



Standard Practice for Examination of Seamless, Gas-Filled, Pressure Vessels Using Acoustic Emission¹

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1. Scope*

1.1 This practice provides guidelines for acoustic emission (AE) examinations of seamless pressure vessels (tubes) of the type used for distribution or storage of industrial gases.

1.2 This practice requires pressurization to a level greater than normal use. Pressurization medium may be gas or liquid.

1.3 This practice does not apply to vessels in cryogenic service.

1.4 The AE measurements are used to detect and locate emission sources. Other nondestructive test (NDT) methods must be used to evaluate the significance of AE sources. Procedures for other NDT techniques are beyond the scope of this practice. See [Note 1](#).

NOTE 1—Shear wave, angle beam ultrasonic examination is commonly used to establish circumferential position and dimensions of flaws that produce AE. Time of Flight Diffraction (TOFD), ultrasonic examination is also commonly used for flaw sizing.

1.5 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Specific precautionary statements are given in Section 7.*

¹ This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.04 on Acoustic Emission Method.

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2. Referenced Documents

2.1 ASTM Standards:²

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

[E650 Guide for Mounting Piezoelectric Acoustic Emission Sensors](#)

[E976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response](#)

[E1316 Terminology for Nondestructive Examinations](#)

[E2223 Practice for Examination of Seamless, Gas-Filled, Steel Pressure Vessels Using Angle Beam Ultrasonics](#)

[E2075 Practice for Verifying the Consistency of AE-Sensor Response Using an Acrylic Rod](#)

[E2374 Guide for Acoustic Emission System Performance Verification](#)

2.2 ASNT Standards:³

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

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

2.3 Code of Federal Regulations:

[Section 49, Code of Federal Regulations, Hazardous Materials Regulations of the Department of Transportation, Paragraphs 173.34, 173.301, 178.36, 178.37, and 178.45⁴](#)

2.4 Compressed Gas Association Standard:⁵

[Pamphlet C-5 Service Life, Seamless High Pressure Cylinders](#)

² 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.

³ Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, <http://www.asnt.org>.

⁴ Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, <http://www.access.gpo.gov>.

⁵ Available from Compressed Gas Association (CGA), 4221 Walney Rd., 5th Floor, Chantilly, VA 20151-2923, <http://www.cganet.com>.



CGA-C18 Methods for Acoustic Emission Qualification of Seamless Steel Compressed Gas Tubes

2.5 AIA Document:

NAS-410 Certification and Qualification of Nondestructive Testing Personnel⁶

2.6 ISO Standards:⁷

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

ISO 16148 Gas Cylinders—Acoustic Emission Testing (AT) for Periodic Inspection

3. Terminology

3.1 *Definitions*—See Terminology E1316 for general terminology applicable to this practice.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *fracture critical flaw*—a flaw that is large enough to exhibit unstable growth at service conditions.

3.2.2 *marked service pressure*—pressure for which a vessel is rated. Normally this value is stamped on the vessel.

3.2.3 *normal fill pressure*—level to which a vessel is pressurized. This may be greater, or may be less, than *marked service pressure*.

4. Summary of Practice

4.1 The AE sensors are mounted on a vessel, and emission is monitored while the vessel is pressurized above normal fill pressure.

4.2 Sensors are mounted at each end of the vessel and are connected to an acoustic emission signal processor. The signal processor uses measured times of arrival of emission bursts to determine linear location of emission sources. If measured emission exceeds a prescribed level (that is, specific locations produce enough events), then such locations receive secondary NDT (for example, ultrasonic examination).

4.3 Secondary examination establishes presence of flaws and measures flaw dimensions.

4.4 If flaw depth exceeds a prescribed limit (that is, a conservative limit that is based on construction material, wall thickness, fatigue crack growth estimates, and fracture critical flaw depth calculations), then the vessel must be removed from service.

