APPENDIX G

AWS D1.5:2015 ANNEX K MARKUPS

G.1 Annex K

Annex K (Normative)
Advanced Ultrasonic Examination

This annex is part of AWS D1.5M/D1.5:2015, *Bridge Welding Code*, and includes mandatory elements for use with this standard.

K1. Introduction

This annex provides mandatory requirements that shall apply when phased array ultrasonic testing (PAUT) is used. The alternative techniques presented in this annex require written procedures, advanced operator training and qualification, and calibration methods specific to PAUT.

K2. Scope

The procedures and standards set forth in this annex govern phased array examinations of groove welds (excluding tubular T-, Y-, and K-connection welds), including heat-affected zones (HAZ), for thicknesses between 5 mm and 100 mm [3/16 in and 4 in] using automatic data acquisition (encoded line scanning).

K3. Definitions

K3.1 Bandpass filtering. A function of the receiver circuit in most modern UT and PAUT equipment designed to filter out unwanted returned sound frequencies outside of that used for sound wave generation. The frequencies of sound on return are of much broader range than the range of frequencies put into the test piece.

K3.2 Channel. A send/receive circuit in the phased array unit. The number of channels dictates the maximum number of elements that the phased array unit can support as a whole.

K3.3 Dead elements. Individual elements that are no longer functional due to broken cables, connectors, or element failure. This can also include elements with substandard performance.

K3.4 E-Scan. A single focal law multiplexed across a grouping of active elements for a single beam angle that is stepped along the phased array probe length in defined incremental steps.

K3.5 Element. An individual crystal (piezo-composite material) within a phased array probe.

K3.6 Encoded. ~~Done~~ Performed with an encoder.

K3.7 Encoder. A device, normally in the form of a wheel or string, that records probe position for computer analysis for an automatic data acquisition system.

K3.8 Encoding. Using an encoder.

K3.9 Focal law. A phased array operational file defining search unit elements and time delays for transmitted and received signals.

K3.10 FSH. Full screen height.

K3.11 Imaging views. Images defined by different plane views between the ultrasonic path (ultrasonic axis), beam movement (index axis), and probe movement (scan axis) (see Figure K.1). Also called "scans" (see K3.11.1 ─ K3.11.5).

K3.11.1 A-Scan. A representation (view) of the received ultrasonic pulse amplitude versus time of flight in the ultrasonic path, also called a waveform.

K3.11.2 C-Scan. A 2-D plan or top view of the recorded A-scan data showing the beam movement (index axis) versus the probe movement (scan axis) path, using the maximum amplitude of the A scans at each transverse location. The C-scan may be presented in the volume-corrected or uncorrected form.

K3.11.3 Sectorial View. A 2D view of all A-scans from a specific set of elements corrected for delay and refracted angle.

K3.11.4 Side View. A 2-D view of the recorded A-scan data for one angle showing the ultrasonic path (ultrasonic axis) along the probe movement (scan axis) path. The A-scan amplitude is color coded. The side view may be presented in the volume-corrected or uncorrected form.

K3.11.5 End view. ~~is a~~A 2-D view which is very similar to the side view. The end view is at 90° to the side view and shows the ultrasonic path (ultrasonic axis) versus the beam movement axis (index axis).

K3.12 Line scan. The phased array scanning technique in which an E-scan, S-scan, or combination thereof is performed with the beams directed perpendicular to the weld, at a fixed distance from the welds, in a manner demonstrated to provide full weld coverage. Also called a linear scan.

K3.13 PAUT. Phased array ultrasonic testing.

K3.14 Phased array instrument. A multichannel test instrument used with multiple-element probes that enable the application of delay/focal laws when transmitting, and receiving, before summing.

K3.15 Phased array technique. A technique wherein UT data is generated by constructive phase interference formed by multiple elements controlled by accurate time delayed pulses. This technique can perform beam sweeping through an angular range (S-scans), beam scanning at fixed angle (E-scans), beam focusing, lateral scanning, and a variety of other scans depending on the array and programming.

K3.16 Phased array probe. A probe made up of several piezoelectric elements individually connected so that the signals they transmit or receive may be treated separately or combined as desired. The elements can be pulsed individually, simultaneously, or in a certain pattern relative to each other to create the desired beam angles or scan pattern.

K3.17 Pitch. The center to center distance between two successive phased array probe elements.

K3.18 Pulser. The instrument component that generates the electrical pulse. The number of pulsers dictates how many elements within a phased array probe may be applied within a given focal law.

K3.19 S-scan. The S-scan beam movement is a set of focal laws that provides a fan-like series of beams through a defined range of angles using the same set of elements.

K3.20 Saturated Signal. A signal in which the true peak amplitude cannot be measured in the stored data file due to bit depth of the phased array system.

K3.21 Scan plan. A document specifying key process elements such as equipment detail, focal law settings, and probe positions as necessary to complete an examination; also depicts weld and HAZ coverage.

K3.22 Scanner. A device used for holding the phased array probes in place while collecting data by means of an encoder. Scanners contain an encoder and may be automated or semi-automated types as described below.

K3.22.1 Automated scanner. A mechanized device in which the PA probe movement is computerized or driven by remote control.

K3.22.2 Semi-Automated Scanner. A scanner that is manually driven along welds.

K3.23 Sound-path or depth calibration (horizontal linearity). A specific action used to compensate and adjust instrument time delay over all focal laws for specific wedge geometry for a depth or sound-path calibration.

K3.24 TCG. Time corrected gain.

K3.25 Time corrected gain (TCG). A calibration technique in which the search unit computes the dB gain difference needed to balance standard calibration reflectors (side drilled holes) at various material depths at one set screen amplitude. When completed, all side-drilled hole reflectors equal the same approximate amplitude regardless of their varying metal path distances.

K3.26 Virtual probe aperture (VPA). The number of elements in a phased array probe used for the examination.

K3.27 Volume-corrected scan. A presentation in which correction is made to the index axis A-scan point locations based off true positional information relative to the beam angle or angles used during the inspection.

K3.28 VPA. Virtual probe aperture.

K4 Personnel Requirements.

K4.1 Personnel Qualification Requirements. Individuals who perform PAUT shall at a minimum be qualified for PAUT per 6.1.3.4. In satisfying the requirements of 6.1.3.4, the qualification of the PAUT operator shall include a specific and practical examination that shall be based on the requirements of this code. This examination shall require the PAUT operator to demonstrate the ability to apply the rules of this code in the accurate detection and disposition of discontinuities.

K4.2 Certification Requirements. ~~Certification of Level II PAUT personnel shall be performed by an NDT UT Level III who both meets the requirements of 6.1.3.4 for PAUT and also has received a minimum of 80 hours of formal training in PAUT.~~ A PAUT technician shall be deemed to be certified when the individual has:

- Met the requirements in 6.1.3.4 for ASNT SNT-TC-1A as an NDT UT Level II including the Phased Array method. This includes, but not limited to, successful completion of the education, training, experience, and written examination prescribed in ASNT SNT-TC-1A.
- Successfully demonstrated through performance testing he or she is capable of:
    - Performing calibration, which includes accounting for the possible differences in acoustic properties between the calibration standard and the test piece used in the exam;
    - Developing scan plans for the test plates which meets the coverage requirements of this specification;
    - Reliably detecting and classifying known flaws according to this specification in the test plates;
    - Accurately reporting the results of the inspection of the test plates and documenting essential variables.

K5. Equipment

K5.1 Phased Array Instruments. Inspections shall be performed using phased array pulse-echo equipment meeting the requirements of 6.15, qualified in accordance with K6. Phased array instruments shall also meet the following requirements:

K5.1.1 Number of Pulsers. The instrument shall be equipped with a minimum of 16 pulsers and channels (16:16 minimum). A minimum of 16:64 is required if E-scans are to be used.

K5.1.2 Imaging Views. The phased array instrument shall be equipped with sufficient display options, including A, C, sectorial and side views, and encoded scans, to provide thorough data analysis through the entire scan length and through all beams.

K5.2 Straight-Beam (Longitudinal Wave) Probes. The straight-beam (longitudinal wave) phased array probe shall produce frequencies in the range of 1 to 6 MHz. Probe dimensions shall be small enough that standing wave signals do not appear on the display. The phased array probe shall be a linear array probe capable of providing a resolution of three side drilled holes of the RC block. Alternatively, a UT search unit meeting the requirements of 6.15.6 may be used.

K5.3 Angle-Beam Search Units. Angle-beam search units shall consist of a phased array probe and an angle wedge to produce the desired refracted angles.

K5.3.1 Phased Array Probe. The probe shall be a linear array type with a minimum of 16 elements. Nominal probe center ~~and shall produce~~ frequencies shall be between ~~1~~ 2.25 MHz and ~~6~~ 5 MHz. Probe dimensions shall be chosen in order to optimize the beam formation within the area of the coverage. Difference in attenuation associated with different frequence probes must be accounted for during calibration. Probe pitch dimensions shall be small enough that standing wave signals do not appear on the display.

K5.3.2 Angled Phased Array Wedge. The wedge shall be of a sufficient incident angle to produce sound beams in the material between ~~45º~~ 40° and 70° ±2°. Wedges shall be used within the angular range specified by the manufacturer.

K5.4 Encoder. The encoder shall be digital and capable of line scanning.

K5.5 Scanner. Encoding shall be performed by using a semi-automated or automated scanner as defined in K3.22.

