Designation: E215 – 16

Standard Practice for Standardizing Equipment and Electromagnetic Examination of Seamless Aluminum-Alloy Tube[1]

This standard is issued under the fixed designation E215; 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 U.S. Department of Defense.

1. Scope*

1.1 This practice[2] is for standardizing eddy current equipment employed in the examination of seamless aluminum-alloy tube. Artificial discontinuities consisting of flat-bottomed or through holes, or both, are employed as the means of standardizing the eddy current system. General requirements for eddy current examination procedures are included.

1.2 Procedures for fabrication of reference standards are given in Appendixes X1.1 and X2.1.

1.3 This practice is intended for the examination of tubular products having nominal diameters up to 4 in. [101.6 mm] and wall thicknesses up to the standard depth of penetration (SDP) of eddy currents for the particular alloy (conductivity) being examined and the examination frequency being used.

NOTE 1—This practice may also be used for larger diameters or heavier walls up to the effective depth of penetration (EDP) of eddy currents as long as adequate resolution is obtained and as specified by the using party or parties.

1.4 This practice does not establish acceptance criteria. They must be established by the using party or parties.

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

1.6 *This standard does not purport to address all of the safety problems, 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:*[3]

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

2.2 *Federal Standard:*

Fed Std. No. 245D Tolerance for Aluminum Alloy and Magnesium Alloy Wrought Products[4]

2.3 *Other Documents:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing[5]

ANSI/ASNT-CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel[5]

NAS-410 NAS Certification and Qualification of Nondestructive Personnel (Quality Assurance Committee)[6]

2.4 *ISO Standards:*[7]

ISO 9712 Non-Destructive Testing—Qualification and Certification of NDT Personnel

3. Terminology

3.1 *Definitions*—For definitions of terms used in this practice, refer to Terminology E1316.

4. Significance and Use

4.1 The examination is performed by passing the tube lengthwise through or near an eddy current sensor energized with alternating current of one or more frequencies. The electrical impedance of the eddy current sensor is modified by

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.07 on Electromagnetic Method.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Practice SE-215 in the Code.

[3] 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.

[4] Available from Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://dodssp.daps.dla.mil.

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

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

[7] 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.

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

the proximity of the tube. The extent of this modification is determined by the distance between the eddy current sensor and the tube, the dimensions, and electrical conductivity of the tube. The presence of metallurgical or mechanical discontinuities in the tube will alter the apparent impedance of the eddy current sensor. During passage of the tube, the changes in eddy current sensor characteristics caused by localized differences in the tube produce electrical signals which are amplified and modified to actuate either an audio or visual signaling device or a mechanical marker to indicate the position of discontinuities in the tube length. Signals can be produced by discontinuities located either on the external or internal surface of the tube or by discontinuities totally contained within the tube wall.

4.2 The depth of penetration of eddy currents in the tube wall is influenced by the conductivity (alloy) of the material being examined and the excitation frequency employed. As defined by the standard depth of penetration equation, the eddy current penetration depth is inversely related to conductivity and excitation frequency (Note 2). Beyond one standard depth of penetration (SDP), the capacity to detect discontinuities by eddy currents is reduced. Electromagnetic examination of seamless aluminum alloy tube is most effective when the wall thickness does not exceed the SDP or in heavier tube walls when discontinuities of interest are within one SDP. The limit for detecting metallurgical or mechanical discontinuities by way of conventional eddy current sensors is generally accepted to be approximately three times the SDP point and is referred to as the effective depth of penetration (EDP).

NOTE 2—The standard depth of penetration is defined by the following equations:

$$SDP = 503.3 \sqrt{\frac{1}{f\sigma}}$$

where:

SDP = one standard depth of penetration, m
f = frequency, Hz (cycles per second), and
σ = conductivity, Siemens/metre.

or:

$$SDP = 26 \sqrt{\frac{1}{f\sigma}}$$

where:

SDP = one standard depth of penetration, inches
f = frequency in Hz (cycles per second), and
σ = conductivity, % IACS.

5. Basis of Application

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

NOTE 3—MIL-STD-410 is canceled and has been replaced with NAS-410, however, it may be used with agreement between contracting parties.

5.2 If specified in the contractual agreement, NDT agencies shall be qualified and evaluated in accordance with Specification E543. The applicable edition of Specification E543 shall be specified in the contractual agreement.

6. Apparatus

6.1 *Electronic Apparatus*—The electronic apparatus shall be capable of energizing eddy current sensors with alternating currents of suitable frequencies and shall be capable of sensing the changes in the electromagnetic characteristics of the eddy current sensors. Equipment may include a detector, phase discriminator, filter circuits, gating circuits, and signaling devices as required for the particular application.

6.2 *Eddy Current Sensors*—Eddy current sensors shall be capable of inducing currents in the tube and sensing changes in the electrical characteristics of the tube. The eddy current sensors may be of the encircling coil (annular) type or surface probe type.

7. Standardization of Apparatus

7.1 The apparatus shall be adjusted with an appropriate reference standard to ensure that the equipment is operating at the proper level of sensitivity, with the following considerations:

7.1.1 Primary reference standards employed for this purpose shall be prepared in accordance with the methods described in Appendix X1.1.

7.1.2 Equivalent secondary reference standards, prepared in accordance with methods described in Appendix X2.1, also may be employed for standardizing the apparatus.

7.1.3 Reference standards normally are of the same alloy, temper, and dimensions as the tube to be examined.

7.1.4 Examinations shall not be conducted unless the equipment can be set to the levels required by this standardization procedure.

7.1.5 For practical applications, reference standards also may be employed to establish quality control levels.

8. Procedure

8.1 Standardize the examination instrument using the appropriate reference standard prior to examination and check at least every 4 h during continuous operation, or whenever improper functioning of the examination apparatus is suspected. If improper functioning occurs, restandardize the apparatus in accordance with Section 7, and reexamine all tubes examined since the last successful standardization.

