### ARTICLE 26
EDDY CURRENT STANDARDS

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RECOMMENDED PRACTICE FOR STANDARDIZING EQUIPMENT FOR ELECTROMAGNETIC TESTING OF SEAMLESS ALUMINUM-ALLOY TUBE

1. Scope

1.1 This recommended practice is intended as a guide for eddy current testing of seamless aluminum-alloy tube. General requirements for eddy current testing procedures are included.

1.2 Specific test sensitivity as related to outside diameter, wall thickness, alloy, and temper is given in Appendixes A1 and A2.

1.3 This specification covers the inspection of tubes ranging in diameter from 0.250 in. to 1.5 in. (6.35 mm to 38.20 mm) and wall thickness range from 0.018 in. to 0.083 in. (0.46 mm to 2.11 mm).

NOTE 1—The values stated in inch & pound units are to be regarded as the standard.

2. Principles of Eddy Current Test

2.1 The test is performed by passing the tube lengthwise through or near a coil energized with alternating current of one or more frequencies. The electrical impedance of the coil is modified by the proximity of the tube. The extent of this modification is determined by the distance between the coil and the tube, the dimensions, electrical conductivity, and magnetic permeability of the tube. The presence of metallurgical or mechanical discontinuities in the tube will alter the apparent impedance of the coil. During passage of the tube, the changes in coil characteristics caused by localized differences in the tube produce electrical signals which are amplified and modified to actuate either an audio or video signalling 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.

3. Definitions

3.1 Frequency—The number of cycles per second of alternating electric current induced into the tubular product. For eddy current testing described herein, the frequency is normally 1 to 125 kHz, incl.

3.2 Indications—Eddy current signals caused by any change in the uniformity of a tube. These changes in uniformity affect the electrical characteristic of the tube but may not be detrimental to the end use of the product.

3.3 Sensitivity Control—The control in the instrument which adjusts the amplifier gain, and is one of the factors that determines the capacity to detect discontinuities.

3.4 Threshold Setting—The setting of the instrument which causes it to register only those changes in eddy current response greater than a specified magnitude.

NOTE 2—Sensitivity and threshold settings usually are indicated by arbitrary numbers on the control panel of the testing instrument.
These numerical settings differ among instruments of different types. It is, therefore, not proper to translate a numerical setting on one instrument to that of another type. Even among instruments of the same design and from the same manufacturer, sensitivity and threshold settings may vary slightly when detecting the same discontinuity. Therefore, undue emphasis on the numerical value of sensitivity and threshold settings is not justified. The sensitivity and threshold settings of the device, when determined in accordance with the recommendations in Appendixes A1 and A2, will result in reliable detection of undesirable discontinuities.

3.5 **Reference Standard**—A tube with artificial discontinuities used for establishing the test sensitivity setting and for periodically checking and adjusting sensitivity setting as required.

3.6 **Acceptance Standard**—A tube with artificial discontinuities specified in the applicable product standard used to establish the acceptance level.

3.7 **End Effect**—The loss in sensitivity to discontinuities located near the extreme ends of the tube as the ends of the tube enter or leave the test coil.

4. **Apparatus**

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

4.2 **Test Coils**—Test coils shall be capable of inducing currents in the tube and sensing changes in the electrical characteristics of the tube.

5. **Standardization of Apparatus**

5.1 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:

5.1.1 Primary reference standards employed for this purpose shall be prepared and used in accordance with the methods described in Appendix A1.

5.1.2 Equivalent secondary reference standards, prepared and used in accordance with methods described in Appendix A2, also may be employed for standardizing the apparatus.

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

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

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

6. **Procedure**

6.1 Standardize the testing instrument using the appropriate reference standard prior to testing and check at least every 4 h during continuous operation, or whenever improper functioning of the testing apparatus is suspected. If improper functioning occurs, restandardize the apparatus in accordance with Section 5, and retest all tubes tested since the last successful standardization.

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

6.3 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. During the test, the end effect may be minimized by butting the tube ends together as they pass through the test coil.

**APPENDIXES**

A1. **Purpose, Description, Fabrication, and Checking of Primary Reference Standards**

A1.1 **Purpose:**

A1.1.1 Primary reference standards are used to standardize testing equipment under operating conditions to ensure that acceptable limits of sensitivity, reproducibility, and capability are established for detecting defects of a severity likely to cause leaks or substantial weakening of the tube.

A1.1.2 The dimensions of the appropriate primary reference standard are determined by the size of the
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**TABLE A1**

**RANGE OF SIZES FOR TUBES TESTED WITH SENSITIVITY ESTABLISHED BY SECONDARY REFERENCE STANDARDS**

Note — Alloys 6061 and 6062 should be inspected before heat treatment.

<table>
<thead>
<tr>
<th>Tube Outside Diameter</th>
<th>Maximum Wall Thickness, t</th>
<th>Minimum Wall Thickness, t</th>
</tr>
</thead>
<tbody>
<tr>
<td>(mm)</td>
<td>(in.)</td>
<td>(mm)</td>
</tr>
<tr>
<td>6.35 to 9.40</td>
<td>0.250 to 0.370</td>
<td>1.25</td>
</tr>
<tr>
<td>9.41 to 12.70</td>
<td>0.371 to 0.500</td>
<td>1.65</td>
</tr>
<tr>
<td>12.71 to 38.20</td>
<td>0.501 to 1.500</td>
<td>2.11</td>
</tr>
</tbody>
</table>

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**FIG. A1 PRIMARY REFERENCE STANDARD FOR SEAMLESS ALUMINUM-ALLOY TUBE**

The primary reference standard shall contain six artificial discontinuities in the form of flat-bottomed drilled holes in a 183-cm (6-ft) length of tube which is free from significant natural discontinuities. Figure A1 describes the primary reference standard for aluminum-alloy seamless tube.

**A1.2 Description:**

- **A1.2.1** The primary reference standard shall contain six artificial discontinuities in the form of flat-bottomed drilled holes in a 183-cm (6-ft) length of tube which is free from significant natural discontinuities. Figure A1 describes the primary reference standard for aluminum-alloy seamless tube.

- **A1.2.2** 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 152 mm (6 in.). The minimum distance between a hole and either end of the tube shall be approximately 500 mm (20 in.).

- **A1.2.3** Three of each of the reference standard holes A and 2A shall be drilled consecutively to the depth specified in Table A2 in radial longitudinal planes 120 ± 5 degrees apart.

- **A1.2.4** The diameter, $d$, of the flat-bottomed drill used to make a primary reference standard hole shall be determined from Table A2.
### TABLE A2
APPLICABLE PRIMARY STANDARD DIMENSIONS, DRILL SIZES, AND HOLE DEPTHS FOR VARIOUS RANGES OF TESTED TUBE SIZES

#### U.S. Customary Units, in.

<table>
<thead>
<tr>
<th>Size of Tube to Be Tested</th>
<th>Nominal Primary Standard Dimensions</th>
<th>Drill Size</th>
<th>Hole Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outside Diameter Wall Thickness Dia, D</td>
<td>Wall Thickness Dia, d</td>
<td>Gage No. A, 2A</td>
</tr>
<tr>
<td>0.250 to 0.370</td>
<td>0.018 to 0.058</td>
<td>0.250</td>
<td>0.035</td>
</tr>
<tr>
<td>0.371 to 0.438</td>
<td>0.018 to 0.083</td>
<td>0.375</td>
<td>0.049</td>
</tr>
<tr>
<td>0.439 to 0.562</td>
<td>0.018 to 0.083</td>
<td>0.500</td>
<td>0.049</td>
</tr>
<tr>
<td>0.563 to 0.688</td>
<td>0.018 to 0.083</td>
<td>0.625</td>
<td>0.049</td>
</tr>
<tr>
<td>0.689 to 0.812</td>
<td>0.018 to 0.083</td>
<td>0.750</td>
<td>0.049</td>
</tr>
<tr>
<td>0.813 to 0.938</td>
<td>0.018 to 0.083</td>
<td>0.875</td>
<td>0.049</td>
</tr>
<tr>
<td>0.939 to 1.000</td>
<td>0.018 to 0.083</td>
<td>1.000</td>
<td>0.049</td>
</tr>
<tr>
<td>1.001 to 1.188</td>
<td>0.025 to 0.083</td>
<td>1.125</td>
<td>0.058</td>
</tr>
<tr>
<td>1.189 to 1.312</td>
<td>0.025 to 0.083</td>
<td>1.250</td>
<td>0.058</td>
</tr>
<tr>
<td>1.313 to 1.500</td>
<td>0.025 to 0.083</td>
<td>1.375</td>
<td>0.058</td>
</tr>
</tbody>
</table>