K5.6 Couplant. A couplant material shall be used between the search unit and the test material. Any commercial couplant, water, or oil may be used when performing calibrations and examinations. The same couplant shall be used for calibration as for examination of the test object.

~~**K5.7 Reference Standard for Determining SSL.** The standard reflector used for test standard sensitivity level (SSL) shall be the 1.5 mm [0.06 in] diameter side drilled hole in an IIW block in conformance with ASTM E164, *Standard Practice for Contact Ultrasonic Testing of Weldments*.~~

K5.7 Calibration for Variation in Acoustic Properties. The following section includes requirements for calibration to account for differences in acoustic properties.

K5.7.1 ~~Supplemental~~ Calibration Block Geometric and Temperature Requirements. ~~A supplemental~~ The calibration block shall ~~be used allowing~~ allow for a minimum of a 3-point TCG establishment throughout the usable sound path range of all configured angles. The standard reflector used for setting the standard sensitivity level (SSL) shall be the 1.5 mm [0.06 in] diameter side drilled hole. A minimum spacing of 12.5 mm [0.5”] shall be provided between the center of the side drilled hole and the surface of the plate if TCG calibration will utilize sound propagation skipping off of the surface nearest to the hole.

The block shall be of sufficient thickness and length to allow calibration of reflectors throughout the entire examination volume to be tested. The calibration block shall be of sufficient width to allow for adequate beam spread at the longest sound path used for calibration. It is recommended that the width of the calibration block be greater than the following:

$$W > \frac{2\lambda S}{D}$$

Where:
W: width of the test block
λ: wavelength
S: maximum sound path
D: transducer width

The temperature of the calibration standard utilized shall be within ± 25 degrees F [± 14 degrees C] of the temperature of the test object.~~The block shall be of sufficient thickness and length to allow calibration of reflectors throughout the entire examination volume to be tested. Each calibration block shall have at least three side drilled holes at a range of depths to cover the entire material range to be tested.~~

~~**K5.7.2 Optional Mockup Verification.** At the option of the PAUT operator or when required by the Engineer, detectability of the standard reflector (1.5 mm [0.06 in] side drilled hole) may be verified in a mockup or the production part. When weld mock-ups and sections of production weldments are used, the reflector shall be in locations where it is difficult to direct sound beams, thereby ensuring detection of discontinuities in all areas of interest. Mock reflectors shall be placed a minimum of 1.5 mm [0.06 in] clear distance from edges. When this verification is required, the standard reflector shall be detectable above the DRL established in K8.2.4.2. Example placements of the standard sensitivity reflector in a mockup or production part are shown in Figure K.2. If the standard reflector is not detectable, the scan plan shall be adjusted.~~

K5.7.2 Acoustic Property Verification. Acoustic properties of the test object and calibration block shall be verified to be within the tolerances specified in Articles K5.7.2.1 and K5.7.2.2.

K5.7.2.1 Attenuation Requirements. Correction for attenuation is required when the calibration block is less attenuating than the test object and the absolute difference in amplitude between the calibration block and the test object exceeds 2 dB at the longest sound path used in the inspection. Removal of gain shall not be used as a means of correction without consideration of the amplitude difference at shorter sound paths.

In certain steels, the use of probes with a frequency greater than 2.25 MHz requires correction for differences in attenuation between the test object and the calibration block when the plate thickness exceeds 0.5”. This correction shall be performed by either:

- Fabricating a calibration block of acoustically equivalent steel as the test object or;
- Application of a transfer correction.

If a transfer correction is selected, it shall be performed by a pitch-catch setup on the test object and calibration block. No correction is required if the greatest difference in amplitude between the calibration block and test object is 2 dB or less at the longest sound path. If the amplitude difference is greater than 2 dB but not greater than 12 dB, the difference may be compensated in the TCG gain. If the amplitude difference is greater than 12 dB, the roughness of the scanning surface of the test object shall either be reconditioned to better match the surface roughness of the calibration block or a calibration block which is more acoustically similar to the test object shall be used.

K5.7.2.2 Shear Wave Velocity Requirements. The shear wave velocity (v_S) in the direction of sound propagation in the test object shall be measured and compared to the calibration block. Allowable incidence angles as a function of the percent difference in these velocities is given in Table K.1.

When this difference exceeds 2.5%, calibration shall be performed using a different calibration block that is within 2.5% of the test object's shear wave velocity in the direction of sound propagation.

K5.7.2.3 Acoustically Anisotropic Materials. It shall be verified the shear wave velocity in the rolling and transverse to rolling directions do not differ by more than 1%. Materials that have an anisotropic ratio (i.e., ratio of velocity in rolled and transverse to the rolling direction) of 1% or greater shall be defined as acoustically anisotropic. When inspecting acoustic anisotropic materials at an oblique orientation (i.e., neither parallel or perpendicular) to the rolling direction during line scanning or follow-up raster scanning the allowable incidence angles shall be limited to 40°-60° and +4 dB shall be added to the reference gain.

K5.7.2.4 Additional Requirements for ESW Welds. The amplitude and location associated with a 1.5 mm [0.06 in] diameter side drilled hole shall be measured and evaluated in a full-scale mockup of a portion of the weld using base metal of similar acoustic properties to the actual test object. The reflector shall be placed in a location which will maximize the sound path traveling through the weld metal.

K6. Equipment Qualification

K6.1 System Linearity. System linearity verifications shall be validated at a maximum of 12 month intervals. Validation shall be performed as detailed in K14.

K6.2 Internal Reflections. Maximum internal reflections from each search unit shall be verified by the PAUT operator at a maximum time interval of 40 hours of instrument use and checked in accordance with 6.22.3.

K6.3 Resolution Requirements. Testing of the resolution of the combination of search unit and instrument shall be performed and documented per 6.16.3.

K6.4 Probe Operability Checks. An element operability check shall be performed by the PAUT operator prior to initial calibration and use and weekly on each phased array probe to determine if dead (inactive) or defective elements are present. No more than 10% of the elements may be dead and in a given aperture, and no more than two adjacent elements may be dead within a given aperture. This check shall also be performed upon each 8-hour period of use. In addition, each element within a phased array probe shall be evaluated to check for comparable amplitude responses throughout the aperture. Each element shall be verified to be within 6 dB of the element yielding the highest amplitude response. If the amplitude of any of the elements within the probe yields responses outside the 6 dB requirement, the element shall be declared dead.

K6.4.1 The probe operability check shall be performed by scanning through each element with the probe on the side of an IIW block or any reference block, and observing the back wall signal.

K7. Scan Plans

K7.1 Scan Plans. A scan plan, as defined in K3, shall be developed for the welds to be examined. The scan plan shall provide the specific attributes necessary to achieve examination coverage, including those variables subject to material and geometric variation that are not addressed in a general procedure. Scan plan contents shall consider all essential variables listed in Table K.5~~2~~.

K7.1.1 The scan plan shall demonstrate by plotting or computer simulation the appropriate refracted angles to be used during the examination for the groove weld geometry and areas of concern with the requirements of K5.7.2 incorporated as needed. The scan plan shall demonstrate coverage of the required examination volume. Performance shall be verified through the calibration (i.e., beam index point and beam angle verifications).

K7.1.2 Whenever a scan plan is developed, values of essential variables shall be established and an initial calibration performed by a PAUT Level II or III to confirm adequate sound pressure throughout the configured ultrasonic range. A new calibration shall be required if an essential variable has changed.

K7.1.3 The scan plan shall document the examination volume covered.

K7.2 Focal Law Configuration. Focal laws shall be configured to provide the necessary coverage requirements stipulated in K7.4. Focal laws shall be created using ~~14 to~~ a minimum of 16 elements.~~; however, more elements may be used if additional penetration is shown to be needed during calibration.~~ S-scans shall be used as the primary scan to optimize coverage and shall be configured in angular sweep increments of no greater than 1°. E-scans may be used as described below to supplement S-scans but shall not be used as a sole inspection technique.

K7.2.1 Index Positions. A sufficient number of index positions shall be configured to accomplish the coverage requirements of K7.4. These may be multiple physical index positions, multiple electronic index positions (grouping), or a combination of both. Scans shall contain sufficient overlap to demonstrate full coverage in the scan plan. The requirements of K5.7.2 shall be incorporated as needed.

K7.2.2 Focusing. An unfocused (naturally focused) sound beam shall be used for scanning. Focusing may be used to better define and dimension a given indication, but shall not be used during evaluation of the indication for acceptance.

K7.2.3 Supplemental E-Scans. E-scans may be used to supplement the S-scans. When E-scans are used, a minimum overlap of 50% of each VPA shall be configured for and specified in the scan plan.

K7.2.4 Grouping. Combinations of multiple S-scans or of S-scans and E-scans may be used through grouping features to assist in joint coverage. When combined, the minimum overlap between each scan shall be 10% of coverage.

K7.3 Procedure Variables. Essential examination parameters are listed in Table K.5~~2~~. All essential variables shall be documented in the scan plan. Any changes to an essential variable shall require the development of a new scan plan.

K7.4 Testing of Welds. The entire base metal through which ultrasound must travel to test the weld shall be tested for laminar reflectors using a straight-beam search unit conforming to K5.2. If any area of base metal exhibits total loss of back reflection or an indication equal to or greater than the original back reflection, refer to 6.19.5.