8.2 Tubes may be examined in the final drawn, annealed, or heat-treated temper, or in the drawn temper prior to the final anneal or heat treatment.

8.3 The length of tube over which end effect is significant may be determined by placing a series of holes or notches in special reference tubes and determining the distance from the tube end at which the signal amplitude from the discontinuities begins to decrease.

8.3.1 When standardizing and testing using secondary standard Method B (X2.5.2), if full length testing is required, the tube must be ordered to be electromagnetic tested in a rough cut length and have the untested 7 in. (175 mm) removed from each end.

NOTE 4—There is an area near each end which cannot be tested either because of an alarm from end effect or because end suppression is used to eliminate an alarm from end effect. Up to 7 in. (175 mm) on each end is to be considered untested, regardless of the standard used. Customers must specify if they want these untested areas removed.

9. Application

9.1 This application covers the electromagnetic examination of aluminum-alloy seamless tube using primary and secondary reference standards.

9.2 Primary and secondary reference standards, described in Appendixes X1.1 and X2.1, respectively, when used as acceptance standards, will establish probable detection of defects that are of a severity likely to cause leaks or substantial weakening of the tube.

9.3 Using electronic apparatus and eddy current sensors described in Section 6, the equipment sensitivity shall be standardized in accordance with Section 7 under the following examination conditions:

9.3.1 *Frequency*—The frequency shall be in the range from 1 to 125 kHz. The examination frequency should be adjusted to provide optimum penetration of the tube wall or to place discontinuities of interest within one SDP. Discontinuities located deeper than the SDP point will be detected with less sensitivity. The SDP point will vary as a function of the tube alloy (conductivity) and examination frequency and may be determined by the depth of penetration equation given in Section 4, Note 2.

9.3.2 *Speed of Examination*—The examination rate, or speed of the tube with respect to the eddy current sensor, may vary with the application. In encircling coil applications, examination speeds of 50 ft/min (15 m/min) to 500 ft/min (150 m/min) are recommended where possible, but examination speeds as high as 1000 ft/min (300 m/min) are permissible. In surface probe applications, examination speeds are inherently slower due to reduced surface coverage and the necessity to rotate the eddy current sensor or the tube to produce a helical scan. All instrument adjustments, that is, frequency, phase setting, filter setting, sensitivity setting, threshold-level setting, etc., shall be made with the reference standard or acceptance standard or both passing through or by the eddy current sensor at the same speed at which the examination of tube is to be conducted.

9.3.3 *Phase Setting*—The phase setting should be selected to provide the best signal-to-noise ratio for the reference standard employed, that is, the maximum ratio of indication height from the appropriate artificial discontinuities to the indication height from non-detrimental discontinuities.

9.3.4 *Filter Setting*—The filter setting should be selected commensurate with the examination speed to provide optimum filtering of non-detrimental, time-varying discontinuities such as geometry, pathline variation, high-frequency noise, etc.

9.3.5 *Sensitivity Setting*—The sensitivity setting shall be adjusted to provide clearly discernible indications of a convenient height for the appropriate accept holes (A or d_a), but it shall not be high enough to cause off-scale or saturated indications for the appropriate reject holes ($2A$ or d_b) of the reference standard.

9.3.6 *Threshold-Level Setting*—The threshold-level setting (reject level) shall be adjusted to automatically trigger an audio or visual-signaling device or a mechanical marker when the appropriate artificial discontinuity (or discontinuities) of the acceptance standard passes through or by the eddy current sensor.

9.4 *Using Reference Standards as Acceptance Standards:*

9.4.1 *Method A (X2.1) Reference Standards:* When using reference standards as acceptance standards the threshold level should be adjusted to accept tubes exhibiting eddy current responses smaller than those obtained from the appropriate reject holes ($2A$ or d_b) and to reject those with responses equivalent to or greater than those obtained from the appropriate reject holes ($2A$ or d_b) in the reference standard. Experience shows that this procedure will aid in the rejection of severe defects and, at the same time, minimize erroneous rejection of tubes that might exhibit noise from non-detrimental discontinuities.

9.4.2 *Method B (X2.2) Reference Standard Selection:* Reference standards selected for use must be the same alloy, temper, diameter, and wall thickness as the material being tested. The reference standard selected for use must contain the proper size reject holes and must have been fabricated and identified in accordance with this procedure.

9.4.2.1 When using reference standards as acceptance standards the threshold level should be adjusted as required in X2.5.2.2. Tubes that do not exceed the alarm limits established by the reference standard shall be considered as acceptable under this method.

10. Keywords

10.1 aluminum alloy; eddy currents; electromagnetic examination; equipment standardization; NDT; nondestructive testing; tubing

APPENDIXES

(Nonmandatory Information)

X1. PURPOSE, DESCRIPTION, FABRICATION, AND CHECKING OF PRIMARY REFERENCE STANDARDS

X1.1 Purpose

X1.1.1 Primary reference standards are used to standardize examination equipment under operating conditions to establish acceptable limits of sensitivity, reproducibility, and capability for detecting defects of a severity likely to cause leaks or substantial weakening of the tube.

X1.1.2 The dimensions of the appropriate primary reference standard are determined by the size of the tube to be examined. A primary reference standard shall be a tube of the same alloy, temper, outside diameter, *D*, and wall thickness, *t*, as the tube to be examined. This appendix covers the preparation of primary standards for test of seamless aluminum-alloy tube.

X1.2 Description

X1.2.1 The primary reference standard shall contain six artificial discontinuities in the form of flat-bottomed drilled holes in a 6-ft (180-cm) length of tube which is free of significant natural discontinuities. Fig. X1.1 describes the primary reference standard for aluminum-alloy seamless tube.

