Standard Guide for Evaluating Performance Characteristics of Phased-Array Ultrasonic Testing Instruments and Systems[1]

This standard is issued under the fixed designation E2491; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This guide describes procedures for evaluating some performance characteristics of phased-array ultrasonic examination instruments and systems.

1.2 Evaluation of these characteristics is intended to be used for comparing instruments and systems or, by periodic repetition, for detecting long-term changes in the characteristics of a given instrument or system that may be indicative of impending failure, and which, if beyond certain limits, will require corrective maintenance. Instrument characteristics measured in accordance with this guide are expressed in terms that relate to their potential usefulness for ultrasonic examinations. Other electronic instrument characteristics in phased-array units are similar to non-phased-array units and may be measured as described in Guide E1065 or E1324.

1.3 Ultrasonic examination systems using pulsed-wave trains and A-scan presentation (rf or video) may be evaluated.

1.4 This guide establishes no performance limits for examination systems; if such acceptance criteria are required, these must be specified by the using parties. Where acceptance criteria are implied herein they are for example only and are subject to more or less restrictive limits imposed by customer's and end user's controlling documents.

1.5 The specific parameters to be evaluated, conditions and frequency of test, and report data required, must also be determined by the user.

1.6 This guide may be used for the evaluation of a complete examination system, including search unit, instrument, interconnections, scanner fixtures and connected alarm and auxiliary devices, primarily in cases where such a system is used repetitively without change or substitution. This guide is not intended to be used as a substitute for calibration or standardization of an instrument or system to inspect any given material.

1.7 Required test apparatus includes selected test blocks and position encoders in addition to the instrument or system to be evaluated.

1.8 Precautions relating to the applicability of the procedures and interpretation of the results are included.

1.9 Alternate procedures, such as examples described in this document, or others, may only be used with customer approval.

1.10 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.11 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Instruments and Systems without the Use of Electronic Measurement Instruments

E494 Practice for Measuring Ultrasonic Velocity in Materials

E1065 Practice for Evaluating Characteristics of Ultrasonic Search Units

E1316 Terminology for Nondestructive Examinations

E1324 Guide for Measuring Some Electronic Characteristics of Ultrasonic Testing Instruments

3. Terminology

3.1 Refer to Terminology E1316 for definitions of terms in this guide.

4. Summary of Guide

4.1 Phased-array instruments and systems have similar individual components as are found in traditional ultrasonic

[1] This guide is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.06 on Ultrasonic Method.

Current edition approved June 1, 2013. Published June 2013. Originally approved in 2006. Last previous edition approved in 2008 as E2491 - 08. DOI: 10.1520/E2491-13.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

systems that are based on single channel or multiplexed pulse-echo units. These include pulsers, receivers, probes and interconnecting cables. The most significant difference is that phased-array systems form the transmitted ultrasonic pulse by constructive phase interference from the wavelets formed off the individually pulsed elements of the phased-array probes.

4.2 Each phased-array probe consists of a series of individually wired elements that are activated separately using a programmable time delay pattern. Varying the number of elements used and the delay time between the pulses to each element allows control of the beam. Depending on the probe design, it is possible to electronically vary the angle (incident or skew), or the focal distance, or the beam dimensions, or a combination of the three. In the receiving mode, acoustic energy is received by the elements and the signals undergo a summation process utilizing the same type of time delay process as was used during transmission.

4.3 The degree of beam steering available is dependent on several parameters including; number of elements, pitch of the element spacing, element dimensions, element array shape, resonant frequency of the elements, the material into which the beam is directed, the minimum delay possible between firing of adjacent pulsers and receivers and the pulser voltage characteristics.

4.4 Pulser and receiver parameters in phased-array systems are generally computer controlled and the received signals are typically displayed on computer monitors via computer data acquisition systems and may be stored to computer files.

4.5 Although most systems use piezo-electric materials for the elements, electro-magnetic acoustic transducer (EMAT) devices have also been designed and built using phased-array instrumentation.

4.6 Most phased array systems can use encoders for automated and semi-automated scanning.

4.7 Side Drilled Holes used as targets in this document should have diameters less than the wavelength of the pulse being assessed and long enough to avoid end effects from causing interfering signals. This will typically be accomplished when the hole diameter is between about 1.5 mm and 2.5 mm and 20 mm to 25 mm in length.

5. Significance and Use

5.1 This guide is intended to evaluate performance assessment of combinations of phased-array probes and instruments. It is not intended to define performance and acceptance criteria, but rather to provide data from which such criteria may be established.

5.2 Recommended procedures described in this guide are intended to provide performance-related measurements that can be reproduced under the specified test conditions using simple targets and the phased-array test system itself. It is intended for phased-array flaw detection instruments operating in the nominal frequency range of 1 MHz to 20 MHz, but the procedures are applicable to measurements on instruments utilizing significantly higher frequency components.

5.3 This guide is not intended for service calibration, or maintenance of circuitry for which the manufacturer's instructions are available.

5.4 Implementation of specific assessments may require more detailed procedural instructions in a format of the using facility.

5.5 The measurement data obtained may be employed by users of this guide to specify, describe, or provide a performance criteria for procurement and quality assurance, or service evaluation of the operating characteristics of phased-array systems.

5.6 Not all assessments described in this guide are applicable to all systems. All or portions of the guide may be used as determined by the user.

6. Procedure

6.1 Procedures for assessment of several parameters in phased-array systems are described in Annexes A1 to A7.

6.1.1 These include; determination of beam profile, beam steering capability, element activity, focusing capability, software calculations (controls and display of received signals), compensation for wedge attenuation, receiver gain linearity.

7. Keywords

7.1 characterization; focal point; phased-array; phased-array probe; sound beam profile; ultrasound

ANNEXES

(Mandatory Information)

A1. DETERMINATION OF PHASED-ARRAY BEAM PROFILE

A1.1 Introduction

A1.1.1 This annex describes procedures to determine beam profiles of phased-array probes. Either immersion or contact probe applications can be addressed using these procedures. However, it should be cautioned that assessments of contact probes may suffer from variability greater than imposed tolerances if proper precautions are not taken to ensure constant coupling conditions.

A1.2 Test Setup

A1.2.1 For single focal laws where the beam is fixed (that is, not used in an electronic or sectorial scan mode) and the probe is used in an immersion setup, the ball-target or hydrophone options described in E1065 may be used. For phased array probes used in a dynamic fashion where several focal laws are used to produce sectorial or electronic scanning it may be possible to make beam-profile assessments with no or little mechanical motion. Where mechanical motion is used it shall be encoded to relate signal time and amplitude to distance moved. Encoder accuracy shall be verified to be within tolerances appropriate for the measurements made. Descriptions made for electronic scan and sectorial scan beam profile assessments will be made for contact probes; however, when assessment in water is required the machined targets may be replaced with rods or balls as appropriate.

A1.2.2 *Linear-Array Probes*—Linear-array probes have an active plane and an inactive or passive plane. Assessment of the beam in the active plane should be made by use of an electronic scan sequence for probes with sufficient number of elements to electronically advance the beam past the targets of interest. For phased array probes using a large portion of the available elements to form the beam the number of remaining elements for the electronic raster may be too small to allow the beam to pass over the target. In this case it will be necessary to have encoded mechanical motion and assess each focal law along the active plane separately.

A1.2.3 Side-drilled holes should be arranged at various depths in a flaw-free sample of the test material in which focal laws have been programmed for. Using the linear scan feature of the phased-array system the beam is passed over the targets at the various depths of interest. The electronic scan is illustrated schematically in Fig. A1.1.

A1.2.4 Data collection of the entire waveform over the range of interest shall be made. The display shall represent amplitude as a color or grayscale. Time or equivalent distance in the test material shall be presented along one axis and distance displaced along the other axis. This is a typical B-scan as illustrated in Fig. A1.2.

A1.2.5 Data display for an electronic scan using a phased-array probe mounted on a wedge can be similarly made using simple orthogonal representation of time versus displacement or it can be angle corrected as illustrated in Fig. A1.3.

A1.2.6 Resolution along the displacement axis will be a function of the step size of the electronic scan or, if the scan uses an encoded mechanical fixture the resolution will be dependent on the encoder step-size used for sampling.