5. Significance and Use

5.1 Because of safety considerations, regulatory agencies (for example, U.S. Department of Transportation) require periodic examinations of vessels used in transportation of industrial gases (see Section 49, Code of Federal Regulations). The AE examination has become accepted as an alternative to the common hydrostatic proof test. In the common hydrostatic test, volumetric expansion of vessels is measured.

5.2 An AE examination should not be performed for a period of one year after a common hydrostatic test. See Note 2.

NOTE 2—The Kaiser effect relates to decreased emission that is expected during a second pressurization. Common hydrostatic tests use a relatively high pressure (167 % of normal service pressure). (See Section 49, Code of Federal Regulations.) If an AE examination is performed too soon after such a pressurization, the AE results will be insensitive to a lower examination pressure (that is, the lower pressure that is associated with an AE examination).

5.3 Pressurization:

5.3.1 General practice in the gas industry is to use low pressurization rates. This practice promotes safety and reduces equipment investment. The AE examinations should be performed with pressurization rates that allow vessel deformation to be in equilibrium with the applied load. Typical current practice is to use rates that approximate 3.45 MPa/h [500 psi/h].

5.3.2 Gas compressors heat the pressurizing medium. After pressurization, vessel pressure may decay as gas temperature equilibrates with ambient conditions.

5.3.3 Emission from flaws is caused by flaw growth and secondary sources (for example, crack surface contact and contained mill scale). Secondary sources can produce emission throughout vessel pressurization.

5.3.4 When pressure within a vessel is low, and gas is the pressurizing medium, flow velocities are relatively high. Flowing gas (turbulence) and impact by entrained particles can produce measurable emission. Considering this, acquisition of AE data may commence at some pressure greater than starting pressure (for example, $\frac{1}{3}$ of maximum examination pressure).

5.3.5 *Maximum Test Pressure*—Serious flaws usually produce more acoustic emission (that is, more events, events with higher peak amplitude) from secondary sources than from flaw growth. When vessels are pressurized, flaws produce emission at pressures less than normal fill pressure. A maximum examination pressure that is 10 % greater than normal fill pressure allows measurement of emission from secondary sources in flaws and from flaw growth.

5.3.6 *Pressurization Schedule*—Pressurization should proceed at rates that do not produce noise from the pressurizing medium and that allow vessel deformation to be in equilibrium with applied load. Pressure holds are not necessary; however, they may be useful for reasons other than measurement of AE.

5.4 Excess background noise may distort AE data or render them useless. Users must be aware of the following common sources of background noise: high gas-fill rate (measurable flow noise); mechanical contact with the vessel by objects; electromagnetic interference (EMI) and radio frequency interference (RFI) from nearby broadcasting facilities and from other sources; leaks at pipe or hose connections; and airborne sand particles, insects, or rain drops. This practice should not be used if background noise cannot be eliminated or controlled.

5.5 Alternate procedures are found in ISO 16148 and CGA C18. These include hydrostatic proof pressurization of individual vessels and data interpretation using modal analysis techniques

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), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, <http://www.iso.org>.

6. Basis of Application

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

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

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

6.4 *Time of Examination*—The timing of examination shall be in accordance with 5.2 unless otherwise specified.

6.5 *Extent of Examination*—The extent of examination includes the entire pressure vessel unless otherwise specified.

6.6 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with Section 11 unless otherwise specified. Since acceptance criteria (for example, reference radiographs) are not specified in this practice, they shall be specified in the contractual agreement.

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

7. Apparatus

7.1 Essential features of the apparatus required for this practice are provided in Fig. 1. Full specifications are in Annex A1.

7.2 Couplant must be used to acoustically connect sensors to the vessel surface. Adhesives that have acceptable acoustic properties, and adhesives used in combination with traditional couplants, are acceptable.

7.3 Sensors may be held in place with magnets, adhesive tape, or other mechanical means.

7.4 The AE sensors are used to detect strain-induced stress waves produced by flaws. Sensors must be held in contact with the vessel wall to ensure adequate acoustic coupling.