#### Metric Units, mm

<table>
<thead>
<tr>
<th>Size of Tube to Be Tested</th>
<th>Nominal Primary Standard Dimensions</th>
<th>Drill Size</th>
<th>Hole Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outside Diameter Wall Thickness Dia, D</td>
<td>Wall Thickness Dia, d</td>
<td>Gage No. A, 2A</td>
</tr>
<tr>
<td>6.35 to 9.40</td>
<td>0.46 to 1.47</td>
<td>6.35</td>
<td>0.89</td>
</tr>
<tr>
<td>9.41 to 11.13</td>
<td>0.46 to 2.11</td>
<td>9.53</td>
<td>1.24</td>
</tr>
<tr>
<td>11.14 to 14.27</td>
<td>0.46 to 2.11</td>
<td>12.70</td>
<td>1.24</td>
</tr>
<tr>
<td>14.28 to 17.47</td>
<td>0.46 to 2.11</td>
<td>15.88</td>
<td>1.24</td>
</tr>
<tr>
<td>17.48 to 20.62</td>
<td>0.46 to 2.11</td>
<td>19.05</td>
<td>1.24</td>
</tr>
<tr>
<td>20.63 to 23.82</td>
<td>0.46 to 2.11</td>
<td>22.23</td>
<td>1.24</td>
</tr>
<tr>
<td>23.83 to 25.40</td>
<td>0.46 to 2.11</td>
<td>25.40</td>
<td>1.24</td>
</tr>
<tr>
<td>25.41 to 30.17</td>
<td>0.64 to 2.11</td>
<td>28.57</td>
<td>1.47</td>
</tr>
<tr>
<td>30.18 to 33.32</td>
<td>0.64 to 2.11</td>
<td>31.75</td>
<td>1.47</td>
</tr>
<tr>
<td>33.33 to 38.10</td>
<td>0.64 to 2.11</td>
<td>34.92</td>
<td>1.47</td>
</tr>
</tbody>
</table>

†Editorially changed.

### A1.3 Identification:

**A1.3.1** Each primary reference standard shall be clearly marked within the first 50 mm (2 in.) from the end of the tube adjacent to the 2A holes. The standard shall be marked in a manner which 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.

**A1.3.2** 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 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.

### A1.4 Fabricating Procedure:

**A1.4.1** 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 A1.3. The use of a jig with suitable interchangeable drill bushings is recommended for drilling the flat-bottomed holes.
A1.4.2 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.

A1.4.3 The holes shall be drilled with flat-bottomed drills which are flat to within 2 per cent 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 ±0.025 mm (0.001 in.) 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.

A1.4.4 Tube stock for fabrication of the reference standard shall be free from surface irregularities, bends, and other obvious defects and shall have no bow or out-of-roundness in excess of the maximum specified for tube.

A1.5 Checking:

A1.5.1 The finished primary reference standard should be rechecked by recognized gaging procedures to ensure that the outside diameter wall thickness, maximum bow, and maximum out-of-roundness fall within requirements.1

A1.5.2 Each primary reference standard shall be subjected to an eddy current test in which the results are recorded on a chart. Annular test coils, through which the tube must pass, shall 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 2A holes.

A1.5.3 To qualify as an acceptable primary reference standard, the response or indication height from any A hole must be within ±20 per cent of the mean indication height for the three A holes, and the indication height for the 2A holes must be within ±10 per cent of the mean indication height for the 2A holes.

A1.5.4 The critical portion of the primary reference standard, which extends between points 200 mm (8 in.) beyond the two outermost holes and includes all of the holes, shall not exhibit eddy current noise or extraneous indications greater than 80 per cent of the indication height obtained from the A holes.

A1.6 Report:

A1.6.1 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 2A holes. The report form shall further indicate that the reference standard complies with requirements specified in A1.5 Checking.

A1.6.2 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 test coil size, the speed of inspection, and the frequency used in obtaining the chart record also shall be noted.

A1.6.3 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 coil size, the frequency, the degree of filtering, the phase setting, and the speed of inspection. These differences in response may be observed even though the instructions given in A1.5 Checking are followed meticulously, but they do not preclude the usefulness of the primary reference standard for its intended application.

A2. Purpose, Description, Fabrication, and Application of Secondary Reference Standards

A2.1 Purpose:

A2.1.1 Secondary reference standards are used to standardize the test sensitivity of equipment employed for the electromagnetic inspection of aluminum-alloy tubes. They may be used in conjunction with the appropriate primary standard to ensure acceptable limits of test sensitivity, reproducibility, and capability for detecting defects of a severity likely to cause leaks or substantial weakening of the tube.

A2.1.2 In common practice, secondary reference standards are also used as acceptance standards. However, the use of secondary reference standards as acceptance standards should be established by mutual agreement between the manufacturer and the purchaser.
A secondary reference shall be a tube of the same alloy, temper, outside diameter $D$ and wall thickness $t$ as the tube to be tested. This appendix covers the preparation and application of secondary standards for test of tube within the size ranges specified in Table A1.

**A2.2 Description:**

**A2.2.1** The secondary reference standard shall contain six artificial discontinuities in the form of drilled holes in a 6-ft (183 cm) length of tube which is free from significant natural discontinuities. Figure A2 describes the secondary reference standard for aluminum-alloy seamless tube.

**A2.2.2** The six drilled holes shall be 3 each of the 2 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 152 mm (6 in.). The minimum distance between a hole and either end of the tube shall be approximately 500 mm (20 in.).

**A2.2.3** Three holes designated $d_a$ shall be drilled consecutively in radial longitudinal planes $120 \pm 5$ deg apart. The remaining three holes designated $d_b$ also shall be drilled in radial longitudinal planes $120 \pm 5$ deg apart.

**A2.2.4** 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:

$$d_a = \frac{39.4 \times 10^{-3}}{t} \times D$$

$$d_b = \frac{59.2 \times 10^{-3}}{t} \times D$$

where:

- $D$ = tube diameter, $D$ mm
- $t$ = tube wall thickness, $t$ mm
- $d_a$ = drill diameter equivalent to 2A hole in mm (in.)
- $d_b$ = drill diameter equivalent to 2A hole in mm (in.)

**NOTE A1**—In computing the appropriate drill diameters, the dimensions $D$, $t$, $d_a$, and $d_b$ must be expressed in the same units of measurement, that is, mm or in. It is important to use the appropriate constants, $k_a$ or $k_b$, for the selected units of measurement.

**A2.2.5** A standard drill size (drill gage number) nearest the calculated drill diameter ($d_a$ and $d_b$) may
be employed for drilling each of the two hole sizes required.

A2.3 Identification:
A2.3.1 Identification of secondary standards is recommended but is not required for conformance to this recommended practice.

A2.4 Fabricating Procedure:
A2.4.1 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.
A2.4.2 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.
A2.4.3 The tube stock used for fabricating secondary reference standards shall be free from surface irregularities, excessive bends, and other obvious defects. They shall be representative of the tubes in the production lot to be inspected. Tubes shall be free from any eddy current indication greater than 80 per cent of the d_a indication.

A2.5 Checking:
A2.5.1 Each secondary reference standard should be evaluated with an eddy current test employing annular test coils through which the tube must pass. 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_a holes (equivalent 2A holes).
A2.5.2 To qualify as an acceptable secondary reference standard, the response or indication height from any d_a hole must be within ±20 per cent of the mean indication height for all three d_a holes, and the indication height from the d_b holes must be within ±10 per cent of the mean indication height for the three d_b holes.
A2.5.3 The critical portion of the reference standard, which extends between points 200 mm (8 in.) beyond the two outermost holes and includes all of the holes, shall not exhibit eddy current noise or extraneous indications greater than 80 per cent of the indications obtained from the d_a holes.