The scan plan, utilizing array configurations specified in K7.2, shall demonstrate full ultrasonic coverage in two crossing directions to cover the HAZ and full weld volume~~ including weld fusion face coverage within ±10° of perpendicular (90° to the weld fusion face) for S-scans or ±5° of perpendicular for supplemental E-scans~~. Welds shall be tested using an angle-beam search unit conforming to the requirements of K5.3.

All welds in butt joints examined by PAUT shall be tested from the same face but opposite side of the weld axis where access is possible. ESW welds shall be inspected from both sides of the weld with sound entering the plate from the outside of each HAZ. ~~Welds in corner and T-joints shall be primarily tested from one side of the weld axis only.~~ All welds shall be tested using applicable line scans or scanning patterns necessary to detect both longitudinal and transverse discontinuities.

K7.4.1 Scanning Near Edges. If edges and corners prevent access or result in other limitations for encoded PAUT, these areas may be scanned by running the scan in the opposite direction toward the edge, or by nonencoded PAUT using scanning patterns described in Clause 6. Use of nonencoded PAUT shall be noted in the examination report.

K7.4.2 Restricted Access Welds. Groove welds in butt joints that cannot be examined from both sides of the weld axis using the angle-beam technique shall be scanned from alternate faces where possible to assure full coverage of the weld and HAZ is obtained. These situations shall be addressed with a modified scan plan and noted in the examination report.

K7.4.3 Backing. For joint configurations that will contain backing that is left in place, the scan plan shall consider the effects of the backing (see C-6.26.12 of AWS D1.1 for additional guidance on inspecting welds with steel backing).

K7.4.4 Inspection for Transverse Indications. Welds that are ground flush shall be inspected for transverse indications using scanning pattern D as shown in Figure 6.7. Scanning pattern E shall be used on welds with reinforcement. Encoding is not required for the transverse indication inspection.

K7.5 Scan Plan Storage. Scan plan parameters shall be configured on the phased array system storage and stored in a manner that will allow repeatability for subsequent examinations.

K8. Calibration for Testing

The phased array configuration as prepared in the scan plan shall be verified at intervals in accordance with 6.18.3 and as described below.

K8.1 Straight Beam Calibration. The ultrasonic range of the search unit shall be adjusted, using an E-scan at 0° set-up (or conventional straight beam probe), such that it will produce the equivalent of at least two plate thicknesses on the display. The sensitivity shall be adjusted at a location free of indications so that the first back reflection from the far side of the plate will be 80% ±5% of FSH. Minor sensitivity adjustments may be made to accommodate for surface roughness.

K8.2 Shear Wave Calibration

K8.2.1 Beam Angle Verification. The PAUT operator shall verify the beam angles to be within 2° of the minimum and maximum angles configured in S-scans or within 2° of the first and last VPAs configured for E-scans using the procedure stipulated in 6.21.2.2.

K8.2.2 Horizontal Sweep. The horizontal sweep shall be adjusted to represent the actual material path distance throughout all the configured angles using an IIW block or other alternate block as detailed in 6.16.1. The screen range shall be set at 3 times the material thickness at the minimum configured angle in the true depth display mode. If the joint configuration or thickness prevents full examination of the weld at these settings, the distance calibration shall be made at increased screen ranges as depicted in the scan plan.

K8.2.3 Time Corrected Gain (TCG). By use of the ~~supplemental~~ calibration block as specified in K5.7.1, a TCG shall be established throughout all configured angles at a minimum of three points throughout the material range to be tested. The TCG shall balance all calibration points within ±5% amplitude of each other.

K8.2.4 Amplitude Levels. The following amplitude levels shall be used when evaluating the test object for detection and rejection of indications (see Table K.2).

K8.2.4.1 Standard Sensitivity Level (SSL). The uncorrected standard sensitivity level shall be established at ~~50~~80% ±5% of full screen height off of the 1.5 mm [0.06 in] reflector in the calibration block as specified in K5.7. The SSL shall be modified by making any applicable corrections in accordance with K5.7.2. ~~This dB level shall be noted as the primary reference level dB~~The SSL including any applicable corrections shall be used for further evaluation of the test object.

K8.2.4.2 Automatic Reject Level (ARL). The ARL shall be defined as ~~5 dB over~~ 10 dB under SSL for tension welds and equal to the SSL for compression welds. ~~, which equals 89% FSH (see Figure K.4).~~

K8.2.4.3 Disregard Level (DRL). The DRL shall be defined as ~~6 dB~~18 dB under SSL for tension welds and 6 dB under SSL for compression welds.~~, which equals 25% FSH (see Figure K.4).~~

K8.2.4.4 Evaluation Level (EVL). The EVL shall be defined as 13 dB under SSL for tension welds and equal to the DRL for compression welds.

K8.3 Encoder Calibration. The encoder shall be calibrated at least weekly by the operator and verified through daily in-process checks to be within 1% of measured length for a minimum of half the total scan length. Encoder resolution shall be configured so that data is taken at 1 mm [0.04 in] increments or smaller.

K9. Examination Procedure

K9.1 X and Y. Coordinates shall be identified prior to scanning as required in 6.19.1 and 6.19.2.

K9.2 Straight Beam Scanning. Straight beam phased array examination using an E-scan at 0° shall be performed over the entire base metal area through which sound must pass. This straight beam examination may be performed using a conventional UT probe.

K9.2.1 Scanning shall be continuous over 100% of the area to be examined.

K9.2.2 When a discontinuity is observed during general scanning, the instrument shall be adjusted to produce a first reflection from the opposite side of a sound area of the plate to 80% full screen height. This instrument setting shall be maintained during evaluation of the discontinuity condition. All areas that cause a 50% reduction in the back-wall reflection or greater shall be recorded.

K9.2.3 Any indication evaluated as laminar reflectors in base material, which interfere with the scanning of examination volumes, shall require modification of the angle-beam examination technique such that the maximum feasible volume is examined, and the modification shall be noted in the record of the examination. If any area of base metal exhibits total loss of back reflection or an indication equal to or greater than the original back reflection height is located in a position that will interfere with the normal weld scanning procedure, its size and location shall be determined and reported on the UT report, and an alternate weld scanning procedure shall be used.

K9.3 Angle-Beam Scanning. Tension and compression welds shall be evaluated differently using angle-beam scanning.~~Automatic computer recording of essential ultrasonic data in the manner of line scans shall be performed down the axial length of each weld. Scanning shall be performed in accordance with the documented and approved scan plan as detailed in K7.~~

K9.3.1 Angle-Beam Scanning of Tension Welds. Angle-beam inspection of tension welds shall be performed using a two-part inspection procedure: (1) encoded line scanning shall be performed along the longitudinal axis of each weld with automated recording of essential ultrasonic data and (2) follow-up manual raster scanning shall be performed at all locations where an indication observed during an encoded line scan exceeded the DRL. Line scanning shall be performed in accordance with the documented and approved scan plan as detailed in K7.

K9.3.2 Angle-Beam Scanning of Compression Welds. Encoded line scanning shall be performed along the longitudinal axis of each weld with automated recording of essential ultrasonic data. Line scanning shall be performed in accordance with the documented and approved scan plan as detailed in K7.

K9.3.3~~1~~ Line Scanning Gain. Encoded line ~~S~~scanning shall be at SSL for compression welds and a minimum of 12 dB over SSL for tension welds. ~~may be performed at primary reference level sensitivity as configured in K8.2.4, provided soft gain or color palette alterations are made during evaluation to aid in detection. If scanning is performed at primary reference level, soft gain shall be increased by 6dB or the color palette adjusted to end at 50% screen height during the evaluation of the weld data. If color palette adjustment or soft gain increase is not used, 6dB of additional gain over primary reference level shall be applied during scanning. For manual supplemental examinations such as for transverse flaw detection, scanning shall be a minimum of 6dB over primary reference level.~~

K9.3.4~~2~~ Encoded Line Scanning. Scanning shall be ~~done~~performed with an encoder~~. Encoded line scanning shall be performed by using~~ and a mechanical fixture or apparatus which ~~to help~~ maintains fixed index offset positioning.

K9.3.5~~3~~ Scanning Speed. The indicated speed of acquisition that is established for the instrument for the given setup shall not be exceeded. If data dropout is noted, it shall not exceed 1% of the recorded data and no two consecutive lines of data shall be missed.

K9.3.6~~4~~ Data Collection. The PAUT operator shall ensure that ultrasonic examination data is recorded in an unprocessed form. A full and complete data recording set of the original A-scan data with no exclusionary gating or filtering other than receiver bandpass shall be included in the data record.

K9.3.7 Manual Raster Scanning. Manual raster scanning of tension welds shall be performed by manual manipulation of the probe when required per K9.3.1. The manual raster scanning shall be performed using Movement A, B, and C shown in Figure 6.7 in order to sweep all possible incidence angles over the indication. A screenshot shall be recorded and data documented at the location of maximum indication amplitude for all indications exceeding the DRL regardless of whether they are acceptable or rejectable.