X1.2.2 The six flat-bottomed holes shall be of equal diameter, *d*, and shall be located in the mid-portion of the tube. The distance between adjacent holes is 6 in. (150 mm). The minimum distance between a hole and either end of the tube shall be approximately 20 in. (500 mm).

X1.2.3 Three of each of the reference standard holes *A* and 2*A* shall be drilled consecutively to depths of one third and two thirds the wall thickness, respectively in radial longitudinal planes 120 ± 5° apart.

X1.2.4 The diameter, *d*, of the flat-bottomed drill used to make a primary reference standard hole shall be determined mathematically with the following equation:

$$d = k\left(D/t\right) \times 10^{-3} \qquad (X1.1)$$

where:

d = drill diameter of A and $2A$ flat-bottom holes, in. (mm),
k = 3.0 in. (76 mm),
D = tube outside diameter, in. (mm), and
t = tube wall thickness, in. (mm).

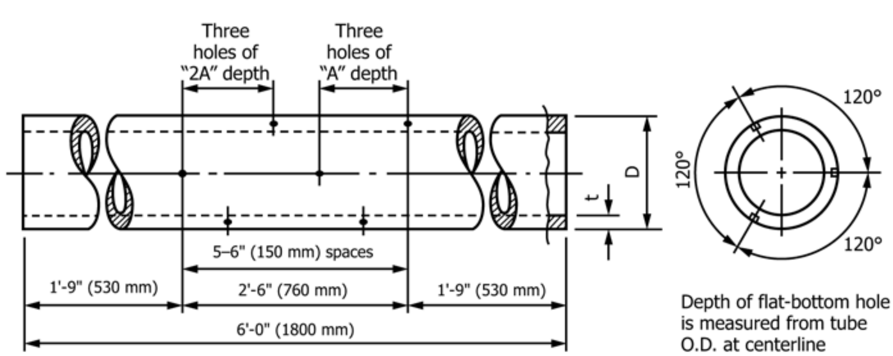
X1.2.5 In computing the appropriate drill diameters, it is recommended that the nominal dimensions for *D* and *t* listed in Table X1.1 be used for tubes having heavy or very thin wall thicknesses or outside diameter-to-wall thickness ratios that calculate to drill sizes outside the standard drill size range of gage No. 1 to gage No. 80. The dimensions *D*, *t*, and *d* must be expressed in the same units of measurement, that is, inches or millimetres when calculating the appropriate drill diameters.

X1.2.6 A standard drill size (drill gage between No. 1 and No. 80 inclusive) nearest the calculated drill diameter, *d*, may be employed for drilling the hole size required.

X1.3 Identification

X1.3.1 Each primary reference standard shall be clearly marked within the first 2 in. (50 mm) from the end of the tube adjacent to the 2*A* holes. The standard shall be marked in a manner that provides rapid identification of the manufacturer, outside diameter, wall thickness, identifying number, alloy, and temper. Permanent identification shall be accomplished by a method not harmful to the tube.

X1.3.2 As a further means of identification, the primary reference standard may be anodized and dyed. This anodizing and coloring provides positive identification and a wear-resistant surface and does not affect the eddy current response characteristics of the primary reference standard. Caution



NOTE 1—Tolerance: in. ± 0.2 in. (mm ± 5 mm).
NOTE 2—All hole diameters determined by:
$d = \times 10^{-3}$ (tube diameter, *t*) in.
($d = 76.2 \times 10^{-3}$ (tube diameter, *D*/wall thickness, *t*) mm)
NOTE 3—*A* holes and 2*A* holes are flat-bottomed and are one third the wall thickness deep and two thirds the wall thickness deep, respectively.
NOTE 4—Nominal dimensions for *D* and *t* are recommended from Table X1.1 when calculating appropriate drill diameters for tubes having *D*/*t* ratios that result in hole sizes outside the standard drill size range of No. 1 to No. 80.

FIG. X1.1 Primary Reference Standard for Seamless Aluminum-Alloy Tube

TABLE X1.1 Applicable Primary and Secondary Standard Nominal Dimensions and Drill Sizes for Various Ranges of Tube Sizes

Inch-Pound, in.					
Tube Size	Nominal Standard Dimensions		Drill Size		
			Primary	Secondary	
Outside Diameter	Dia., D ± 10 %	Wall Thickness, t ± 10 %	Dia., d	Dia., d_a	Dia., d_b
≤0.0625 to 0.125	0.0938	0.015	0.023	0.010	0.015
>0.125 to 0.250	0.1875	0.022	0.026	0.013	0.019
>0.250 to 0.375	0.3125	0.035	0.027	0.014	0.020
>0.375 to 0.500	0.4375	0.049	0.027	0.014	0.020
>0.500 to 0.625	0.5625	0.049	0.034	0.018	0.027
>0.625 to 0.750	0.6875	0.049	0.042	0.021	0.032
>0.750 to 1.000	0.8750	0.049	0.054	0.028	0.042
>1.000 to 1.250	1.125	0.058	0.058	0.030	0.045
>1.250 to 1.500	1.375	0.058	0.071	0.036	0.055
>1.500 to 1.750	1.625	0.067	0.073	0.038	0.057
>1.750 to 2.000	1.875	0.067	0.083	0.043	0.065
>2.000 to 2.500	2.250	0.076	0.089	0.046	0.069
>2.500 to 3.000	2.750	0.083	0.099	0.051	0.077
>3.000 to 3.500	3.250	0.095	0.103	0.053	0.080
>3.500 to 4.000	3.750	0.095	0.118	0.061	0.092
SI Units, mm					
			Primary	Second	
Outside Diameter	Dia., D	Wall Thickness, t	Dia., d	Dia., d_a	Dia., d_b
≤1.59 to 3.18	2.38	0.38	0.58	0.25	0.38
>3.18 to 6.35	4.76	0.56	0.66	0.33	0.48
>6.35 to 9.53	7.94	0.89	0.69	0.36	0.51
>9.53 to 12.70	11.11	1.24	0.69	0.36	0.51
>12.70 to 15.88	14.29	1.24	0.86	0.46	0.69
>15.88 to 19.05	17.46	1.24	1.07	0.53	0.81
>19.05 to 25.40	22.23	1.24	1.37	0.71	1.07
>25.40 to 31.75	28.58	1.47	1.47	0.76	1.14
>31.75 to 38.10	34.93	1.47	1.80	0.91	1.40
>38.10 to 44.45	41.28	1.70	1.85	0.97	1.45
>44.45 to 50.80	47.63	1.70	2.11	1.09	1.65
>50.80 to 63.50	57.15	1.93	2.26	1.17	1.75
>63.50 to 76.20	69.85	2.11	2.51	1.30	1.96
>76.20 to 88.90	82.55	2.41	2.62	1.35	2.03
>88.90 to 101.60	95.25	2.41	3.00	1.55	2.34

