Designation: B 594 – 97

Standard Practice for Ultrasonic Inspection of Aluminum-Alloy Wrought Products for Aerospace Applications[1]

This standard is issued under the fixed designation B 594; 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 covers the requirements for pulse-echo ultrasonic inspection and includes criteria used to define applicable quality levels of aluminum-alloy wrought products for aerospace applications when performance of the ultrasonic test by the producer is specified, or when ultrasonic inspection is performed by the purchaser upon receipt.

1.2 This practice is not applicable if plastic deformation is introduced into the material after delivery.

1.3 The ultrasonic test described in this practice is employed to detect internal discontinuities oriented in a direction parallel to, or nearly parallel to, the surface of the product. The test is performed either by the immersion method or the contact method using pulsed longitudinal waves which are transmitted and received by a search unit containing either a single crystal or a combination of electrically interconnected multiple crystals. Ultrasonic tests employing either the through-transmission or the angle-beam techniques are not included.

NOTE 1—Ultrasonic tests employing angle-beam techniques require special reference blocks, search units, and scanning procedures and are subject to negotiation between the purchaser and the seller when such tests are required by the contract or purchase order.

1.4 The values stated in inch-pound units are the standard. The SI units in parentheses are for information only.

1.5 *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 The following documents of the issue in effect on date of material purchase form a part of this practice to the extent referenced herein:

2.2 *ASTM Standards:*

E 114 Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method[2]

E 127 Practice for Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks[2]

E 214 Practice for Immersed Ultrasonic Examination by the Reflection Method Using Pulsed Longitudinal Waves[2]

E 317 Practice for Evaluating Performance Characteristics of Ultrasonic Pulse-Echo Testing Systems Without the Use of Electronic Measurement Instruments[2]

2.3 *American Society for Nondestructive Testing Standard:*

ASNT Recommended Practice for Nondestructive Testing Personnel Qualification and Certification—Ultrasonic Testing Method, SNT-TC-1A[3]

2.4 *Military Standard:*

MIL-STD-410 Certification of Inspection Personnel[4]

3. Terminology

3.1 *Definitions:*

3.1.1 The following definitions of aluminum-alloy wrought products shall be used in conjunction with this practice:

3.1.2 *plate*—a rolled product, rectangular in cross section and form, of thickness equal to or greater than 0.250 in. (6.35 mm) with sawed or sheared edges.

3.1.3 *bar*—a solid product that is long in relation to its cross section which either is a square or rectangle (excluding plate and flattened wire) with sharp or rounded corners, or is a regular hexagon or octagon and in which at least one perpendicular distance between parallel faces is equal to or greater than 0.375 in. (9.53 mm).

3.1.4 *shape*—a wrought product that is long in relation to the dimensions of its cross section which is of a form other than that of sheet, plate, rod, bar, tube, or wire.

3.1.5 *die forging*—a forging that is worked to the required shape and size in impression dies.

3.1.6 *rolled ring*—a cylindrical product of short length in relation to its diameter which is formed by rolling a hollow section in the circumferential direction.

[1] This practice is under the jurisdiction of ASTM Committee B-7 on Light Metals and Alloys and is the direct responsibility of Subcommittee B07.03 on Aluminum Alloy Wrought Products.

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

[3] Available from American Society for Nondestructive Testing, 3200 Riverside Dr., P.O. Box 5642, Columbus, OH 43221.

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

3.1.7 *hand forging*—a forging that is worked to the required shape and size between flat or simply shaped dies by repeated strokes or blows and manipulation of the piece.

4. Summary of Practice

4.1 The product is inspected ultrasonically by scanning specified entry surfaces with a beam of pulsed longitudinal waves oriented in a direction perpendicular to the entry surface. The ultrasound is transmitted into the product either by the direct contact or the immersion method. During the scan, indications representing discontinuities are displayed on an A-scan screen of the test instrument and may be detected by auxiliary electronic monitors, if used.

4.2 When the test system sensitivity level is appropriately adjusted, detected discontinuities and variations in back reflection patterns are evaluated by comparing amplitudes of indications with the ultrasonic responses from selected ultrasonic standard reference blocks. The evaluated ultrasonic discontinuity responses are then classified and compared with applicable acceptance criteria.

NOTE 2—Additional information describing ultrasonic tests by the direct contact method and by the immersion method is available in Practices E 114 and E 214.

5. Significance and Use

5.1 A number of factors such as the condition of the entry and back surfaces of the inspected part, the inclination of the ultrasonic beam with respect to the entry surface, and variations in the performance characteristics of the test system may cause significant differences in amplitudes of discontinuity indications and back reflections. These factors can seriously impair the reliability and the quantitative value of the ultrasonic test outlined in this practice.

