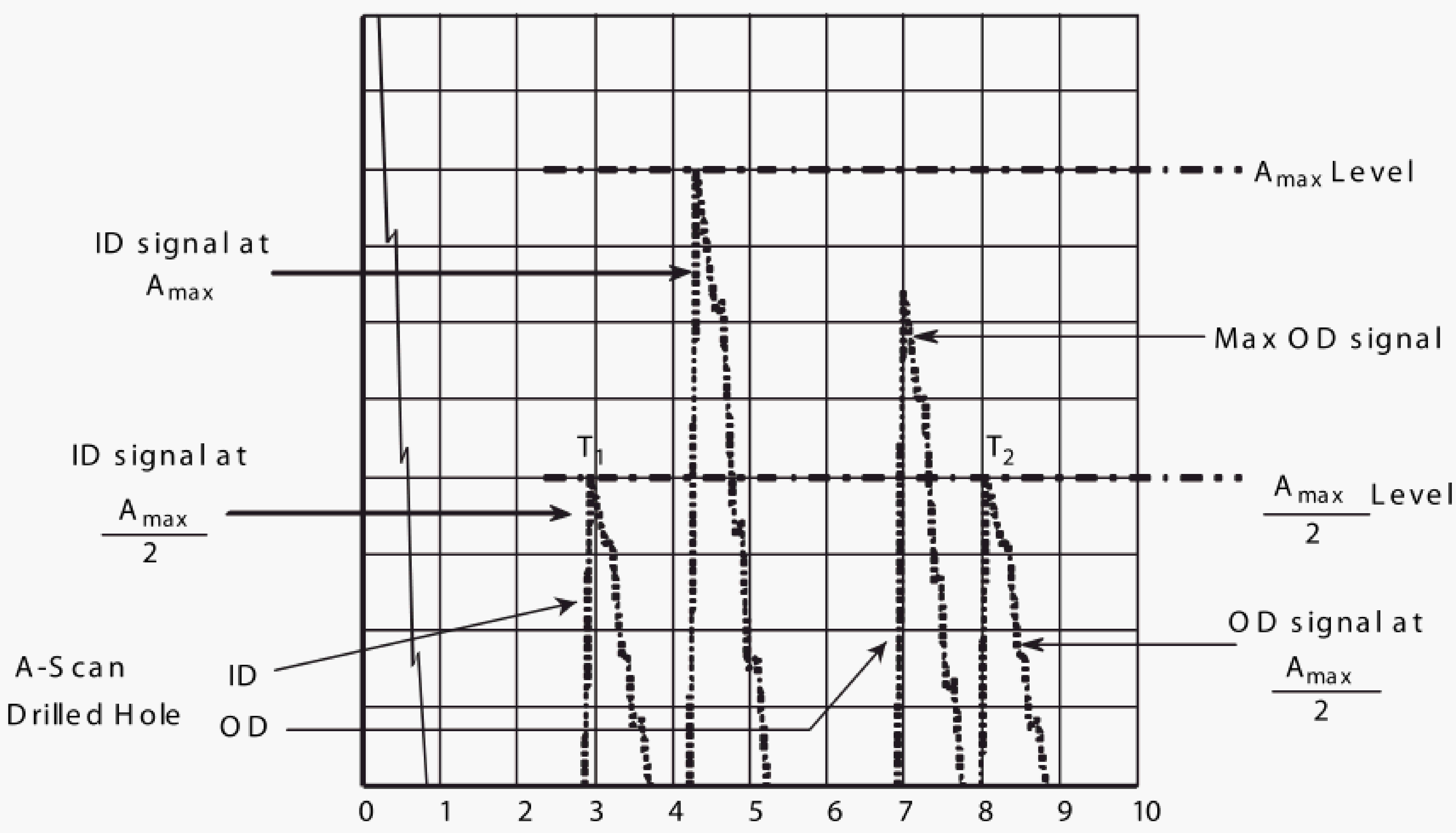


Figure A.2.b

A.3 Ultrasonic Instruments with Active Peak Memory Capability

When using digital ultrasonic instrumentation with active peak memory capability, it is not necessary to calculate the k factor. The gate is used to measure $T_2 - T_1$ by plotting the signal envelope of the imperfection while in the peak memory mode and adjusting the gate such that it encompasses the displayed signal envelope at 50% of A_{max}. When applied as such, the gate width value becomes $(T_2 - T_1)$. This value can be manipulated by adjusting the instrument material velocity control (the resultant value may not be the actual velocity of the material being inspected). It should be noted that most digital ultrasonic instruments have a minimum velocity value of 0.025 in. per microsecond or more, which in many cases is not sufficiently low. For this reason, it may be necessary to use $^1/2$ or some other fraction of A_{max} when formulating the equations.

The signal envelope of the A-Scan (Figure A.3.a) is captured by scanning across an imperfection as shown in Figure A.3.b with the instrument peak memory mode enabled.

Standardization is performed by scanning over the reference reflector while in the instrument peak memory mode, adjusting the gate level to 50% of A_{max}, and adjusting the gate start and width to span the width of the signal envelope as shown in Figure A.3.c. As shown in Figure A.3.d, when standardizing with a through drilled hole, the signal envelope will encompass both the ID and OD signals as the transducer is scanned over the hole (Figure A.3.e). Record T_1 at $^1/2$ of A_{max} of the ID reflector and T_2 from the OD reflector. The following equation is then used to calculate the gate width value required for standardization:

$$GW = d_r / (A_{max} / 2)$$

where

GW = gate width,

d_r = depth of reference indicator,

A_{max} = peak signal amplitude.

The instrument material velocity control is then adjusted until the appropriate gate width value is achieved. The establishment of the reference gain value and the instrument material velocity control value, both of which are constants, constitutes standardization of the instrument to the material being inspected and the specific transducer being utilized. The gain value used to establish standardization must remain constant during imperfection depth measurement.

Radial depth measurement is performed by plotting the signal envelope and adjusting the gate as illustrated in Figure A.3.c. The radial depth is calculated using the equation:

$$d_i = (A_{max} / 2)GW$$

where

d_i = imperfection depth,

A_{max} = peak signal amplitude,

GW = gate width.

A.3.1 Standardization Example

Determine gate width value:

where

d_r = 0.028 in.,

A_{max} = 830% FSH,

$A_{max}/2$ = 40% FSH,

GW = 0.028 / (0.80 / 2),

GW = 0.028 / 0.40,

GW = 0.070.

A.3.2 Imperfection Measurement Example (Figure A.3.2)

A_{max} = 88% FSH,

$A_{max}/2$ = 44% FSH,

GW = 0.073 in.

$$d_i = (0.88 / 2) \times 0.073$$
$$d_i = 0.44 \times 0.073$$
$$d_i = 0.032$$

Because of its relatively time consuming nature, the ADDT is recommended for use in determining the final disposition of imperfections whose depth cannot be determined using other methods, and when the ACT results are within 3 dB of the reference amplitude. The ADDT method is also recommended for use when the differential time of flight measurement from the imperfection exceeds that of the reference indicator regardless of amplitude.