A1.2.7 Resolution along the beam axis will be a function of the intervals between the target paths. For highly focused beams it may be desirable to have small differences between the sound paths to the target paths (for example, 1 mm or 2 mm).

A1.2.8 Beam profiling in the passive plane can also be made. The passive plane in a linear-array probe is perpendicular to the active plane and refers to the plane in which no beam steering is possible by phasing effects. Beam profiling in the passive direction will require mechanical scanning.

A1.2.9 Waveform collection of signals using a combination of electronic scanning in the active plane and encoded mechanical motion in the passive plane provides data that can be projection-corrected to provide beam dimensions in the passive

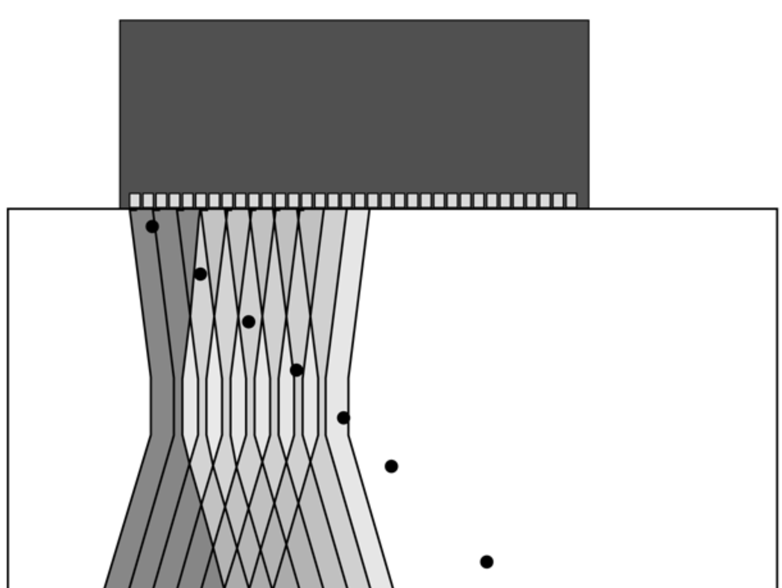


FIG. A1.1 Electronic Scan of Side Drilled Holes

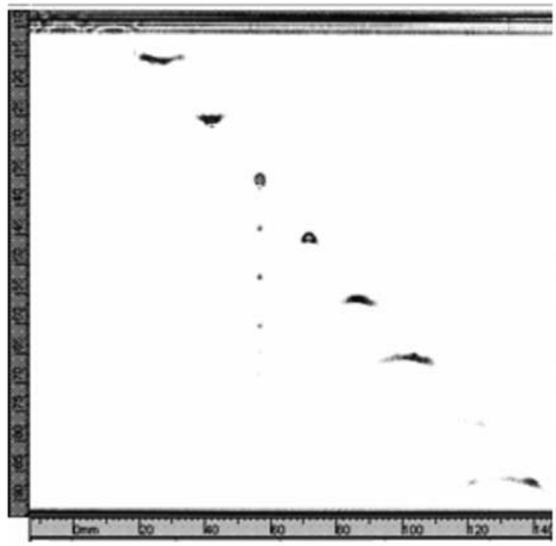


FIG. A1.2 B-Scan Display of Electronic Scan Represented in Fig. A1.1 (Depth is in the vertical axis and electronic-scan distance is represented along the horizontal axis.)

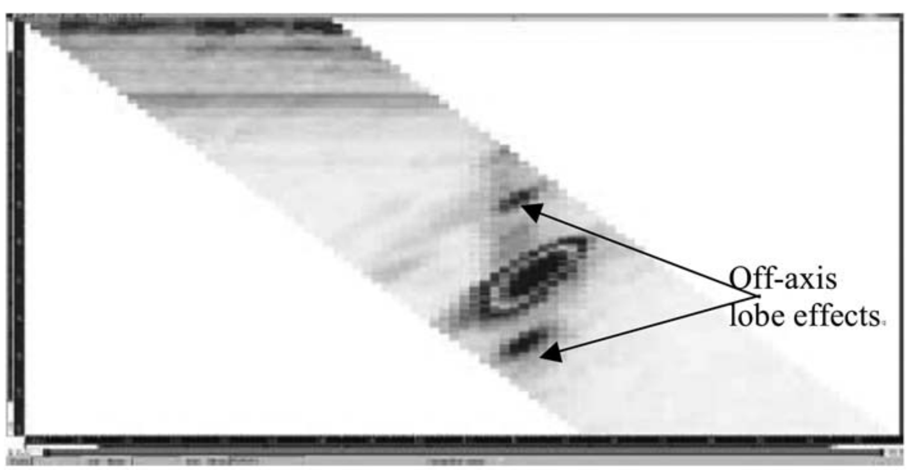


FIG. A1.3 Angle-Corrected B-Scan of a Phased-Array Beam (in Shear Wave Mode) from a Side Drilled Hole (Off-axis lobe effects can be seen in the display.)

plane. Fig. A1.4 illustrates a method for beam assessment in the passive plane. This technique uses a corner reflection from an end-drilled hole at depths established by a series of steps.

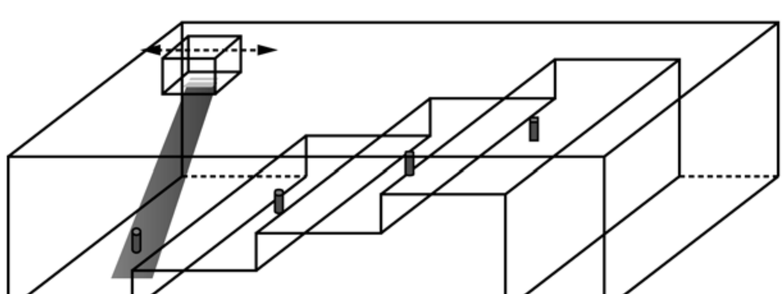


FIG. A1.4 Scanning End-Drilled Holes to Obtain Beam Dimensions in Passive Plane

A1.2.10 Fig. A1.5 illustrates an alternative to the stepped intervals shown in Fig. A1.4. A through hole may be arranged perpendicular to the required refracted angle to provide a continuous transition of path length to the target.

A1.2.11 A projected C-scan can be used to size the beam based on either color or grayscale indicating amplitude drop or a computer display that plots amplitude with respect to displacement. The projected C-scan option is schematically represented in Fig. A1.6.

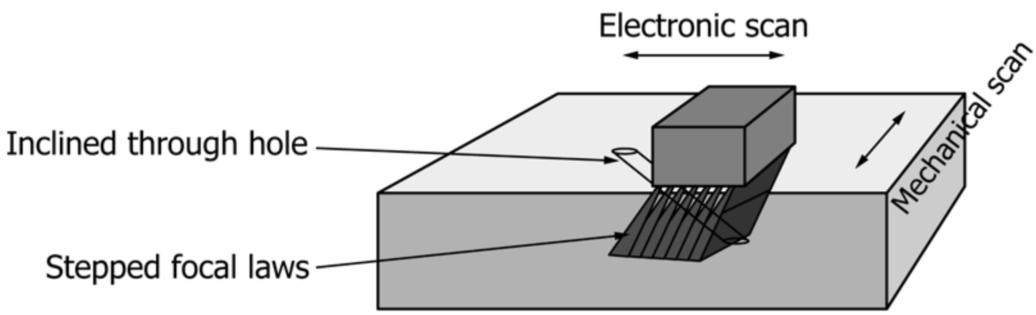


FIG. A1.5 Representation of an Inclined Hole for Beam Characterization in the Passive Plane

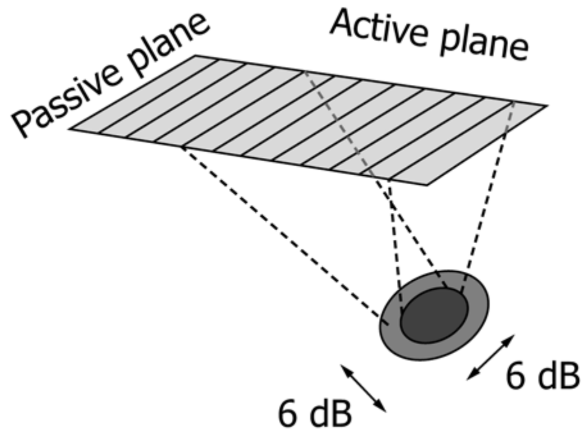


FIG. A1.6 Representation of Projected C-Scan of Corner Effect Scan Seen in Fig. A1.4

A2. DETERMINATION OF PHASED-ARRAY BEAM STEERING LIMITS

A2.1 Introduction

A2.1.1 This annex describes procedures to determine practical limits for beam steering capabilities of a phased-array probe and as such applies to the active plane(s) only. Either immersion or contact probe applications can be addressed using these procedures. However, it should be cautioned that assessments of contact probes may suffer from variability greater than imposed tolerances if proper precautions are not taken to ensure constant coupling conditions.