7.5 A preamplifier may be enclosed in the sensor housing or in a separate enclosure. If a separate preamplifier is used, cable length, between sensor and preamp, must not exceed 2 m [6.6 ft].

7.6 Power/signal cable length (that is, cable between preamp and signal processor) shall not exceed 150 m [500 ft]. See A1.5.

7.7 Signal processors are computerized instruments with independent channels that filter, measure, and convert analog information into digital form for display and permanent storage. A signal processor must have sufficient speed and capacity to independently process data from all sensors simultaneously. The signal processor should provide capability to filter data for replay. A printer should be used to provide hard copies of examination results.

7.7.1 A video monitor should display processed examination data in various formats. Display format may be selected by the equipment operator.

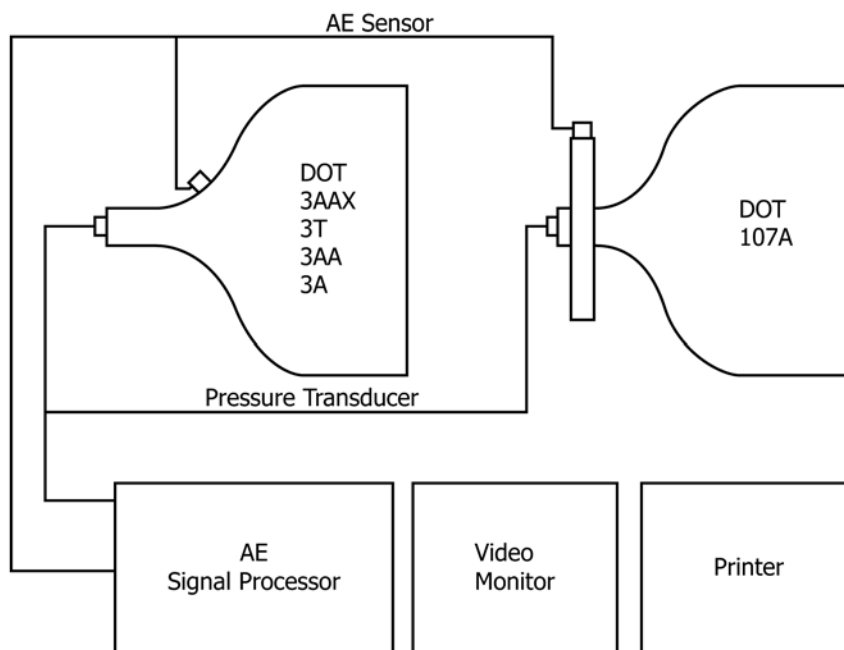


FIG. 1 Essential Features of the Apparatus with Typical Sensor Placements



7.7.2 A data storage device may be used to provide data for replay or for archives.

7.7.3 Hard copy output capability should be available from a printer or equivalent device.

8. Safety Precautions

8.1 As in any pressurization of metal vessels, ambient temperature should not be below the ductile-brittle transition temperature of the pressure vessel construction material.

9. Calibration and Standardization

9.1 Annual calibration and verification of pressure transducer, AE sensors, preamplifiers (if applicable), signal processor (particularly the signal processor time reference), and AE electronic waveform generator should be performed. Equipment should be adjusted so that it conforms to equipment manufacturer's specifications. Instruments used for calibrations must have current accuracy certification that is traceable to the National Institute for Standards and Technology (NIST).

9.2 Routine electronic evaluation of the signal processor should be performed monthly and any time there is concern about signal processor performance. An AE electronic waveform generator should be used in making evaluations. Each signal processor channel must respond with peak amplitude reading within ± 2 dBV of the electronic waveform generator output.

9.3 Routine evaluation of the sensors should be performed monthly. An accepted procedure for this purpose found in Practice E2075 and Guide E976.