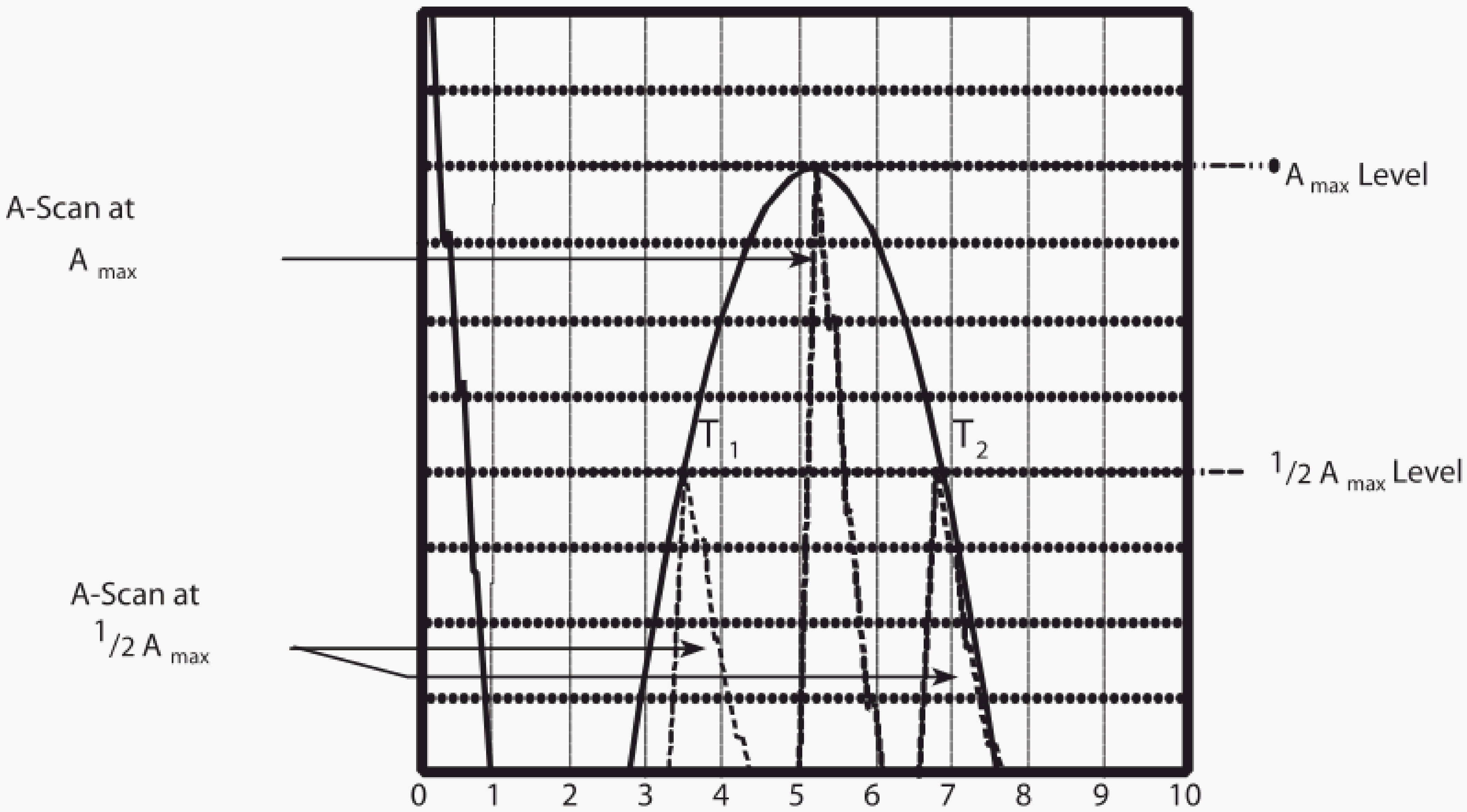


Figure A.3.a

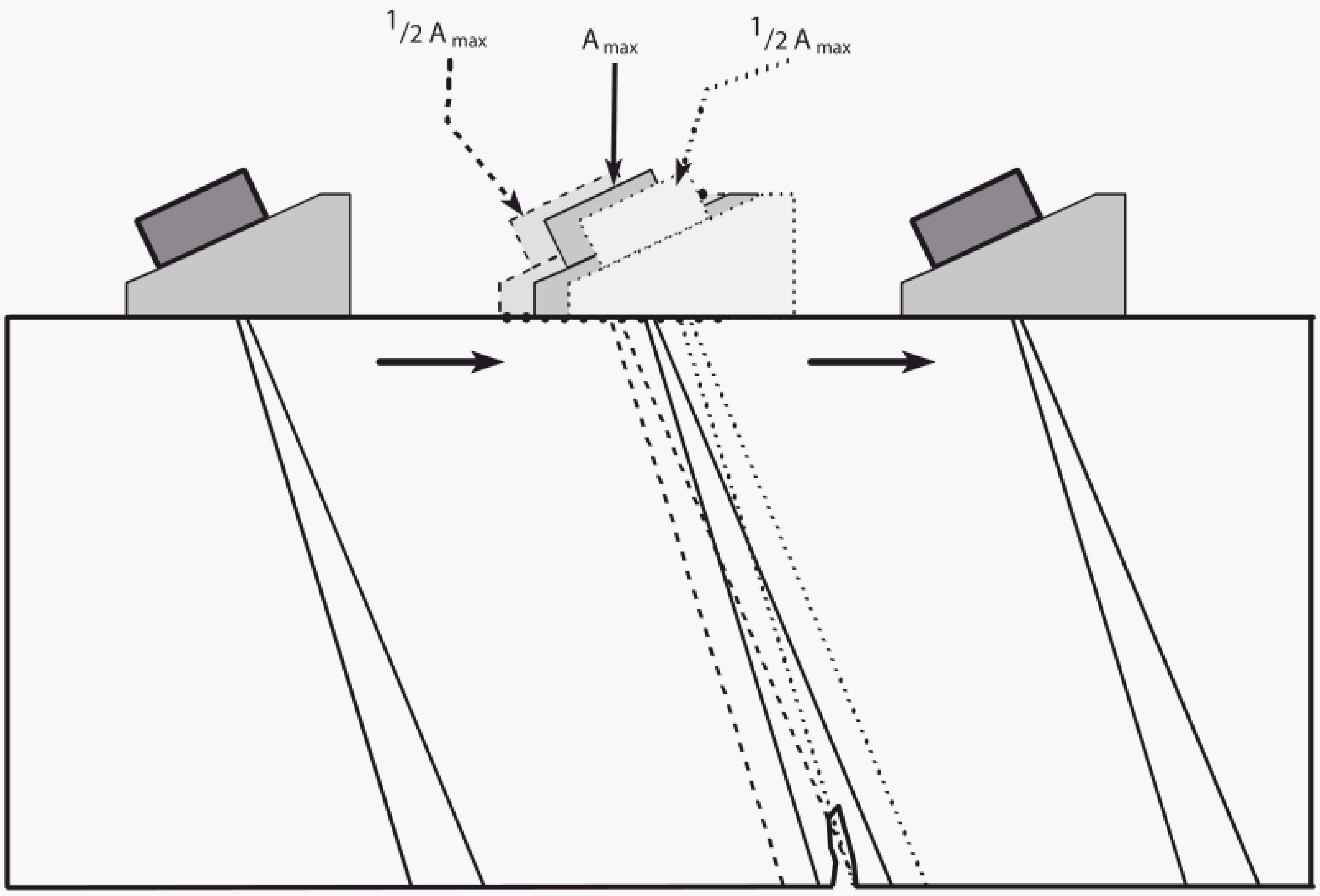


Figure A.3.b

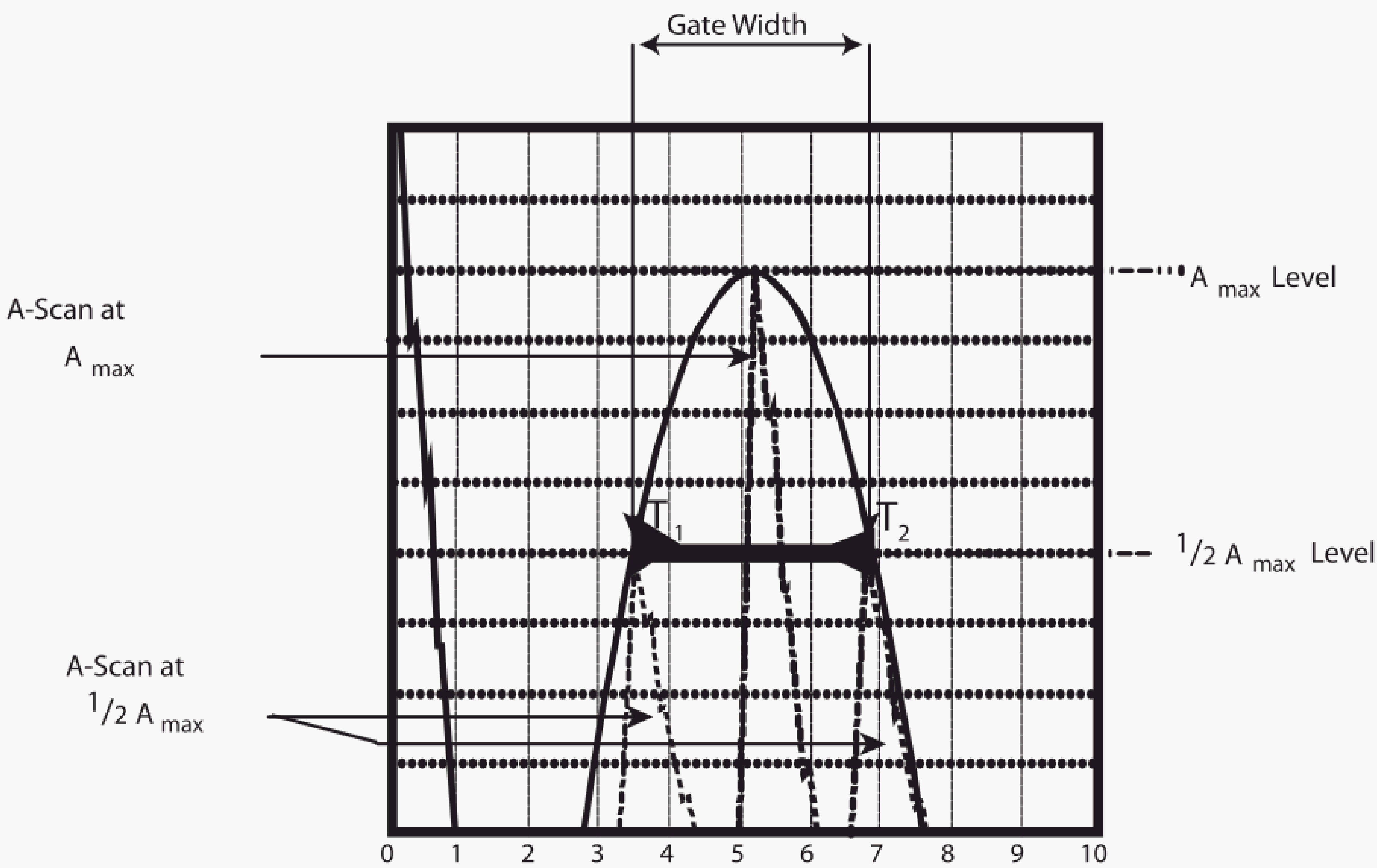


Figure A.3.c

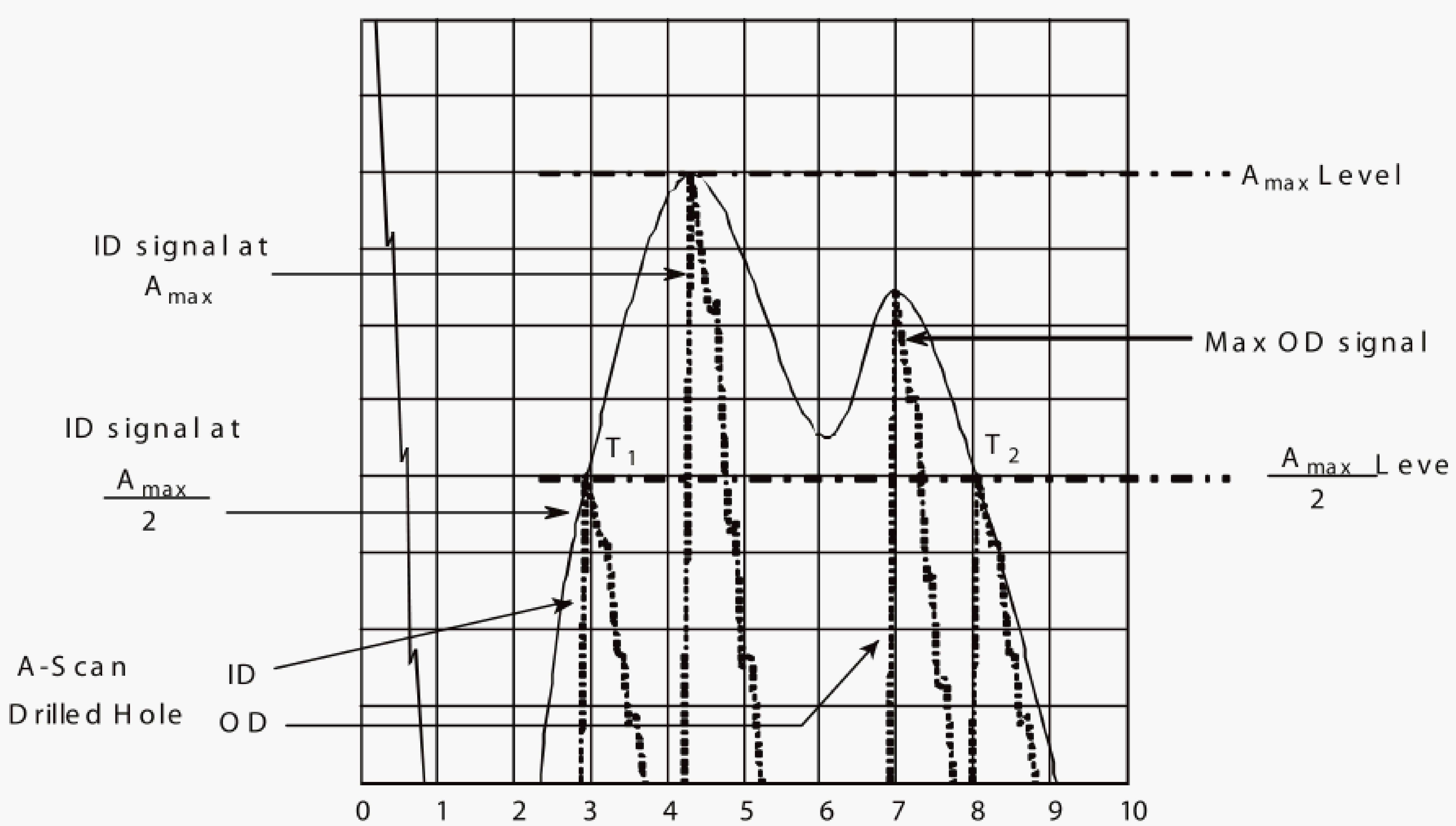


Figure A.3.d

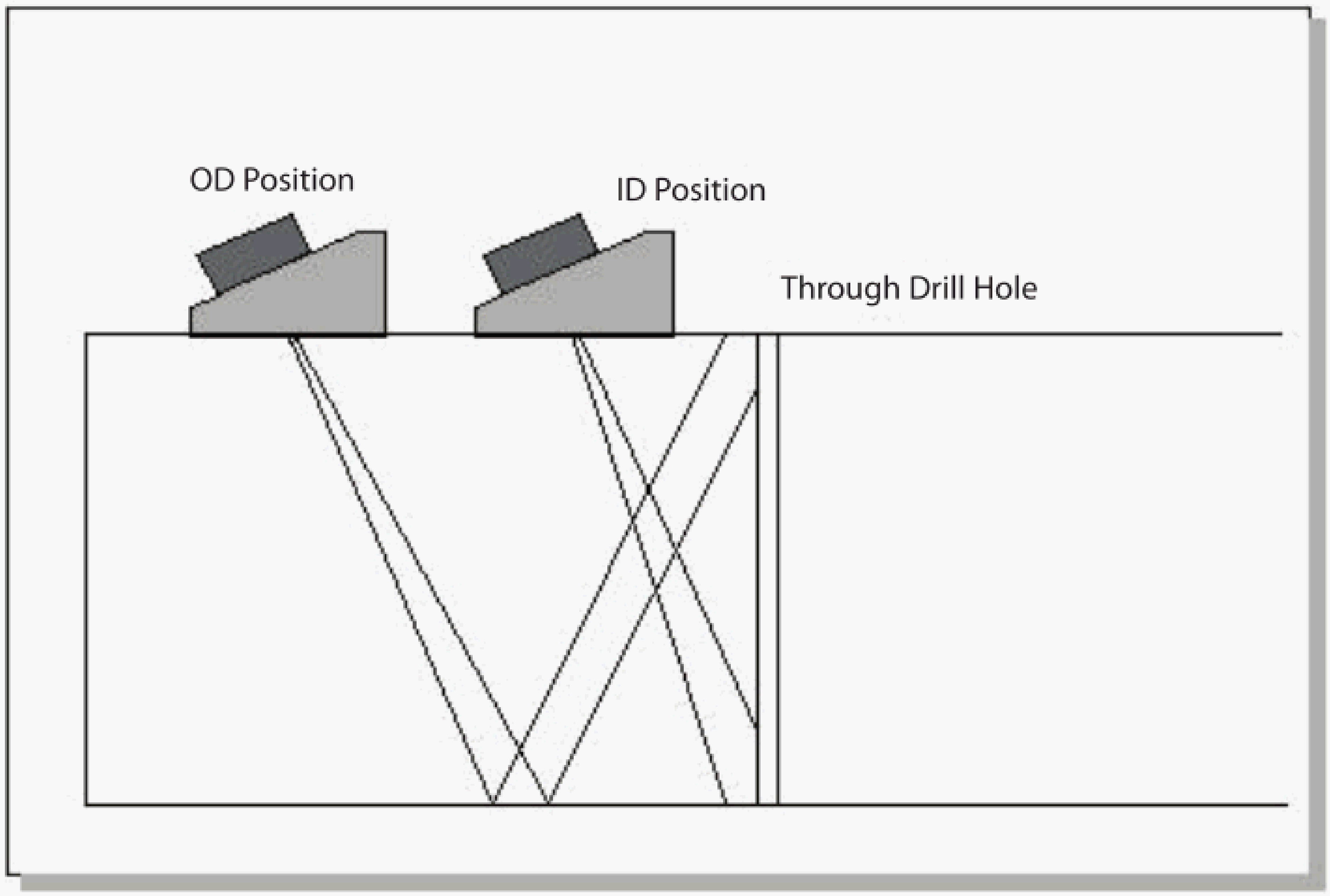


Figure A.3.e

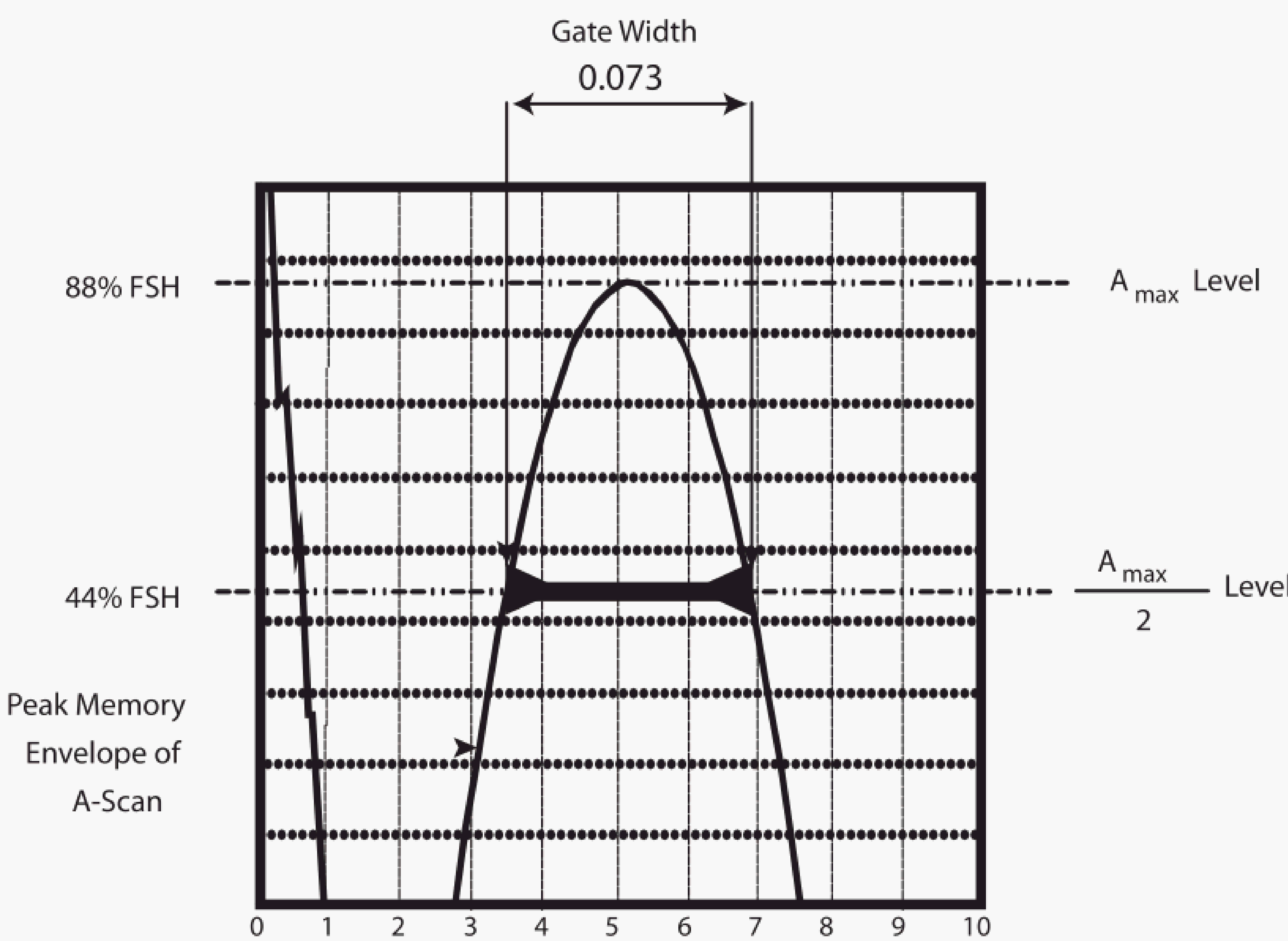


Figure A.3.2

APPENDIX B

B.1 Surface or Subsurface Determination

Since the API specifications referenced throughout this recommended practice only require surface breaking defects to be located and their depth evaluated, except for the weld area of welded product, part of any evaluation process should include a means of determining if the imperfection being evaluated is surface breaking or subsurface. Subsurface imperfections, except those in the weld area of welded product, do not require evaluation.

The following procedure provides one technique for determining if the imperfection to be evaluated breaks the internal surface of the pipe. This procedure is based on a