



Designation: **E1001—16 E1001 – 21**

# Standard Practice for Detection and Evaluation of Discontinuities by the Immersed Pulse-Echo Ultrasonic Method Using Longitudinal Waves<sup>1</sup>

This standard is issued under the fixed designation E1001; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

## 1. Scope\*

1.1 This practice describes procedures for the ultrasonic examination of bulk materials or parts by transmitting pulsed, longitudinal waves through a liquid couplant into the material and observing the indications of reflected waves (see Fig. 1). It covers only examinations in which one search unit is used as both transmitter and receiver (pulse-echo) and in which the part or material being examined is coupled to the part by a liquid column or is totally submerged in the couplant (either method is considered to be immersion testing). This practice includes general requirements and procedures which may be used for detecting discontinuities and for making a relative or approximate evaluation of the size of discontinuities.

1.2 This practice replaces Practice E214 and provides more detailed procedures for the selection, standardization, and operation of an examination system and for evaluation of the indications obtained.

1.3 *Units*—The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

[C1212 Practice for Fabricating Ceramic Reference Specimens Containing Seeded Voids](#) (Withdrawn 2018)<sup>3</sup>

[C1336 Practice for Fabricating Non-Oxide Ceramic Reference Specimens Containing Seeded Inclusions](#) (Withdrawn 2018)<sup>3</sup>

[E127 Practice for Fabrication and Control of Flat Bottomed Hole Ultrasonic Standard Reference Blocks](#)

[E214 Practice for Immersed Ultrasonic Testing by the Reflection Method Using Pulsed Longitudinal Waves](#) (Withdrawn 2007)<sup>3</sup>

<sup>1</sup> This practice 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 Dec. 1, 2016. Nov. 1, 2021. Published December 2016. November 2021. Originally approved in 1984. Last previous edition approved in 2014 as E1001—14. E1001 – 16. DOI: 10.1520/E1001-16.10.1520/E1001-21.

<sup>2</sup> 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.

<sup>3</sup> The last approved version of this historical standard is referenced on www.astm.org.

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

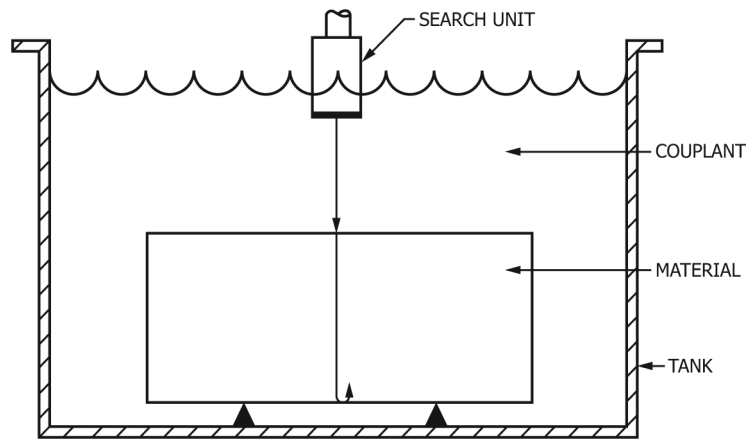


FIG. 1 Basic Immersion Setup

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

~~[E428 Practice for Fabrication and Control of Metal, Other than Aluminum, Reference Blocks Used in Ultrasonic Testing \(Withdrawn 2019\)<sup>3</sup>](#)~~

[E543 Specification for Agencies Performing Nondestructive Testing](#)

~~[E1158 Guide for Material Selection and Fabrication of Reference Blocks for the Pulsed Longitudinal Wave Ultrasonic Testing of Metal and Metal Alloy Production Material \(Withdrawn 2019\)<sup>3</sup>](#)~~

[E1316 Terminology for Nondestructive Examinations](#)

2.2 *ASNT Documents*:<sup>4</sup>

[SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing](#)

[ANSI/ASNT-CP-189 for Qualification and Certification of Nondestructive Testing Personnel](#)

2.3 *Aerospace Industries Association AIA Document*:<sup>5</sup>

[NAS-410 Certification and Qualification of Nondestructive Testing Personnel](#)

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NOTE 1—For DoD contracts, unless otherwise specified, the issues of the documents, which are DoD adopted, are those listed in the issue of the DoDISS (Department of Defense Index of Specifications Standards) cited in the solicitation.