9.4 Routine verification of the system's ability to locate and cluster data should be performed monthly. With two sensors mounted on one tube and a ruler taped to the tube surface, use a pencil lead break (PLB) at 60 cm [2 ft.] intervals along the entire length of the tube (5 PLBs at each point). Examine the recorded data to verify that locations and clusters are in the correct positions.

9.5 Pre-examination and post-examination, system performance verification must be conducted immediately before, and immediately after, each examination. System performance verification uses a mechanical device to induce stress waves into the vessel wall at a specified distance from each sensor. Induced stress waves stimulate a sensor in the same way as emission from a flaw. System performance verification verifies performance of the entire system (including sensors, cables, and couplant). Procedures for system performance verification are found in Guide E2374.

9.5.1 The preferred technique for conducting a system performance verification is a PLB. Lead should be broken on the vessel surface no less than 10 cm [4 in.] from the sensor. The 2H lead, 0.3-mm [0.012-in.] diameter, 3-mm [0.012-in.] long should be used (see Fig. 5 of Guide E976).

9.5.2 *Auto Sensor Test (AST)*—An electromechanical device such as a piezoelectric pulser (and sensor which contains this function) can be used in conjunction with pencil lead break (9.5.1) as a means to assure system performance. If AST is used in conjunction with PLB for pre-examination then AST may be used, solely, for post examination system performance verification.

10. Procedure

10.1 Visually examine accessible exterior surfaces of the vessel. Note observations in examination report.

10.2 Isolate vessel to prevent contact with other vessels, hardware, and so forth. When the vessel cannot be completely isolated, indicate, in the examination report, external sources which could have produced emission.

10.3 Connect fill hose and pressure transducer. Eliminate any leaks at connections.

10.4 Mount an AE sensor at each end of each tube (see Fig. 1 for typical sensor placement). Use procedures specified in Guide E650. Sensors must be at the same angular position and should be located at each end of the vessel so that the AE system can determine axial locations of sources in as much of the vessel as possible.

NOTE 3—AE instrumentation utilizing waveform based analysis techniques may require sensor placement inboard of the tube ends to achieve optimum source location results.

10.5 Adjust signal processor settings. See Appendix X1 for example.

10.6 Perform system performance verification at each sensor (see 9.5). Verify that peak amplitude is greater than a specified value (see Table X1.2). Verify that the AE system displays a correct location (see Note 5) for the mechanical device that is used to produce stress waves (see 9 and Table X1.2). Prior to pressurization, verify that there is no background noise above the signal processor threshold setting.

NOTE 4—Sensors must be mounted as close to the tube end as possible to optimize linear source location accuracy (refer to Fig. 1). Mounting on the tube shoulder, close to the tube neck is acceptable.

NOTE 5—If desired location accuracy cannot be attained with sensors at two axial locations, then more sensors should be added to reduce sensor spacing.

10.7 Begin pressurizing the vessel. The pressurization rate shall be low enough that flow noise is not recorded.

10.8 Monitor the examination by observing displays that show plots of AE events versus axial location. If unusual response (in the operator's judgment) is observed, interrupt pressurization and conduct an investigation.

10.9 Store all data on mass storage media. Stop the examination when the pressure reaches 110 % of normal fill pressure or 110 % of marked service pressure (whichever is greater). The pressure shall be monitored with an accuracy of ± 2 % of the maximum examination pressure.

10.9.1 Examples:

10.9.1.1 A tube trailer is normally filled to a gage pressure of 18.20 MPa [2640 psi]. Pressurization shall stop at 20 MPa [2900 psi].

10.9.1.2 A gas cylinder is normally filled to a gage pressure of 4.23 MPa [613 psi]. The marked service pressure is 16.55 MPa [2400 psi]. Pressurization shall stop at 18.20 MPa [2640 psi].

10.10 Perform a system performance verification at each sensor (see 9.5). Verify that peak amplitude is greater than a specified value (see Table X1.2).