known sound path distance, at a given refracted angle, to the internal surface and a corresponding wall thickness value that correlate within a given tolerance.

B.2 When an imperfection is located, scribe a line on the surface of the pipe directly in front of the wedge (with the indication peaked—position A in Figure B.2).

B.2.1 Repeat B.2 from the opposite side of the imperfection.

B.2.2 Determine the average wall thickness surrounding the indication (position B in Figure B.2).

B.2.3 After peaking up on the indication using the shear wave method, adjust the gain such that the maximized signal is approximately 80% FSH. Note the gain value and the sound path distance as indicated on the A-scan display or the digital readout.

Note: Most analog and some digital ultrasonic instruments that provide numerical sound path distance base the "depth" calculation on flat plate. This calculation will be correct during an axial scan but due to the pipe curvature, the calculation will not be correct during a circumferential scan; however, some digital instruments contain curvature correction software and thus provide a correct "depth" calculation.

The formula in B.3 may be used to develop a look-up reference table from which the correct depth value may be obtained based on a given wall thickness when using ultrasonic instruments without curvature correction software or a digital readout.

B.2.4 For digital instruments with curvature correction software or for any instrument with a digital readout when performing an axial scan, adjust the instrument controls to display the "depth" mode on the digital readout and note the reading.

B.2.5 For instruments without a digital readout, refer to a look up table (based on the formulas in B.3) and note the wall thickness value corresponding to the circumferential sound path distance noted in B.2.3.

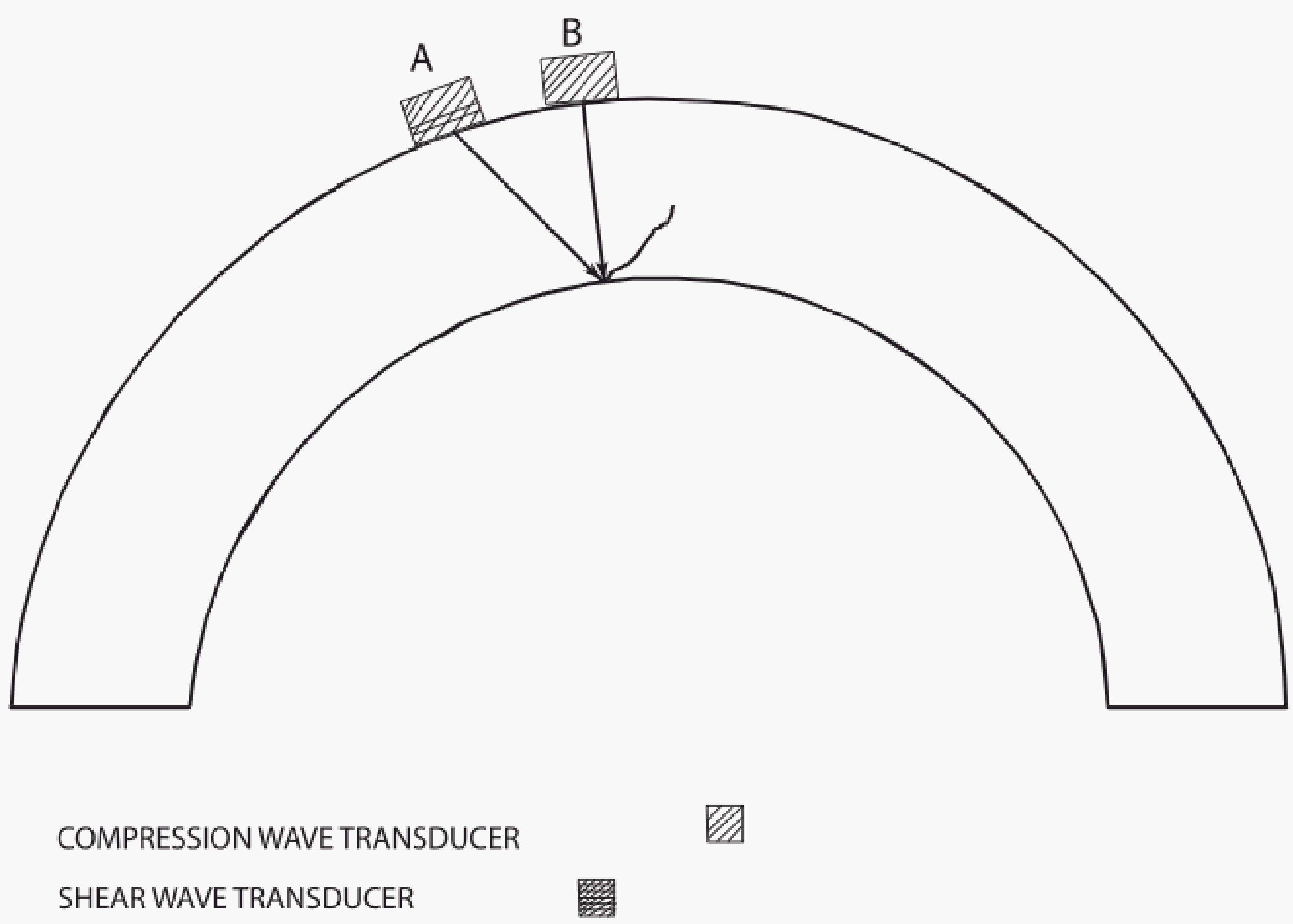


Figure B.2

B.2.6 Repeat the applicable portions of B.2.3 through B.2.5 from both sides of the indication.