2.4 *ISO Documents*:<sup>6</sup>

[ISO 9712 Non-destructive Testing—Qualification and Certification for NDT Personnel](#)

### 3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, see Terminology [E1316](#).

3.2 *Definitions of Terms Specific to This Standard*:

3.2.1 *effective beam diameter*—*diameter, n*—that distance through which a search unit can be traversed across a reference reflector so that the corresponding echo amplitude is at least one half ( $-6$  dB) ( $-6$  dB) of the maximum amplitude. The effective beam diameter is not a characteristic of the search unit alone, but is dependent on propagating medium, distance to the discontinuity, reflector geometry, etc.

3.2.2 *scan index*—*index, n*—the length of the step created by indexing the scan of the search unit over the part, that is continuously scanning in one direction, then stepping in the direction perpendicular to the scan or making a linear advance per rotation (pitch) for rotary scan of cylindrical parts. The allowable scan index should be correlated with the search unit effective beam diameter to ensure full coverage of the part as described in [8.2](#) below.

3.2.3 *transfer*—*transfer, n*—a change in scanning gain to compensate for differences in attenuation of the reference standard and the part or material being examined.

<sup>4</sup> Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, <http://www.asnt.org>.

<sup>5</sup> Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, <http://www.aia-aerospace.org>.

<sup>6</sup> Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, <http://www.iso.org>.

#### 4. Summary of Practice

4.1 This practice describes a means for obtaining an evaluation of discontinuities in materials by immersed examination with longitudinal ultrasonic waves. Equipment, reference standards, examination and evaluation procedures, and documentation are described in detail.

#### 5. Basis of Application

5.1 The following items are subject to contractual agreement between the parties using or referencing this standard practice.

5.2 *Personnel Qualification:*

5.2.1 If specified in the contractual agreement, personnel performing examinations to this standard practice shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

5.3 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Specification **E543**. The applicable edition of Specification **E543** shall be specified in the contractual agreement.

5.4 *Procedures and Techniques*—The procedures and techniques to be utilized shall be as specified in the contractual agreement.

5.5 *Surface Preparation*—The pre-examination surface preparation criteria shall be in accordance with **8.1** unless otherwise specified.

5.6 *Extent of Examination*—The extent of examination shall be in accordance with **12.3**, unless otherwise specified.

5.7 *Reporting Criteria/Acceptance Criteria*—Reporting criteria and acceptance criteria for the examination results shall be in accordance with **12.3**, unless otherwise specified.

5.8 *Reexamination of Repaired/Reworked Items*—Reexamination of repaired/reworked items is not addressed in this standard practice and if required shall be specified in the contractual agreement.

#### 6. Significance and Use

6.1 This practice provides guidelines for the application of immersed longitudinal wave examination to the detection and quantitative evaluation of discontinuities in materials.

6.2 Although not all requirements of this practice can be applied universally to all examination situations and materials, it does provide a basis for establishing contractual criteria between suppliers and purchasers of materials for performing immersed pulse-echo examination, and may be used as a general guide for writing detailed specifications for particular applications.

6.3 This practice is directed towards the evaluation of discontinuities detectable at normal beam incidence. If discontinuities at other orientations are of concern, alternate scanning techniques are required.