A2.6 Application:
A2.6.1 This application covers the electromagnetic testing of aluminum-alloy seamless tube within the range of sizes and alloys specified in Table A1.
A2.6.2 Secondary reference standards, described in A2, when used as acceptance standards, will ensure the detection of defects that are of a severity likely to cause leaks or substantial weakening of the tube.
A2.6.3 Using electronic apparatus described in Section 4 and annular test coils through which the tube must pass, the equipment sensitivity shall be standardized in accordance with Section 5 under the following test conditions.
A2.6.3.1 Frequency—The frequency shall be in the range of 1 to 5 kc.
A2.6.3.2 Speed of Inspection—The testing rate, or speed at which the tube passes through the test coil, may vary with the application. Inspection speeds of 15.2 m/min (50 fpm) to 30.5 m/min (100 fpm) are recommended where possible, but inspection speeds as high as 152 m/min (500 fpm) are permissible. All instrument adjustments, that is, phase setting, sensitivity setting, threshold level setting, etc. shall be made with the reference standard or acceptance standard or both passing through the test coil at the same speed at which the test of tubes is to be conducted.
A2.6.3.3 Phase Setting—That 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 d_a holes to the indication height from non-detrimental discontinuities.
A2.6.3.4 Sensitivity Setting—The sensitivity setting shall be adjusted to provide clearly discernible indications of a convenient height for the d_a holes, but it shall not be high enough to cause off-scale or saturated indications for the d_b holes of the reference standard.
A2.6.3.5 Threshold Level Setting—The threshold level setting (reject level) shall be adjusted to automatically trigger an audio or video signalling device or a mechanical marker when the appropriate artificial discontinuity (or discontinuities) of the acceptance standard passes through the coil unit.
A2.6.4 When using reference standards as acceptance standards experience shows that setting the threshold level to accept tubes exhibiting eddy current responses equivalent to or smaller than those obtained from the $d_a$ holes, and to reject those with responses equivalent to or greater than those obtained from $d_b$ holes in the reference standard will ensure the rejection of severe defects and, at the same time, minimize erroneous rejection of tubes that might exhibit noise from non-detrimental discontinuities.
ARTICLE 26 — EDDY CURRENT STANDARDS

STANDARD PRACTICE FOR
ELECTROMAGNETIC (EDDY CURRENT) TESTING OF
SEAMLESS COPPER AND COPPER-ALLOY TUBES

(SE-243)

(Identical with ASTM Specification E 243-85)

1. Scope

1.1 This practice covers the procedures that shall be followed in eddy-current testing of copper and copper-alloy tubes for detecting discontinuities of a severity likely to cause failure of the tube. These procedures are applicable for tubes with outside diameters to 2 in. (50.8 mm), inclusive, and wall thicknesses from 0.035 in. (0.889 mm) to 0.120 in. (3.04 mm), inclusive, or as otherwise stated in ASTM product specifications; or by other users of this practice. These procedures may be used for tubes beyond the size range recommended, upon contractual agreement between the purchaser and the manufacturer.

1.2 The procedures described in this practice are based on methods making use of encircling annular test coil systems.

1.3 The values stated in inch-pound units are to be regarded as the standard.

NOTE 1—This practice may be used as a guideline for the examination, by means of internal probe test coil systems, of installations using tubular products where the outer surface of the tube is not accessible. For such applications, the technical differences associated with the use of internal probe coils should be recognized and accommodated. The effect of foreign materials on the tube surface and signals due to tube supports are typical of the factors that must be considered.

1.4 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whomever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Applicable Documents

2.1 ASTM Standards:
B 111 Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock
B 395 Specification for U-Bend Seamless Copper and Copper Alloy Heat-Exchanger and Condenser Tubes
B 593 Specification for Welded Copper and Copper Alloy Heat-Exchanger Tubes
E 268 Definitions of Terms Relating to Electromagnetic Testing

3. Definitions

3.1 In addition to the definitions listed in Definitions E 268, the following terms apply in connection with the procedures outlined in this practice:

3.1.1 artificial discontinuity calibration standard—a standard consisting of a selected tube with defined artificial discontinuities, used when adjusting the system controls to obtain some predetermined system output signal level. This standard may be used for periodic checking of the instrument during a test.

3.1.2 percent maximum unbalance calibration standard—a method of calibration that can be used with speed-insensitive instruments (see 3.1.4). The acceptance level of the test is established at the operating test frequency as an accurately calibrated fraction of the maximum unbalance signal resulting from the end effect of a tube. Any low-noise tube from the production run having a squared end may be used as this standard.
This standard may be used for periodic checking of the instrument during a test.

3.1.3 electrical center—the center established by the electromagnetic field distribution within the test coil. A constant-intensity signal, irrespective of the circumferential position of a discontinuity, is indicative of electrical centering. The electrical center may be different from the physical center of the test coil.

3.1.4 speed-sensitive equipment—test equipment that produces a variation in signal response with variations in the test speed. Speed-insensitive equipment provides a constant signal response with changing test speeds.

4. Summary of Practice

4.1 Testing is usually performed by passing the tube lengthwise through a coil energized with alternating current at one or more frequencies. The electrical impedance of the coil is modified by the proximity of the tube, the tube dimensions, electrical conductivity and magnetic permeability of the tube material, and metallurgical or mechanical discontinuities in the tube. During passage of the tube, the changes in electromagnetic response caused by these variables in the tube produce electrical signals which are processed so as to actuate an audio or visual signaling device or mechanical marker which produces a record.

5. Significance and Use

5.1 Eddy-current testing is a nondestructive method of locating discontinuities in a product. Signals can be produced by discontinuities located either on the external or internal surface of the tube or by discontinuities totally contained within the walls. Since the density of eddy currents decreases nearly exponentially as the distance from the external surface increases, the response to deep-seated defects decreases.

5.2 Some indications obtained by this method may not be relevant to product quality; for example, a reject signal may be caused by minute dents or tool chatter marks that are not detrimental to the end use of the product. Irrelevant indications can mask unacceptable discontinuities. Relevant indications are those which result from nonacceptable discontinuities. Any indication above the reject level that is believed to be irrelevant shall be regarded as unacceptable until it is demonstrated by retest or other means to be irrelevant (see 9.3.2).

5.3 Eddy-current testing systems are generally not sensitive to discontinuities adjacent to the ends of the tube (end effect).

5.4 Discontinuities such as scratches or seams that are continuous and uniform for the full length of the tube may not always be detected.

6. Apparatus

6.1 Electronic Apparatus—The electronic apparatus shall be capable of energizing the test coil with alternating currents of suitable frequencies (for example, 1 kHz to 125 kHz), and shall be capable of sensing the changes in the electromagnetic response of the coils. Electrical signals produced in this manner are processed so as to actuate an audio or visual signaling device or mechanical marker which produces a record.

6.2 Test Coils—Test coils shall be capable of inducing current in the tube and sensing changes in the electrical characteristics of the tube. The test coil diameter should be selected to yield the largest practical fill-factor.

6.3 Driving Mechanism—A mechanical means of passing the tube through the test coil with minimum vibration of the test coil or the tube. The device shall maintain the tube substantially concentric with the electrical center of the test coil. A uniform speed (±5.0% speed variation maximum) shall be maintained.

6.4 End Effect Suppression Device—A means capable of suppressing the signals produced at the ends of the tube. Individual ASTM product specifications shall specify when an end effect suppression device is mandatory.

NOTE 2—Signals close to the ends of the tube may carry on beyond the limits of end suppression. Refer to 8.5.

7. Calibration Standards

7.1 Artificial Discontinuity Calibration Standard:

7.1.1 The tube used when adjusting the sensitivity setting of the apparatus shall be selected from a typical production run and shall be representative of the purchaser’s order. The tubes shall be passed through the test coil with the instrument sensitivity high enough to determine the nominal background noise inherent in the tubes. The calibration standard shall be selected from tubes exhibiting low background noise.

7.1.2 The artificial discontinuities shall be spaced to provide signal resolution adequate for interpretation.
The artificial discontinuities shall be prepared in accordance with one of the following options:

(a) A round bottom transverse notch on the outside of the tube in each of three successive transverse planes at 0, 120, and 240° (Fig. 1).

(b) A hole drilled radially through the tube wall in each of three successive transverse planes at 0, 120, and 240° (Fig. 2).

(c) One round bottom transverse notch on the outside of the tube at 0° and another at 180°, and one hole drilled radially through the wall at 90° and another at 270°. Only one notch or hole shall be made in each transverse plane (Fig. 3).

(d) Four round bottom transverse notches on the outside of the tube, all on the same element of the tube (Fig. 4).

(e) Four holes drilled radially through the tube wall, all the same element of the tube (Fig. 5).

7.1.2.1 Round Bottom Transverse Notch—The notch shall be made using a suitable jig with a 0.250-in. (6.35-mm) diameter No. 4 cut, straight, round file. The outside surface of the tube shall be stroked in a substantially straight line perpendicular to the axis of the tube. The notch depth shall be in accordance with the ASTM product specification and shall not vary.
from the prescribed depth by more than ± 0.0005 in. (± 0.013 mm) when measured at the center of the notch (see Table X1.1).

NOTE 3—Tables X1.1 and X1.2 should not be used for acceptance or rejection of materials.

7.1.2.2 Drilled Holes—The hole shall be drilled radially through the wall using a suitable drill jig that has a bushing to guide the drill, care being taken to avoid distortion of the tube while drilling. The diameter of the drilled hole shall be in accordance with the ASTM product specification and shall not vary by more than + 0.001, − 0.000 in. (+ 0.026 mm) of the hole diameter specified (see Table X1.2) (Note 3).

7.1.2.3 Other Artificial Discontinuities—Discontinuities of other contours may be used in the calibration standard by mutual agreement between supplier and purchaser.

7.2 Percent Maximum Unbalance Calibration Standard—This method of standardization shall be used only with speed-insensitive equipment, and equipment specifically designed or adapted to accommodate the use of this calibration method. Maximum unbalance of differential coils is obtained by placing the squared end of a tube in only one of the differential coils and using an accurately calibrated attenuator to obtain the (100%) maximum unbalance signal. A percentage of the maximum unbalance signal shall define the test acceptance level at a specific operating frequency and this percentage shall be obtained from the ASTM product specification.