B.2.7 If the actual wall thickness differs by 0.010 in. or less from the wall thickness value(s) noted in either B.2.4 or B.2.5, the indication may be considered to be surface breaking.

B.2.8 If the actual wall thickness differs by more than 0.010 in. and by less than 0.020 in. from the wall thickness value(s) noted in either B.2.4 or B.2.5, the indication should be visually inspected with a borescope to determine if the imperfection is surface breaking. Magnetic particles may be used in conjunction with the borescope to enhance detection.

B.2.9 If the imperfection is determined to be surface breaking, proceed in accordance with 9.2.3.

B.3 Sound Path Formulas

Circumferential Scan:

$$a^2 = R_2^2 + R_1^2 - 2R_2R_1\cos[\sin^{-1}((R_2/R_1)\sin\beta) - \beta]$$

Axial Scan:

$$a = t/(\cos\beta)$$

where

a = 1 leg of the sound path (1/2 skip),

R_2 = $Radius_2$ = O.D./2,

R_1 = $Radius_1 = R_2 - t$,

t = wall thickness,

β = refracted angle.

B.4 Sample Look-up Table

The above formula may be used to develop a Look-up Table by pipe size and corresponding wall thickness. Below is such an example:

Ultrasonic Sound Path Distances in Inches—O.D.: 9.625 Refracted Angle: 45°:

Wall	Circumferential Sound Path 1/2 Skip	Axial Sound Path 1/2 Skip
0.470	0.705	0.665
0.475	0.713	0.672
0.480	0.721	0.679
0.485	0.730	0.686
0.490	0.738	0.693
0.495	0.746	0.700
0.500	0.754	0.707
0.505	0.762	0.714
0.510	0.770	0.721
0.515	0.778	0.728
0.520	0.787	0.735
0.525	0.795	0.742
0.530	0.803	0.750
0.535	0.811	0.757
0.540	0.820	0.764
0.545	0.828	0.771
0.550	0.836	0.778
0.555	0.844	0.785
0.560	0.853	0.792

APPENDIX C

C.1 Evaluation of Welds With Filler Metal

The preferred angle of inspection is $Beta_{Max}$ minus 5 degrees to minimize the signal from the weld caps and include inspection of the internal and external surfaces ($Beta_{Max}$ is the refracted angle of the beam centerline at the OD surface which will meet the ID surface tangentially). Alternately, the imperfection may be evaluated with an angle specific to its known location. Move the angle beam transducer backward and forward in a zigzag path from the weld toe, making sure you cover a full skip distance, as shown in Figure C-1.

Verify the location of the imperfection through the weld by using the trigonometric formulas and confirm that the signal received is not from the weld cap as shown in Figure C-2. The sound path is displayed on the instrument's calibrated screen. Surface distance is calculated using the sound path multiplied by the sin of the inspection angle and depth is calculated using sound path multiplied by the cosine of the inspection angle.

For a transverse type reflector, the beam direction must be closely parallel to the weld. (Figure C-3). The bead may be ground flush and in these cases a probe can be operated directly on top of the weld. (Figure C-4).

C.2 Observations and Considerations

Care must be taken to ensure the "first skip" occurs on the surface of the parent metal and not in the weld area to prevent mistaking a weld cap signal for the imperfection. Use the trigonometric formulas for surface distance and depth given in C.1 to verify position when an indication is produced.

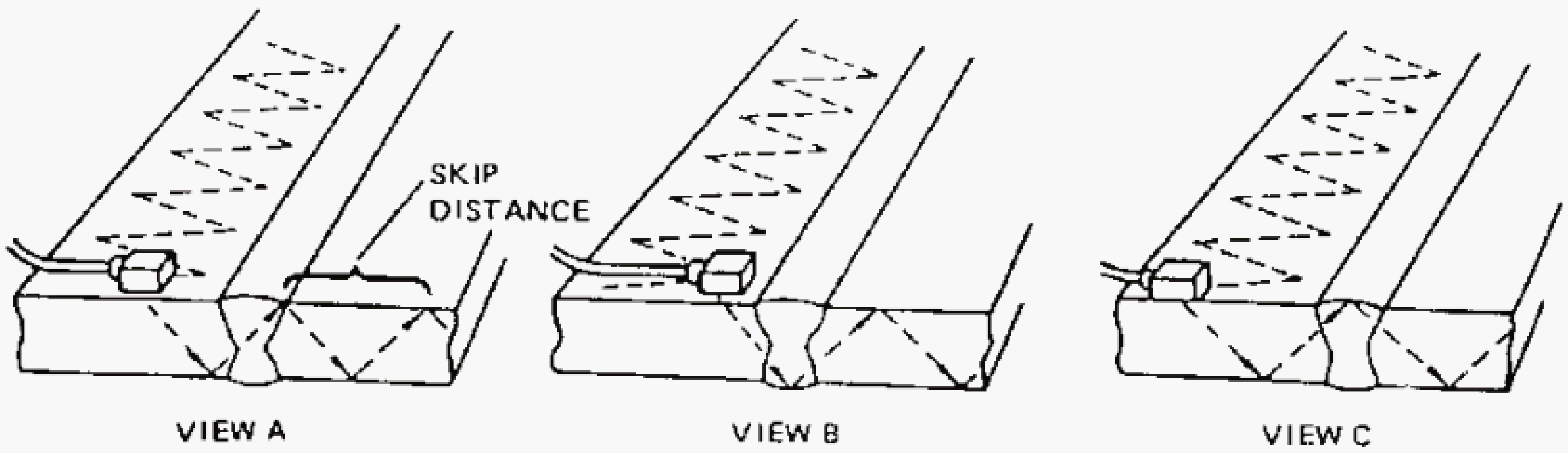
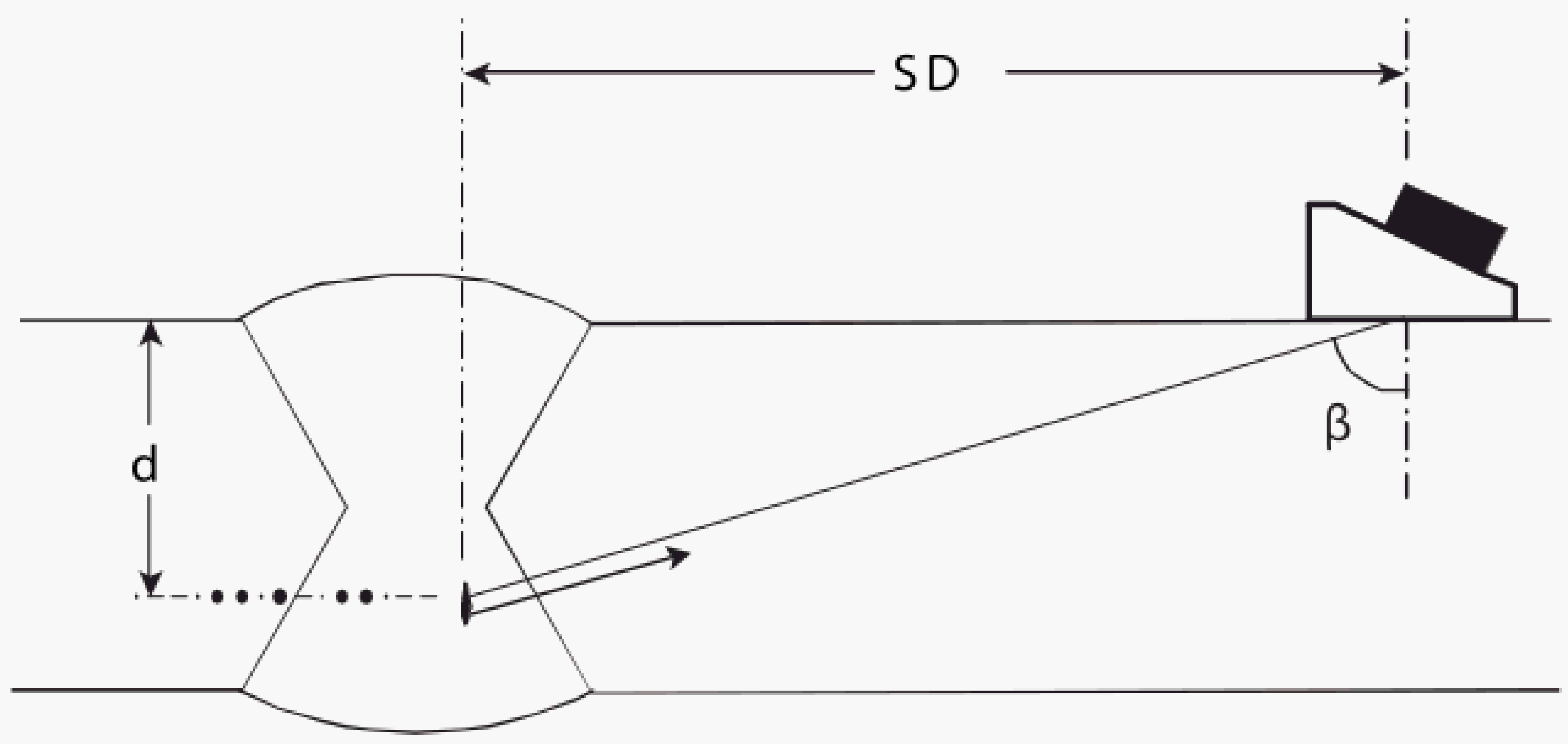