should be exercised to maintain a uniform anodic coating along the entire length of the tube because boundaries between anodized and unanodized areas may appear as discontinuities during testing.

X1.4 Fabricating Procedure

X1.4.1 The fabricating procedure includes cutting the tube to length, locating and drilling the flat-bottomed holes, deburring and finishing the sawed ends, and identifying the tube as prescribed by X1.3. The use of a jig with suitable interchangeable drill bushings is recommended for drilling the flat-bottomed holes.

X1.4.2 The original outside and inside surfaces of the tube shall be retained without any mechanical refinishing. Care must be taken to avoid dents, abrasions, and other conditions that mar the surface or distort the contour of the tube wall.

X1.4.3 The holes shall be drilled with flat-bottomed drills which are flat to within 2 % of the hole diameter. The drills must meet recognized manufacturers' tolerance for wire-sized drills. The hole depth shall be measured from the outside diameter of the tube to the bottom of the hole along the radial centerline through the hole. Hole depths must be held to within ±0.001 in. (±0.025 mm) of the specified depths. A scribe or vibrating pencil should be used to mark the tube surface for drilling in order to avoid local deformation of the tube. The use of a center punch for this purpose is prohibited.

X1.4.4 Tube stock for fabrication of the reference standard shall be free of surface irregularities, bends, and other obvious defects and shall have no bow or out-of-roundness in excess of the maximum specified for tube. (See Fed. Std. No 245.) Tubes shall be free of any eddy current indication greater than 80 % of the *A* hole indication prior to fabrication of the standard.

X1.5 Checking

X1.5.1 The finished primary reference standard should be rechecked by recognized gauging procedures to ensure that the outside diameter wall thickness, maximum bow, and maximum out-of-roundness fall within requirements.[2]

X1.5.2 Each primary reference standard shall be subjected to an eddy current examination in which the results are recorded on a chart. Annular coils or surface probes may be used for checking reference standards. The instrument shall be adjusted to provide clearly discernible indications of a convenient height for the *A* holes, but the sensitivity setting shall not be high enough to cause off-scale or saturated indications for the 2*A* holes.

X1.5.3 To qualify as an acceptable primary reference standard, the response or indication height from any *A* hole must be within ±20% of the mean indication height for the three *A* holes, and the indication height for the 2*A* holes must be within ±10% of the mean indication height for the 2*A* holes.

X1.5.4 The critical portion of the primary reference standard, which extends between points 8 in. (200 mm) beyond the two outermost holes and includes all of the holes, shall not exhibit eddy current noise or extraneous indications greater than 80 % of the indication height obtained from the *A* holes.

X1.6 Report

X1.6.1 A report shall be prepared for each primary reference standard. The report form shall list the manufacturer, outside diameter, wall thickness, serial number, alloy and temper, the drill size, and the depths of the *A* and 2*A* holes. The report form shall further indicate that the reference standard complies with requirements specified in X1.5.

X1.6.2 The report shall include a chart record that shows the response from the six flat-bottomed holes in the primary reference standard. The type and model number of the eddy current instrument, the eddy current sensor size, the speed of examination, and the frequency used in obtaining the chart record also shall be noted.

X1.6.3 It should be recognized that the eddy current response to the drilled holes may differ somewhat from that originally recorded, depending on the type of instrument used, the eddy current sensor size, the frequency, the degree of filtering, the phase setting, and the speed of examination. These differences in response may be observed even though the instructions given in X1.5 are followed meticulously, but they do not preclude the usefulness of the primary reference standard for its intended application.

X2. PURPOSE, DESCRIPTION, FABRICATION, AND CHECKING OF SECONDARY REFERENCE STANDARDS

X2.1 Purpose

X2.1.1 Secondary reference standards are used to standardize the sensitivity of equipment employed for the electromagnetic examination of aluminum-alloy tubes. They may be used in conjunction with the appropriate primary standard to ensure acceptable limits of sensitivity, reproducibility, and capability for detecting defects of a severity likely to cause leaks or substantial weakening of the tube.

X2.1.2 In common practice, secondary reference standards are also used as acceptance standards. The use of secondary reference standards as acceptance standards is allowed unless prohibited by the purchase order.

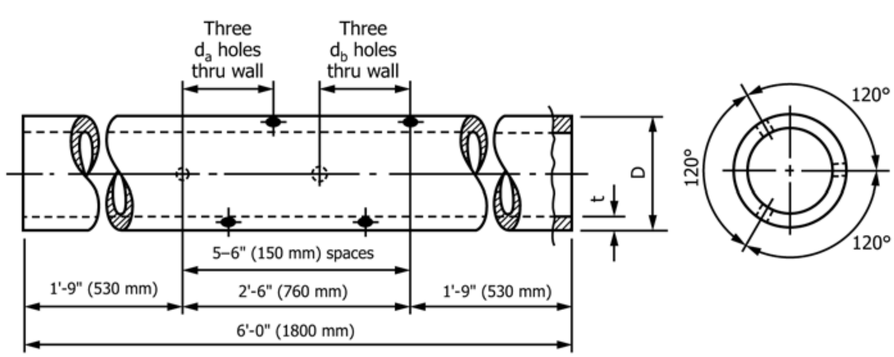
X2.1.3 A secondary reference shall be a tube of the same alloy, temper, outside diameter *D* and wall thickness *t* as the tube to be examined. This appendix covers the preparation of secondary standards for examination of seamless aluminum-alloy tube.