10.11 Reduce pressure in vessel to normal fill pressure by bleeding excess gas to a receiver, or vent the vessel.

10.12 Raw AE data should be filtered to eliminate emission from nonstructural sources, for example, electronic noise.

10.13 Replay examination data. Examine the location distribution plots (AE events versus axial location) for all vessels in the examination.

10.14 All locations on a pressure vessel (e.g. DOT 3AAX tube) with five or more located AE events that occurred within a 20.3 cm [8 in.] axial distance, on the cylindrical portion of a tube, must have a follow-up inspection using Practice E2223. Appendix X1 provides examples of such determinations.

11. Report

11.1 Prepare a written report from each examination. Report the following information:

11.1.1 Name of the owner of the vessel and the vehicle number (if appropriate).

11.1.2 Examination date and location.

11.1.3 Previous examination date and previous maximum pressurization. See Note 6.

NOTE 6—If the operator is aware of situations where the vessel was subject to pressures that exceeded normal fill pressure, these should be described in the report.

11.1.4 Any U.S. Department of Transportation (DOT) specification that applies to the vessel.

11.1.5 Any DOT exemption numbers that apply to the vessel.

11.1.6 Normal fill pressure and marked service pressure.

11.1.7 Pressurization medium.

11.1.8 Amplitude measurements from pre- and post-performance verification.

11.1.9 Pressure at which data acquisition commenced.

11.1.10 Maximum examination pressure.

11.1.11 Record wave velocity and threshold used in the location calculation.

11.1.12 Locations of AE sources that exceed acceptance criteria. Location shall include distance from end of vessel that bears the serial number (usually this is stamped in the vessel wall).

11.1.13 Signature of examiner.

11.1.14 Stacking chart that shows relative locations of vessels (if a multiple vessel array is tested).

11.1.15 Visual examination results.

11.1.16 AE examination results, including events versus location plots for each vessel and cumulative events versus pressure plot for each vessel.

12. Keywords

12.1 acoustic emission; flaws in steel vessels; gas pressure vessels; seamless gas cylinders; seamless steel cylinders; seamless vessels

ANNEX

(Mandatory Information)

A1. INSTRUMENTATION SPECIFICATIONS

A1.1 Sensors

A1.1.1 The AE sensors shall have high sensitivity within the frequency bandpass of intended use. Sensors may be broad band or resonant.

A1.1.2 Sensitivity shall be greater than 70 dBV from a PLB source (as described in subsection 4.3.3 of Guide E976).

A1.1.3 Sensitivity within the range of intended use shall not vary more than 3 dB over the intended range of temperatures in which sensors are used.

A1.1.4 Sensors shall be shielded against electromagnetic interference through proper design practice or differential (anticoincidence) element design, or both.

A1.1.5 Sensors shall be electrically isolated from conductive surfaces by means of a shoe (a wear plate).

A1.2 Signal Cable

A1.2.1 The sensor signal cable which connects sensor and preamplifier shall not reduce sensor output more than 3 dB (2 m [6.6 ft] is a typical maximum length). Integral preamplifier sensors meet this requirement. They have inherently short, internal, signal cables.

A1.2.2 Signal cable shall be shielded against electromagnetic interference. Standard coaxial cable is generally adequate.

A1.3 Couplant

A1.3.1 A couplant shall provide adequate ultrasonic coupling efficiency throughout the examination.

A1.3.2 The couplant must be temperature stable over the temperature range intended for use.

A1.3.3 Adhesives may be used if they satisfy ultrasonic coupling efficiency and temperature stability requirements.

A1.4 Preamplifier

A1.4.1 The preamplifier shall have noise level no greater than 7 μ V rms (referred to a shorted input) within the bandpass range.

A1.4.2 The preamplifier gain shall vary no more than ± 1 dB within the frequency band and temperature range of use.