K10. Evaluation

K10.1 Length Measurements. Indication length to mark the limits of repair or for evaluation against the length limits in Table K.4 shall be determined by using the 6 dB drop method described in 6.23.2. For saturated indications, in which the true peak amplitude measurement cannot be obtained, additional scans at lower gain levels shall be performed. For tension welds, the indication length shall be determined from manual raster scanning. For compression welds, the indication length shall be determined from the encoded line scan data files. ~~For saturated indications, in which the true peak amplitude measurement cannot be obtained, additional scans at lower gain levels shall be performed for Class B and C indications with near rejectable lengths or proximities to adjacent indications or weld intersections where applicable. The length may be determined from the stored data file.~~

K10.2 Acceptance Criteria. Except for additional requirements in K10.2.1 for T and corner joints loaded perpendicular to the weld, welds shall be acceptable provided they have no ~~cracks, nor any~~ indications ~~that~~ whose amplitude or amplitude and length exceed that specified in Table K.4~~2~~ for the applicable type of loading. Discontinuities shall be classified based on their maximum amplitude in accordance with Table K.3~~1~~. Acceptance evaluation is performed on the results of manual raster scanning for tension welds and encoded line scanning for compression welds. ~~(also see Figure K.4):~~

~~Manual PAUT may be used to supplement the scan in order to determine whether a discontinuity is a crack.~~

~~Indications characterized as cracks shall be considered unacceptable regardless of length or amplitude.~~

Class B ~~and C~~ indications shall be separated by at least 2L, L being the length of the longer indication, except that when two or more such indications are not separated by at least 2L, but the combined length of indications and their separation distance is equal to or less than the maximum allowable length under the provisions of Class B ~~or C~~, the flaw shall be considered a single acceptable indication.

Class B ~~and C~~ shall not begin at a distance less than 2L from the weld ends carrying primary tensile stresses, L being the indication length.

~~For Class C, determination of depth of discontinuity shall be determined by the location of the peak amplitude, at the angle producing the maximum signal amplitude.~~

K10.2.1 T and Corner Joints Loaded Perpendicular to the Weld. T and corner joints which are loaded in tension perpendicular to the weld axis shall be evaluated using the following acceptance criteria.

- Indications located within the middle half of the plate thickness shall be evaluated per K10.2.
- Indications located within the top or bottom quarter of the plate thickness (i.e., near the surface) shall be rejectable if the amplitude during follow-up raster scanning exceeds the EVL, regardless of the length.

K10.3 Repair. Repairs to welds found unacceptable by PAUT shall be made in accordance with 3.7. Repaired areas shall be retested using the same scan plan and techniques as used for the original inspection, unless the scan plan does not provide coverage of the repaired area. In this case, a new scan plan shall be developed for the repair area. The minimum length of the repair that shall be reinspected shall be the length of the gouge plus 50 mm [2 in] on each end.

K11. Data Analysis

K11.1 Validation of Coverage. Recorded data shall be assessed to ensure full execution of the scan plan over 100% of the required examination length.

K11.2 Data Analysis and Recording Requirements. The following are requirements for evaluation of data:

(1) The entire exam volume shall be analyzed, using gates and available cursors, to locate and identify the source, location, and nature for all indications exceeding the DRL for both the longitudinal and transverse scans. ~~Alternately, manual plotting may be used to augment on-board analysis, e.g., nonparallel or inconsistent geometries.~~

(2) Responses resulting from surface roughness, weld root, or ~~and~~ weld cap geometries shall be investigated and the basis for this classification should be noted on the report form.

(3) Any indication warranting evaluation shall be recorded to support the resultant disposition. The extent of recording shall be sufficient for reviewers and subsequent examiners to repeat the result and should stand alone as a written record.

(4) ~~Rejectable indications~~With the exception of indications noted in Item 2, all indications exceeding the DRL shall be reported as follows:

- For tension welds, indications greater than the DRL but less than the EVL, the report shall include a screenshot with the peak amplitude obtained from the follow-up raster scan and the corresponding location in the plate cross-referenced to the encoded line scan.
- For both tension and compression welds, indications greater than the EVL, the report shall include peak amplitude, discontinuity classification, length of indication, depth below the surface, and relative position to provide adequate information when repair is required. For tension welds the peak amplitude shall be documented with a a screenshot obtained from the follow-up raster scan and the corresponding location in the plate cross-referenced to the encoded line scan.

~~the report shall include peak amplitude, indication rating, length of indication, depth below the surface, and relative position to provide adequate information for the repair. Cursor placement, measurement features, and annotations and comments shall clearly support disposition.~~

(~~5) For welds designated in the contract documents as being Fracture Critical, indication ratings up to and including 6 dB less critical (higher) than acceptance levels shall be recorded on the test report for informational purposes.~~

K12. Data Management

K12.1 Data Management System. There shall be a data management scheme established consistent with job requirements and size.

K12.2 File Nomenclature. A systematic file naming scheme shall be used to control data management of calibration and set-up files, phased array data files, and digitally generated data report forms.

K12.3 Raw Data. All phased array data shall be saved in the original raw A-scan format.

K12.4 Data Reviewing. Any review and evaluation of the phased array data shall not change or affect the original A-scan data.

K13. Documentation and Reporting

K13.1 Reporting. Examination reports shall meet the requirements of 6.20 and may be output from the on-board reporting feature of the phased array unit provided all necessary information is included. Reports may also be produced ~~in the written manual UT conventional format or~~ by external computer-generation.

I~~f PAUT is being substituted for RT, t~~The written report shall include, at a minimum, encoded C-scans covering the entire length inspected and A~~, C,~~ and sectorial~~, and side~~ view~~s~~ (see K3.11) of all reportable indications. All raw data for PAUT substituted for RT shall be retained for the same duration required for radiographic film.

K13.2 Repairs. Results from PAUT inspections of repaired welds shall be tabulated on the original form (if available) or additional report forms, and shall be indicated by the appropriate repair number (R1, R2, R3, etc.)

K13.3 Scan Plan Reporting. The scan plan used during inspection shall accompany the report form.

K14. System Linearity Verification

K14.1 General Requirements. Linearity verifications shall be conducted at a minimum of every 12 months and recorded on a form similar to that shown in Table K.64. The verifications shall be conducted by a PAUT Level II or III, or at the Contractor's option, the equipment may be sent to the manufacturer for verification.

K14.1.1 The phased array instrument shall be configured to display an A-scan presentation.

K14.1.2 The time base of the A-scan shall be adjusted to a suitable range to display the pulse-echo signals selected for the particular linearity verification to be performed. A standard IIW or other linearity block similar to that described in ASTM E317, *Standard Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments*, shall be selected to provide signals to assess linearity aspects of the instrument (see Figure 6.5).

K14.1.3 Pulser parameters shall be selected for the frequency and bandpass filter to optimize the response from the probe used for the linearity verifications.

K14.1.4 The receiver gain shall be set to display nonsaturating signals of interest for display height and amplitude control linearity assessments.

K14.2 Display Height Linearity Verification Procedure

(1) With the phased array instrument connected to a probe (shear or longitudinal) and coupled to any block that will produce two signals, the probe shall be adjusted such that the amplitude of the two signals are at 80% and 40% of the display screen height.

(2) The gain shall be increased using the receiver gain adjustment to obtain 100% of full screen height of the larger response. The height of the lower response is recorded at this gain setting as a percentage of full screen height.

(3) The height of the higher response shall be reduced in 10% steps to 10% of full screen height and record the height of the second response for each step.

(4) The larger signal shall be returned to 80% to ensure that the smaller signal has not drifted from its original 40% level due to coupling variation. Repeat the test if variation of the second signal is greater than 41% or less than 39% full screen height.

(5) For an acceptable tolerance, the responses from the two reflectors shall bear a 2-to-1 relationship to within ±3% of full screen height throughout the range 10% to 100 % (99% if 100% is saturation) of full screen height.

(6) The results shall be recorded on an instrument linearity form as shown in Table K.64.

K14.3 Amplitude Control Linearity Verification Procedure

Each of the pulser-receiver components shall be checked to determine the linearity of the instrument amplification capabilities. For instruments configured to read amplitudes greater than can be seen on the display, a larger range of checkpoints may be used. For these instruments, the gated output instead of the A-scan display shall be verified for linearity.

(1) A flat (normal incidence) linear array phased array probe shall be selected having at least as many elements as the phased array ultrasonic instrument has pulsers.

(2) The phased-array ultrasonic instrument shall be configured using this probe to have an E-scan at 0°. Each focal law will consist of one element. The scan will start at element number 1 and end at the element number that corresponds to the number of pulsers in the phased-array instrument.

(3) The probe shall be coupled to a suitable surface to obtain a pulse-echo response from each focal law. The backwall echo from the 25 mm [1 in] thickness of the IIW block or similar block provides a suitable target option. Alternatively, immersion testing may be used.

(4) Channel 1 of the pulser-receivers of the phased-array instrument shall be selected. Using the A-scan display, monitor the response from the selected target. Adjust the gain to bring the signal to 40% screen height.

(5) The gain shall be added to the receiver in the increments of 1 dB, then 2 dB, then 4 dB, and then 6 dB. Remove the gain added after each increment to ensure that the signal has returned to 40% display height. Record the actual height of the signal as a percentage of the display height.

(6) The signal shall be adjusted to 100% display height, remove 6 dB gain and record the actual height of the signal as a percentage of the display height.

(7) Signal amplitudes shall fall within a range of +/- 3% of the display height required in the allowed height range of Table K.64.

(8) The sequence from (4) to (7) shall be repeated for all other pulser-receiver channels and record results on a linearity report form as shown in Table K.64.