X2.2 Description

X2.2.1 *Method A Secondary Standard:*

X2.2.1.1 The secondary reference standard shall contain six artificial discontinuities in the form of drilled holes in a 6-ft (180-cm) length of tube which is free of significant natural discontinuities. Fig. X2.1 describes the secondary reference standard for aluminum-alloy seamless tube.

X2.2.1.2 The six drilled holes shall be three each of the two diameters d_a and d_b through one wall and shall be located in the midportion of the tube. The distance between adjacent holes is



NOTE 1—All dimensions in inches ± 0.2 in. (mm ± 5 mm).

NOTE 2—Hole sizes determined by:
$d_a = 1.55 \times 10^{-3}$ (tube diameter, *D*/wall thickness, *t*) in.
($d_a = 39.4 \times 10^{-3}$ (tube diameter, *D*/wall thickness, *t*) mm)
$d_b = 2.53 \times 10^{-3}$ (tube diameter, *D*/wall thickness, *t*) in.
($d_b = 59.7 \times 10^{-3}$ (tube diameter, *D*/wall thickness, *t*) mm)

NOTE 3—All holes drilled through the tube wall.

NOTE 4—Nominal dimensions for *D* and *t* are recommended from Table X1.1 when calculating appropriate drill diameters for tubes having *D*/*t* ratios that result in hole sizes outside the standard drill size range of No. 1 to No. 80.

FIG. X2.1 Secondary Reference Standard for Aluminum-Alloy Tube for Method A

6 in. (150 mm). The minimum distance between a hole and either end of the tube shall be approximately 20 in. (500 mm).

X2.2.1.3 Three holes designated d_a shall be drilled consecutively in radial longitudinal planes 120 ± 5° apart. The remaining three holes designated d_b also shall be drilled in radial longitudinal planes 120 ± 5° apart.

X2.2.1.4 The diameters, d_a or d_b, of the drills used to fabricate a secondary reference standard shall be determined mathematically with the following equations:

$$d_a = [k_a(D/t)] \times 10^{-3} \quad \text{(X2.1)}$$

$$d_b = [k_b(D/t)] \times 10^{-3}$$

where:

d_a = drill diameter equivalent to *A* hole, in. (mm),
d_b = drill diameter equivalent to 2*A* hole, in. (mm),
k_a = 1.55 in. (39.4 mm),
k_b = 2.33 in. (59.2 mm),
D = tube outside diameter, in. (mm), and
t = tube wall thickness, in. (mm).

X2.2.1.5 In computing the appropriate drill diameters, it is recommended that the nominal dimensions for *D* and *t* listed in Table X1.1 be used for tubes having heavy or very thin wall thicknesses or outside diameter-to-wall thickness ratios that calculate to drill sizes outside the standard drill size range of gage No. 1 to gage No. 80. The dimensions *D*, *t*, d_a, and d_b must be expressed in the same units of measurement, that is, millimetres or inches. It is important to use the appropriate constants k_a or k_b, for the selected units of measurement.

X2.2.1.6 A standard drill size (drill gage between No. 1 and No. 80) nearest the calculated drill diameter (d_a and d_b) may be employed for drilling each of the two hole sizes required.

X2.2.2 *Method B Secondary Standard:*

X2.2.2.1 *Reference Standard Selection:* Reference standards selected for use must be the same alloy, temper, diameter, and wall thickness as the material being tested. The reference standard selected for use must contain the proper size reject holes and must have been fabricated and identified in accordance with this procedure. If a suitable standard meeting these requirements is not available, a new reference standard shall be constructed.

X2.2.2.2 *Reference Standard Construction:*

(1) When a reference standard is required to be fabricated, a suitable length of material shall be chosen from the job that is to be inspected. Visually examine the piece to verify it is as free of surface conditions as possible. Identify the reference standard with the alloy, temper, diameter, wall thickness and (reject) hole size.

(2) The proper drill bit size must be chosen from Table X2.1 (Table X2.2). If the exact tube OD and wall size is not available in Table X2.1 (Table X2.2), calculate the appropriate drill hole size from the following formula: Reject drill size = 0.00233 × OD (in.)/Wall thickness (in.) with a maximum drill hole size of #50 and a minimum drill hole size of #80. (for SI units—Reject drill size = 0.0592 × OD (mm)/Wall thickness (mm) with a maximum drill hole size of 1.80 mm and a minimum drill hole size of 0.35 mm). If calculation falls between drill sizes, select the closest drill size. Table X2.3 lists popular drill numbers and size conversions. Calculate drill size for sizes not listed. Measure the appropriate drill bit with a micrometer to verify diameter in accordance with Table X1.1.

(3) The secondary reference standard shall contain six artificial discontinuities in the form of drilled holes in a tube at least 6 ft (180 cm) in length which is free of significant natural discontinuities. Fig. X2.2 describes the secondary reference standard for aluminum-alloy seamless tube. A reject hole shall be drilled no more than 7 in. (228 mm) from each end in order to verify that the end suppression system is detecting within this distance. Four (4) additional reject holes shall be placed between the end suppression check holes. Spacing between all reject holes shall be a minimum of 1 ft (300 mm). The four holes after the end suppression check hole shall be rotated 90 degrees from the adjacent hole. See Fig. X2.2 for the diagram of the spacing and rotation of the reject holes.

