Designation: E 1001 – 99a

Standard Practice for Detection and Evaluation of Discontinuities by the Immersed Pulse-Echo Ultrasonic Method Using Longitudinal Waves[1]

This standard is issued under the fixed designation E 1001; 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.

This standard has been approved for use by agencies of the 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 (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 totally submerged in the couplant (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 complements Practice E 214 by providing more detailed procedures for the selection and calibration of the inspection system and for evaluation of the indications obtained.

1.3 *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:*

C 1212 Practice for Fabricating Ceramic Reference Specimens Containing Seeded Voids[2]

C 1336 Practice for Fabricating Non-Oxide Ceramic Reference Specimens Containing Seeded Inclusions[2]

E 127 Practice for Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks[3]

E 214 Practice for Immersed Ultrasonic Examination by the Reflection Method Using Pulsed Longitudinal Waves[3]

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments[3]

E 428 Practice for Fabrication and Control of Steel Reference Blocks Used in Ultrasonic Inspection[3]

E 1316 Terminology for Nondestructive Examinations[3]

2.2 *ASNT Documents:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing[4]

ANSI/ASNT-CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel[4]

2.3 *Military Standards:*

MIL-STD-410E Nondestructive Testing Personnel Qualification and Certification (Eddy-Current, Liquid Penetrant, Magnetic Particle, Radiographic, and Ultrasonic)[5]

NAS-410 Nondestructive Testing Personnel Qualification and Certification[5]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this practice, see Terminology E 1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *effective beam diameter*—that distance through which a search unit can be traversed across a calibration reflector so that the corresponding echo amplitude is at least one half (-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 *evaluation*—the determination of the relative or approximate size of a discontinuity, or its indication amplitude relative to the amplitude of a reference discontinuity.

3.2.3 *examination*—the automatic or manual scanning of a part to locate discontinuities.

[1] This practice is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.06 on Ultrasonic Testing Procedure.

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[2] *Annual Book of ASTM Standards,* Vol 15.01.

[3] *Annual Book of ASTM Standards,* Vol 03.03.

[4] Available from American Society for Nondestructive Testing, 1711 Arlingate Plaza, P.O. Box 28518, Columbus, OH 43228-0518.

[5] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

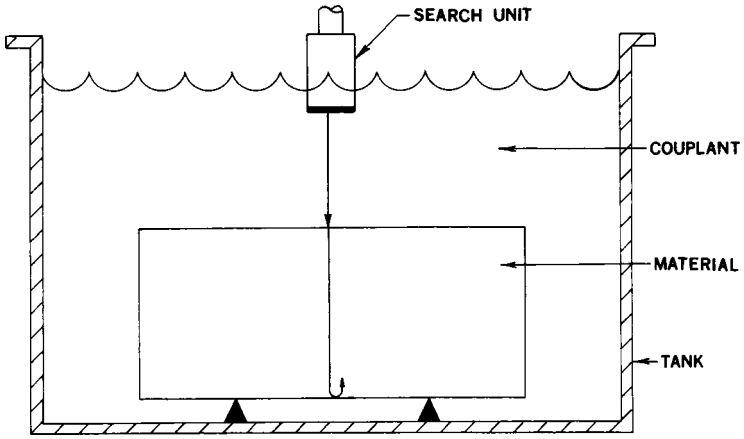

FIG. 1 Basic Immersion Setup

3.2.4 *gain*—the amount of amplification or attenuation, or both, applied to an electrical signal that dictates its amplitude as displayed on the cathode-ray tube (CRT).

3.2.5 *scan index*—the length of the step created by rastering the search unit over the part, that is continuously scanning in one direction, then stepping in the direction perpendicular to the scan. The allowable scan index should be correlated with the search unit effective beam diameter to ensure full coverage of the part.

3.2.6 *standardize*—to adjust the gain of an ultrasonic instrument so that the amplitude of the echo from a specified reference reflector is a specified value.

3.2.7 *transfer*—a change in scanning gain to compensate for differences in attenuation of the reference blocks and the part or material being inspected.

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. Significance and Use

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

5.2 Although not all requirements of this practice can be applied universally to all inspection 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.

5.3 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.

6. Apparatus

6.1 *Electronic Equipment*—The electronic equipment should be capable of producing and processing electronic signals at frequencies in the range of search unit frequencies being used. The equipment and its display should 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 E 317 or equivalent procedures (see Note 1). These requirements are applicable only for the frequencies required for the inspection. Also, the equipment, including the search unit, should 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 inspected. Alternatively, if these conditions can be met at one half the part thickness, the part may be inspected from both sides.

NOTE 1—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.

6.2 *Voltage Regulator*—If fluctuations in line voltage cause variations exceeding ±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.