A2.1.2 Recommended limits to establish the working range of angular sweep of a phased-array probe relate to the divergence of the beam of each element in the probe array. When used in pulse-echo mode the steering limit is considered to be within the 6-dB divergence envelope of the individual elements. It is therefore possible to calculate a theoretical limit based on nominal frequency and manufacturer provided information on the element dimensions. However, several parameters can affect the theoretical calculations. These are primarily related to the nominal frequency of the probe. Some parameters affecting actual frequency include; pulse length, damping, use of a delay-line or refracting wedge and variations in manufacturing processes on thickness lapping and matching layers.

A2.1.3 For the purposes of this procedure, assessment of beam steering capability will be based on a comparison of signal to noise ratios at varying angular displacements. Beam steering capability will also be affected by project requirements of the beam. Applications where focusing is necessary may not achieve the same limits as applications where the beam is not focused as well as steered.

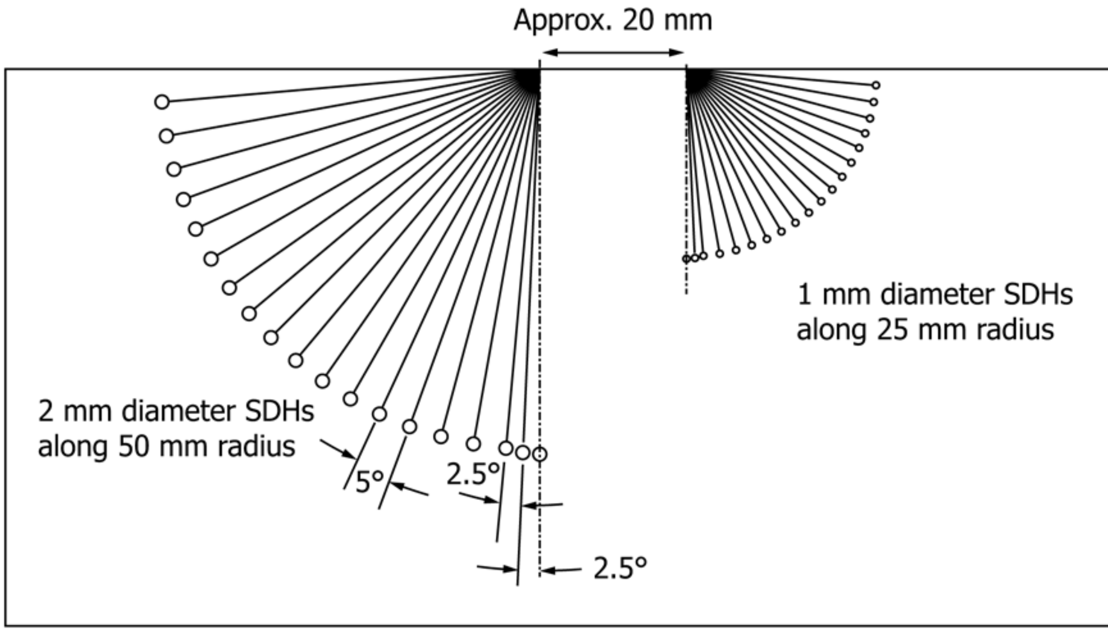
A2.1.4 Steering capability may be specific to a sound path distance, aperture and material.

A2.2 *Test Set-Up*—Configure the probe focal laws for the conditions of the test. This will include immersion or contact, refracting wedge or delay-line, unfocused or a defined focal distance and the test material to be used.

A2.2.1 Prepare a series of side drilled holes in the material to be used for the application at the distance or distances to be used in the application. The side-drilled-hole pattern should be as illustrated in Fig. A2.1. Holes indicated in Fig. A2.1 are at 5° intervals at a 25-mm and 50-mm distance from a center where the probe is located.

A2.2.2 Similar assessments are possible for different applications. When a set of focal laws is arranged to provide resolution in a plane instead of a sound path distance, the plane of interest may be used to assess the steering limits of the beam. The block used for assessment would be arranged with side drilled holes in the plane of interest. Such a plane-specific block is illustrated in Fig. A2.2 where a series of holes is made in a vertical and horizontal plane at a specified distance from the nominal exit point. Side drilled holes may be arranged in other planes (angles) of interest.

A2.2.3 Assessments are made placing the probe such that the center of beam ray enters the block at the indicated centerline. For analysis of a probe where all the elements in a single plane are used without a delay line or refracting wedge the midpoint of the element array shall be aligned with the centerline. For focal laws using only a portion of the total available elements the midpoint of the element aperture shall be aligned with the centerline. When delay lines, refracting wedges or immersion methods are used corrections will be required to compensate for movement of the "apparent" exit point along the block entry surface. When a probe is used in direct contact with a verification block as illustrated in Fig.



NOTE 1—Block dimensions 150 by 75 by 25 mm (typical)