TABLE X2.3 Drill Sizes

Drill No.	Dia (in.)	Dia (mm)
80	0.0135	0.35
79	0.0145	0.35
78	0.0160	0.40
77	0.0180	0.45
76	0.0200	0.50
75	0.0210	0.55
74	0.0225	0.55
73	0.0240	0.60
72	0.0250	0.65
71	0.0260	0.65
70	0.0280	0.70
69	0.0292	0.75
68	0.0310	0.80
67	0.0320	0.80
66	0.0330	0.85
65	0.0350	0.90
64	0.0360	0.90
63	0.0370	0.95
62	0.0380	0.95
61	0.0390	1.00
60	0.0400	1.00
59	0.0410	1.05
58	0.0420	1.05
57	0.0430	1.10
56	0.0465	1.20
55	0.0520	1.30
54	0.0553	1.40
53	0.0595	1.50
52	0.0635	1.60
51	0.0670	1.70
50	0.0700	1.80

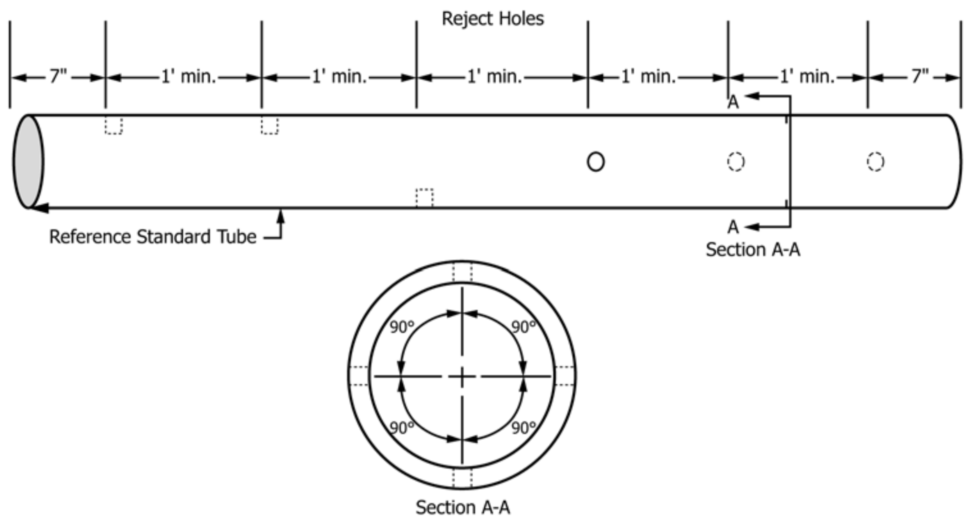


FIG. X2.2 Secondary Reference Standard for Aluminum-Alloy Tube for Method B

TABLE X2.1 Reject Hole Sizes (in.)

NOTE 1—(Reject drill size = 0.00233 in. × OD (in.)/Wall (in.) with max. drill hole size of #50 and a min. drill hole size of #80.) Calculate sizes not shown below using the above formula.

OD	Wall	Reject Hole Size	Reject Drill Size
0.250	0.020	0.0291	70
0.250	0.022	0.0265	71
0.250	0.025	0.0233	74
0.250	0.028	0.0208	76
0.250	0.032	0.0182	77
0.250	0.035	0.0166	78
0.250	0.042	0.0139	80
0.250	0.049	0.0119	80
0.312	0.020	0.0363	65
0.312	0.022	0.0330	66
0.312	0.025	0.0291	70
0.312	0.028	0.0260	71
0.312	0.032	0.0227	74
0.312	0.035	0.0208	76
0.312	0.042	0.0173	78
0.312	0.049	0.0148	79
0.375	0.020	0.0437	57
0.375	0.022	0.0397	61
0.375	0.025	0.0349	66
0.375	0.028	0.0312	68
0.375	0.032	0.0273	72
0.375	0.035	0.0251	73
0.375	0.042	0.0208	76
0.375	0.049	0.0178	78
0.438	0.020	0.0510	56
0.438	0.022	0.0131	56
0.438	0.025	0.0408	59
0.438	0.028	0.0364	64
0.438	0.032	0.0319	67
0.438	0.035	0.0292	69
0.438	0.042	0.0243	73
0.438	0.049	0.0208	75
0.500	0.020	0.0582	54
0.500	0.022	0.0530	55
0.500	0.025	0.0466	56
0.500	0.028	0.0416	58
0.500	0.032	0.0364	64
0.500	0.035	0.0333	66
0.500	0.042	0.0277	70
0.500	0.049	0.0238	73
0.625	0.020	0.0700	50
0.625	0.022	0.0662	51
0.625	0.025	0.0582	53
0.625	0.028	0.0520	55
0.625	0.032	0.0455	57
0.625	0.035	0.0416	58
0.625	0.042	0.0347	65
0.625	0.049	0.0297	69
0.750	0.035	0.0490	56
0.750	0.042	0.0416	59
0.750	0.049	0.0357	64
0.750	0.058	0.0301	69
0.750	0.065	0.0269	71
0.750	0.083	0.0211	75
0.875	0.035	0.0582	54
0.875	0.042	0.0485	56
0.875	0.049	0.0416	58
0.875	0.058	0.0352	65
0.875	0.065	0.0314	68
0.875	0.083	0.0246	73
1.000	0.035	0.0666	52
1.000	0.042	0.0555	54
1.000	0.049	0.0476	56
1.000	0.058	0.0402	60
1.000	0.065	0.0358	64
1.000	0.083	0.0281	70
1.125	0.035	0.0700	50
1.125	0.042	0.0624	52
1.125	0.049	0.0535	55
1.125	0.058	0.0452	57
1.125	0.065	0.0403	60
1.125	0.083	0.0316	68
1.250	0.035	0.0700	50
1.250	0.042	0.0693	51
1.250	0.049	0.0594	53
1.250	0.058	0.0502	56
1.250	0.065	0.0448	57
1.250	0.083	0.0351	65
1.375	0.035	0.0700	50
1.375	0.042	0.0700	50
1.375	0.049	0.0654	52
1.375	0.058	0.0552	54
1.375	0.065	0.0493	56
1.375	0.083	0.0386	62
1.500	0.035	0.0700	50
1.500	0.042	0.0700	50
1.500	0.049	0.0700	50
1.500	0.058	0.0603	53