7.3 Other Calibration Standards—Other calibration standards may be used by mutual agreement between supplier and purchaser.

NOTE 4—Artificial discontinuities and the percent of maximum unbalance are not intended to be representative of natural discontinuities or produce a direct relationship between instrument response and discontinuity severity; they are intended only for establishing sensitivity levels as outlined in Section 8. The relationship between instrument response and discontinuity size, shape, and location is important and should be established separately, particularly as related to test frequency.

8. Adjustment and Standardization of Apparatus Sensitivity

8.1 The tube manufacturer shall select equipment, calibration standard, and test parameters consistent for
### TABLE X1.1
#### NOTCH DEPTH

<table>
<thead>
<tr>
<th>Tube Wall Thickness</th>
<th>Over ( \frac{1}{4} ) to ( \frac{5}{32} ), incl.</th>
<th>6.35 to 15.9, incl.</th>
<th>Over ( \frac{1}{8} ) to ( \frac{5}{32} ), incl.</th>
<th>15.9 to 19.0, incl.</th>
<th>Over ( \frac{1}{4} ) to ( \frac{5}{32} ), incl.</th>
<th>19.0 to 22.2, incl.</th>
<th>Over ( \frac{1}{4} ) to ( \frac{5}{32} ), incl.</th>
<th>22.2 to ( 1 ), incl.</th>
<th>Over ( \frac{1}{4} ) to ( 25.4 ), incl.</th>
</tr>
</thead>
<tbody>
<tr>
<td>in.</td>
<td>mm</td>
<td>in.</td>
<td>mm</td>
<td>in.</td>
<td>mm</td>
<td>in.</td>
<td>mm</td>
<td>in.</td>
<td>mm</td>
</tr>
<tr>
<td>0.035</td>
<td>0.889</td>
<td>0.006</td>
<td>0.152</td>
<td>0.006</td>
<td>0.152</td>
<td>0.006</td>
<td>0.152</td>
<td>\ldots</td>
<td>\ldots</td>
</tr>
<tr>
<td>0.042</td>
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<td>0.0065</td>
<td>0.165</td>
<td>0.0065</td>
<td>0.165</td>
<td>0.007</td>
<td>0.178</td>
<td>0.007</td>
<td>0.178</td>
</tr>
<tr>
<td>0.049</td>
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<td>0.007</td>
<td>0.178</td>
<td>0.0075</td>
<td>0.190</td>
<td>0.0075</td>
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<tr>
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<td>0.178</td>
<td>0.0075</td>
<td>0.190</td>
<td>0.0075</td>
<td>0.190</td>
<td>0.008</td>
<td>0.203</td>
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<td>0.0075</td>
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<td>0.203</td>
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<td>0.072</td>
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<td>0.0075</td>
<td>0.190</td>
<td>0.008</td>
<td>0.203</td>
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<td>0.083</td>
<td>2.11</td>
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<td>0.008</td>
<td>0.203</td>
<td>0.0085</td>
<td>0.216</td>
<td>0.009</td>
<td>0.229</td>
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<td>0.092</td>
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<td>0.009</td>
<td>0.229</td>
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<td>0.009</td>
<td>0.229</td>
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<td>\ldots</td>
<td>\ldots</td>
<td>\ldots</td>
<td>0.010</td>
<td>0.254</td>
<td>0.010</td>
<td>0.254</td>
</tr>
</tbody>
</table>

### TABLE X1.2
#### DIAMETER OF DRILLED HOLES

<table>
<thead>
<tr>
<th>Tube Outside Diameter</th>
<th>Diameter of Drilled Holes</th>
</tr>
</thead>
<tbody>
<tr>
<td>in.</td>
<td>mm</td>
</tr>
<tr>
<td>( \frac{1}{8} ) to ( \frac{5}{32} ), incl.</td>
<td>6.35 to 19.0, incl.</td>
</tr>
<tr>
<td>Over ( \frac{1}{4} ) to ( \frac{1}{4} ), incl.</td>
<td>Over 19.0 to 25.4, incl.</td>
</tr>
<tr>
<td>Over 1 ( \frac{1}{4} ) to 1 ( \frac{1}{4} ), incl.</td>
<td>Over 25.4 to 31.8, incl.</td>
</tr>
<tr>
<td>Over 1 ( \frac{1}{4} ) to 1 ( \frac{1}{4} ), incl.</td>
<td>Over 31.8 to 38.1, incl.</td>
</tr>
<tr>
<td>Over 1 ( \frac{1}{4} ) to 1 ( \frac{1}{4} ), incl.</td>
<td>Over 38.1 to 44.4, incl.</td>
</tr>
<tr>
<td>Over 1 ( \frac{1}{4} ) to 2, incl.</td>
<td>Over 44.4 to 50.8, incl.</td>
</tr>
</tbody>
</table>
the product, unless otherwise agreed upon between manufacturer and purchaser.

8.2 When using the artificial discontinuity calibration standard, prepared in accordance with one of the five options, adjust the apparatus to the lowest sensitivity required to detect the following:

8.2.1 For Figs. 1, 2, and 3: all artificial discontinuities in the standard. The tube speed maintained during calibration shall be the same as the speed used in production testing.

8.2.2 For Figs. 4 and 5: a minimum of two of the four artificial discontinuities as the tube is rotated by 120 deg. intervals through 0, 120, and 240 deg., or by 90 deg. intervals through 0, 90, 180, and 270 deg. on successive passes. The tube speed maintained during calibration shall be the same as the speed used in production testing.

8.3 When using the percent maximum unbalance calibration standard, adjust the apparatus to the percent unbalance called for in the ASTM product specification.

NOTE 5—Sensitivity control settings are usually indicated by arbitrary numbers on the control panel of the testing instruments. These numerical settings differ among instruments of different types. It is, therefore, not proper to transfer numerical settings on one instrument to those of another instrument, unless the percent maximum unbalance calibration standard is used. Even among instruments of the same design and from the same manufacturer, sensitivity control settings may vary. Undue emphasis on the numerical value of sensitivity control settings is not justified and shall not be used unless referenced accurately to the maximum unbalance signal.

8.4 Discard and replace the tube used as the calibration standard when erroneous signals are produced from mechanical, metallurgical, or other damage to the standard.

8.5 Determine the length of tubing requiring suppression of end effect signals by selecting a tube of low background noise and making a series of calibration holes or notches at 0.5-in. (12.7-mm) intervals near the end of this special tube. Pass the tube through the test coil at the production test speed with the artificial discontinuity end first, and then with the artificial discontinuity end last. Determine the distance from the tube end at which the signal response from successive discontinuities is uniform with a recording device such as a pen recorder or memory oscilloscope. Use a signal suppression method (photo relay, mechanical switches, or proximity devices are commonly used) to permit testing only when the length of tubing exhibiting uniform signals is within the test coil. The section of tube passing through the test coil during end effect suppression is not tested in accordance with 8.2 or 8.3.

8.5.1 As an option to 8.5, when a recording device is not available, the length of tubing requiring end suppression may be determined by selecting a tube of low background noise and making a calibration hole or notch at 6 to 8 in. (152 to 203 mm) from the tube end. Pass the tube through the test coil at the production test speed with the artificial discontinuity end first and then with the artificial discontinuity end last. If the artificial discontinuity is not detected, another artificial discontinuity should be made further from the end. If it is detected, cut off 0.5-in. (12.7-mm) increments from the end of the tube until the artificial discontinuity is no longer detected. The shortest distance from the end that the artificial discontinuity can be detected is that length of tube which shall require end effect signal suppression.

9. Procedure

9.1 Electrically center the tubing in the test coil at the start of the test run. The tube manufacturer may use the artificial discontinuity calibration standard or prepare a separate tube for this purpose in accordance with 7.1 and 7.2. Pass the tube through the test system and mechanically adjust its position in the test coil such that the requirements of 8.2 are satisfied.

9.2 Calibrate the test system at the start of the test run and at periodic intervals (for example, every 2 h) of continuous operation or whenever improper functioning of the system is suspected.

9.3 Pass the tubes through the test system standardized as described in Section 8.

9.3.1 Accept those tubes that produce output signals conforming to the limits in the applicable ASTM product specification.

9.3.2 Tubes that produce output signals not conforming to the limits in the applicable ASTM product specification may, at the option of the manufacturer, be set aside for retest (see 5.2). Upon retest, accept the tubes if the output signals are within acceptable limits (9.3.1) or demonstrated by other retest to be irrelevant.