FIG. A2.1 Beam Steering Assessment Block—Constant Sound Path

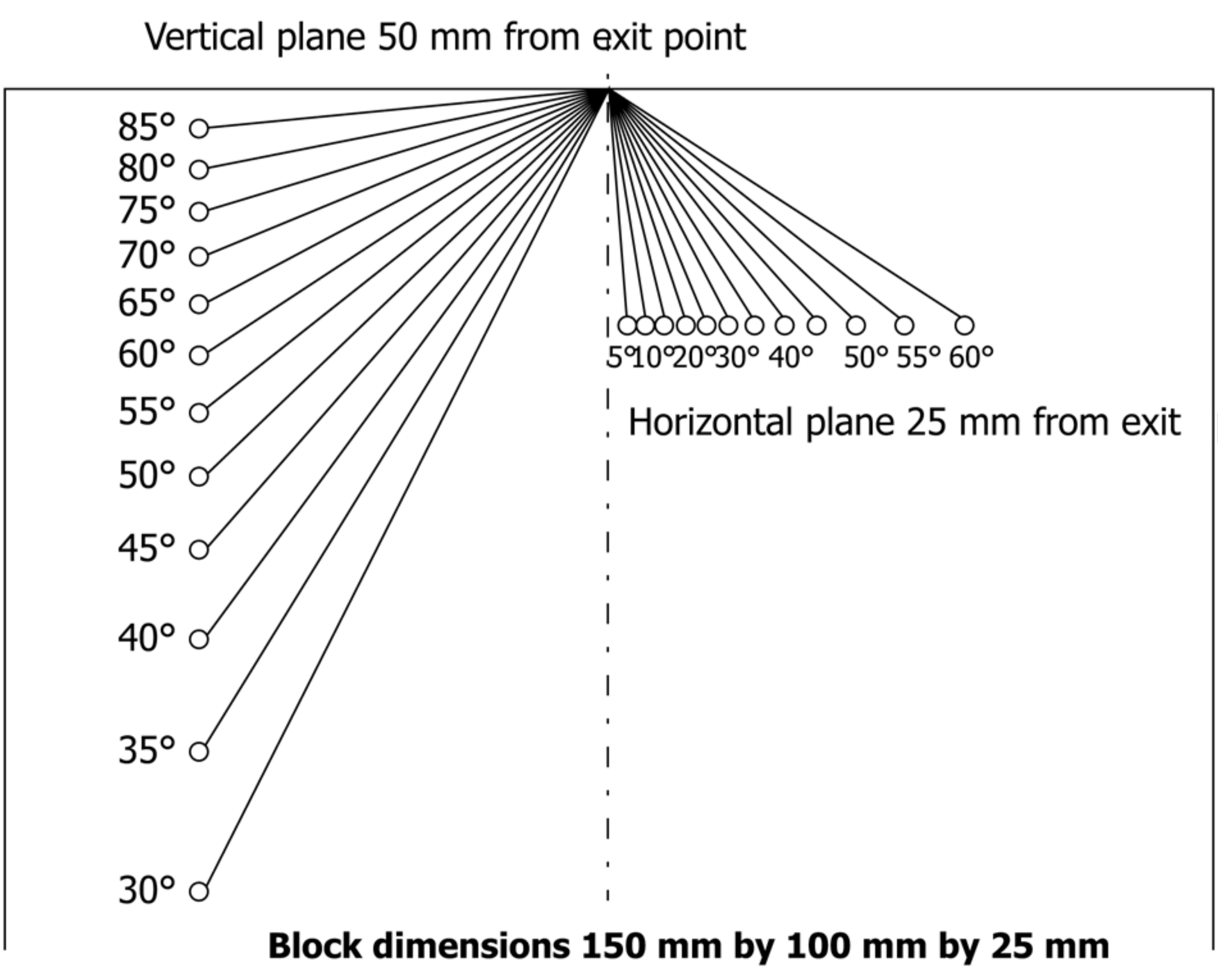


FIG. A2.2 Beam Steering Assessment Block—Single Plane

A2.2 the lack of symmetry either side of the centerline prevents both positive and negative sweep angles being assessed simultaneously. To assess the sweep limit in the two directions when using this style of block requires that the probe be assessed in one direction first and then rotated 180° and the opposite sweep assessed.

A2.2.4 Angular steps between A-scan samples will have an effect on the perceived sweep limits. A maximum of 1° between S-scan samples is recommended for steering assessment. Angular steps are limited by the system timing-delay capabilities between pulses and element pitch characteristics. Most of the targets illustrated in Fig. A2.1 and Fig. A2.2 are separated by 5°; however, greater or lesser intervals may be used depending on the required resolution.

A2.2.5 Assessment of steering limits shall be made using the dB difference between the maximum and minimum signal amplitudes between two adjacent side drilled holes. For example, when a phased array probe is configured to sweep +45° on a block such as illustrated in Fig. A2.1, the higher of the pair of the SDHs which achieves a 6-dB separation shall be considered the maximum steering capability of the probe configuration.

A2.2.6 Acceptable limits of steering may be indicated by the maximum and minimum angles that can achieve a pre-specified separation between adjacent holes. Depending on the application a 6-dB or 20-dB (or some other value) may be specified as the required separation.

A2.2.7 Steering capabilities may be used as a prerequisite; for example, a phased array system is required to achieve a minimum steering capability for 5° resolution of 2-mm diameter side drilled holes of plus and minus 20° from a nominal mid-angle. Conversely, a system may be limited to S-scans not exceeding the angles assessed to achieve a specified signal separation, for example, –20 dB between 2-mm diameter SDHs separated by 5°.

A2.3 An alternative assessment may use a single SDH at a specified depth or sound path distance. Displaying the A-scan for the maximum and minimum angles used would assess the steering capability by observing the S/N ratio at the peaked response. Steering limit would be a pre-defined S/N ratio being achieved. Caution must be taken when using this method so as to not peak on grating lobe signals. This method will also require confirmation that the SDH is positioned at the calculated refracted angle.

A3. DETERMINATION OF PHASED-ARRAY ELEMENT ACTIVITY

A3.1 Introduction

A3.1.1 This assessment is used to determine that all elements of the phased array probe are active and of uniform acoustic energy. Because, during normal operation in a timed sequence, each of the elements is addressed by a separate pulser and receiver, a method must be used that ensures the electronic performance of the phased-array instrument is identical from element to element and any differences are attributable to the probe itself. To ensure that any variation of element performance is due only to probe construction, a single pulser-receiver channel is selected to address each element.

A3.2 Test Set-Up

A3.2.1 Connect the phased array probe to be tested to the phased-array ultrasonic instrument and remove any delay line or refracting wedge from the probe.

A3.2.2 Acoustically couple the probe to the 25-mm thickness of an IIW (International Institute of Welding) block with a uniform layer of couplant. This may be accomplished by a contact-gap technique such that the probe-to-block interface is under water (to ensure uniform coupling). Alternatively an immersion method using a fixed water path may be used and the water-steel interface signal monitored instead of the steel wall thickness.

A3.2.3 Configure an electronic scan consisting of one element that is stepped along one element at a time for the total number of elements in the array. (This should ensure that the pulser-receiver number 1 is used in each focal law or if the channel is selectable it should be the same channel used for each element). Set the pulser parameters to optimize the response for the nominal frequency of the probe array and establish a pulse-echo response from the block backwall or waterpath to 80 % display height for each element in the probe.

A3.2.4 Observe the A-scan display for each element in the array and record the receiver gain required to achieve the 80 % signal amplitude for each element. Results may be recorded on a table similar to that in Table A3.1.

TABLE A3.1 Probe Element Activity Chart: Enter Receiver Gain for 80 % FSH

Element	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gain																
Active (□) Inactive (x)																

A3.2.5 Note and record any elements that do not provide a backwall or waterpath signal (inactive elements). Results may be recorded on a table similar to that in Table A3.1.

A3.2.6 If a prepackaged program is available for checking element activity, this can be used as an alternative.

A3.2.7 Data collected is used to assess probe uniformity and functionality. Comparison to previous assessments is made using the same instrument settings (including gain) that were saved to file. The receiver gain to provide an 80 % response should be within a range of ±2 dB of any previous assessments and within ±2 dB of each other.

A3.2.8 The total number of inactive elements and number of adjacent inactive elements in a probe should be agreed upon and identified in a written procedure. This number may be different for baseline and in-service verifications. Some phased array probes may have several hundred elements and even new phased-array probes may be found to have inactive elements as a result of manufacturing difficulties ensuring the electrical connections to elements with dimensions on the order of a fraction of a millimetre.

A3.2.9 The number of inactive elements allowed should be based on performance of other capabilities such as focusing and steering limits of the focal laws being used. No simple rule for the number of inactive elements can be made for all phased-array probes. Typically, if more than 25 % of the elements in a probe are inactive, sensitivity and steering capabilities may be compromised. Similarly, the number of adjacent elements allowed to be inactive should be determined by the steering and electronic raster resolution required by the application.

A3.2.10 Stability of coupling is essential for the comparison assessment. If using a contact method and the assessment of elements produces signals outside the ±2-dB range the coupling should be checked and the test run again. If still outside the acceptable range the probe should be removed from service and corrected prior to further use. The test using a fixed water path to a water/steel interface will reduce coupling variations.

A3.2.11 Prior to removing the probe from service the cable used for the test should be exchanged with another cable, when possible, to verify that the inactive elements are not due to a bad cable.

A3.2.12 Cable continuity adapters can be made that allow the multi-strand connectors to be tested independently. These adaptors can be connected to the phased array instrument directly to verify that all output channels are active or they can be connected to the probe-end of the cable to indicate the continuity of the individual co-axial connectors in the interconnecting cable. Fig. A3.1 illustrates an example of a display used to identify inactive channels in a phased array instrument or cable.