Figure C.1



S Sound Path = BW/cos β

SD Surface distance = S P x sin β

d Depth = SP x cos β

Note: Sound path to the ID surface = Wall Thickness/ cosine beta

Figure C.2

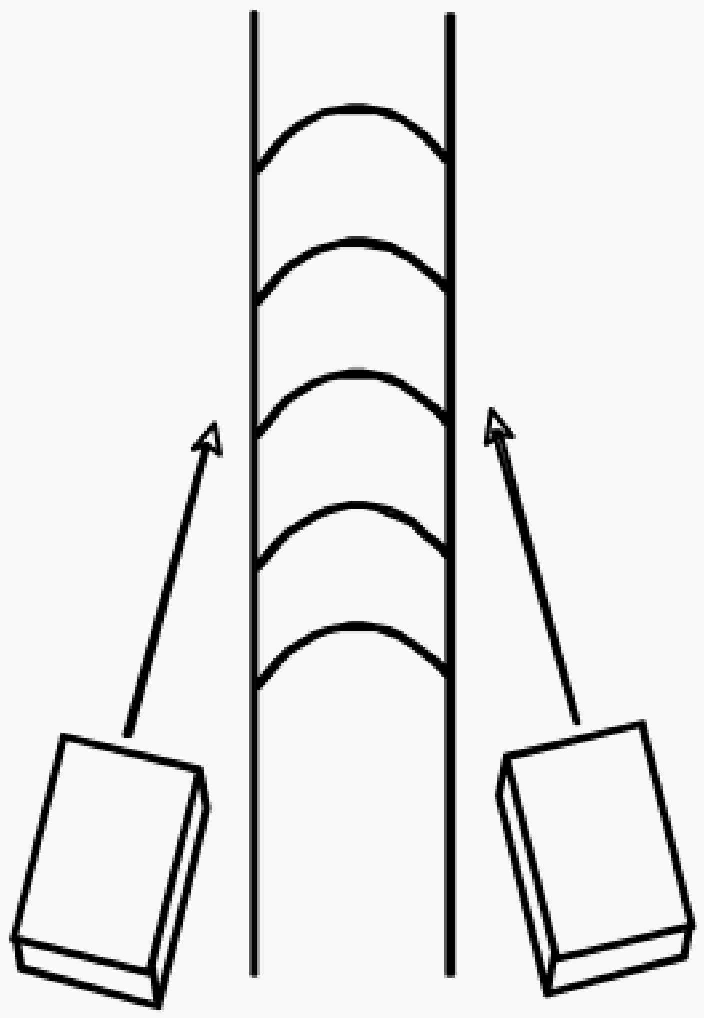


Figure C.3

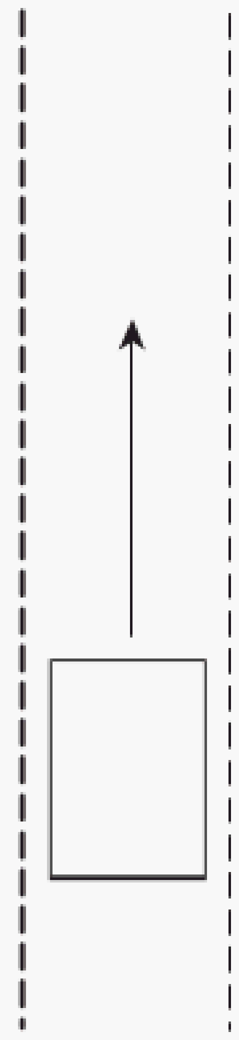


Figure C.4

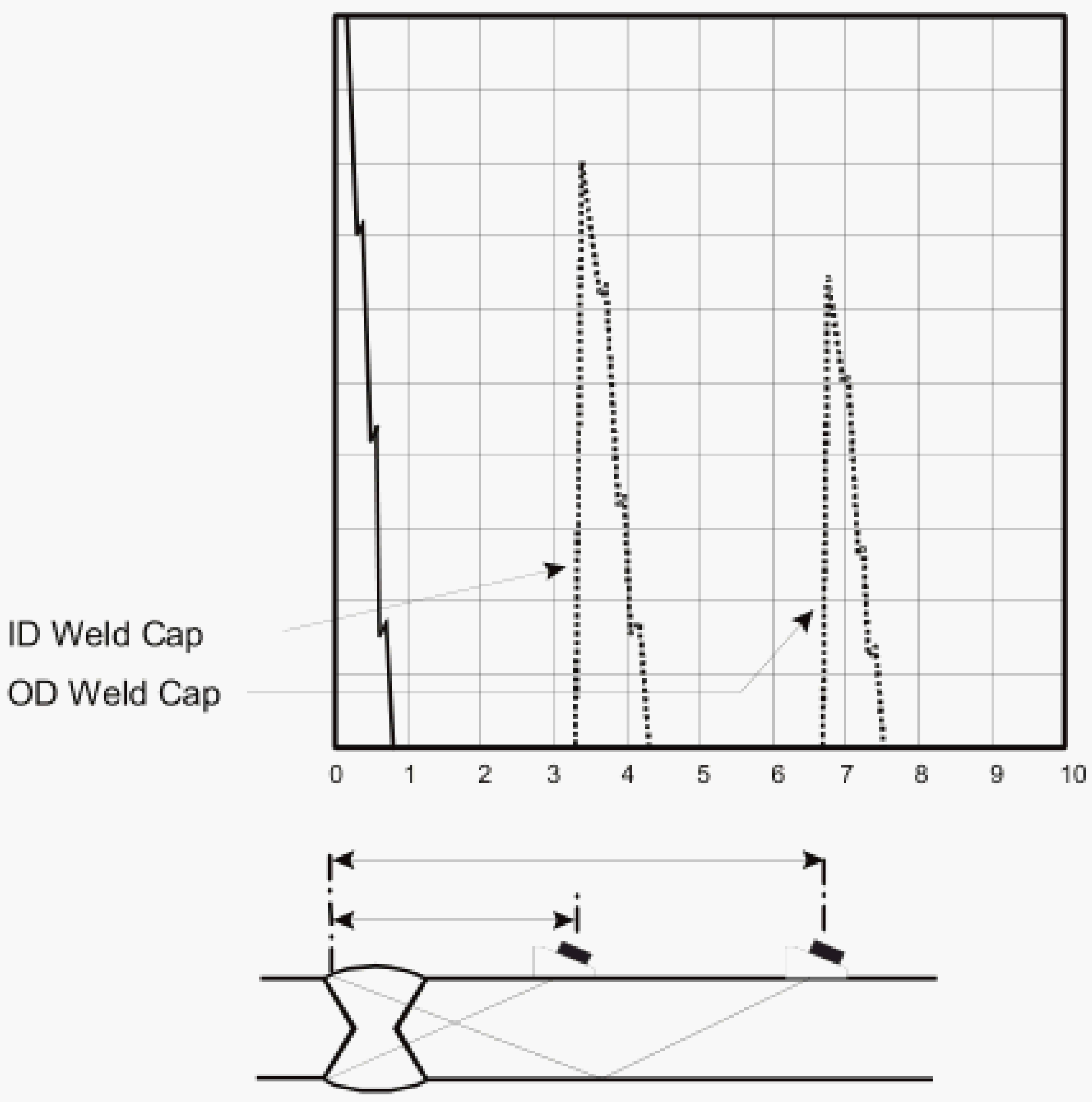


Figure C.5—Skip in Weld Area

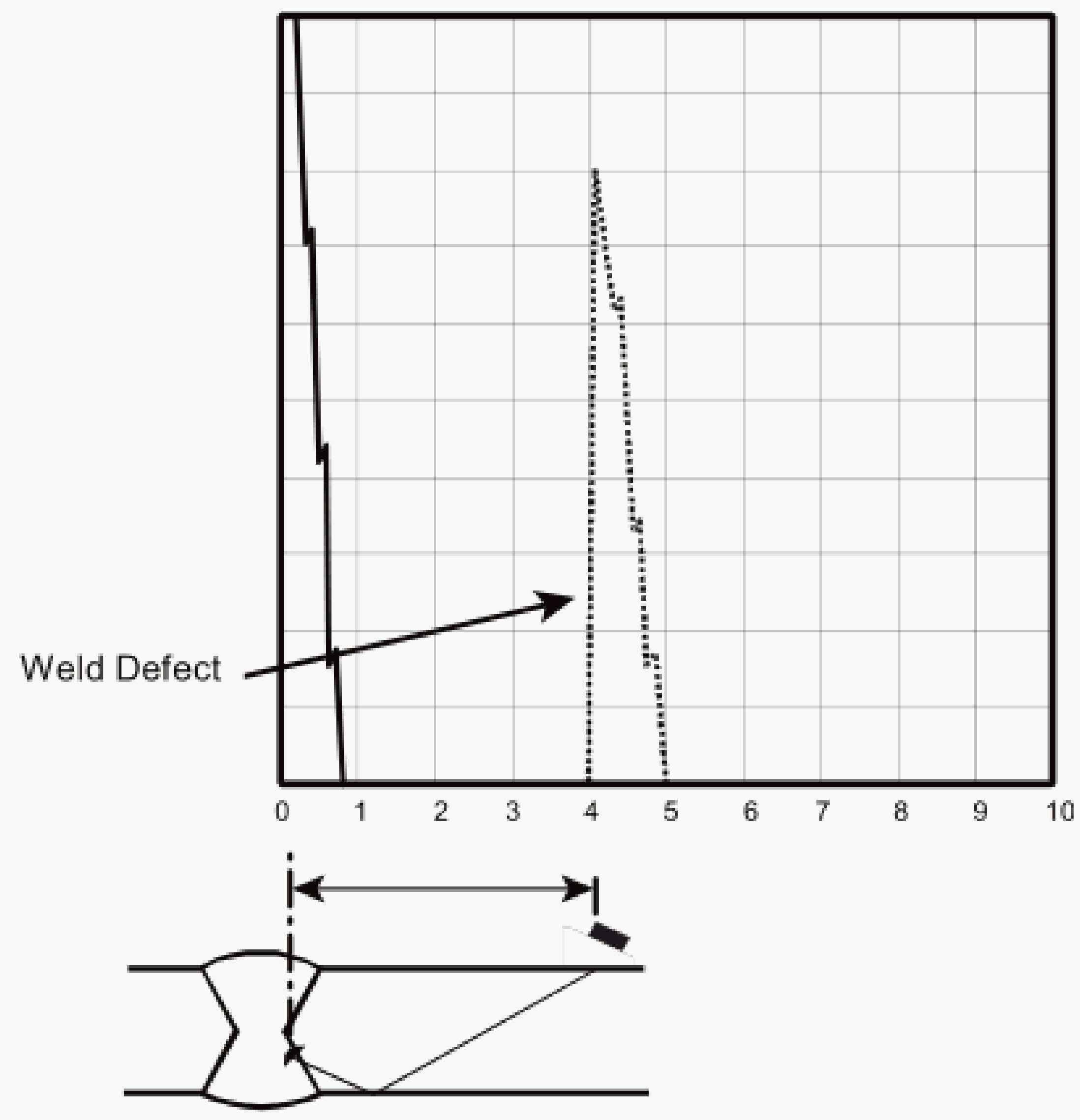


Figure C.6—Skip in Parent Metal

APPENDIX D

D.1 Sizing of Subsurface Planar Imperfections

This appendix establishes minimum requirements related to manual ultrasonic compression wave prove-up of subsurface planar imperfections (primarily inclusions and laminations) using an ultrasonic flaw detector, or similar instrument with an A-scan display. This technique is applicable for outlining the edges of these imperfections from the outside pipe surface of API tubular products.

Other techniques may be used by agreement between the purchaser and the agency.

D.2 Equipment Requirements

D.2.1 Ultrasonic Instrument

The ultrasonic instrumentation shall be the pulse-echo type with an A-scan display.

D.2.2 Compression Wave Transducer

The high resolution, dual-element, compression wave transducer shall be capable of detecting a 1/32 in. (0.8 mm)
09 flat-bottom hole at least 3/8 in. (9.5 mm) from the front surface of a parallel-surface test block with a measurement accuracy of ± 0.010 in. (± 0.25 mm).

A transducer having a diameter of 0.375 in. (9.5 mm) and a nominal frequency of 7.0 MHz or higher is suggested. These characteristics have proven capable of providing the resolution specified in the preceding paragraph.

An adapter cable or connector may be required to connect some dual element transducers to flaw detectors.

D.2.3 Reference Standard

An area of the pipe to be inspected, which is imperfection free and represents the pipe's specified wall thickness, within applicable tolerances, shall be used for Distance Standardization.

D.2.4 Linear Measuring Device

A linear measuring device, such as a vernier caliper or steel rule, capable of resolving 1/32 in. (1 mm) or smaller.

D.3 Standardization Procedure

D.3.1 For analog ultrasonic instruments, the A-scan shall be viewed perpendicular at all times during standardization and evaluation to eliminate parallax error.

D.3.2 The material to be inspected, equipment, couplants and the reference standard shall be exposed to the same ambient temperature for a minimum of 30 minutes prior to standardization.

D.3.3 Use of the REJECT/noise suppression control is not recommended.

D.3.4 Distance Standardization

Note: Because acceptance/rejection criteria for subsurface imperfections is based on imperfection area and is not dependent on imperfection depth from the outside surface, precise distance standardization is not required. The standardization procedures below will result in relative distance discrimination only.