5.2 Accurate evaluations of discontinuity size are also significantly affected by variations in search unit characteristics and by irregularities in discontinuity surfaces which can influence reflectivity. For these reasons, the discontinuity sizes that may be implied by the ultrasonic comparisons outlined in this practice must be regarded as "apparent" or "estimated" in recognition of the limited quantitative value of the measurement.

5.3 Because numerous interacting variables in a test system can adversely influence the results of an ultrasonic inspection, the actual quantitative effects of detected discontinuities upon the mechanical properties of the inspected product are difficult to establish. Although this practice provides a reliable control of product quality during manufacture, it is not applicable as an exclusive indicator of the ultimate quality and performance of components fabricated from the inspected products covered by this practice.

6. Special Requirements

6.1 When ultrasonic inspection of the finished product is required of the producer, purchase orders or contracts shall include the following information:

6.1.1 *Special Acceptance Limits*—Discontinuity class limits, if other than those defined in Section 11, shall be subject to negotiation between the purchaser and the producer and shall be in accordance with an agreement established between the purchaser and the producer at the time of quotation or acceptance of purchase order or contract.

6.1.2 *Engineering Drawings*—When ultrasonic inspection is specified for alloys, section thicknesses, and weights outside limits established in applicable product specifications, the special discontinuity class limits shall be as negotiated between the purchaser and the producer and shall be indicated on zoned engineering drawings describing the material to be inspected on part machine drawings. The drawings shall also indicate noncritical areas on the material and areas that will be removed by machining.

6.1.3 *Special Testing Procedures*—Cylindrical sections or specified areas of parts containing fillets may require additional inspections employing special ultrasonic testing procedures (for example, angle-beam, shear-wave technique) not covered by this practice. Such special testing procedures and acceptance limits shall be established by negotiation and agreement between the purchaser and producer.

7. Apparatus

7.1 The required ultrasonic test system shall consist of the following:

7.1.1 *Basic Test Instrument*—Any electronic device that produces electrical pulses to activate a search unit and displays pulses representing ultrasonic reflections on an A-scan screen is satisfactory if the minimum performance characteristics specified in 7.1.3 are met. The instrument shall provide stable linear amplification of received pulses at a selected test frequency and required sensitivity levels within the specified minimum performance limits.

7.1.2 *Search Unit*—The recommended search unit is the flat nonfocusing type and contains a piezoelectric crystal which generates and receives longitudinal waves at the rated frequency when connected to the test instrument through a suitable coaxial cable. A dual-crystal search unit containing both a transmitting and a receiving crystal in one container may be used provided the test instrument will accommodate two-crystal operation. Special tests employing focusing search units may be used provided such tests are established by negotiation and agreement between purchaser and producer.

7.1.2.1 *Search Unit Size*—Any search unit of either circular or rectangular configuration may be used for initial scanning. For a circular configuration that provides an effective crystal area greater than 1.00 in.^{2} (6.45 cm^2) and for all rectangular search units a documented method of providing a uniform entry surface for the full extent of the sound beam shall be agreed upon between the purchaser and producer. A search unit containing a circular crystal of an effective diameter no greater than 0.75 in. (19.0 mm) is required to evaluate the ultrasonic response from detected discontinuities. When connected to the test instrument and used for initial scanning and evaluating responses from discontinuities, the search unit shall meet or exceed the required minimum performance characteristics at the selected test frequency. Search units used only for initial scanning of a part prior to evaluation of suspect discontinuities shall, as a minimum, have adequate performance of sensitivity and signal to noise ratio appropriate to the class of inspection described in Section 11.

NOTE 3—The same search unit used for initial scanning may also be used for evaluating discontinuities provided its effective crystal diameter is no greater than 0.75 in. (19.0 mm) and minimum test system performance requirements are satisfied. Rectangular search units may be used for evaluation if the method of use is established in writing by the producer and approved by the purchaser.

7.1.2.2 *Effective Beam Width*—The effective beam width of the search unit shall be established by determining the total traverse distance over which response is maintained within limits specified below. The hole size in the standard Practice E 127 reference block to be used for determining effective beam width shall be in accordance with those listed in Table 1 for the applicable class of inspection. The metal distance of the reference block shall be that which produces the smallest clearly resolved hole indication. The same water distance to be used for scanning shall be used to determine effective beam width.

(*a*) For round search units, a maximum indication shall be obtained from the hole and then the instrument gain control shall be adjusted to obtain a hole indication that is equal to 80 % of the vertical limit. The effective beam width shall be the traverse distance in the index direction over which the indication from the flat-bottom hole equals or exceeds 40 % of the vertical limit.

(*b*) For rectangular search units, an indication shall be obtained from the hole at any point along the longitudinal axis of the search unit and then the instrument gain control shall be adjusted to obtain a hole indication that is equal to 80 % of the vertical limit. The effective beam width shall be the traverse distance in the index direction over which the indication from the flat-bottom hole equals or exceeds 40 % of the vertical limit. The effective beam width establishes the maximum allowable index distance used during the initial scan sensitivity for each inspection.