TABLE X2.1 *Continued*

OD	Wall	Reject Hole Size	Reject Drill Size
1.500	0.065	0.0538	55
1.500	0.083	0.0421	58
1.625	0.035	0.0700	50
1.625	0.042	0.0700	50
1.625	0.049	0.0700	50
1.625	0.058	0.0653	52
1.625	0.065	0.0582	54
1.625	0.083	0.0456	57
1.750	0.035	0.0700	50
1.750	0.042	0.0700	50
1.750	0.049	0.0700	50
1.750	0.058	0.0700	50
1.750	0.065	0.0627	53
1.750	0.083	0.0491	56
1.875	0.035	0.0700	50
1.875	0.042	0.0700	50
1.875	0.049	0.0700	50
1.875	0.058	0.0700	50
1.875	0.065	0.0672	51
1.875	0.083	0.0526	55
2.000	0.035	0.0700	50
2.000	0.042	0.0700	50
2.000	0.049	0.0700	50
2.000	0.058	0.0700	50
2.000	0.065	0.0700	50
2.000	0.083	0.0561	54
2.250	0.035	0.0700	50
2.250	0.042	0.0700	50
2.250	0.049	0.0700	50
2.250	0.058	0.0700	50
2.250	0.065	0.0700	50
2.250	0.083	0.0632	52
2.500	0.035	0.0700	50
2.500	0.042	0.0700	50
2.500	0.049	0.0700	50
2.500	0.058	0.0700	50
2.500	0.065	0.0700	50
2.500	0.083	0.0700	50
2.750	0.035	0.0700	50
2.750	0.042	0.0700	50
2.750	0.049	0.0700	50
2.750	0.058	0.0700	50
2.750	0.065	0.0700	50
2.750	0.083	0.0700	50
3.000	0.035	0.0700	50
3.000	0.042	0.0700	50
3.000	0.049	0.0700	50
3.000	0.058	0.0700	50
3.000	0.065	0.0700	50
3.000	0.083	0.0700	50

TABLE X2.2 Reject Hole Sizes (SI Units)

NOTE 1—(Reject drill size = 0.0592 mm × OD (mm)/Wall thickness (mm) with max. drill hole size of 1.80 mm and a min drill hole size of 0.35 mm.) Calculate sizes not shown below using the above formula.

OD	Wall	Reject Hole Size	Reject Drill Size
6.0	0.5	0.710	0.70
6.0	0.6	0.592	0.60
6.0	0.7	0.507	0.50
6.0	0.8	0.444	0.45
6.0	0.9	0.395	0.40
6.0	1.0	0.355	0.35
6.0	1.1	0.323	0.35
8.0	0.5	0.947	0.95
8.0	0.6	0.789	0.80

TABLE X2.2 *Continued*

OD	Wall	Reject Hole Size	Reject Drill Size
8.0	0.7	0.677	0.70
8.0	0.8	0.592	0.60
8.0	0.9	0.526	0.50
8.0	1.0	0.474	0.45
8.0	1.1	0.431	0.45
10.0	0.5	1.184	1.20
10.0	0.6	0.987	1.00
10.0	0.7	0.846	0.85
10.0	0.8	0.740	0.75
10.0	0.9	0.658	0.65
10.0	1.0	0.592	0.60
10.0	1.1	0.538	0.55
12.0	0.5	1.421	1.40
12.0	0.6	1.184	1.20
12.0	0.7	1.015	1.00
12.0	0.8	0.888	0.90
12.0	0.9	0.789	0.80
12.0	1.0	0.710	0.70
12.0	1.1	0.646	0.65
14.0	0.5	1.658	1.65
14.0	0.6	1.381	1.40
14.0	0.7	1.184	1.20
14.0	0.8	1.036	1.05
14.0	0.9	0.921	0.90
14.0	1.0	0.829	0.85
14.0	1.1	0.753	0.75
15.0	0.5	1.776	1.80
15.0	0.6	1.480	1.50
15.0	0.7	1.269	1.30
15.0	0.8	1.110	1.10
15.0	0.9	0.987	1.00
15.0	1.0	0.888	0.90
15.0	1.2	0.740	0.75
16.0	0.5	1.800	1.80
16.0	0.6	1.579	1.60
16.0	0.7	1.353	1.35
16.0	0.8	1.184	1.20
16.0	0.9	1.052	1.05
16.0	1.0	0.947	0.95
16.0	1.2	0.789	0.80
18.0	0.5	1.800	1.80
18.0	0.6	1.776	1.80
18.0	0.7	1.522	1.50
18.0	0.8	1.332	1.35
18.0	0.9	1.184	1.20
18.0	1.0	1.066	1.05
18.0	1.2	0.888	0.90
20.0	0.9	1.316	1.30
20.0	1.0	1.184	1.20
20.0	1.2	0.987	1.00
20.0	1.5	0.789	0.80
20.0	1.6	0.740	0.75
20.0	2.0	0.592	0.60
22.0	0.9	1.447	1.45
22.0	1.0	1.302	1.30
22.0	1.2	1.085	1.10
22.0	1.5	0.868	0.85
22.0	1.6	0.814	0.80
22.0	2.0	0.651	0.65
25.0	0.9	1.644	1.65
25.0	1.0	1.480	1.50
25.0	1.2	1.233	1.25
25.0	1.5	0.987	1.00
25.0	1.6	0.925	0.90
25.0	2.0	0.740	0.75
28.0	0.9	1.800	1.80
28.0	1.0	1.658	1.65
28.0	1.2	1.381	1.40
28.0	1.5	1.105	1.10
28.0	1.6	1.036	1.05
28.0	2.0	0.829	0.85
30.0	0.9	1.800	1.80