9.4 Tubes may be tested at the finish size after the final anneal or heat treatment, or at the finish size prior to the final anneal or heat treatment unless otherwise agreed upon between the supplier and the purchaser.
1. Scope

1.1 This practice covers a procedure for applying the eddy-current method to detect discontinuities in ferromagnetic pipe and tubing (Note 1) where the article being examined is rendered substantially non-magnetic by the application of a concentrated, strong magnetic field in the region adjacent to the examining coil.

NOTE 1 — For convenience, the term tube or tubular product will hereafter be used to refer to both pipe and tubing.

1.2 The procedure is specifically applicable to eddy-current examination methods using an encircling-soil assembly. However, eddy-current techniques that employ either fixed or rotating probe-coil assemblies may be used to either enhance discontinuity sensitivity on the large diameter tubular products or to maximize the response received from a particular type of discontinuity.

1.3 This practice is intended for use on tubular products having outside diameters from approximately 1/4 to 10 in. (6.35 to 254.0 mm). These techniques have been used for smaller and larger sizes however, and may be specified upon contractual agreement between the purchaser and the supplier.

2. Applicable Documents

2.1 ASTM Standard:
E 268 Definitions of Terms Relating to Electromagnetic Testing

3. Significance and Use

3.1 The purpose of this practice is to outline a procedure for the detection and location of discontinuities such as pits, voids, inclusions, cracks, or abrupt dimensional variations in ferromagnetic tubing using the electromagnetic (eddy-current) method. Furthermore, the relative severity of a discontinuity may be indicated, and a rejection level may be set with respect to the magnitude of the indication.

3.2 The response from natural discontinuities can be significantly different than that from artificial discontinuities such as drilled holes or notches. For this reason, sufficient work should be done to establish the sensitivity level and set-up required to detect natural discontinuities of consequence to the end use of the product.

3.3 Eddy-current testing systems are generally not sensitive to discontinuities adjacent to the ends of the tube. The extent of the end effect region can be determined per 8.6.

4. Basis of Application

4.1 The following are acceptance criteria that may require agreement between the purchaser and the supplier and may be specified in the purchase specification or elsewhere:

4.1.1 Time of examination, that is, the point(s) in the manufacturing process at which the material will be examined.
4.1.2 Type, method of manufacture, dimensions, location, and number of artificial discontinuities to be placed on the calibration standard.

4.1.3 Size and type of product.

4.1.4 Extent of examination, that is, full length weld only if welded, etc.

4.1.5 Disposition of material with indications.

4.1.6 Methods of verifying dimensions and allowable tolerances of artificial discontinuities.

4.1.7 Maximum time interval between equipment calibration checks.

4.1.8 Operator qualifications and certification, if required.

4.1.9 Methods for determining the extent of end effect.

5. Summary of Method

5.1 The examination is conducted using one of two general requirements shown in Fig. 1.

5.1.1 One technique employs one or more exciter and sensor coils that encircle the tube and through which the tubular product to be examined is passed. Some circuit configurations employ one or more coils that concurrently function as both excitors and sensors. Alternating current passes through the exciting coil which, by reason of its proximity, induces corresponding currents (eddy currents) to flow in the tubular product. The sensor coil detects the resultant electromagnetic flux related to these currents. The presence of discontinuities in the tubular product will alter the normal flow of currents and this change is detected by the sensor. The encircling-coil technique is capable of examining the entire circumference of a tubular product.

5.1.2 Another technique employs a probe coil with one or more sensors that are in close proximity to the surface of the tubular product to be examined. Since the probe is generally small and does not encircle the article being examined, it examines only a limited area in the vicinity of the probe. This technique is frequently used for examination of welded tubular products in which only the weld is examined by scanning along the weld zone.

5.1.3 The magnetic permeability of ferromagnetic materials severely limits the depth of penetration of induced eddy currents. Furthermore, the permeability variations inherent in ferromagnetic tubular products often cause anomalous test results. A useful solution to this problem involves the application of a strong external magnetic field in the region of the examining coil or probe. This technique, known as magnetic saturation, is applied to a magnetic material, such as a steel tube, to suppress the magnetic characteristics of permeability, hysteresis, etc., so that the material under examination is effectively rendered nonmagnetic. When achieved, this condition allows an eddy-current system to measure and detect electrical resistivity and geometrical variations (including defects) independent of concurrent variations in magnetic properties.

5.1.4 Changes in electromagnetic response caused by the presence of discontinuities are detected by the sensor, amplified, and modified in order to actuate audio or visual indicating devices, or both, a mechanical marker, or a signal-recording device, or a combination of these. Signals can be caused by outer surface, inner surface, or subsurface discontinuities if the eddy-current frequency provides sufficient depth of penetration (see 11.1). The eddy-current method is sensitive to metallurgical variations that occur as a result of processing, thus all received indications are not necessarily indicative of defective tubing.

6. Definitions

6.1 Definitions of terms relating to electromagnetic examination may be found in Definitions E 268.

7. Apparatus

7.1 Electronic Apparatus — The electronic apparatus shall be capable of energizing the coils or probes with alternating currents of a selected frequency and shall be capable of sensing the changes in the electromagnetic response of the sensors. Equipment may include appropriate signal processing circuits such as a phase discriminator, filter circuits, etc., as required for the particular application.

7.2 Encircling-Coil Assembly — The encircling-coil assembly shall consist of one or more electrical coils that encircle the article being examined.

7.3 Probe-Coil Assembly — The probe-coil assembly normally contains an exciting coil and a sensor, although in some cases the exciter and sensor are one and the same.

7.4 Magnetic Saturation System — The magnetic saturation system shall consist of a suitable method of applying a strong magnetic field to the region of the
tube adjacent to the coil or probe-coil assembly so as to render that region of the tube effectively nonmagnetic. Typical systems employ either permanent magnets or electromagnets.

7.5 Driving Mechanism — The movement of the tube through the coil or past the probe shall be performed at uniform speed and with minimum vibration of the tube, coil, and probe.

7.6 Reference Standard — The standard used to adjust the sensitivity of the apparatus shall be free of interfering discontinuities and shall be of the same nominal alloy, temper, and dimensions as the tubes to be examined on a production basis. It shall be of sufficient length to permit the spacing of artificial discontinuities to provide good signal resolution and be mechanically stable while in the examining position in the apparatus. Artificial discontinuities placed in the tube shall be one or more of the following types. (See Fig. 2.)

7.6.1 Notches — Notches may be produced by Electric Discharge Machining (EDM), milling, or other means. Longitudinal, traverse, or both may be used (Note 2). Orientation, dimensions (width, length, and depth), and configuration of the notches affect the response of the eddy-current system. Notch depth is usually specified as a percentage of nominal wall thick-
ness of the tubular product being examined. Notches may be placed on the outer, inner, or both surfaces of the reference (calibration) standard. Outer surface notches provide an indication of system response to discontinuities originating on the outer tube surface; whereas inner surface notches provide an indication of system response to discontinuities originating on the inner tube surface.

NOTE 2 — Longitudinal notch standards are normally used when testing with a rotating-probe system.

7.6.2 Holes — Drilled holes may be used. They are usually drilled completely through the wall. Care should be taken during drilling to avoid distortion of the tube and hole.

7.6.3 The configuration, orientation, and dimensions (diameter of holes and the width, length, and depth of notches) of the artificial discontinuities to be used for establishing acceptance limits should be subject to agreement between the purchaser and the supplier.

8. Adjustment and Standardization of Apparatus

8.1 Select the apparatus, examining frequency, coil or probe configuration, or both, magnetic saturation system, phase discrimination, and other circuitry, as well as speed of examination.

8.2 Fabricate applicable reference standards in accordance with the agreement between the purchaser and the tubing supplier.

8.3 Adjust the field strength of the magnetic saturation system to obtain an adequate level of magnetization in the tube in accordance with 8.3.1 and 8.3.2. This is the minimum degree of magnetization required for the successful examination of the type and size tube represented by the reference standard.

8.3.1 Adjust the eddy-current system sensitivity such that without the application of the external magnetization field the examination of the reference standard results in excessive “noise.” This condition is characterized by repeated alarms from the instrument over the entire length of the tube.

8.3.2 On repeated examinations of the calibration standard, increase the magnetizing current or the magnetic field to the point where no further reduction in the tube “noise” is obtained from a further increase in magnetizing field strength.

NOTE 3 — It should be pointed out that there is sometimes a false indication of saturation that can result in acceptance of a false saturation level (Fig. 4).

8.4 Adjust the apparatus to obtain an optimum signal-to-noise ratio by adjusting for the minimum sensitivity required to reliably detect the artificial discontinuities in the reference standard. This shall be performed under conditions (such as testing speed) identical to those to
be used in the production examination of the tubular products if the system is influenced by these conditions.

8.5 While performing 8.4, or as a separate operation, rotate the calibration standard in either 90 or 120-deg. increments to determine the location of the “electrical” center in the examining coil. Mechanically adjust the position of the tube within the coil to obtain nearly equal responses from the artificial discontinuities regardless of their circumferential location.