7.1.2.3 *Distance-Amplitude Characteristics*—The distanceamplitude characteristics shall be established and recorded for each search unit by obtaining the ultrasonic response from a complete distance-amplitude set of ultrasonic standard reference blocks containing the No. 5 (0.078-in. diameter (1.98-mm diameter)) flat-bottomed holes (see 7.4) at a nominal sensitivity level to be used for evaluating the estimated size of detected discontinuities. When using the search unit during testing, a check of the established distance-amplitude characteristics shall be conducted at least once per 8-h shift and shall be performed by noting the ultrasonic response from at least three selected No. 5 distance-amplitude reference blocks at the established sensitivity level. If the response from any block differs by more than ±10 % of the original distance-amplitude curve established for the selected search unit, the performance of the search unit shall be reevaluated and the test system shall be restandardized to ensure proper conformance to the requirements in this practice, and all metal tested since the previous standardization shall be retested.

TABLE 1 Applicable Reference Block Hole Sizes Used to Standardize Scan Sensitivity and Classify Ultrasonic Discontinuities

Class	Hole Number	Hole Diameter, in. (mm)
AA	2	0.031 (0.79)
A	3	0.047 (1.19)
B	5	0.078 (1.98)
C	8	0.125 (3.18)

NOTE 4—The distance amplitude curve may be established on one or more sets of ultrasonic standard reference blocks, containing other than No. 5 flat bottomed holes, when justified by the inspection class of Section 11.

NOTE 5—This section is not applicable when using the alternative procedure allowed by 10.5.2.

7.1.2.4 *Uniformity of Response for Rectangular Search Units*—Rectangular search units shall exhibit beam uniformity within ±10 % of the mean amplitude of indication from the flat-bottomed hole during a traverse along the longitudinal axis of the search unit at the scanning sensitivity established with reference blocks for the applicable class (exclusive of end lobe responses).

7.1.3 *Test System Performance*—When used with appropriate auxiliary equipment described in subsequent paragraphs, the test system shall be capable of meeting or exceeding the minimum performance characteristics listed in Table 2 as determined by procedures outlined in Practice E 317. If instrument A-scan display dimensions exceed the 2.5-in. (63.5-mm) vertical limit and the 3.5-in. (88.9-mm) horizontal limit, the instrument shall be considered usable throughout the entire A-scan screen height or width found to be linear with the procedures prescribed in Practice E 317. All other minimum characteristics listed in Table 2 remain applicable.

7.2 *Auxiliary Equipment*—In addition to the ultrasonic test system previously described, the following equipment is necessary:

7.2.1 *Tank*—For tests by the immersion method, any container is satisfactory that will facilitate the accurate, stable positioning of both the search unit and the product to be inspected.

7.2.2 *Scanning Apparatus*—During the inspection procedure, the scanning apparatus shall permit measurement of both the scan distance and the index distance within ±0.1 in. (±2.5 mm). The search unit shall be supported by any one of the following devices:

7.2.2.1 *Manipulator and Bridge*—When a manipulator is used in tests by the immersion method, the manipulator shall adequately support a search tube containing a search unit and shall provide fine adjustment of angle within 1° in two vertical planes that are perpendicular to each other. The bridge shall be of sufficient strength to provide rigid support for the manipulator and shall allow smooth, accurate positioning of the search unit within ±0.05 in. (±1.3 mm).

7.2.2.2 *Special Fixtures*—Special search unit-supporting fixtures such as bubblers and wheel search units may be used provided they meet the requirements prescribed for a manipulator and bridge and provided the test results obtained with special fixtures are equivalent to those obtained by the immersion method.

7.2.2.3 *Contact Scanning Unit*—During tests by the contact method, the search unit usually is supported and positioned manually on the entry surface of the inspected product.

TABLE 2 Minimum Performance Characteristics Required for Ultrasonic Test Systems

NOTE 1—The minimum requirements shown in this table are applicable as indicated only for the selected frequencies used for the inspection. The test system is required to meet the limits only for the test frequencies actually used.

Performance Characteristics	Test Frequency, MHz			
	2.25	5.0	10.0	15.0
Vertical limit, in. (mm), min	2.5 (63.5)	2.5 (63.5)	2.5 (63.5)	2.5 (63.5)
Upper linearity limit, min[A]	95	95	95	95
Lower linearity limit, max[A]	10	10	10	10
Ultrasonic sensitivity, min[A]	50[B]	100[B]	80[B]	50[B]
Signal-to-noise ratio, min	65[B]	100[B]	100[B]	100[B]
Entry surface resolution, in. (mm) of aluminum, max	0.7 (18)	0.5 (13)	0.3 (8)	0.2 (5)
Back surface resolution, in. (mm) of aluminum, max	0.3 (8)	0.2 (5)	0.1 (3)	0.1 (3)
Horizontal limit, in. (mm), min	3.5 (89)	3.5 (89)	3.5 (89)	3.5 (89)
Horizontal linearity, min[C]	85	85	85	85

[A] % of vertical limit.
[B] ASTM Reference Block 1-0300.
[C] %of horizontal limit.