#### 7. Apparatus

7.1 *Electronic Equipment*—The electronic equipment shall be capable of producing and processing electronic signals at frequencies in the range of search unit frequencies being used. The equipment and its display shall be capable of meeting the requirements to be completed in **Table 1**, as agreed upon between the supplier and the purchaser, and as measured in accordance with procedures described in Practice **E317** or equivalent procedures (see **Note 2**). These requirements are applicable only for the frequencies required for the examination. Also, the equipment, including the search unit, shall be capable of producing echo amplitudes of at least 60 %, of full scale, with the noise level no greater than 20 %, from the appropriate reference reflector at a material distance equal to the thickness of the part to be examined. Alternatively, if these conditions can be met at one half the

**TABLE 1 Minimum Equipment Requirements (Longitudinal Wave)**

Instrument Characteristics	Ultrasonic Test Frequency, MHz			
	2.25	5.0	10.0	15.0
Instrument Characteristics: Ultrasonic Test Frequencies 2.25, 5.0, 10.0, 15.0 MHz				
Vertical limit, in. (mm), trace to peak or percent of full screen height				
Upper linearity limit, in. (mm), trace to peak or percent of full screen height				
Lower linearity limit, in. (mm), trace to peak or percent of full screen height				
Ultrasonic sensitivity, reflector size, material distance, in. (mm)				
Signal-to-noise ratio				
Entry surface resolution, in. (mm)				
Back surface resolution, in. (mm)				
Horizontal limit, in. (mm) or percent of full screen width				
Horizontal linearity range, in. (mm) or percent of full screen width				

part thickness, the part may be examined from both sides. The instrument must have a pulser of the sufficient voltage, repetition rate, and waveshape to provide total volume coverage at the desired scanning speed.

NOTE 2—Significantly higher frequencies than those shown in Table 1 (for example, 50 MHz) may be necessary for the smaller critical flaw size of advanced ceramics.

7.2 *Voltage Regulator*—If fluctuations in line voltage cause variations exceeding  $\pm 5\%$  of the vertical limit in an indication with an amplitude of one half the vertical limit, a voltage regulator should be required on the power source. This requirement is not applicable to battery-operated units.

7.3 *Search Units*—The search unit selected shall be compatible with the electronic equipment being used and with the material to be examined. The search units shall be of the immersion type. Only straight-beam (longitudinal) search units, with flat or focused acoustic lenses, shall be used. Focused or dual element search units may provide better near-surface resolution and detection of small discontinuities. Generally, round or rectangular search units are used for examination whereas round search units with symmetrical sound beam patterns are used for evaluation.

7.4 *Alarm*—For the examination of parts or material with regular shape and parallel surfaces, such as plate, machined bar stock, and forgings, an audible alarm shall be used in preference to a visual alarm, since the examination process can be accomplished at a speed which prevents reliable visual monitoring of the instrument screen. As a matter of practicality, an audible alarm should be used in conjunction with visual monitoring wherever possible. The alarm shall be adjustable to allow triggering at any commonly required level of indication amplitude and depth of material. During operation, the audible or visible signal produced by the alarm shall be easily detectable by the operator.

NOTE 3—Alarm requirements are not applicable if recording equipment is used unless otherwise specified in the contractual agreement.

7.4.1 *Alarm Gate Synchronization*—To ensure that the alarm gate tracks the examination area, the gate shall lock on the first interface pulse from the part rather than on the initial pulse from the system. Gating from the initial pulse can result in either partial loss of the examination area from the gate, or the inclusion of the back reflection and interface signal in the gated area. This will trigger the gate as would an imperfection.

7.5 *Manipulating Equipment* shall be provided to adequately support a search tube, containing the search unit, and to allow angular adjustment in two mutually perpendicular, vertical planes, so that proper alignment of the sound beam to the part or material surface can be achieved. A manipulator may be attached between the search tube and search unit to provide the necessary angular adjustments. The scanning and indexing apparatus shall have sufficient structural rigidity to provide support for the manipulator and shall allow smooth, accurate positioning of the search unit. This apparatus shall permit control of the scan in accordance with 9.3.1 and control of the index in accordance with 9.2.1. Also, the scanning apparatus shall be sufficiently rigid to keep search unit backlash to within tolerances as specified in the contractual agreement. Water-path distances shall be continuously adjustable.