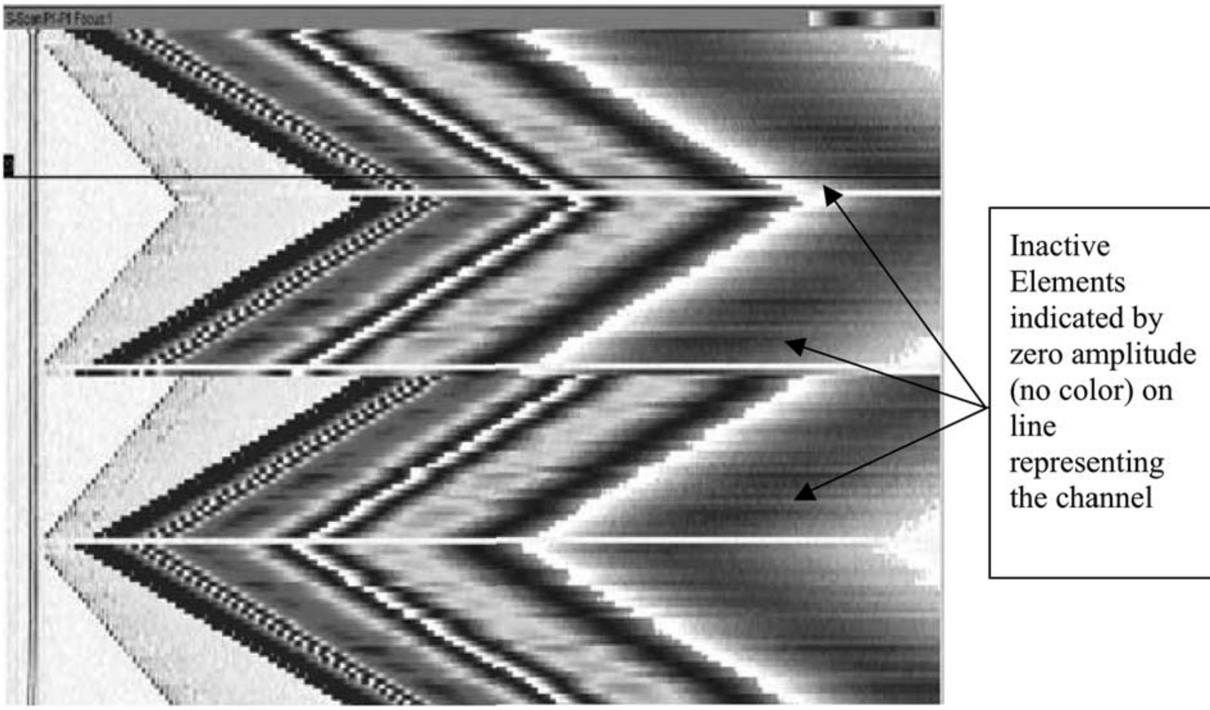


FIG. A3.1 Continuity Display for Phased-Array Instrument or Cable

A4. ASSESSMENT OF PHASED-ARRAY FOCUSING ABILITY

A4.1 Introduction

A4.1.1 Focusing of ultrasonic beams is based on well known principles. However, unlike single element probes, phased-array systems can be configured to focus over a range of sound paths and in both transmit and receive modes. Effectiveness of the focusing algorithms can be assessed by determining the beam response dimensions. This is similar to the beam profiling described in Annex A1. Limits of focusing are intrinsic in the probe parameters and subject to the minimum timing-delay capabilities of the phased-array ultrasonic instrument.

A4.2 Test Set-Up

A4.2.1 Configure the phased-array system for the focusing focal laws to be assessed and acoustically couple the phased-array probe to a block with inclined side drilled holes as illustrated in Fig. A1.1. Compression modes with or without a delay-line and shear modes using a refracting wedge can be assessed by this method.

A4.2.2 Focusing at a single refracted angle is assessed by this method. Where several angles are used it will be necessary to assess the focusing ability for each angle separately.

A4.2.3 Using either an electronic scan or encoded mechanical scan in the plane of interest, the full waveforms are collected and displayed in a depth corrected B-scan projection image as illustrated in Fig. A4.1.

A4.2.4 Effectiveness of the focusing algorithm is assessed by sizing the diameter of the projected image based on a dB drop from maximum amplitude and comparing that dimension to the actual machined diameter of the side drilled hole.

A4.2.5 Working range of the focusing algorithm may be determined by agreement as to the maximum dimension of the oversizing of the side-drilled hole diameter. For example, if 2-mm diameter SDH's are used and the 6-dB drop is used to gauge diameter from the B-scan, the working range can be defined as the depth or sound-path distance that the B-scan can maintain the 6-dB dimension to less than twice the actual diameter.

A4.2.6 Practical limits for hole diameters and focal spot sizes are required. Practical focal spots for focused beams cannot be made smaller than about 1.5 times the wavelength used. For a 5-MHz compression wave in steel this is about 1.7 mm. The focal spot size is also a function of sound path; the deeper the holes, the weaker the focusing.

A4.2.7 In order that the diameter assessment be meaningful, the sample interval must be small compared to the target assessed. It is recommended that at least four samples per hole diameter be used. For example, for a 2-mm diameter SDH target the sample interval of a mechanized encoded scan should be 0.5 mm or for an electronic scan the step between each focal law should not exceed 0.5 mm (this will be limited by the element pitch of the probe).

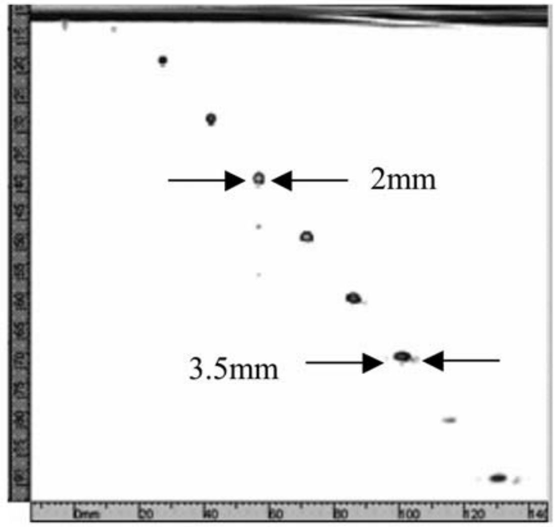


FIG. A4.1 B-Scan Projected Image of Dynamic Depth Focusing Algorithm

A5. ASSESSMENT OF PHASED-ARRAY COMPUTER CONTROL OF PARAMETERS AND DATA DISPLAY

A5.1 Introduction

A5.1.1 Phased-array beam control is based on the Fermat Principle which implies that sound follows the path of least time. This principle is used in ray-tracing of sound paths of transmitted wavefronts from the elements of a phased-array probe to calculate the delays required in the timing electronics to direct a beam to a specified location. Using the Fermat Principle, refracted angles and focal positions are calculated by entering the acoustic velocities of the materials through which the sound propagates. If the material acoustic velocities are accurate then the calculated position of the beam will also be accurate. Accuracy of the calculations is therefore a function of several variables including; acoustic velocity of the materials used, dimensions of the probe components (element size, dominant frequency, divergence, travel distance in the delay line or wedge) and pulser timing accuracy to affect the necessary phase interference patterns. If all the variables are accurately entered in the appropriate equations the beam should be accurately positioned. In a computer controlled system the only evidence available to the operator is the data display. This provides a coordinate system that positions the response from a target in two or three dimensions. Relating the theoretical plotted position on the display to actual known positions of specific targets is the only effective method of assessing the validity of the combination of variables and the computer algorithms for the display.

A5.2 Test Set-Up

A5.2.1 Using a contact linear phased-array probe, nominally 5 MHz and having at least 16 elements with a pitch not greater than 1 mm, configure the software for two separate S-scans, one at ±30° with a focal distance of 25 mm in steel (that is, focused at a sound path of 25 mm in steel), the other at ±30° with a focal distance of 50 mm in steel (that is, focused at a sound path of 50 mm in steel). For both sets of focal laws program an angular step interval of 0.5° and all focal laws shall use 16 adjacent elements.

A5.2.2 Ensure that the digitizing frequency for data collection is at least 80 MHz.

A5.2.3 Prepare a series of side drilled holes in a steel block that has acoustic velocity determined in accordance with E494. This velocity value will be used in the focal laws.

A5.2.4 Acoustically couple and align the probe on the block illustrated in Fig. A2.1 such that the centre of the element array aligns with the centerline of the hole pattern.

A5.2.5 Scan and save the S-scan for the 25-mm focal distance.

A5.2.6 Scan and save the S-scan for the 50-mm focal distance.

A5.2.7 Using the computer display coordinate cursors assess and record the depths, off-sets from the centerline and angles to the side drilled holes in a tabular form. For the side drilled holes at 50-mm radius use the results of the focal laws configured for 50-mm focus and for the holes at 25-mm radius use the focal laws configured for 25 mm.