D.3.4.1 Couple the transducer to the reference standard ensuring that the barrier between the transmitting and receiving sides of the transducer is perpendicular to the longitudinal axis of the pipe.

D.3.4.2 A signal corresponding to the pipe's wall thickness should appear on the A-scan display. This will be the "back wall reflection."

D.3.4.3 If no signal appears, adjust the sweep, delay and gain controls until the initial pulse and back wall reflection
are visible on the A-scan display. The initial pulse should be 09
on the left side of the screen and the pipe's back wall reflection on the right side of the screen.

D.3.4.4 Adjust the sweep and delay controls until the initial pulse is located at zero (0) and the pipe's back wall reflection is located at eight (8) on the horizontal baseline. The distance between the positions of the initial pulse and back wall reflection represents the inspection area.

D.3.4.5 Adjust the gain until the back wall reflection is at 100% full screen height (FSH), then add 6 dB for scanning.

D.3.5 Standardization checks shall be performed at the start of each shift, or either of the following conditions.

D.3.5.1 If the power source (battery or AC) to the instrument is terminated for any reason.

D.3.5.2 Anytime another technician uses the instrument.

D.4 Procedure

D.4.1 The area requiring investigation shall have been previously marked on the material outside surface prior to this examination using a digital ultrasonic thickness gauge.

D.4.2 Place the transducer firmly onto the surface in the area of the indication, ensuring that the barrier between the transmitting and receiving sides of the transducer is perpendicular to the longitudinal axis of the pipe.

D.4.3 Once an imperfection to be evaluated is located, adjust the gain until the indication signal is at approximately 80% FSH.

D.4.4 Scan the transducer over the imperfection slowly in minute increments, searching for the edge of the imperfection.

D.4.5 If multiple indications are noted on the display, at varying baseline positions (time), these are separate imperfections and their size must be determined individually (see Figure D.1).

D.4.6 As the edge of the subsurface imperfection is located, by noting when the signal amplitude drops by 50% (6 dB), mark the edge with a metal scribe or similar fine-point
09 marking device (do not use chalk, crayon, or a metal marker), (see Figure D.2). The mark shall be located to coincide with the middle of the transducer, not it's edge or side.

Repeat this process in the opposite direction and also in the other orientation until a complete outline of the subsurface imperfection is present. In other words, the longitudinal dimension must be determined and the transverse dimension must be determined.