A1.4.3 The preamplifier shall be shielded from electromagnetic interference.

A1.4.4 The preamplifiers of differential design shall have a minimum of 40-dB common mode rejection.

A1.5 Power/Signal Cable

A1.5.1 The power/signal cables provide power to preamplifiers, and conduct amplified signals to the main processor. These shall be shielded against electromagnetic interference. Signal loss shall be less than 1 dB/ 30 m [100 ft] of cable length. Standard coaxial cable is generally adequate. Signal loss from a power/signal cable shall be no greater than 3 dB.

A1.6 Power Supply

A1.6.1 A stable, grounded, power supply that meets the signal processor manufacturer's specification shall be used.

A1.7 Signal Processor

A1.7.1 The electronic circuitry gain shall be stable within ± 2 dB in the temperature range of 40°C [100°F].

A1.7.2 Threshold shall be accurate within ± 2 dB.

A1.7.3 Measured AE parameters shall include: threshold crossing counts, peak amplitude, arrival time, rise time, and duration for each hit. Also, vessel internal pressure shall be measured.

A1.7.4 The counter circuit shall count threshold crossings within an accuracy of ± 5 % of true counts.

A1.7.5 Peak amplitude shall be accurate within ± 2 dBV.

A1.7.6 Duration shall be accurate to within ± 10 μ s.

A1.7.7 Threshold shall be accurate to within ± 1 dB.

A1.7.8 Arrival time shall be accurate to 0.5 μ s.

A1.7.9 Rise time shall be accurate to ± 10 μ s.

A1.7.10 Parametric voltage readings from pressure transducers shall be accurate to within ± 5 % of the marked service pressure.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE INSTRUMENT SETTINGS AND REJECTION CRITERIA

X1.1 A database and rejection criteria are established for some DOT specified vessels. These have been described in the NDT Handbook.⁸ More recent criteria are described in this section. Some vessel types, typical dimensions, and service pressures are listed in **Table X1.1**.

X1.2 Criteria for determining the need for secondary examination were established while working with AE equipment with setup conditions listed in **Table X1.2**.

X1.3 Need for secondary examination is based on location distribution plots (that is, plots of AE events versus axial location) after AE data acquisition is completed.

X1.3.1 *Location Error Due to Hyperbola Error*—The accuracy of linear location techniques used on two dimensional objects such as gas tubes is very good on a straight line

TABLE X1.2 Acoustic Emission Equipment, Characteristics, and Setup Conditions

Sensor sensitivity	>70 dBV using PLB source (see A1.1.2)
Couplant	silicone grease
Preamplifier gain	40 dB ($\times 100$)
Preamplifier filter	100 to 300-kHz bandpass
Power/signal cable length	<500 ft (152.4 m)
Signal processor filter	100 to 300-kHz bandpass
Dead time	10 ms
Background noise	<27 dBV (for example, 1 μ V = 0 dBV at preamplifier input)
Sensitivity check	>70 dBV (PLB, 0.3 mm [0.012 in.], 3 mm [0.12 in.], 10 cm [4 in.]

between the sensors. However, off axis, linear source location accuracy diminishes significantly for sources near the tube ends. The poorest source location accuracy is 180° from the axis. The reason for the inaccuracy can be explained by investigating the algorithm that forms the basis for linear source location, a series of hyperbolas. The vertex of each hyperbola lies on the axis (hence good accuracy along the