K14.4 Time-Base Linearity (Horizontal Linearity) Verification Procedure

(1) The phased array instrument shall be configured to display an A-scan presentation using a 250 mm [10 in] range.

(2) Any longitudinal (compression) wave probe shall be selected and the phased-array instrument shall be configured to display a range obtaining at least ten multiple back reflections from the 25 mm [1 in] wall thickness of the calibration block.

(3) The phased-array instrument shall be set to an analog-to-digital conversion rate of at least 80 MHz.

(4) With the probe coupled to the block and the A-scan displaying 10 clearly defined multiples as illustrated in Figure K.2~~5~~, the display software shall be used to assess the interval between adjacent backwall signals.

(5) The acoustic velocity of the test block shall be set by calibration (ASTM E494 may be used as a guide), the acoustic velocity in the display software shall be entered, and the display shall be configured to read out in distance (thickness).

(6) Using the reference and measurement cursors, the interval between each multiple shall be determined and the interval of the first 10 multiples shall be recorded.

(7) Each intermediate trace deflection shall be correct within 2% of the screen width.

K15. Background References

K15.1 ASTM E494, *Standard Practice for Measuring Ultrasonic Velocity in Materials*

K15.2 ASTM E2491, *Standard Guide for Evaluating Performance Characteristics of Phased-Array Ultrasonic Examination Instruments and Systems*

K15.3 ASTM E2700, *Standard Practice for Contact Ultrasonic Testing of Welds Using Phased Arrays*

K15.4 ISO 2400, *Non-destructive testing – Ultrasonic examination specification for calibration block No. 1*

K15.5 NCHRP Project 14-35, *Acceptance Criteria of Complete Joint Penetration Steel Bridge Welds Evaluated Using Enhanced Ultrasonic Methods*

Table K.1
Allowable Incidence Angles (See K5.7.2.2)

Percent Difference in Shear Wave Velocity (v_s)	Allowable Incidence Angles
<1%	40°-70°
Between 1% and 2.5%	40°-60°

Table K.2
Sensitivity Levels

Sensitivity Level	Compression	Tension
SSL	1.5 mm [0.06 in] SDH	1.5 mm [0.06 in] SDH
ARL	Same as SSL	10 dB under SSL
DRL	6 dB under SSL	18 dB under SSL
EVL	6 dB under SSL	13 dB under SSL

Table K.3~~1~~
Discontinuity Classification

Discontinuity Classification	Description[a]
A	≥ ARL
B	~~> SLL~~≥ EVL, < ARL
~~C~~	~~> DRL, ≤ SLL~~
~~D~~	~~≤ DRL~~

[a] See K8.2.4.

Table K.4~~3~~
PAUT Acceptance Criteria (see K10.2)

Maximum Discontinuity Amplitude Level Obtained	Maximum Discontinuity Lengths by Type of Loading	
	Compression[a]	Tension[b]
Class A (> ARL)	None allowed	None allowed
Class B (~~> SLL~~> EVL, < ARL)	~~20 mm [3/4 in]~~50 mm [2 in]	~~12 mm [1/2 in]~~25 mm [1 in]
~~Class C (> DRL, < SLL)~~	~~50 mm [2 in]~~	~~Middle half of weld: 50 mm [2 in]~~
		~~Top or bottom quarter of weld: 20 mm [3/4 in]~~
~~Class D (< DRL)~~	~~Disregard~~	~~Disregard~~

[a] Evaluation based on encoded line scan results
[b] Evaluation based on manual raster scan results

Table K.5~~2~~ **Essential Variables for PAUT (see K7.1 and K7.3)**
Element numbers used for focal laws
Angular range of S-scan
Calibration block geometry
Direction of sound propagation in relation to rolling direction
Acoustic property verification
Attenuation correction, if required
Manufacturer's documented permitted wedge angular range
Weld configurations to be examined, including thickness dimensions and base material product form (pipe, plate, etc.)
Weld type (ESW or non-ESW)
Compression or tension scanning method
Surface curvature along index axis (e.g., for longitudinal weld in tubular member)
The surfaces from which the examination is performed
Techniques (straight beam, angle beam, contact)
Search unit types, frequencies, element sizes and shapes
Phased array units
Manual vs. automated/semi-automated scanning
Method for discriminating geometric from weld flaw~~defect~~ indications
Decrease in scan overlap
Method for determining focal/delay laws if other than on-board equipment algorithms included in the software revision specified
Acquisition or analysis software type
Probe manufacturer and model
Any increase in scanning speed
Couplant, if not listed in 6.19.4
Computer enhanced data analysis

Table K.64
Linearity Verification Report Form (see K14)

Location:			Date:		
Operator:			Signature:		
Instrument:			Couplant:		
Pulser Voltage (V):		Pulse Duration (ns):	Receiver (band):		Receiver Smoothing:
Digitization Frequency (MHz):			Averaging		
Display Height Linearity			Amplitude Control Linearity		
Large %	Small Allowed Range %	Small Actual %	Ind. Height %	dB	Allowed Range %
100	47-53		40	+1	42-47
90	42-48		40	+2	48-52
80	40	40	40	+3	60-66
70	32-38		40	+4	77-83
60	27-33		40	+6	47-53
50	22-28				
40	17-23				
30	12-18				
20	7-13				
10	2-8				

Amplitude Control Linearity Channel Results: (Note any channels that do not fall in the allowed range)															
Channel (Add more if required for 32 or 64 pulser-receiver units)															
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Time Based (Horizontal) Linearity (for 25 mm [1 in] IIW Blocks)										
Multiple	1	2	3	4	5	6	7	8	9	10
Thickness	25 mm [1 in]	50 mm [2 in]	75 mm [3 in]	100 mm [4 in]	125 mm [5 in]	150 mm [6 in]	175 mm [7 in]	200 mm [8 in]	225 mm [9 in]	250 mm [10 in]
Measured Interval										
Allowed deviation (Yes/No)										

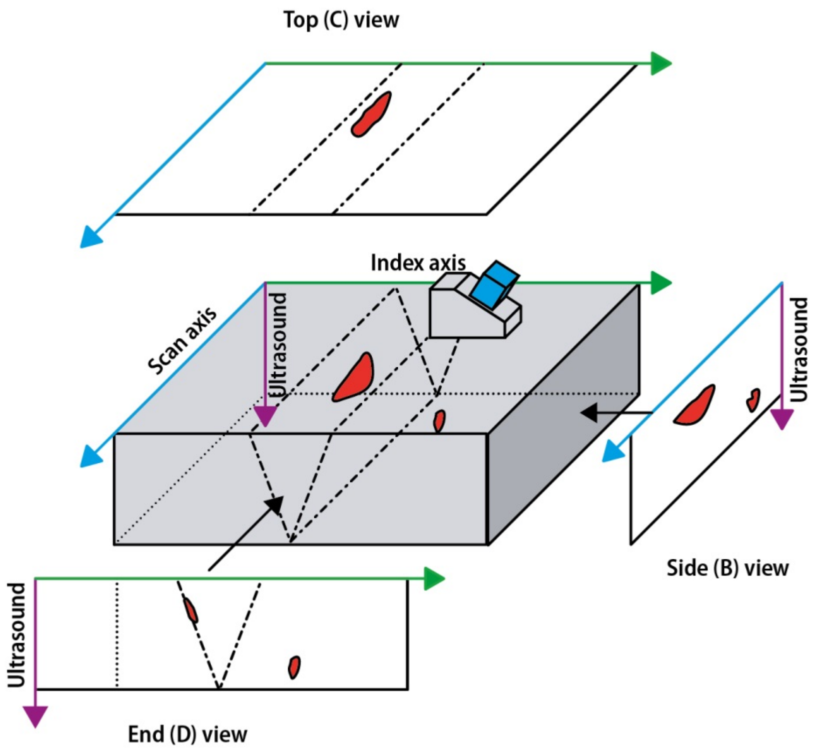
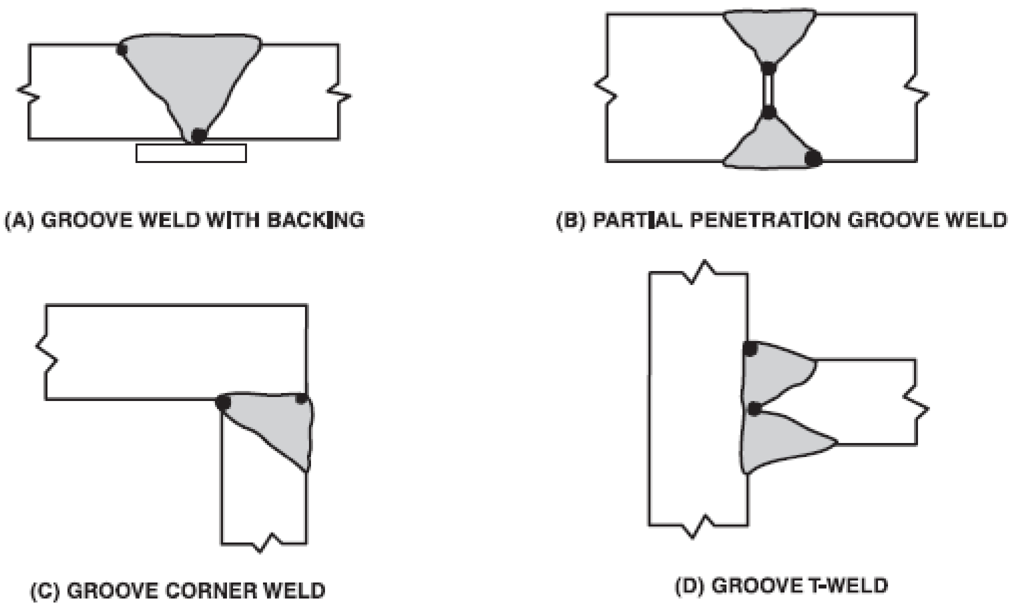