7.6 *Tank*—The container or tank shall permit accurate positioning of the search unit, reference blocks, and part or material to be examined in accordance with the requirements of Section 8.

7.7 *Reference Standards*—Ultrasonic reference blocks, or reference specimens, are used to standardize the ultrasonic equipment

and to evaluate the indications received from discontinuities within the part. The ultrasonic characteristics of the reference standards such as attenuation, noise level, surface condition, and sound velocity, shall be similar to the material being examined. Metal reference standards should not be used for examining advanced-ceramics because of the large differences in attenuation velocity and acoustic impedance. Standardization (1) verifies that the instrument/search unit combination is performing as required, and (2) establishes a detection level for discontinuities. Reference blocks as described in Practices Practice E127 and E428 have been used as standards for standardizing system performance, and may continue to be so used in cases where much sufficient empirical evidence has shown that satisfactory examination results are obtained. However, it is more desirable in the general case to use a part identical in shape, dimensions, and material properties to the parts to be examined. (See Ref. (1)<sup>7</sup>.) The procedures established in Guide Practice EH58E127 are recommended for selection of reference standard material and manufacturing ultrasonic reference block beam testing.

**7.7.1 Flat Blocks**—The three most commonly used sets of reference blocks are (1) area-amplitude blocks, containing blocks with the same material path and various sizes of reference reflectors; (2) distance-amplitude blocks containing blocks with one-size reference reflector at various material paths; and (3) a combination including both area-amplitude and distance-amplitude blocks in one set. These sets are described in Practice E127. However, in general their use is not recommended for system standardization (see 7.7 above) in cases where the item under test is not flat. Other types of reference blocks may be used when mutually agreed upon between the supplier and the purchaser. Practices C1212 and C1336 containing seeded voids and seeded inclusions may be used for advanced-ceramics.

**7.7.2 Curved Surfaces**—Reference blocks with flat surfaces should not be used for establishing gain settings for examinations on examination surfaces with radii of curvature less than about 8 in. (203 mm). For examination surfaces with radii of curvature less than 8 in. (203 mm), reference blocks shall be within  $\pm 10\%$  of the radius curvature of the part being examined.

**7.8 Reference Reflectors (Targets)**—Flat-bottom holes, (FBH), or other artificial discontinuities, located either directly in the part or material, in a representative sample of the part or material, or, if previously found to yield satisfactory examination, in reference blocks, shall be used to establish the reference echo amplitude or to perform distance-amplitude correction, or both. For most examinations, the bottom surface of a suitable diameter flat-bottom hole is the common reference reflector. However, other types of artificial discontinuities (notches, side-drilled holes, etc.) may be used when mutually agreed upon between the supplier and the purchaser. Seeded voids (Practice C1212), seeded inclusions (Practice C1336), and laser-drilled holes are common reflectors for advanced ceramics.

## 8. General Examination Requirements

**8.1 Material Condition**—Perform ultrasonic examination of parts or material before machining if surface roughness and part geometry are within the tolerance specified in the contractual agreement. Surfaces may already be sufficiently free of roughness and waviness to permit a uniform examination over the required areas. When it is determined that surface roughness precludes adequate detection and evaluation of subsurface discontinuities, smooth the areas in question by machining, grinding, or other means before the examination is performed. For advanced-ceramics, care shall be taken to avoid generating surface or near-surface cracks by the smoothing operation. During examination and evaluation, ensure that the entry surface and back surface are free of loose scale, machining, or grinding particles or other loose foreign matter.