A5.2.8 Compare the values assessed using the software to the physical positions of the holes in the block. Sound path distances indicated on the computer display should indicate hole positions within ±0.5 mm. Depth and off-set positions of holes should be within ±0.5 mm and all angles to the holes should be within ±1.0°.

A6. ASSESSMENT OF PHASED-ARRAY WEDGE ATTENUATION AND DELAY COMPENSATIONS

A6.1 Introduction

A6.1.1 When an electronic or sectorial scan is used the variations between the electronics of each pulser and receiver and variations between probe elements may result in small gain variations from one focal law to the next. Also, the efficiency of generation varies with angle, and declines away from the "natural" angle of the wedge. When a delay line or refracting wedge is used, variations in path distances within the wedge will result in some focal laws requiring more or less amplifier gain. A method of compensating for gain variations so as to "normalize" the set of focal laws in an electronic or S-scan is required.

A6.1.2 When a phased array probe is used on a delay line or refracting wedge, calculations for beam steering and projection displays rely on the Fermat principle. This requires that the operator identify the position in space of the probe elements. This ensures that the path lengths to the wedge-steel interface are accurately known. It is necessary to verify that the coordinates used by the operator provide correct depth calculations. This ensures that the display software correctly positions indications detected.

A6.1.3 Compensation for attenuation variations and delay times may be made one focal law at a time or software can be configured to make the compensations dynamically.

A6.2 Wedge-attenuation Compensation

A6.2.1 This guide applies to assessments of wedge-attenuation compensations for E-scan or electronic raster scans where 1D linear array probes are used.

A6.2.2 Configure the phased-array system for the focal laws to be used in the electronic raster scan application.

A6.2.3 Acoustically couple the phased array probe to the block with a side drilled hole at a known depth. The 1.5-mm diameter SDH in the IIW block is a convenient target for this purpose.

A6.2.4 Select the A-scan display for the first focal law configured and move the probe forward and backward to locate the maximum amplitude signal from the SDH.

A6.2.5 Adjust the response from the SDH to 80 % full screen height (FSH) and save the parameters in the focal law file.

A6.2.6 Repeat the process of maximizing the signal from the SDH and setting it to 80 % FSH for each focal law and saving the set-up file after each focal law is completed.

A6.2.7 Alternatively, this process may be computerized so that a dynamic assessment of sensitivity adjustment is calculated by the computer. A dynamic assessment would simply require the operator to move the probe back and forth over the SDH ensuring that all the focal laws used have the SDH target move through the beam. Wedge attenuation corrections would then be calculated by the phased-array system to ensure that the amplitude of the SDH detected by each focal law would be adjusted to the same amplitude.

A6.2.8 Assessment of wedge-attenuation compensation requires a constant steel path to ensure that only the effect wedge variations are assessed. For S-scans where 1D linear array probes are used, a single SDH results in a changing steel path for each angle making it unsuitable for this task. A recommended target is a radius similar to that of the 100-mm radius of the IIW block. For S-scans steps A6.2.2 to A6.2.6 are used replacing the SDH with a suitable radius. Use of the radius for S-scan configurations also provides correction for echo-transmittance effects intrinsic in angle variation.

NOTE A6.1—If appropriate compensation cannot be achieved, for example, if the angular range is so large that the signal amplitude cannot effectively be compensated, then the range must be reduced until it is possible to compensate.

A6.2.9 Probe motion for the various wedge and scan-type configurations are illustrated in Fig. A6.1.

A6.3 Wedge-delay Compensation

A6.3.1 When an angled refracting wedge is used for E-scans or S-scans, or when a fixed thickness delay line is used for S-scans, the sound path in the wedge material varies from one focal law to the next. Compensation for this delay time difference is required so as to ensure that indications detected are correctly positioned in the projection scan displays, that is, depth and angle within the test piece are correctly plotted.

A6.3.2 Configure the phased-array system for the focal laws to be used in the S-scan or electronic raster scan application.

A6.3.3 Acoustically couple the phased array probe to a block with known radius of curvature. The 50-mm or 100-mm radius of the IIW block is a convenient target for this purpose.

A6.3.4 Select the A-scan display for the first focal law configured and move the probe forward and backward to locate the maximum amplitude signal from the radius selected.

A6.3.5 Adjust the delay settings to indicate the sound path in the metal to correctly indicate the radius used and save the focal law parameters.

A6.3.6 Repeat the maximization of the radius response for each focal law in the scan set and save the parameter setting after each delay has been adjusted.

A6.3.7 Alternatively, this process may be computerized so that a dynamic assessment of delay adjustment is calculated by the computer. A dynamic assessment would simply require that the operator move the probe back and forth over the center of the radius assuring that all the focal laws used have the center of beam ray peak on the radius appropriate for their angle.

A6.3.8 Small angle compression wave focal laws may require a custom block to carry out this compensation.

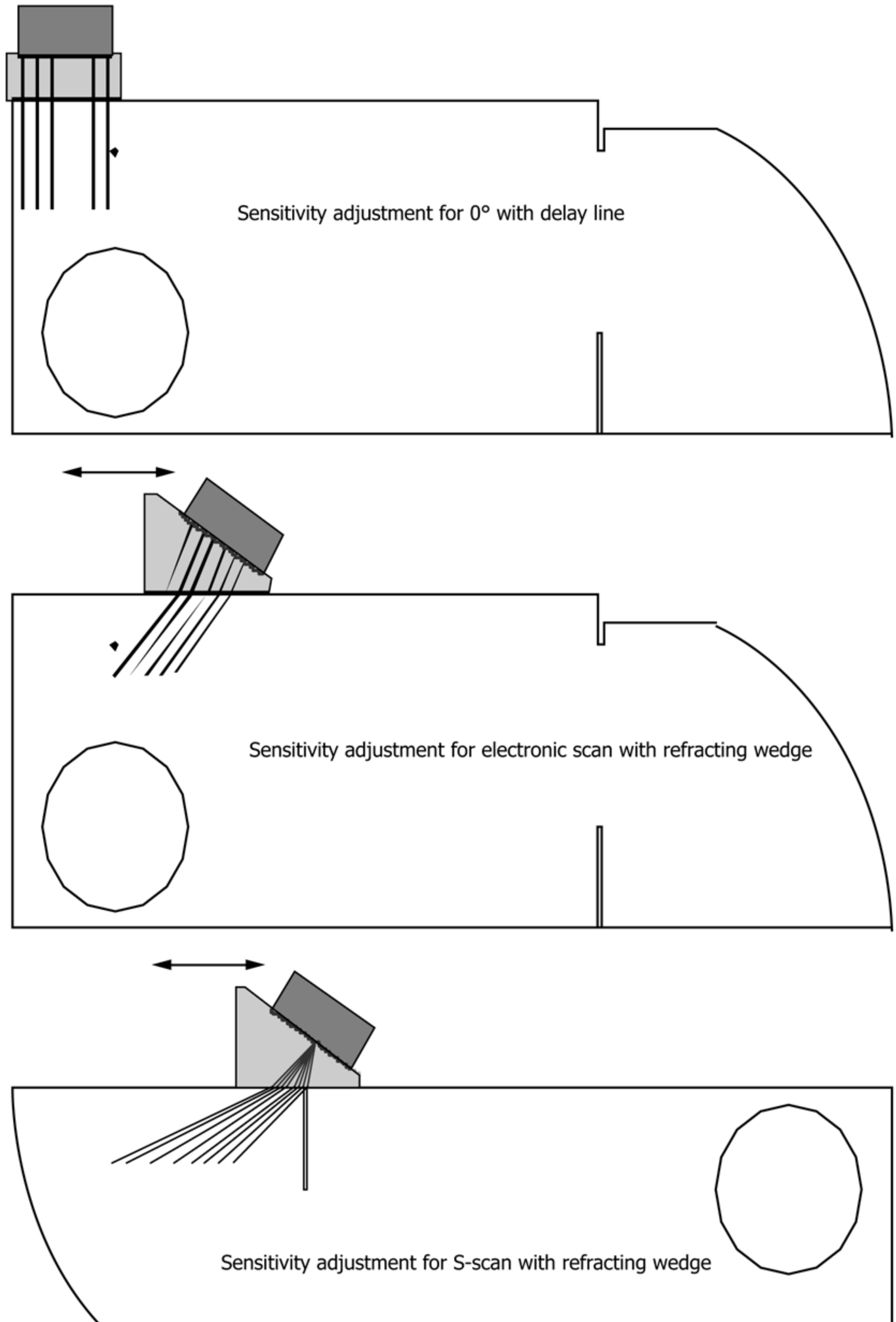


FIG. A6.1 Scan Motion Maximizing Response from SDH to Compensate for Wedge Attenuation

A6.3.9 Probe motion for the various wedge and scan type configurations are illustrated in Fig. A6.2.