Figure K.1—Phased Array Imaging Views (see K3.11)

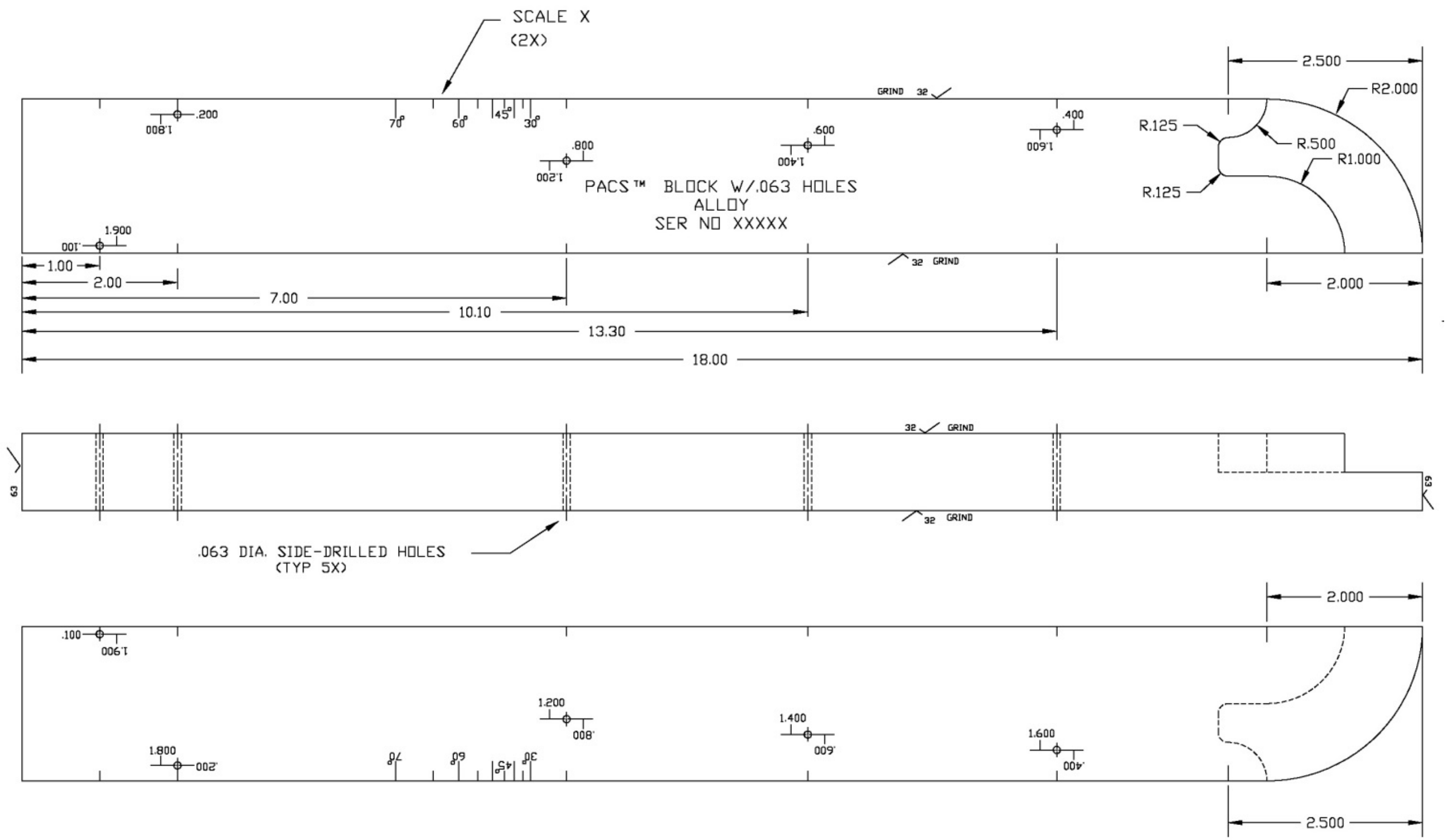


~~**Figure K.2—Example Standard Reflector Locations in Weld Mockup (see K5.7)**~~

~~*Source:* Adapted from AWS D1.1/D1.1M:2015, *Structural Welding Code—Steel*, Figure Q.3, American Welding Society.~~

~~Graphic Artist:~~ ~~**Figure K2(C): Replace "GROOVE CORNER WELD" with "GROOVE WELD IN CORNER JOINT"**~~

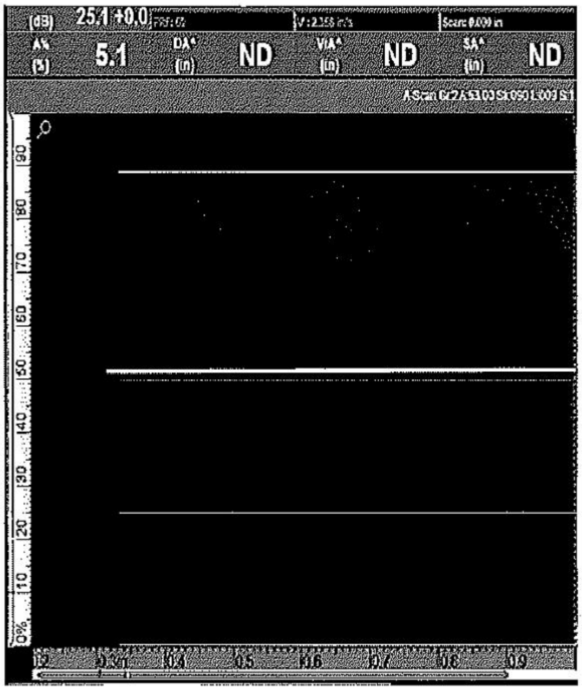
~~**Figure K2(D): Replace "GROOVE T-WELD" with "GROOVE WELD IN T-JOINT"**~~



~~**Figure K.3—Example Phased Array Calibration Standard (PACS) Type Block (see K5.7.1)**~~

~~**SECRETARY NOTE: If any of these units are measurements, we need to have both SI and US Customary shown. I do not know what these numbers represent, so I will need a subcommittee member to do this.**~~

5786



~~ARL~~
~~(5 dB over SSL)~~

~~SSL~~

~~DRL~~
~~(6dB under SSL)~~

~~**Figure K.4—Sensitivity Levels (see K8.2.4 and K10.2)**~~

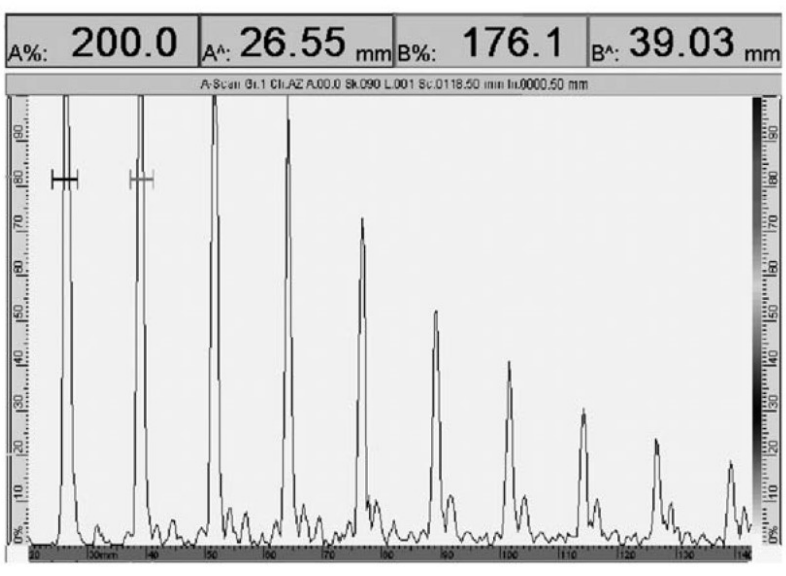


Figure K.2~~5~~—Example of Time Based Linearity Verification (see K14.4)

G.2 Annex K Commentary

C-Annex K

Advanced Ultrasonic Examination

C-K2 – Scope. The upper limit on thickness helps ensure that excessively long sound paths, especially at higher search angles, do not result. Further, Article K5.7.2 provides additional discussion regarding considerations during calibration associated with sound path.

While these provisions are specifically intended to be used using PAUT, many of the provisions provide important considerations when using other methods of ultrasonic inspection.

C-K3.4 E-Scan. Also called an electronic scan.

C-K3.11.1 A-Scan. This is the view by which all other views are formed and is the basis for acceptance or rejection of ultrasonic indications.

C-K3.11.2 C-Scan. Normally the C-scan is uncorrected for angled beam inspections.

C-K3.11.3 Sectorial View. Also called S-scan or sectorial scan. Those terms are not used in this annex because they are also used to refer to a beam movement pattern (see K3.18).