To determine the area if the imperfection, measure its longest dimension in both directions. Multiply these two (2) values for the imperfection's area. 09

The following data should be included on all prove-up reports and defect sheets when documenting imperfection or defect results:

- length
- width
- area (L × W) in in.^{2} or mm^2

D.5 Acceptance/Rejection Criteria

D.5.1 Refer to the applicable product specification for the acceptance limits.

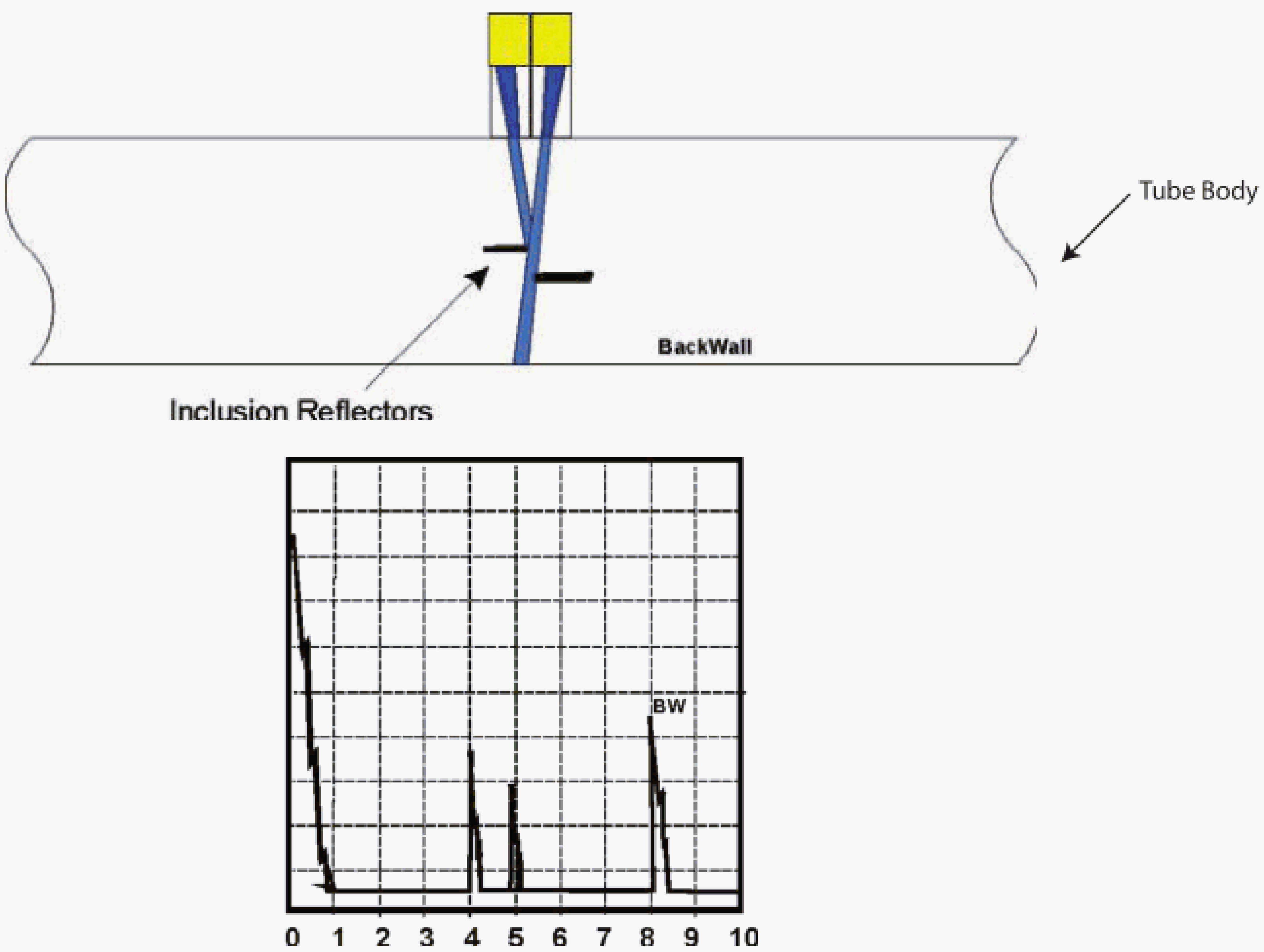


Figure D.1

09

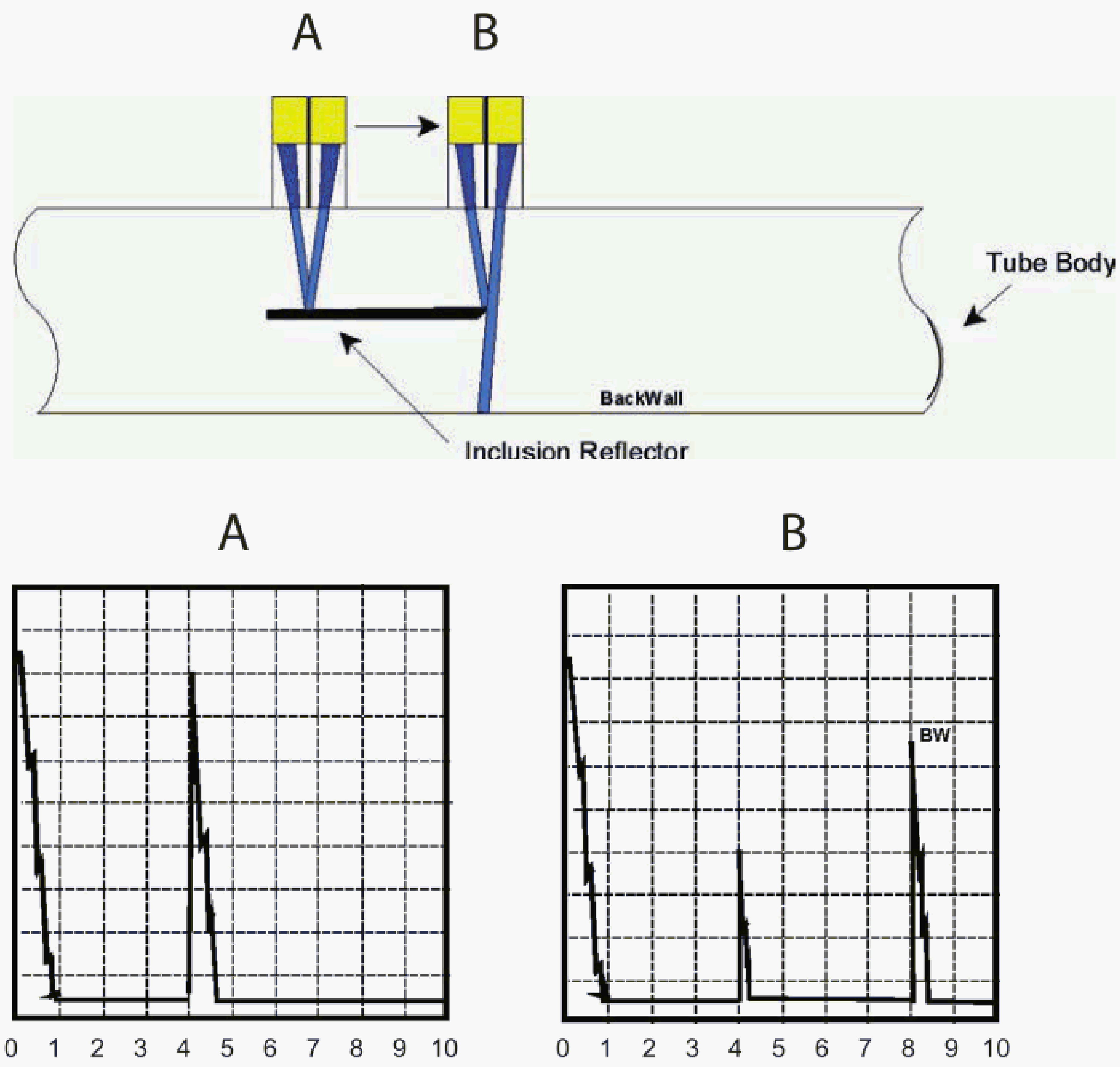

A
B
Tube Body
BackWall
Inclusion Reflector
A
B
BW
0 1 2 3 4 5 6 7 8 9 10
0 1 2 3 4 5 6 7 8 9 10

Figure D.2

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	Spec 5B, Specification for Threading, Gauging, and Thread Inspection of Casing, Tubing, and Line Pipe Threads		$114.00	
	RP 5B1, Gauging and Inspection of Casing, tubing and Line Pipe Threads		$137.00	
	Spec 5CT, Spec 5CT/ISO 11960, Specification for Casing and Tubing		$206.00	
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