**8.2 Coverage**—In all examinations, perform scanning to locate discontinuities that are oriented parallel with the entry surface, or that are in a plane approximately normal to the major working direction parallel to the grain flow of the part, or both. Examine areas of the part, which have not undergone significant material flow, by methods that will detect randomly oriented discontinuities. To ensure complete coverage of the material, it is necessary that the scanning spacing (index) is less than the effective beam length in the index direction at any depth in the material. Furthermore, to insure repeatable response at the same amplitude from a given length discontinuity, it is necessary that the scan index not exceed the absolute difference between minimum discontinuity length and beam length. This is known as “invariant worst case interception”. (See Ref. (2).) Note that conformance to this paragraph does not accomplish examination of the entire volume of the material. Uninspectable zones due to limitations in entry surface resolution and back surface resolution prevent complete volumetric examination.

**8.2.1 Resolution**—If entry surface resolution (based on 2:1 signal-to-noise ratio) is not sufficient to allow detection of the required reference reflectors near the examination surfaces, perform additional examinations from the opposite side. If surface roughness prevents the required resolution from being obtained, correct the problem before performing the examination. Also, for each

<sup>7</sup> The boldface numbers in parentheses refer to a list of references at the end of this standard. Beck, K.H., “Limitations to the Use of Reference Blocks for Periodic and Preinspection Calibration of Ultrasonic Inspection Instruments and Systems,” *Materials Evaluation*, Vol. 57, No. 3, March 1999.

examination direction, perform examinations from opposite sides when the maximum material travel distance is such that the minimum size reference reflector cannot be detected by examinations applied from only one side (see 7.1).

8.3 *Ultrasonic Frequency*—In general, the higher frequencies provide a more directive sound beam and provide better depth and lateral resolution. The lower frequencies provide better penetration and better detection of misaligned planar discontinuities. For a particular examination, select the frequency based on the material being examined, the anticipated type of discontinuities, and other examination requirements.

## 9. Examination (Scanning) Procedure

### 9.1 System Setup:

9.1.1 *Tank*—Immerse the part to be examined, reference standards, and search unit in a suitable tank filled with liquid couplant.

9.1.1.1 The liquid couplant shall be clean and deaerated to eliminate attenuation of the sound beam and to improve system signal-to-noise ratio.

9.1.1.2 Care shall be taken to ensure that extraneous indications caused by particulates, air bubbles, etc. in the couplant, do not interfere with the examination at the required examination sensitivity.

9.1.1.3 Corrosion inhibitors or wetting agents may be added as long as they do not affect the material properties.

9.1.1.4 Residual suspended particulate matter and air bubbles that collect on the material and search unit surfaces shall be removed.

9.1.2 *Reference Standard Selection*—The reference standards shall have the size and type of reference reflectors specified in the contractual agreement. A good basic set for metals is described in Table 2 and in Practice E127 for distance-amplitude reference blocks.

NOTE 4—The recommendations of paragraphs 9.1.2.1, 9.1.2.2, and 9.1.2.3, which follow are not applicable to advanced ceramics.

9.1.2.1 For examination performed only in the near-field portion of the sound beam, select metal paths from those in Table 2. The metal paths selected should be in increments so that the maximum metal path difference between reference reflectors does not

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**TABLE 2 Distance Amplitude Reference Block-Metal Path  
Increments, in. (mm)**

0.125 (3.2)
0.250 (6.4)
0.375 (9.5)
0.500 (12.7)
0.625 (15.9)
0.750 (19.1)
0.875 (22.2)
1.000 (25.4)
1.250 (31.8)
1.500 (38.1)
1.750 (44.5)
2.000 (50.8)
2.250 (57.2)
2.500 (63.5)
2.750 (69.9)
3.000 (76.2)
3.250 (82.6)
3.500 (88.9)
3.750 (95.3)
4.000 (101.6)
4.250 (108.0)
4.500 (114.3)
4.750 (120.7)
5.000 (127.0)
5.250 (133.4)
5.500 (139.7)
5.750 (146.1)
6.000 (152.4)

exceed the requirements described in **Table 3**. This set shall include one reference block with a metal path equal to or less than the required front surface resolution, and one approximately equal to or greater than the thickness of the part (or one half the thickness, if the part is examined from both sides).