C-K3.11.4 Side View. Sometimes called B-scan or D-scan. These terms are not used in this annex because there is no consensus on which letter corresponds to side view or end view.

C-K3.11.5 End View. Sometimes called B-scan or D-scan. These terms are not used in this annex because there is no consensus on which letter corresponds to side view or end view.

C-K3.12 Line Scan. Also called a linear scan. This term is not used in this annex because "linear scan" is also used to refer to an E-scan (see K3.4).

Certain types of PAUT operational software allow for the configuration of multiple scan types (e.g., S-scan + S-scan, or S-scan + E-scan) to be performed in a single line scan. This technology allows for data collection from multiple search units in a single line scan or from a single search unit but with multiple scan types generated in sequences.

C-K3.16 Multiple piezoelectric elements are sometimes arranged in patterns in a common housing; these are usually linear, matrix, or annular in shape.

C-K3.19 S-Scan. Also called a sector scan, sectorial scan, swept angle scan, or azimuthal scan. See C-K3.11.3 for the use of this term and some of its alternatives to mean a type of imaging view or data display.

C-K3.20 Saturated Signal. Some systems contain enough bit depth to read signal amplitudes above 100% FSH, but even then there is an upper voltage limitation that the system can adequately measure the true amount of voltage returned from the search unit.

C-K3.25 Time Corrected Gain. Also called time varied gain (TVG).

C-K3.26 Virtual Probe Aperture (VPA). Also called active aperture.

C-K3.27 Volume-Corrected Scan. This correction is found to be useful to compensate for surface path distance variations in angle-beam inspections.

<u>**C-K4.1 Personnel Qualification Requirements.** While the specific requirements of the practical examination are not provided herein (i.e., the number and geometry of test plates, flaw type, orientation, size, etc.), the owner should verify that the performance testing represents to a reasonable degree the inspections that will be performed by the technician. For example, if transition butt welds will be inspected, it would be prudent to ensure the performance testing includes specimens that include transition butt welds. The number, type, and size of flaws should represent those which are possible with the given weld process. When developing a test matrix, the number of flaws should range between 5 and 15 and be distributed within 4 to 8 plates with consideration given to including blank specimens. Multiple flaw types should also be included (e.g., cracks, porosity, slag, etc.) The length of the scan should be sufficient to ensure the technician understands use of the encoder. A minimum length of 18 inches has been found to be reasonable. Performance testing should also include calibration, in particular as related to Article K5.7 and reporting tasks.</u>

<u>**C-K4.2 Certification Requirements.** Recently completed research has shown that the previous requirements for certification did not ensure operators were capable of reliably detecting and characterizing critical weld flaws. While formal training and time on the job are very important, these do not ensure capability and reliability. The objective of the inspection is to identify flaws and establish if they are rejectable or acceptable. The updated certification requirements are intended to better identify technicians, through more rigorous performance testing, that have demonstrated the skills needed to reliably meet this objective.</u>

<u>**C-K5.3.1 Phase Array Probe.** Optimal probe parameters for butt welds greater than 0.5" thickness can be achieved by selecting a 2.25 MHz frequency probe with an active aperture of 14x14mm to 20x20mm (16x16mm optimal). For thin plates, smaller apertures for 2.25 MHz probes may be more appropriate. It is not recommended to use a 2.25 MHz probe with an active aperture smaller than 8x8mm due to the very short focal distance associated with such a configuration.</u>

<u>Use of higher frequency probes, such as 5 MHz, may be appropriate, especially for thin materials. However, the significant difference in material attenuation between the test object and calibration block must be taken into account for plate thicknesses greater than 0.5". The recommended aperture for 5 MHz probes is between 5x5mm – 10x10mm for plates under 0.5" thickness and 9x9mm -13x13mm for plates greater than 0.5" thickness.</u>

<u>Use of probes with a frequency below 2 MHz is not recommended for most applications using A709 grades of steel.</u>

<u>**C-K5.7 - Calibration for Variation in Acoustic Properties.** Historically, it has been assumed that the acoustic properties (e.g., velocity, attenuation, etc.) of common bridge steels do not vary significantly. However, recently completed research has shown that this assumption is not always</u>

valid. For example, attenuation characteristics of the test object can be much different than the calibration block, in particular when higher frequency probes are used. The velocity of shear waves in some A709 steels produced using thermo-mechanical control process (TMCP) have been shown to be considerably different than the shear wave velocity of the calibration block. Further, some TMCP processed steels have been found to be acoustically anisotropic (i.e., the shear wave velocity varies between rolling and transverse rolling directions). Special caution and calibration steps must be taken when scanning acoustic anisotropic materials at an oblique orientation to the rolling direction. In these instances, the sound beam may split into two beams traveling at different speeds resulting in significant decreases amplitude and a specific indication showing up as two unique indications.

C-K5.7.1 ~~Supplemental~~ Calibration Block Geometric and Temperature Requirements. Calibration blocks are commonly removed from plate material and then rotated to increase the first leg sound path by directing sound into the edge of the plate (i.e., parallel to the plane of the plate). This is commonly done in order to minimize the thickness of the plate from which the calibration block is fabricated. Due to the effects of acoustically anisotropy, the acoustic properties of the calibration block may be different depending whether the block is scanned through the rolled surface or through the edge of the original plate. Therefore, the acoustic properties of the calibration block must be within the requirements of K5.7 for the direction of scanning that will be used during calibration.

In order to establish TCG throughout the usable sound path range of all configured angles in the test object, the calibration block must be able to accommodate a TCG point at a sound path at or beyond the longest sound-path during the inspection. For full V-path examinations from one face of the joint (i.e., only from Face A as illustrated in Table 6.2), the sound path of the last TCG point in the calibration block must accommodate the second leg sound path in the test object. There are two possible methods to accomplish this (1) fabricating a calibration block which is at least 2.25 times the thickness of the test object and performing all of the TCG calibration in the first leg (i.e., rotating the plate) or (2) fabricating a long calibration block and performing calibration using multiple backwall reflections (i.e., third leg). It is also recommended that the block be able to accommodate pitch-catch comparison to the test object. Sample calibration block geometry for the use of multiple backwall reflections for 1” and 2” thick plate material are shown in Figure C-K.1 and Figure C-K.2, respectively. The dimensions for the plate length, width, side drilled hole depth, spacing, and placement may all be different depending on the plate thickness and transducer size and aperture.

C-K5.7.2.1 Attenuation Requirements. Transfer correction using the pitch-catch method involves two probes with one acting as a transmitter and the other as a receiver. The sound is skipped off of the backwall of the calibration block and the test object in a single-V and double-V path, as shown in Figure C-K.3, and the amplitude is measured at each location with the same transducer settings. These amplitude measurements are then plotted against the sound path and lines are drawn through the measurements corresponding to the calibration block and the test object, as shown in Figure C-K.4. The difference in amplitude at the maximum inspection sound path can be directly obtained from these lines. The thickness of the calibration block and the test object do not need to match, but the amplitude measurements must be made in the far field in order to ensure that the change in amplitude is due to attenuation.

C-K5.7.2.2 Shear Wave Velocity Requirements. Difference between the velocity of shear waves in the test object and the calibration block can lead to significant errors in measured amplitude and cause beam divergence, especially at higher search angles (e.g., >60 degrees) leading to mis-location of the indication.

Measurement of the shear wave velocity in the test object and calibration may be provided either directly or indirectly. The direct method includes use of a normal incidence shear wave transducer which emits a polarized shear wave and can be used similar to a normal incidence compression wave (i.e., straight beam) probe to measure the shear wave velocity in a specific polarized direction by using successive backwall signals. Shear wave couplant is required in order to propagate shear waves directly from the transducer to the test piece. Use of this method can directly evaluate acoustic anisotropic behavior by rotating the polarized shear wave transducer between the rolled and transverse to rolled directions.

The indirect method for measuring the shear wave velocity involves measuring the actual incidence angle of a shear wave probe in the test piece and using Snell's Law, along with the standard wedge angle and velocity, to calculate the corresponding velocity in the test piece. The actual incidence angle may be determined through maximizing the amplitude of a reference reflector or pitch-catch measurement in a single-V path. The incidence angle is then measured using the horizontal and vertical components of the sound path (i.e., index offset and depth).

C-K7.1 Scan Plans. ~~The same scan plan may be used for similar weld geometries with similar surrounding component geometries as long as the weld and HAZ are covered.~~ -It may be desirable to develop a library of scan plans that are applicable to common welded joints used in bridges. For example, a set of accepted scan plans for transition butt welds of plates of various thickness. However, the user must ensure that all calibration checks noted in Article 5.7.2 have been performed to account for various in acoustic properties of the base metal and weld metal.

C-K7.1.1 Caution should be applied when using computer modeling programs for creating scan plan because computation errors are possible, which can lead to inadequate coverage. Due to this, manual plotting should be used to verify scan plan coverage of the initial configuration when computer modeling is used.

C-K7.2.1 Index Positions. The number of index positions required will increase as the material thickness increases. For thinner materials of approximately 6 mm [1/4 in] or less, a single index may supply the proper coverage if the part configuration allows, but sound coverage must be provided in two crossing directions. For material thickness above this, 2 or more index positions are typically required. Ultimately, the adequacy of the number of index positions is determined by the coverage shown in the scan plan and dictated by the ability to meet the coverage requirements of K7.4.