TABLE X1.1 Specified Cylinders, Typical Dimensions, and Service Pressures

Specification	DOT 3AAX	DOT 3T	DOT 3A	DOT 3AA	DOT 107A
Outside diameter	56 cm [22 in.]	56 cm [22 in.]	25 cm [9.8 in.]	25 cm [9.8 in.]	46 cm [18 in.]
Nominal wall thickness	1.4 cm [0.55 in.]	1.1 cm [0.43 in.]	0.79 cm [0.31 in.]	0.64 cm [0.25 in.]	1.9 or 2.2 cm [0.75 or 0.86 in.]
Length	5.5 to 12 m [18 to 40 ft]		4 to 10 m [13 to 33 ft]		10 m [33ft]
Typical service pressure	16.6 MPa [2400 psi]				18 or 23 MPa [2600 or 3300 psi]
Typical fill pressure	14.14 to 20.7 [600 to 3000]				18 to 23 MPa [2600 to 3300 psi]
Alternate retest method	hydrostatic test, at 1.67 times marked service pressure every five years with volumetric expansion measurement				

⁸ Miller, R. K., and McIntire, P., *Nondestructive Testing Handbook*, 2nd ed., Vol 5, *Acoustic Emission Testing*, American Society for Nondestructive Testing, Columbus, Ohio, 1987, pp. 161–165.

axis). When the algorithm is used on a plane (two-dimensional) each hyperbola maps out positions on the tube which will be reported as having the same source location. At the exact center between the sensors there is no inaccuracy for positions around the tube. As we move away from the center, the curve of the hyperbolas bends toward the sensor. The hyperbola error is illustrated in **Fig. X1.1**. **Table X1.3** is a compilation of the error (difference between on-axis and 180° off-axis hyperbola coordinates). Data is presented for tubes of different diameters. The error was determined graphically using the equation for a hyperbola to calculate several coordinate points to construct the hyperbola line. The error decreases at the end due to the hemispherical shape.

X1.3.2 Follow-up inspection is necessary at the position of any cluster ± 460 mm [± 18 in.]. Follow-up inspection involves a secondary NDT method (for example, ultrasonic examination). Any indication that is detected must be precisely located, and flaw dimensions must be determined.

X1.4 Rejection Criterion:

X1.4.1 Vessels that contain flaws that are large enough to be “fracture critical flaws,” or that contain flaws large enough to

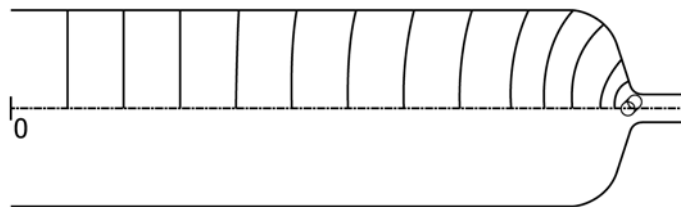


FIG. X1.1 Hyperbolas drawn on a 56 cm [22 in.] diameter tube with 1016 cm [400 in.] sensor spacing. The tube is drawn as a two-dimensional flat surface. The drawing is not to scale.

grow to fracture critical size before another re-examination is performed, shall be removed from service.

X1.4.2 “Fracture critical” flaw dimensions are based upon fracture mechanics analysis of a vessel using strength properties that correspond to materials of construction.

X1.4.3 Analyses of DOT 3AAX and 3T tubes are described by Blackburn and Rana.⁹ Fracture critical flaw depths were calculated, and fatigue crack growth (under worst case conditions) was estimated. Flaw depths that could grow to half the fracture critical size were judged too large. They should not remain in service. Based upon this conservative approach, DOT Specification 3AAX and 3T tubes with maximum flaw depths of 2.54 mm [0.10 in.], or more, should be permanently removed from service.

X1.4.3.1 The DOT 3AAX and 3T cylinders have been evaluated by Blackburn and Rana.⁹ The maximum allowable flaw depth was calculated to be 2.5 mm [0.10 in.].

X1.4.3.2 The DOT 3AA and 3A cylinders were evaluated by Blackburn.¹⁰ Maximum allowable depths were calculated, and 1.5 mm [0.06 in.] was specified for both specifications.

X1.4.3.3 The DOT 107A cylinders have been evaluated by Toughiry.¹¹ The maximum flaw depth was calculated to be 3.8 mm [0.150 in.].