8.5.1 Determine the electrical center of a probe coil with respect to the probe field-to-material normality and uniform circumferential lift-off. Adjust the probe field-to-material normality such that uniform signals are obtained from the calibration notches or holes regardless of their position within the intended examination area under the probe. This adjustment is typically encountered when a probe is scanned along a line such as a weld zone.

8.5.2 Establish electrical centering of a rotating probe by adjusting the apparatus to obtain uniform signals from the calibration notches or holes when positioned at 0, 90, 180, and 270 deg. This adjustment is typically accomplished by ensuring uniform probe lift-off around the circumference of the tube.

8.6 The extent of end effect (Note 4) is determined by using a special reference tube containing a series of similar notches or holes near one or both of the ends (Fig. 3). To evaluate the end effect when notches or holes are placed near only one of the ends, pass the tube through the system twice, once each with the notches or holes at the leading and trailing ends. When the notches or holes are located on the front end of the tube, then the end effect region, or the region of inadequate examination, extends from the front end of the tube to the point where the first of the holes or notches are detected with uniform response. When the holes or notches are on the last end through the system, then the end effect region for that end extends from the point at which the last hole or notch is detected with uniform response to the end of the tube.

NOTE 4 — It is intended that the extent of the end effect region be determined only once for each specific diameter, gage, speed, coil configuration, and test frequency, and need not be repeated for each run or during the periodic calibration checks.

9. Procedure

9.1 Calibrate the system at the start and end of each run and at the beginning of each shift (or turn) using the reference standard.

9.2 Pass the tubes to be tested through the encircling coil, or past the probe coil, with the apparatus adjusted in accordance with Section 8. Tubes that produce output signals not conforming to the limits in the purchase order or other agreed upon specifications may at the option of the manufacturer be set aside for re-examination. If upon re-examination the output signals are within acceptable limits, or are demonstrated by other examination to be irrelevant, the tubes shall be accepted.

9.3 Tubes may be examined in the final drawn, annealed, heat-treated, or as-welded condition, or at the point specified in the purchase specification. The point in processing at which the examination is made should be agreed upon by the supplier and the purchaser. The tubes shall be free of foreign substances that could interfere with the effectiveness of the examination.

10. Typical Sizes of Artificial Discontinuities

10.1 Longitudinal Notches — Longitudinal notch depth is usually specified as a percentage of nominal wall thickness and values of 10, 121/2, or 20% are typical. Longitudinal notch width is a relevant variable for eddy-current testing and should be specified. Notch length is usually specified in the form of a maximum dimension. Maximum notch lengths of 1/4, 1/2, and 1.0 in. are typical.

10.2 Transverse Notches — Transverse notch depth is measured at the deepest point and is usually specified as a percentage of nominal wall thickness. Values of 10, 121/2, and 20% are typical. Transverse notch width is a relevant variable for eddy-current testing and is typically specified as follows: "The width of the trans-
verse notches shall be the minimum practical but not more than \( \frac{1}{16} \) in."

10.3 Holes — When holes are used for calibration, they are usually drilled all the way through one wall of the tube. The diameter of these holes may be specified as a percentage of wall thickness, or arbitrary sizes may be chosen based on factors involving intended service or other appropriate criteria. Typical hole diameters range from 20 to 50% of the nominal tube wall thickness; although a \( \frac{1}{16} \)-in. diameter hole is specified for use with all sizes of tubing in one widely used industrial standard. It is considered good practice to include holes with diameters greater and smaller than the reference size used to set the reject level since these provide a useful means of verifying that the dynamic response of the equipment is adequate.

11. Precautionary Information

11.1 Since the density of eddy currents decreases nearly exponentially as the distance from the external surface increases, the response to deep-seated discontinuities decreases. Correspondingly, discontinuity orientation also affects the system response and should be taken into consideration when establishing the examination sensitivity.

11.2 In preparing a reference standard for welded tubing, artificial discontinuities should be placed in both the weld metal and the parent metal when the responses are expected to be different and if both are to be examined. The apparatus is then adjusted to obtain an optimum signal-to-noise ratio.

11.2.1 When examining only the weld area, the discontinuities shall be placed only in the weld area.

11.3 The examination frequency and the type of apparatus being used should be considered when choosing the examining speed. Certain types of equipment are effective only over a given speed range; therefore, the examining speed should fall within this range.

11.4 Discontinuities such as scratches or seams that are continuous and uniform over the full length of the tube may not always be detected with differential encircling coils or probes scanned along the tube length.
1. Scope

1.1 This practice covers procedures that may be followed for eddy-current examination of seamless and welded tubular products made of stainless steel and similar alloys such as nickel alloys. Austenitic chromium-nickel stainless steels, which are generally considered to be nonmagnetic, are specifically covered as distinguished from the martensitic and ferritic straight chromium stainless steels which are magnetic.

1.2 This practice is intended as a guide for eddy-current examination of both seamless and welded tubular products using either an encircling coil or a probe-coil technique. Coils and probes are available that can be used inside the tubular product; however, their use is not specifically covered in this document. This type of examination is usually employed only to examine tubing which has been installed such as in a heat exchanger.

1.3 This practice covers the examination of tubular products ranging in diameter from 0.125 to 5 in. (3.2 to 127.0 mm) and wall thicknesses from 0.0005 to 0.250 in. (0.127 to 6.4 mm).

1.4 The values stated in inch-pound units are to be regarded as the standard.

1.5 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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 Document

2.1 ASTM Standard:
E 268 Definitions of Terms Relating to Electromagnetic Testing

3. Definitions

3.1 Definitions of terms relating to electromagnetic testing are given in Definitions E 268.

4. Principles of Test

4.1 The test is conducted using one of two general techniques shown in Fig. 1. One of these techniques employs one or more exciter and sensor coils which encircle the pipe or tube and through which the tubular product to be inspected is passed. Some circuit configurations employ separate exciter and sensor coils; whereas other configurations employ one or more coils that concurrently function as both exciters and sensors. Alternating current passes through the exciting coil which by reason of its proximity induces current in the tubular product. The sensor coil detects the resultant electromagnetic flux related to these currents. The presence of discontinuities in the tubular product will affect the normal flow of currents and this change is detected...
Changes in electromagnetic response caused by the presence of discontinuities are detected by the sensor, amplified and modified in order to actuate audio or visual indicating devices, or both, or a mechanical marker. Signals can be caused by outer surface, inner surface, or subsurface discontinuities. The eddy-current test is sensitive to many factors that occur as a result of processing (such as variations in conductivity, chemical composition, permeability, and geometry) as well as other test factors not related to the tubing. Thus, all received indications are not necessarily indicative of defective tubing.

5. Apparatus

5.1 Electronic Apparatus — The electronic apparatus shall be capable of energizing the test coils or probes with alternating currents of suitable frequencies and shall be capable of sensing the changes in the electromagnetic response of the sensors. Equipment may include a detector, phase discriminator, filter circuits, modulation circuits, magnetic-saturation devices, recorders, and signaling devices as required for the particular application.

5.2 Test Coils — Test coils shall be capable of inducing current in the tube and sensing changes in the electrical characteristics of the tube.

NOTE 1 — Fill factor effect is an important consideration since coupling variations can affect the test significantly.

5.3 Probe Coils — Probe coils shall be capable of inducing current in the tube and sensing changes in the electrical characteristics of the tube (Note 2). Probes generally consist of an exciting coil or Hall element mounted in a common holder. A Hall element is a semiconductor that by reason of the Hall effect is capable of responding in a manner directly proportional to magnetic-flux density. However, when used with an exciting coil, it should be remembered that eddy-current flow is influenced by the excitation frequency.

NOTE 2 — Lift-off effect is an important consideration since coupling variations can affect the test significantly.

5.4 Driving Mechanism — A mechanical device capable of passing the tube through the test coil or past the probe. It shall operate at a uniform speed with minimum vibration of coil, probe, or tube and maintain the article being examined in proper register or concentricity with the probe or test coil. Where required, the mechanism shall be capable of uniformly rotating the tube or probe.

5.5 Reference Standard — The standard used to adjust the sensitivity setting of the apparatus shall be
sound and of the same nominal alloy, temper, and nominal dimensions as the lot of tubes or pipes to be tested on a production basis. It shall be of sufficient length to permit the required spacing of the artificial discontinuities (at least 4 ft, and preferably longer). Artificial discontinuities made in the tube or pipe shall be centered as nearly as possible on one inside or outside diameter surface of the tube and shall preferably be of one of the following types:

5.5.1 Holes — Holes that are usually drilled completely through the wall may be used. Care should be taken during drilling to avoid distortion of the tube (or pipe) and hole.