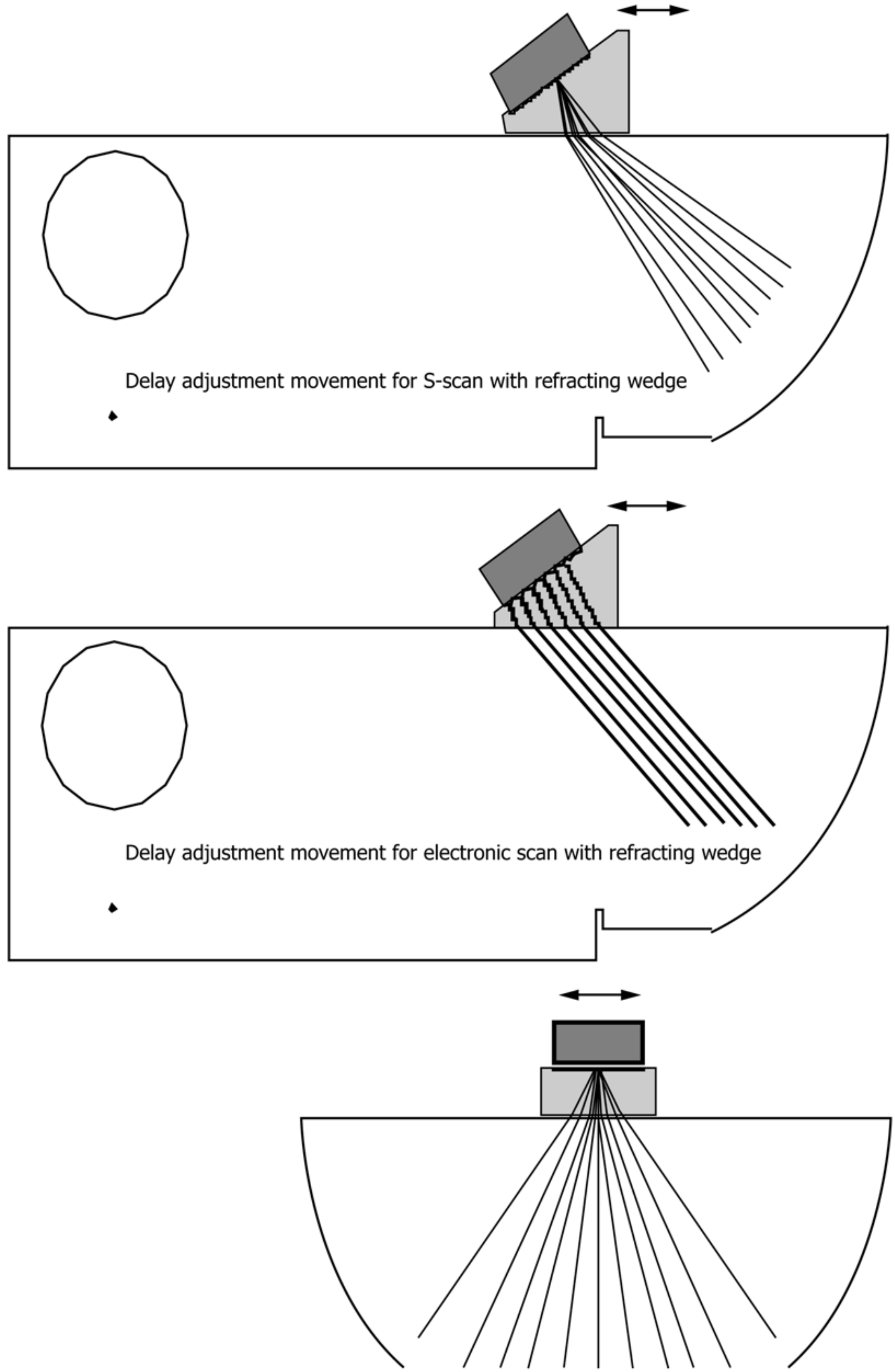


FIG. A6.2 Delay Adjustment Scans Using Curved Surfaces

A7. ASSESSMENT OF PHASED-ARRAY INSTRUMENT LINEARITIES

A7.1 Introduction

A7.1.1 The individual pulser and receiver components of phased-array ultrasonic instruments operate essentially the same as any single channel ultrasonic instrument. Conformance to linearity requirements as described in E317 may be carried out. However, due to the digital-control nature of all phased-array instruments and the fact that multiple pulsers and receivers are used, it is required that phased array instruments be assessed for linearity differently than traditional single-channel units.

A7.2 Test Set-Up

A7.2.1 The phased array instrument is configured to display an A-scan presentation.

A7.2.2 Adjust the time-base of the A-scan to a suitable range to display the pulse-echo signals selected for the linearity verifications. A linearity block similar to that described in E317 is selected to provide signals to assess linearity aspects of the instrument. Such a block is shown in Fig. A7.1 with a single element probe mounted on it.

A7.2.3 Pulser parameters are selected for the frequency and bandpass filter to optimize the response from the pulse-echo (single element) probe used for the linearity verifications.

A7.2.4 The receiver gain is set to display non-saturating signals of interest for display height and amplitude control linearity assessments.

A7.3 Display Height Linearity

A7.3.1 With the phased array instrument connected to a probe (shear or longitudinal) and coupled to any block that will produce two signals as shown in Fig. A7.2 adjust the probe such that the amplitude of the two signals are at 80 % and 40 % of the display screen height. If the phased-array instrument has provision to address a single element probe in pulse-echo mode then the two flat bottom holes with adjustable acoustic impedance inserts in the custom linearity block shown in Fig. A7.1 provides such signals.

A7.3.2 Increase the gain 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.

NOTE A7.1—For 8-bit digitization systems this value should be 99 %, as 100 % would provide a saturation signal.

A7.3.3 The height of the higher response is reduced in 10 % steps to 10 % of full screen height and the height of the second response is recorded for each step.

A7.3.4 Return the larger signal 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 % FSH.

A7.3.5 For an acceptable tolerance, the responses from the two reflectors should 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.

A7.3.6 The results are recorded on an instrument linearity form.

A7.4 Amplitude Control Linearity

A7.4.1 A16/64 phased-array instrument has 16 pulsers and receivers that are used to address up to 64 elements. Each of the pulser-receiver components is checked to determine the linearity of the instrument amplification capabilities.

A7.4.2 Select a flat (normal incidence) linear array phased-array probe having at least as many elements as the phased-array ultrasonic instrument has pulsers.