⁹ Blackburn, P. R., and Rana, M. D., “Acoustic Emission Testing and Structural Evaluation of Seamless, Steel, Tubes in Compressed Gas Service,” *Transactions of the American Society of Mechanical Engineers, Journal of Pressure Vessel Technology*, Vol 108, May 1986, pp. 234–240.

¹⁰ Docket No. 11099, Application for Exemption, Appendix II, “Maximum Allowable Flaw Depth, 3A and 3AA Tubes,” U.S. Department of Transportation, Jan. 14, 1988.

¹¹ Toughiry, M. M., Docket No. 11059, Application for Exemption from the Requirements of *Hazardous Materials Regulations of the DOT*, U.S. Bureau of Mines, Helium Field Operation, June 1993.



TABLE X1.3 Compilation of Error

Distance from Center of Tube	560 mm [22 in.] Diameter Calculated/Actual Error	510 mm [20 in.] Diameter Calculated/Actual Error	460 mm [18 in.] Diameter Calculated/Actual Error	245 mm [9.63 in.] Diameter Calculated/Actual Error
0	0	0	0	0
50 cm [20 in.]	6.3 mm [0.25 in.]	5 mm [0.2 in.]	4.0 mm [0.2 in.]	1.3 mm [0.05 in.]
100 cm [40 in.]	13 mm [0.5 in.]	10.5 mm [0.4 in.]	8.6 mm [0.3 in.]	2.5 mm [0.1 in.]
150 cm [60 in.]	20 mm [0.8 in.]	16.5 mm [0.7 in.]	13.5 mm [0.5 in.]	3.8 mm [0.15 in.]
200 cm [80 in.]	29 mm [1.1 in.]	23.5 mm [0.9 in.]	19 mm [0.8 in.]	5.6 mm [0.22 in.]
250 cm [100 in.]	39 mm [1.5 in.]	32.5 mm [1.3 in.]	26 mm [1.0 in.]	7.6 mm [0.3 in.]
300 cm [120 in.]	53 mm [2.1 in.]	44 mm [1.7 in.]	35.5 mm [1.4 in.]	10 mm [0.4 in.]
350 cm [140 in.]	72.5 mm [2.9 in.]	60 mm [2.4 in.]	48.7 mm [1.9 in.]	14 mm [0.6 in.]
400 cm [16 in.]	105 mm [4.1 in.]	87 mm [3.4 in.]	70 mm [2.8 in.]	20 mm [0.8 in.]
450 cm [180 in.]	167 mm [6.6 in.]	138 mm [5.5 in.]	112 mm [4.4 in.]	32.5 mm [1.3 in.]
500 cm [200 in.]	348 mm [13.7 in.]/ 259 mm [10.2 in.]	290 mm [11.4 in.]/ 250 mm [10.0 in.]	235 mm [9.3 in.]	52.6 mm [2.1 in.]
530 cm [210 in.]	693 mm [27.2 in.]/ 178 mm [7.0 in.]	580 mm [23 in.]/ 178 mm [7.0 in.]	472 mm [18.6 in.]/ 178 mm [7.0 in.]	140 mm [5.5 in.]

SUMMARY OF CHANGES

Committee E07 has identified the location of selected changes to this standard since the last issue (E1419-09) that may impact the use of this standard.

- (1) Document converted to a Combined Standard.
- (2) Added ISO 9712 to paragraphs 2.6 and 6.2.
- (3) Added new Alternative Procedures section (5.5) to document
- (4) Added documents CGA-C18 and ISO-16148 to section 5.5 and section 2, Reference documents.
- (5) Modified paragraph 10.14 to specify criteria when an additional test (Practice E2223) must be performed.

- (6) Added a new paragraph, 11.1.10 to specify that the wave velocity, used in the location calculation is to be recorded in the report.
- (7) Added Location error due to Hyperbola Error, new section X1.3.1.

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