C-K7.2.3 Supplemental E-Scans. E-scans may be useful for welds that can be accessed only from a single side, for welds in T-joints, or other configurations in which complete coverage of the weld, fusion face, or HAZ will be difficult.

C-K7.4 Testing of Welds. In plates greater than 2" thick, excessive beam spread and amplitude differences due to attenuation have been observed. In order to mitigate these effects, consideration should be given to scanning from both faces (i.e., Face A and Face B as illustrated in Table 6.2) in order to limit the sound path needed for full coverage in two crossing directions. For welds in corner or T-joints, the weld may be examined with a straight beam or low-angle longitudinal waves from an appropriate face to aid in obtaining coverage.

C-K7.4.4 Inspection for Transverse Indications. Encoded scanning is possible but not practical with scanning pattern D and not compatible with scanning pattern E. Therefore, encoding is not required for inspection for transverse indications. However, if an encoded line scan is used the coverage provided by the passive direction of the sound beam should be considered.

C-K8.2.4 Amplitude Levels. The amplitude levels used for evaluation of the test object for detection and rejection of indications are based on NCHRP Project 14-35.
~~**C-K8.2.4 Standard Sensitivity Level (SSL).** SSL, ARL, and DRL are based on AWS D1.1 Annex Q. Annex Q rejection level is 5 dB above SSL. 5 dB is a 1.78:1 ratio. 50% (height of SSL) × 1.78 = 89% (height of ARL).~~

C-K9.3.3~~1~~ Line Scanning Gain. Additional scanning gain when TCG is applied is intended to aide in detection of relevant indications. ~~for manual examinations. Most phased array equipment or evaluation software has the capabilities to increase gain (or similar with color palette adjustments) to serve the same purpose of aiding in detection of discontinuities. Additionally, gain settings greater than 6dB above SSL would produce saturated signals that would interfere with relevant signals for acceptance.~~

C-K9.3.5~~3~~ Scanning Speed. Exceeding the indicated scanning speed can cause data dropout.

C-K10.2 Acceptance Criteria. The acceptance criteria are based on the research conducted through NCHRP Project 14-35. These limits are founded in fitness-for-service principles by correlating the amplitude levels associated with critical flaw sizes in steel bridge welds using numerical simulations and experimental testing. ~~Characterizing defects as cracks is done by assessing the location of the indication, signal rise-fall time, pulse duration, echo dynamic patterns, and amplitude. If cracks are suspected but cannot be confidently characterized, alternate NDT methods should be used to help classify the indication. There are various resources and training available for defect characterization. One such resource is the ASME *Boiler and Pressure Vessel Code*, Section V, Nonmandatory Appendix P, "Phased Array (PAUT) Interpretation." Annex Q of AWS D1.1 has diagrams that are useful to understanding these criteria.~~

C-K10.2.1 T and Corner Joints Loaded Perpendicular to the Weld. Smaller amplitude limits are necessary for indications near the surface of T and corner joints loaded perpendicular to the weld axis due to concentration of stresses in this region. The amount of stress concentration depends on the geometry of the joint and stiffness of the connecting elements.

C-K11.2 Data Analysis and Recording Requirements. Benign indications such as those confirmed to be due to geometry and metallurgy need only be noted on the report form. For other indications, which may be more critical, additional documentation is required for the permanent record. Previously, additional reporting requirements were in place for welds in Fracture Critical Members. Since the disregard level used for encoded line scanning and the acceptance criteria for tension welds are based on fracture mechanics and critical flaw sizes, those additional reporting requirements are not necessary. ~~Post-acquisition data analysis will result in numerous evaluative actions and manipulations intended to characterize indication responses from benign geometries and metallurgical responses. This process, by its nature, will require modification to ensure complete and systematic disposition of the examination record.~~

C-K13.1 Reporting. For particularly long retention requirements, measures may need to be taken so that the data remains readable (not only that the storage medium is intact but that there is software to read it).

C-K14.2(1) The probe adjustment may be performed with an angle-beam or 0° technique. The two signals may be obtained by using a block with multiple side drilled holes located close in proximity, multiple signals from radius as in a standard IIW/DSC block, or multiple thicknesses such as the DS block shown in Figure 6.6. The probe is then manipulated to the optimum position over the reflectors to obtain a 2:1 signal ratio. Once the 2:1 ratio is established, the probe will remain in that position and gain adjustments are made to set the indications at the specified amplitude.

(2) The gain shall be increased using the receiver gain adjustment to obtain 100% of full screen height of the larger response. The height of the lower response is recorded at this gain setting as a percentage of full screen height.

(3) The height of the higher response shall be reduced in 10% steps to 10% of full screen height and record the height of the second response for each step.

(4) The larger signal shall be returned to 80% to ensure that the smaller signal has not drifted from its original 40% level due to coupling variation. Repeat the test if variation of the second signal is greater than 41% or less than 39% full screen height.

(5) For an acceptable tolerance, the responses from the two reflectors shall bear a 2 to 1 relationship to within ±3% of full screen height throughout the range 10% to 100 % (99% if 100% is saturation) of full screen height.

(6) The results shall be recorded on an instrument linearity form as shown in Table K4.

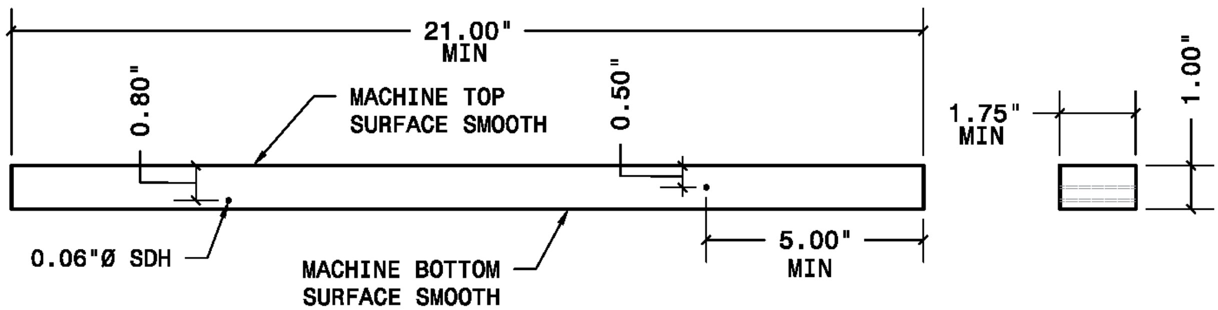


Figure C-K.1 – Sample Calibration Block for 1" Thick Plate

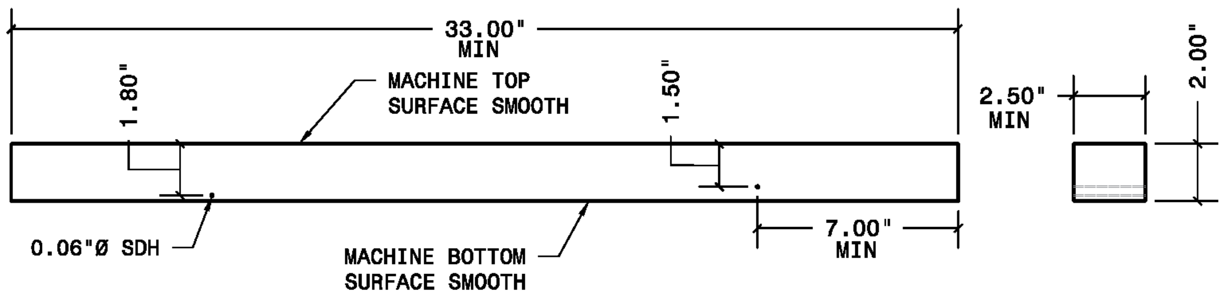


Figure C-K.2 – Sample Calibration Block for 2" Thick Plate

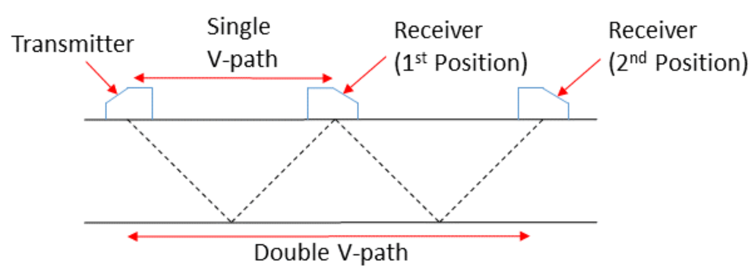


Figure C-K.3 – Transfer Correction Probe Locations

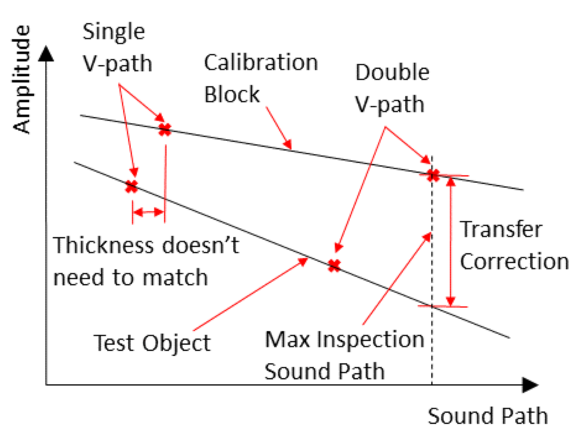


Figure C-K.4 – Transfer Correction Amplitude