5.5.2 Notches — Notches may be produced by electric discharge machining (EDM), milling, or other means. Longitudinal or transverse notches or both may be used (Note 3). Orientation, dimensions (width, length, and depth), and configuration of the notches affect the response of the eddy-current system. Notch depth is usually specified as a percentage of nominal wall thickness of the tubular product being examined. Notches may be placed on the outer, inner, or both surfaces of the reference (calibration) standard. Outer surface notches provide an indication of system response to discontinuities originating on the outer tube surface, whereas inner surface notches provide an indication of system response to discontinuities originating on the inner tube surface (Note 4).

NOTE 3 — Longitudinal notch standards are normally used when examining with rotating probe systems.
NOTE 4 — The density of eddy currents decreases nearly exponentially with increasing distance from the surface nearest the coil, and the sensitivity to subsurface discontinuities decreases with the change in depth allowing the use of phase analysis techniques.

5.5.3 The configuration, orientation, and dimensions (diameter of holes and the width, length, and depth of notches) of the artificial discontinuities to be used for establishing acceptance limits should be subject to agreement between supplier and purchaser.

6. Adjustment and Standardization of Apparatus Sensitivity

6.1 Select the apparatus, test frequency, coil or probe, or both, design, phase discrimination, and other circuitry as well as speed of examining which shall demonstrate the system capability for detecting the discontinuities of interest.

6.2 Fabricate the applicable reference standard in accordance with the agreement between the purchaser and tubing supplier.

6.3 Adjust the apparatus to obtain an optimum signal-to-noise ratio with the minimum sensitivity required to detect the artificial discontinuities in the reference standard. Do this under conditions (such as testing speed) identical to those to be used in production examination of the tubular products.

6.4 Determine the end effect by using a special reference tube or pipe containing a series of notches or holes near one or both of the ends and passing this reference standard through the system at production testing speeds. If notches or holes are placed near only one of the ends, pass the tube through the system backwards and forwards.

7. Procedure

7.1 Calibrate the apparatus at the start of the test run using the reference standard. The recommended maximum interval between recalibration is 4 h although more or less frequent recalibration may be done by agreement between using parties, or whenever improper functioning of the equipment is suspected. If improper functioning is found, recalibrate the apparatus and retest all tubes or pipes tested during the period since the last successful calibration.

7.2 Pass the lot of tubes or pipes to be tested through the test coil or past the probe coil of the apparatus adjusted to the sensitivity as described in Section 6. Set aside tubes or pipes with discontinuities indicated by the apparatus. It is recommended that tubes with discontinuity indications be reexamined or retested in accordance with the purchase specification.

7.3 Tubes or pipes may be tested in the final drawn, annealed, heat treated, as-welded, or other step in processing. The point in processing at which inspection is made should be agreed upon by the supplier and the purchaser. The tubes should be free of any substance that may interfere with the test.

8. Supplemental Information Regarding Eddy-Current Testing of High Alloy Steels and Similar Alloys

8.1 In the eddy-current testing of austenitic chromium-nickel stainless steels it has been found that test frequencies ranging from less than 1 kHz to more than 1 MHz can be used. The more commonly used operating
frequencies are in the range 1 kHz to 125 kHz. The exact frequency used will depend on the application.

Example — If thin-walled tubular products are to be inspected or surface rather than subsurface discontinuities are to be detected, higher frequencies are used. For heavy-walled tubes, subsurface discontinuities well below the surface require the use of a lower frequency. Choice of test frequency will determine the size of discontinuity that can be detected.

8.2 As in any eddy-current test, the depth and orientation of the discontinuity below the entry surface will affect the magnitude of signal received from it. Sensitivity varies significantly with distance from the test coils.

8.3 Under certain conditions austenitic stainless steels can be magnetic. For example, delta ferrite may be present in a welded product. Permeability may vary as a function of cold work. Some nickel alloys, such as Monel Alloy (nickel-copper alloy), are magnetic in nature and others exhibit magnetism if there are slight residual stresses in the material.

8.4 Welded stainless steel products can present a special problem in eddy-current testing. The weld area can usually be distinguished from the parent metal if the tubing has received little or no working after welding. This occurs when the as-welded structure contains delta ferrite which is magnetic and can cause a high-background noise level or spurious indications, or both. If drawn after welding, these effects may be reduced so that welded tubing cannot be distinguished from seamless tubing. These effects do not necessarily preclude the eddy-current testing of as-welded tubing; however, the testing apparatus will probably require different adjustments for materials with as-welded and wrought structures. Thus, the minimum size discontinuity that can be detected may also be different.

8.4.1 For inspecting as-welded tubing, a strong d-c magnetic field is usually applied to improve the signal-to-noise ratio. This bias field is generally applied by an encircling coil or yoke simultaneously with the field from the test coil.

8.4.2 In preparing a reference standard for welded tubing, artificial discontinuities should be placed in both the weld metal and the parent metal if both are to be inspected. The apparatus is then adjusted to obtain an optimum signal-to-noise ratio.

8.4.3 When inspecting only the weld area, the discontinuities shall be placed in the weld area.

8.5 Certain austenitic chromium-nickel stainless steels exhibit changes in magnetic properties as a result of cold work. As a result it may be desirable to prepare reference standards from each lot of material in order to take into account the effect of magnetic permeability. It may also be helpful to employ a magnetic-saturation device to minimize the effects of varying magnetic permeability.

8.6 Both the test frequency and the type of apparatus being used should be considered when choosing the testing speed. Certain types of equipment can detect discontinuities at very slow speeds, while other types require a certain minimum speed. The testing speed may need to be linked to the speed at which the material is being processed at the point of inspection.

8.7 The response from natural discontinuities can be significantly different than that from artificial discontinuities such as drilled holes or notches. For this reason, sufficient work should be done to establish the sensitivity level and setup required to detect natural discontinuities of consequence to the end use of the product.
STANDARD PRACTICE FOR ELECTROMAGNETIC (EDDY-CURRENT) EXAMINATION OF NICKEL AND NICKEL ALLOY TUBULAR PRODUCTS

1. Scope

1.1 This practice covers the procedures for eddy-current testing of nickel and nickel alloy tubes. These procedures are applicable for tubes with outside diameters up to 2 in. (50.8 mm), incl, and wall thicknesses from 0.035 to 0.120 in. (0.889 to 3.04 mm), incl. These procedures may be used for tubes beyond the size range recommended, by contractual agreement between the purchaser and the producer.

1.2 The procedures described in this practice make use of fixed encircling test coils or probe systems.

1.3 The values stated in inch-pound units are to be regarded as the standard.

NOTE 1 — For convenience, the term “tube” or “tubular product” will hereinafter be used to refer to both pipe and tubing.

1.4 This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems 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:
E 268 Definitions of Terms Relating to Electromagnetic Testing
E 309 Practice for Eddy-Current Examination of Steel Tubular Products Using Magnetic Saturation

3. Definitions

3.1 Definitions relating to electromagnetic examination are given in Definitions E 268.

4. Summary of Practice

4.1 Examination is usually performed by the use of one of two general techniques:

4.1.1 Encircling Coil Technique — Examination is performed by passing the tube lengthwise through a coil energized with alternating current at one or more frequencies. See Fig. 1. The electrical impedance of the coil is modified by the proximity of the tube, the tube dimensions, electrical conductivity, saturating magnetic field, magnetic permeability, and metallurgical or mechanical discontinuities in the tube. As the tube passes through the coil, the changes in electromagnetic response caused by these variables in the tube change the coil impedance, which activates an audible or visual signaling device or a mechanical marker.

4.1.2 Probe Coil Technique — Probe coils are positioned in close proximity to the outside diameter or to the inside diameter, or to both diameter surfaces, of the tubular product being examined as shown in Fig. 1. Since the probe is generally small and does not encircle the tube, it examines only a limited area in the vicinity of the probe. When required to examine the entire volume of the tubular product, it is common practice to rate either the tubular product or the probe around the tube. Frequently, in the case of welded
tubular products, only the weld is inspected by scanning along the weld zone.

4.2 The magnetic permeability of magnetic materials severely limits the depth of penetration of induced eddy currents. Furthermore, the permeability variations inherent in magnetic tubular product can cause spurious test results. A useful solution to this problem involves the application of a strong external magnetic field in the region of the examining coil or probe. This technique, known as magnetic saturation, causes a magnetic material to exhibit sufficiently small magnetic characteristics of permeability, hysteresis, etc., so that the material under examination is effectively rendered nonmagnetic. When achieved, this condition allows an eddy-current system to measure and detect electrical resistivity and geometrical variations (including defects) independent of concurrent variations in magnetic properties.

NOTE 2 — Recommended Practice E 309 may be used for strongly magnetic materials.

4.2.1 During the testing of slightly magnetic tubing the signals resulting from the variation of magnetic permeability can mask the signals resulting from small imperfections. A magnetic saturation technique can be used to reduce this interference to an acceptable level.