However, special fixtures for contact scanning may be employed provided their use ensures conformance to the requirements in this practice.

7.3 *Couplant*—Clean water at room temperature, free of visible air bubbles that could interfere with the test, is the recommended couplant for tests by the immersion method. Inhibitors or wetting agents, or both, may be used. For tests by the contact method, the recommended couplant is clean, light-grade oil.

NOTE 6—Other coupling liquids may be employed provided their use does not adversely affect either the test results or the product.

7.4 *Reference Standards*—The ultrasonic reference standards required for the inspection of aluminum-alloy products shall be a distance-amplitude set of aluminum-alloy ultrasonic standard reference blocks fabricated and checked in accordance with Practice E 127.

NOTE 7—When side-wall reflections caused by sound-beam divergence prevents the use of Practice E 127 reference blocks, special blocks of the same material as used in Practice E 127 blocks may be used.

7.4.1 The distance-amplitude set shall consist of three groups of standard Practice E 127 reference blocks with flat-bottom holes of the three diameters listed in Table 1. Discontinuity indications shall be compared with the response having the same metal distance within ±⅛ in. (±3.2 mm) for metal distances from ¼ in. (6.4 mm) through 1.0 in. (25.4 mm), within ±¼ in. for metal distances from over 1.0 in. through 3.0 in. (76.2 mm), and within ±½ in. (±12.7 mm) for metal distances over 3.0 in. The above requirements can be met optionally with blocks having the hole sizes specified in Table 1 and either of the following sets of metal distances:

in. (mm)	in. (mm)
0.25 (6.4)	0.25 (6.4)
0.50 (12.7)	0.37 (9.4)
0.75 (19.0)	0.62 (15.7)
1.00 (25.4)	0.87 (22.1)
1.50 (38.1)	1.25 (31.8)
2.00 (50.8)	1.75 (44.5)
2.50 (63.5)	2.25 (57.2)
3.00 (76.2)	2.75 (69.9)
4.00 (101.6)	3.25 (82.6)
5.00 (127.0)	4.25 (108.0)
6.00 (152.4)	5.25 (133.4)

7.4.2 *Special Reference Standards*—When required by the contract or purchase order instead of appropriate correction factors, special reference blocks containing curved entry surfaces may be employed for tests of cylindrical or irregularly shaped products. The type and number of such special blocks are subject to negotiation and agreement between the purchaser and the seller.

7.4.3 *Ultrasonic Transmission Characteristics*—The transmission characteristics exhibited by the required ultrasonic standard reference blocks shall be within ±40 % of the transmission characteristics of the inspected product as determined with the test frequency and equipment to be used for the inspection (Note 8). Differences in transmission characteristics are determined by comparing the amplitude of a selected back reflection obtained from the inspected product with the amplitude of the equivalent back reflection from a selected reference block at a constant test sensitivity level. The total length of the reference block used for comparison shall be equal to the thickness of the inspected product within ±0.50 in. (±12.7 mm). The back reflection from the block shall be obtained at a location midway between the center and the outside edge of the block entry surface to avoid an indication from the flat-bottom hole.

NOTE 8—If the transmission characteristics of the reference blocks exceed the specified ±40 % limits, correction for significant differences in the ultrasonic response may be required when adjusting test sensitivity for initial scanning and for discontinuity response evaluation. Techniques for ultrasonic response correction shall be subject to negotiation at the time of quotation or acceptance of the purchase order or contract.

7.5 *Attenuator Decade Switch Check*—If the ultrasonic system is equipped with precision attenuator switches or an attenuator decade switch, these items shall be checked in accordance with the applicable method described below:

7.5.1 *Decade Switch*:

7.5.1.1 With a typical straight-beam transducer, any suitable reference block, and the ultrasonic instrument damping, reject, and pulse length at minimum, adjust the instrument until a response from the back surface of the block has an amplitude of 95 % of the A-scan display height at a switch position of 1X (30 dB). The uncalibrated gain may be adjusted to obtain this response height (Fig. 1, A-scan display 1).

7.5.1.2 Switch to 0.1X (10 dB) position and accept as linear any response height from 6 to 13 % (Fig. 1, A-scan display 2).

7.5.1.3 With the switch at 0.1X (10 dB) position, adjust the uncalibrated gain to get a response height of 10 % (Fig. 1,