9.1.2.2 For examination performed only in the far-field portion of the sound beam, select at least three reference blocks with the following metal paths: (1) a metal path equal to or less than the required front-surface resolution; (2) a metal path approximately equal to one half the thickness of the part; and (3) a metal path approximately equal to or greater than the thickness of the part (or the required front-surface resolution, one quarter, and one half the thickness if the part is examined from both sides).

9.1.2.3 For examinations which are performed so that part of the thickness of the part is in the near field and part is in the far field, the set of reference block metal paths shall include blocks which satisfy the above near-field requirements covering the range from the front-surface resolution to the near-field limit and one reference block with a metal path equal to or greater than the thickness of the part (or one half the thickness if the part is examined from both sides).

9.1.3 *Search Unit Adjustment*—Normalize the ultrasonic beam by adjusting the search unit for maximum echo amplitude from the front surface of the part or material. This is accomplished by angling the search unit in two directions, perpendicular to one another and parallel to the sound-entry surface (**Note 5**). This may be accomplished by use of a manipulator with two axes of motion, mutually perpendicular to one another, or in the case of curved surfaces, by use of a manipulator with one axis of motion and a search tube which can be rotated to achieve perpendicularity. During examination, monitor either the front-surface or back-surface indication. If changes in the shape of the part cause the amplitude of the monitored indication to decrease by more than 50 %, re-angle the search unit as necessary over different zones to maintain the beam normal to the examination surface.

NOTE 5—For focused search units, perform beam normalization so that the centerline of the beam is perpendicular to the material entry surface.

9.1.4 *Water Path*—The distance from the face of the search unit to the front surface of the material shall be such that the second front-surface echo does not appear before the first back-surface echo. The water path distance and search unit focal length will determine whether examination will occur in the near zone, far zone, or a combination of these. For focused search units, this distance should be such that the search unit focus is within the material at the depth required to meet front-surface resolution requirements.

NOTE 6—The permissible variation in the water path depends completely on the particular system and application (that is, flat or focused search unit, shape of beam profile, etc.) For establishing the distance-amplitude relationship and evaluating discontinuities, maintain the water path to within  $\pm \frac{1}{8}$  in. ( $\pm 3.2$  mm). During scanning, the maximum variation shall not exceed the amount specified in the contractual agreement or approved examination procedure.

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## 9.2 Initial Scanning Standardization:

9.2.1 *Scan Index Determination*—Using the reference blocks selected in **9.1.2** and the search unit setup in **9.1.3**, determine the maximum allowable scan index as follows: (1) maximize the echo amplitude from the reflector in each reference block and adjust the amplitude from 50 to 100 % of the upper linearity limit; and (2) determine the total traversing distance in the index direction, across each reference target, through which no less than that percentage of the maximized amplitude is obtained, which corresponds to the allowable variation during repeated runs of the reference standard. (See Ref. (2<sup>8</sup>)). This distance is dependent on the material travel to the reflector and will vary from one reference target to another. This is the effective beam diameter at each material distance. The least of the distances shall be used as the maximum allowable scan index.

**TABLE 3 Reference Block-Metal Path Selection in Near Field**

Metal Path Range, in. (mm)	Maximum Metal Path Difference Between Adjacent Reference Blocks, in. (mm)
0 to 0.25 (0 to 6.4)	0.125 (3.2)
0.25 to 1.0 (6.4 to 25.4)	0.250 (6.4)
1.0 to 3.0 (25.4 to 76.2)	0.500 (12.7)
Over 3.0 (over 76.2)	1.000 (25.4)

<sup>8</sup> Beck, K. H., "Effect of Ultrasonic Transducer Beam Profile on Accuracy of Discontinuity Detection During Scanning," *Materials Evaluation*, Vol. 64, No. 2, Feb. 2006, pp. 102–105.