5. Significance and Use

5.1 Eddy-current testing is a nondestructive method of locating discontinuities in metallic materials. Signals can be produced by discontinuities originating on either the external or internal surfaces of the tube or by discontinuities totally contained within the wall. Since the density of eddy currents decreases nearly exponentially with increasing distance from the surface nearest the coil, the response to deep-seated defects decreases correspondingly. Phase changes are also associated with changes in depth, allowing the use of phase analysis techniques.

5.2 The response from natural discontinuities can be significantly different than that from artificial discontinuities, such as drilled holes or notches. For this reason, sufficient work should be done to establish the sensitivity level and setup required to detect natural discontinuities of consequence to the end of the product.

5.3 Some indications obtained by this method may not be relevant to product quality; for example, an irrelevant indication may be caused by minute dents or tool chatter marks, which are not detrimental to end use of the product. Irrelevant indications can mask unacceptable discontinuities. Relevant indications are those which result from discontinuities. Any indication that exceeds the rejection level shall be treated as a relevant indication until it can be demonstrated that it is irrelevant.

5.4 Generally, eddy-current testing systems are not sensitive to discontinuities adjacent to the ends of the tube (end effect).

5.5 Discontinuities such as scratches or seams that are continuous and uniform over the full length of the tube may not always be detected with differential encircling coils or probes scanned along the tube length.

5.6 For material that is magnetic, a strong magnetic field shall be placed in the region of the examining
coil. A magnetic field may also be used to improve the signal-to-noise ratio in tubing that exhibits slight residual magnetism.

6. Ordering Information

6.1 The following are items that require agreement between the purchaser and the supplier and should be specified in the purchase order:

6.1.1 Acceptance criteria.

6.1.2 Type, dimensions, and number of artificial discontinuities to be placed in the reference standard.

6.1.3 Extent of inspection; that is, full circumference of outside or inside diameter, or both, or weld only, if welded.

6.1.4 Operator qualifications, if required.

6.1.5 Calibration intervals.

7. Apparatus

7.1 Electronic Apparatus — The electronic apparatus shall be capable of energizing the encircling coils or probes with alternating current of suitable frequencies and shall be capable of sensing changes in impedance of the encircling coils or probes. Equipment may include any appropriate signal processing circuits such as a phase discriminator, filter circuits, etc., as required for the particular application.

7.2 Encircling Coil Assembly — The encircling coil assembly shall consist of one or more electrical coils which encircle the article being examined. The inside geometry of the coils should closely approximate the surface geometry of the specimen so that when the specimen is passed through the coils all points on the outer circumference of the specimen are effectively equidistant from, and in close proximity to, the inner surfaces of the examining coils.

7.3 Probe Assembly — The probe coil assembly normally contains an exciting coil and a sensor, although in some cases the exciter and the sensor are one and the same. The sensor may consist of one or more electrical coils or a semiconductor device that responds to variations in electromagnetic flux density. Good examination practices require that the spacing between the probe coil assembly and the tube being tested be both small and uniform.

7.4 Driving Mechanism — The mechanical device capable of passing the tube through the examining coil or past the probe shall operate at a uniform speed with minimum vibration of coil, probe, or tube and shall maintain the article being inspected in proper register or concentricity with the probe or coil. Where required, the mechanism shall be capable of rotating the tube or probe with a uniform rotational speed.

8. Reference Standard

8.1 The standard used to adjust the sensitivity of the apparatus shall be free of interfering discontinuities and of the same nominal alloy, temper, and nominal dimensions as the lot of tubes to be examined on a production basis. It shall be of sufficient length to permit the spacing of artificial discontinuities to provide good signal resolution, and to be mechanically stable while in the examining position in the apparatus. Artificial discontinuities placed in the tube shall be of the following types (see Fig. 2):

8.1.1 Notch — Longitudinal or transverse notches, or both, may be produced by milling, filing, EDM (Electric Discharge Machine) or other suitable means. Notches may be placed on the outer, inner, or both surfaces of the reference standard.

NOTE 3 — Longitudinal notch standards are normally used when testing with rotating probe systems.

8.1.2 Hole — The holes shall be drilled radially partially or completely through the tube wall without causing permanent distortion of the tube wall.

8.1.3 Hole size and notch configuration (type, orientation, length, depth, size, etc.) influence the eddy-current response. These factors, plus the method and tolerances used in their measurement, shall be as specified in the agreement between the supplier and the purchaser.

9. Adjustment and Standardization of Apparatus Sensitivity

9.1 Select the apparatus, examining frequency, coil or probe configuration or both, magnetic saturation system if used, phase discrimination, and other circuitry, as well as speed of examination. Demonstrate the system capability for detecting artificial discontinuities of the size and type of interest at production speed.

9.2 Fabricate the applicable reference standard in accordance with the agreement between the purchaser and the tubing supplier. Discard and replace the tube used as the reference standard when erroneous signals
are produced from mechanical, metallurgical or other damage to the reference standard.

9.3 Rotate the reference standard in either 90 or 120° increments to determine the location of the electrical center in the examining coil. Mechanically adjust the position of the tube within the coil to obtain nearly equal responses from the artificial discontinuities regardless of their circumferential orientation.

9.4 The length of tubing not examined due to the end effect may be determined by selecting a tube of low background noise and making a series of holes or notches at appropriate intervals near the end of this special tube. See Fig. 3. Pass the tube through the test setup at the production test speed with the artificial discontinuities end first, and then with the artificial discontinuities end last. Determine the distance from the tube end to the point at which the signal response from successive discontinuities is uniform with a recording device such as a pen recorder or memory oscilloscope. A signal suppression method (photo relay, mechanical switches, or proximity devices are commonly used) may be used to permit examination only when the length of tubing exhibiting uniform signals is within the test coil. The section of tube passing through the test coil representing the end effect is not examined.

9.5 As an option to 9.4, the length of tubing representing the end effect may be determined by selecting a tube of low background noise and making a hole or notch at a point 6 to 8 in. (152 to 203 mm) from the tube end. Pass the tube through the test coil at the production test speed with the artificial discontinuity end last. If the artificial discontinuity is not detected, make another artificial discontinuity farther from the end. If it is detected, cut off 0.5-in. (12.7-mm) increments from the end of the tube until the artificial discontinuity is no longer detected. The length from the tube end to the artificial discontinuity that can be detected is that length of tubing representing the end effect.

NOTE 4 — It is intended that the extent of the end effect region be determined only once for each diameter, wall thickness, speed, and test frequency and need not be repeated for each run or during the periodic calibration check.

NOTE 5 — Any other suitable means of determining the end effect may be used.

10. Procedure

10.1 Electrically center the tubing in the test coil at the start of the test run. The reference standard may be used, or a separate tube may be prepared for this purpose in accordance with 8.1.1 and 8.1.2. Pass the tube through the test system and mechanically adjust its position in the test coil such that the requirements of 9.3 are satisfied.
10.2 Calibrate the test system at the start and end of each shift. Recalibrate at the intervals specified in the agreement between purchaser and supplier; whenever improper functioning occurs, resulting in a loss of apparatus sensitivity, recalibrate the system in accordance with Section 9 and retest all tubes tested since the last standardization.

10.3 After standardization, pass the tubes though the test system, as described in Section 9.

10.3.1 Accept those tubes that produce output signals conforming to the limits in the applicable product specification.

10.3.2 Tubes that produce output signals not conforming to the limits in the applicable specification may, at the option of the manufacturer, be set aside for retest. Upon retest, accept those tubes whose output signals are either within acceptable limits (10.3.1), or are demonstrated by other means to be irrelevant.

10.4 Tubes may be tested at the finish size before or after the final anneal or heat treatment, unless otherwise agreed upon by the supplier and the purchaser.

11. Supplemental Information

11.1 The response to subsurface discontinuities decreases as the distance from the surface increases. This is because the density of the eddy currents decreases nearly exponentially with distance from the coil.

11.2 In preparing a reference standard for welded tubing, artificial discontinuities should be placed in both the weld metal and the parent metal if both are to be examined. If the welded tube is cold worked and recrystallized, or if the weld exhibits the same electrical properties as the parent metal (that is, those metal properties that affect the response of the eddy-current system), the artificial discontinuities may be placed in either weld metal or parent metal. Then adjust the apparatus to obtain an optimum signal-to-noise ratio.

11.3 When examining only the weld bead, place the discontinuities only in the weld bead.

11.4 When choosing the examining speed, consider the examination frequency and the type of apparatus being used. Certain types of equipment can detect discontinuities at very slow speeds, or statically, while other types require a certain minimum speed. The examining speed may need to be linked to the speed at which the material is being processed at the point of examination.

11.5 Magnetic Saturation System — The magnetic saturation system shall consist of a suitable method of applying a strong d-c magnetic field to the region of the tube adjacent to the coil or probe coil assembly so as to render that region of the tube essentially nonmagnetic. Typical systems employ either permanent magnets or controllable electromagnets.