6.3 *Search Units*—The search unit selected should be compatible with the electronic equipment being used and with the material to be inspected. The search units should be of the

TABLE 1 Minimum Equipment Requirements (Longitudinal Wave)

Instrument Characteristics	Ultrasonic Test Frequency, MHz			
	2.25	5.0	10.0	15.0
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				

immersion type. Only straight-beam (longitudinal) search units, with flat or focused acoustic lenses, should 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.

6.4 *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 should 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 should 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 should be easily detectable by the operator.

NOTE 2—This requirement may not be applicable if recording equipment is used.

6.4.1 *Alarm Gate Synchronization*—To ensure that the alarm gate tracks the inspection area, the gate should lock on the first interface pulse from the test piece rather than on the initial pulse from the system. Gating from the initial pulse can result in either partial loss of the inspection 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.

6.5 *Manipulating Equipment* should be provided to adequately support a search tube, containing the search unit, and to allow angular adjustment in two mutually perpendicular, vertical planes. A manipulator may be attached between the search tube and search unit to provide the necessary angular adjustments. The scanning and indexing apparatus should have sufficient structural rigidity to provide support for the manipulator and should allow smooth, accurate positioning of the search unit. This apparatus should permit control of the scan in accordance with 8.3.1 and control of the index in accordance with 8.2.1. Also, the scanning apparatus should be sufficiently rigid to keep search unit backlash to within tolerances as specified in the contractual agreement. Water-path distances should be continuously adjustable.

6.6 *Tank*—The container or tank should permit accurate positioning of the search unit, reference blocks, and part or material to be examined in accordance with the requirements of Section 7.

6.7 *Reference Artifacts*—Ultrasonic reference blocks, often called test blocks or reference specimens, are used to standardize the ultrasonic equipment and to evaluate the indications received from discontinuities within the test part. The ultrasonic characteristics of the reference blocks such as attenuation, noise level, surface condition, and sound velocity, should be similar to the material being inspected. Metal reference blocks 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.

6.7.1 *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 E 127. However, other types of reference blocks may be used when mutually agreed upon between the supplier and the purchaser, for example, those given in Practice E 428. Practices C 1212 and C 1336 containing seeded voids and seeded inclusions may be used for advanced ceramics.

6.7.2 *Curved Surfaces*—Reference blocks with flat surfaces may be used for establishing gain settings for examinations on test surfaces with radii of curvature 5 in. (130 mm) or greater. For test surfaces with radii of curvature less than 5 in., reference blocks with the same nominal curvature should be used, unless otherwise agreed upon between the supplier and the purchaser.

6.8 *Reference Reflectors*—Flat-bottom holes, (FBH), or other artificial discontinuities, located either directly in the test part or material, in a representative sample of the part or material, or in reference blocks, should 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 C 1212), seeded inclusions (Practice C 1336), and laser-drilled holes are common reflectors for advanced ceramics.

7. General Examination Requirements

7.1 *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 should 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.

7.2 *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. Inspect areas of the part, which have not undergone significant material flow, by methods that will detect randomly oriented discontinuities.

7.2.1 *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 test surfaces, perform additional examinations from the opposite side. If surface

roughness prevents the required resolution from being obtained, correct the problem before performing the test. Also, for each inspection 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 6.1).

7.3 *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 test, select the frequency based on the material being inspected, the anticipated type of discontinuities, and other inspection requirements.

8. Examination (Scanning) Procedure

8.1 *System Setup*:

8.1.1 *Tank*—Immerse the part to be inspected, reference blocks, and search unit in a suitable tank filled with liquid couplant.

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

8.1.1.2 Care should 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 test sensitivity.

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

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

8.1.2 *Reference Block Selection*—The reference blocks should have the size and type of reference reflectors specified in the contractual agreement. Unless otherwise specified, for metals, select the increment of metal path distance from the distance-amplitude reference blocks described in Table 2 and in Practice E 127.

NOTE 3—The recommendations of paragraphs 8.1.2.1, 8.1.2.2, and 8.1.2.3 are not applicable to advanced ceramics.

8.1.2.1 For inspection 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 adjacent reference blocks does not exceed the requirements described in Table 3. This set should 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 test-piece thickness (or one half the thickness if the part is inspected from both sides).

8.1.2.2 For inspection 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 test piece thickness; and (*3*) a metal path approximately equal to or greater than the test-piece thickness (or the required front-surface resolution, one quarter, and one half the thickness if the part is inspected from both sides).

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)
6.250 (158.8)
6.500 (165.1)

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)

8.1.2.3 For inspections which are performed so that part of the test-piece thickness is in the near field and part is in the far field, the set of reference block metal paths should 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 test-piece thickness (or one half the thickness if the part is inspected from both sides).

8.1.3 *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 4). During examination, monitor either the front-surface or back-surface indication. If changes in the shape of the test piece 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 test surface.

NOTE 4—For focused search units, perform beam normalization so that the material entry surface is at the focus.

8.1.4 *Water Path*—The distance from the face of the search unit to the front surface of the material should be such that the