TABLE X2.2 *Continued*

OD	Wall	Reject Hole Size	Reject Drill Size
30.0	1.0	1.776	1.80
30.0	1.2	1.480	1.50
30.0	1.5	1.184	1.20
30.0	1.6	1.110	1.10
30.0	2.0	0.888	0.90
32.0	0.9	1.800	1.80
32.0	1.0	1.800	1.80
32.0	1.2	1.579	1.60
32.0	1.5	1.263	1.25
32.0	1.6	1.184	1.20
32.0	2.0	0.947	0.95
35.0	0.9	1.800	1.80
35.0	1.0	1.800	1.80
35.0	1.2	1.727	1.70
35.0	1.5	1.381	1.40
35.0	1.6	1.295	1.30
35.0	2.0	1.036	1.05
40.0	0.9	1.800	1.80
40.0	1.0	1.800	1.80
40.0	1.2	1.800	1.80
40.0	1.5	1.579	1.60
40.0	1.6	1.480	1.50
40.0	2.0	1.184	1.20
50.0	0.9	1.800	1.80
50.0	1.0	1.800	1.80
50.0	1.2	1.800	1.80
50.0	1.5	1.800	1.80
50.0	1.6	1.800	1.80
50.0	2.0	1.480	1.50
60.0	0.9	1.800	1.80
60.0	1.0	1.800	1.80
60.0	1.2	1.800	1.80
60.0	1.5	1.800	1.80
60.0	1.6	1.800	1.80
60.0	2.0	1.776	1.80
75.0	0.9	1.800	1.80
75.0	1.0	1.800	1.80
75.0	1.2	1.800	1.80
75.0	1.5	1.800	1.80
75.0	1.6	1.800	1.80
75.0	2.0	1.800	1.80

X2.3 Identification

X2.3.1 Identification of secondary standards is recommended but is not required for conformance to this practice.

X2.4 Fabricating Procedure

X2.4.1 The fabricating procedure includes cutting the tube to length, locating and drilling the holes, deburring and finishing the sawed ends, and identifying the tube as desired. The use of a jig with suitable, interchangeable drilled bushings is recommended for lining the drill during the drilling operation.

X2.4.2 During the drilling operation, care should be exercised to ensure a uniform cutting speed and a smooth finish along the wall of each hole. A scribe or vibrating pencil should be used to mark the tube surface for drilling in order to avoid local deformation of the tube. The use of a center punch for this purpose is prohibited.

X2.4.3 The tube stock used for fabricating secondary reference standards shall be free of surface irregularities, excessive bends, and other obvious defects. They shall be representative of the tubes in the production lot to be examined. Tubes shall be free of any eddy current indication greater than 80 % of the d_a indication.

X2.5 Checking

X2.5.1 *Inspection using Method A Secondary Standard* (Reference X2.2.1):

X2.5.1.1 Each secondary reference standard should be evaluated with an eddy current examination employing annular coils or surface probes. It is recommended that the results of this check be recorded on a chart. The instrument shall be adjusted to provide clearly discernible indications of a convenient height from the d_a holes (equivalent *A* holes), but the sensitivity setting shall not be high enough to cause saturated indications from the d_b holes (equivalent 2*A* holes).

X2.5.1.2 To qualify as an acceptable secondary reference standard, the response or indication height from any d_a, hole must be within ±20 % of the mean indication height for all three d_a holes, and the indication height from the d_b holes must be within ±10 % of the mean indication height for the three d_b holes.

X2.5.1.3 The critical portion of the reference standard, which extends between points 8 in. (200 mm) beyond the two outermost holes and includes all of the holes, shall not exhibit eddy current noise or extraneous indications greater than 80 % of the indications obtained from the d_a holes.

X2.5.2 *Inspection Using Method B Secondary Standard* (see X2.2.2):

X2.5.2.1 The appropriate secondary reference standard should be evaluated with an eddy current examination employing annular coils. It is recommended that the results of this check be recorded on a chart. The test coils to be used are the self-comparison differential type. The test coil selected shall provide the highest practical fill factor possible. Fill factors over 95 % shall not be selected due to inadequate clearance. Fill factors between 90 % and 95 % shall be used with caution due to close clearance.

X2.5.2.2 *Standardization:*

(1) Run the standard through the unit. Adjust the gain (sensitivity) control to obtain indications from the reject holes on the display. The amplitude of all reject holes displayed on the oscilloscope must meet or exceed 50 %. The centering rolls should be adjusted such that the indication corresponding to each of the four center positioning holes is within approximately ±10 % of the mean (average) indication height for all holes, if possible.

(2) Verify that the alarm is properly functioning at 40 %.

(3) Verify the alarm from the tube ends is being suppressed but that the alarm is sounding on each of the end holes which are not more than 7 in. (175 mm) from each end.

X2.5.2.3 *Standarization re-check: Standardization must be re-verified:*

(1) every four hours

(2) upon completion of each job

(3) after any change in equipment or equipment settings

If the reject hole is not detected on standardization check, all material electromagnetic tested since the last successful standardization must be re-tested.

SUMMARY OF CHANGES

Committee E07 has identified the location of selected changes to this standard since the last issue (E215 -11) that may impact the use of this standard. (December 1, 2016)

(1) Editorial revisions were made throughout the document.
(2) In Section 2.4 and 5.1, changes were made to add ISO 9712 to be consistent with Policy P-10
(3) The title was modified to reflect the document having substantial portions related to equipment standardization and other portions focused on the examination.
(4) X2.5.2.3 was amended to be consistent with Section 8.1.