A7.4.3 Using this probe, configure the phased-array ultrasonic instrument to have an electronic raster scan. Each focal

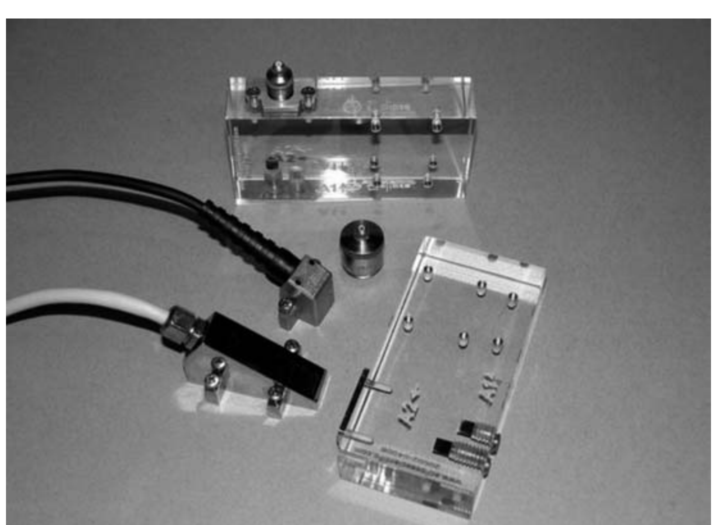


FIG. A7.1 Custom Linearity Blocks for Phased-Array Instrument and Probe Assessments

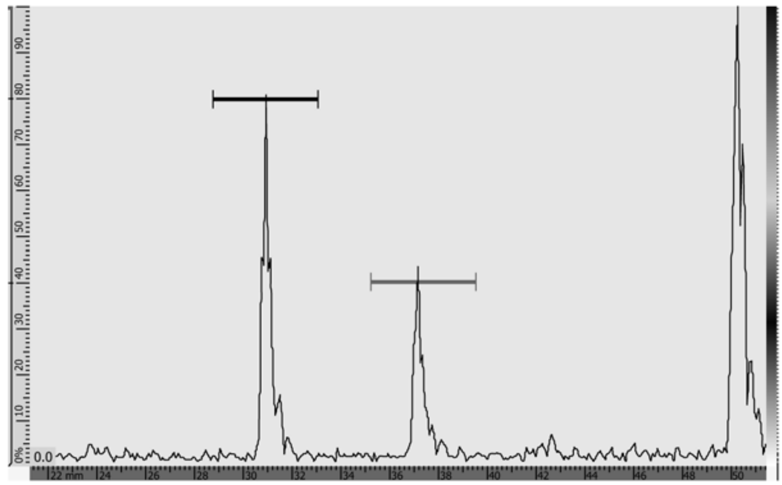


FIG. A7.2 Display Height Linearity

law will consist of one element and 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.

A7.4.4 Couple the probe to a suitable surface to obtain a pulse-echo response from each focal law. The backwall echo from the 25-mm thickness of the IIW block or the backwall from the 20-mm thickness of the custom linearity block illustrated in Fig. A7.1 provides a suitable target option. Alternatively, immersion testing can be used.

A7.4.5 Select Channel 1 of the pulser-receivers of the phased-array instrument. Using the A-scan display, monitor the response from the selected target. Adjust the gain to bring the signal to 40 % screen height. This is illustrated in Fig. A7.3.

A7.4.6 Add gain 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.

A7.4.7 Adjust the signal to 100 % display height, remove 6-dB gain and record the actual height of the signal as a percentage of the display height.

A7.4.8 Signal amplitudes should fall within a range of ±3 % of the display height required in the allowed height range of Table A7.1.

A7.4.9 Repeat the sequence from A7.4.5 to A7.4.7 for all other pulser-receiver channels.

A7.4.10 For instruments having 10- or 12-bit amplitude digitization and configured to read amplitudes in a gated region to amplitudes greater than can be seen on the display, a larger range of check points can be used. For these instruments the gated output instead of the A-scan display would be verified for linearity.

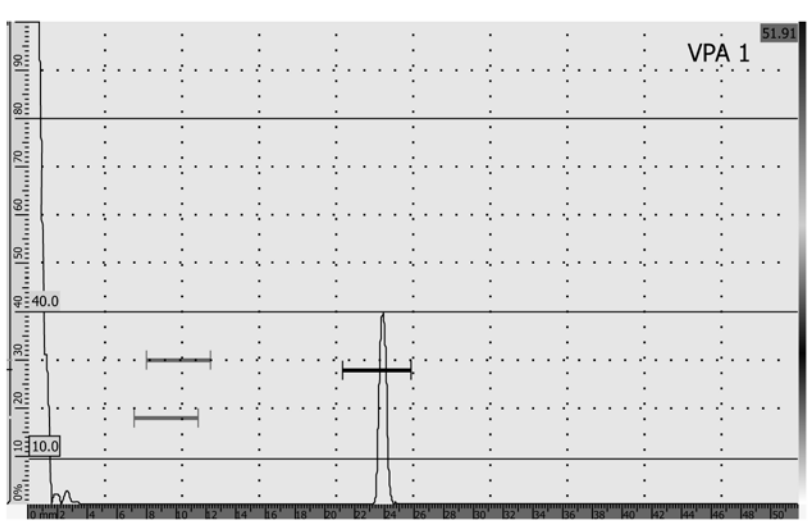


FIG. A7.3 A-Scan Display of Backwall Echo on Channel 1 of a Phased-Array Instrument

TABLE A7.1 LINEARITY VERIFICATION REPORT FORM

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	+4	60-66
70	32-38		40	+6	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-Base Linearity (for 25-mm IIW blocks)										
Multiple	1	2	3	4	5	6	7	8	9	10
Thickness	25	50	75	100	125	150	175	200	225	250
Measured Interval										
Allowed deviation ±0.5 mm(Yes/No)										

NOTE A7.2—an example of amplitudes greater than 100 % display height is seen in Fig. A7.4 where gate A % indicates a 200 % signal and gate B % indicates 176 %.

A7.5 Time-Base Linearity (Horizontal Linearity)

A7.5.1 Configure the phased array instrument to display an A-scan presentation.

A7.5.2 Select any compression wave probe and configure the phased-array instrument to display a range suitable to obtain at least ten multiple back reflections from a block of a known thickness. The 25-mm wall thickness of the IIW block is a convenient option for this test.

A7.5.3 Set the phased-array instrument analog-to-digital conversion rate to at least 80 MHz.

A7.5.4 With the probe coupled to the block and the A-scan displaying 10 clearly defined multiples as illustrated in Fig. A7.4, the display software is used to assess the interval between adjacent backwall signals.

A7.5.5 Acoustic velocity of the test block, determined using the methods described in E494, is entered into the display software and the display configured to read out in distance (thickness).

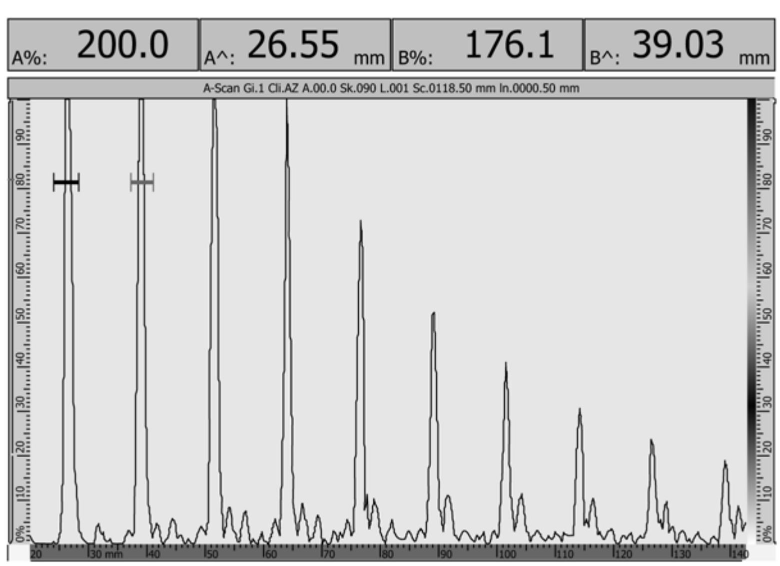


FIG. A7.4 Horizontal Linearity A-Scan

A7.5.6 Using the reference and measurement cursors determine the interval between each multiple and record the interval of the first 10 multiples.

A7.5.7 Acceptable linearity may be established by an error tolerance based on the analog-to-digital conversion rate converted to a distance equivalent. For example, at 100 MHz each sample of the timebase is 10 ns. For steel at 5900 m/s each sample along the timebase (10 ns) in pulse-echo mode represents 30 µm. A tolerance of ±3 timing samples should be achievable by most analog-to-digital systems. Some allowance should be made for velocity determination error (~1 %). Typically the errors on the multiples should not exceed ±0.5 mm for a steel plate.

A7.5.8 A sample recording table for the linearity checks is indicated in Table A7.1.

SUMMARY OF CHANGES

Committee E07 has identified the location of selected changes to this standard since the last issue (E2491-08) that may impact the use of this standard. (June 1, 2013)

(1) Deleted all terms in definitions subsection 3.2 (now located in E1316).

(2) Added Summary of Changes section.