Designation: E1067/E1067M – 11

# Standard Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels[1]

This standard is issued under the fixed designation E1067/E1067M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope*

1.1 This practice covers acoustic emission (AE) examination or monitoring of fiberglass-reinforced plastic (FRP) tanks-vessels (equipment) under pressure or vacuum to determine structural integrity.

1.2 This practice is limited to tanks-vessels designed to operate at an internal pressure no greater than 1.73 MPa absolute [250 psia] above the static pressure due to the internal contents. It is also applicable for tanks-vessels designed for vacuum service with differential pressure levels between 0 and 0.10 MPa [0 and 14.5 psi].

1.3 This practice is limited to tanks-vessels with glass contents greater than 15 % by weight.

1.4 This practice applies to examinations of new and in-service equipment.

1.5 *Units*—The values stated in either SI units or inch-pound units are to be regarded 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.* (For more specific safety precautionary information see 8.1.)

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

D883 Terminology Relating to Plastics

D5436 Specification for Cast Poly(Methyl Methacrylate) Plastic Rods, Tubes, and Shapes

E543 Specification for Agencies Performing Nondestructive Testing

E650 Guide for Mounting Piezoelectric Acoustic Emission Sensors

E750 Practice for Characterizing Acoustic Emission Instrumentation

E1316 Terminology for Nondestructive Examinations

E2075 Practice for Verifying the Consistency of AE-Sensor Response Using an Acrylic Rod

E2374 Guide for Acoustic Emission System Performance Verification

2.2 *ANSI/ASNT Standards:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification[3]

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel[3]

2.3 *AIA Standard:*

NAS-410 Certification and Qualification of Nondestructive Personnel (Quality Assurance Committee)[4]

## 3. Terminology

3.1 Complete definitions of terms related to plastics and acoustic emission will be found in Terminology D883 and E1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *FRP*—fiberglass reinforced plastic, a glass-fiber polymer composite with certain mechanical properties superior to those of the base resin.

3.2.2 *operating pressure*—the pressure at the top of a vessel at which it normally operates. It shall not exceed the design pressure and it is usually kept at a suitable level below the setting of the pressure-relieving devices to prevent their frequent opening.

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[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.

Current edition approved July 1, 2011. Published July 2011. Originally approved in 1985. Last previous edition approved in 2007 as E1067 - 07. DOI: 10.1520/E1067-11.

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

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

3.2.3 *pressure, design*—the pressure used in design to determine the required minimum thicknesses and minimum mechanical properties.

3.2.4 *processor*—a circuit that analyzes AE waveforms. (See Section 7 and A1.8.)

3.2.5 *summing amplifier (summer, mixer)*—an operational amplifier that produces an output signal equal to a weighted sum of the input signals.

3.2.6 *zone*—the area surrounding a sensor from which AE can be detected by that sensor.

## 4. Summary of Practice

4.1 This practice consists of subjecting equipment to increasing pressure or vacuum while monitoring with sensors that are sensitive to acoustic emission (transient stress waves) caused by growing flaws. The instrumentation and techniques for sensing and analyzing AE data are described.

4.2 This practice provides guidelines to determine the location and severity of structural flaws in FRP equipment.

4.3 This practice provides guidelines for AE examination of FRP equipment within the pressure range stated in 1.2. Maximum test pressure (or vacuum) for an FRP vessel will be determined upon agreement among user, manufacturer, or test agency, or a combination thereof. Pressure vessels will normally be tested to 1.1 × operating pressure. Atmospheric storage vessels and vacuum vessels will normally be tested under maximum operating conditions. Vessels will normally be tested at ambient temperature. In the case of elevated operating temperature the test may be performed either at operating or ambient temperature.

## 5. Significance and Use

5.1 The AE examination method detects damage in FRP equipment. The damage mechanisms that are detected in FRP are as follows: resin cracking, fiber debonding, fiber pullout, fiber breakage, delamination, and bond failure in assembled joints (for example, nozzles, manways, etc.). Flaws in unstressed areas and flaws that are structurally insignificant will not generate AE.

5.2 This practice is convenient for on-line use under operating stress to determine structural integrity of in-service equipment usually with minimal process disruption.

5.3 Indications located with AE should be examined by other techniques; for example, visual, ultrasound, dye penetrant, etc., and may be repaired and tested as appropriate. Repair procedure recommendations are outside the scope of this practice.

## 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:*

6.2.1 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, 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 *Procedures and Techniques*—The procedures and techniques to be utilized shall be as specified in the contractual agreement.

6.5 *Surface Preparation*—The pre-examination surface preparation criteria shall be in accordance with 9.2 unless otherwise specified.

6.6 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with Section 13 unless otherwise specified. Since acceptance criteria are not specified in this practice, they shall be specified in the contractual agreement.

## 7. Instrumentation

7.1 The AE instrumentation consists of sensors, signal processors, and recording equipment. Additional information on AE instrumentation can be found in Practice E750.

7.2 Instrumentation shall be capable of recording AE hits, signal strength and hit duration and have sufficient channels to localize AE sources in real time. It may incorporate (as an option) peak-amplitude detection for each input channel or for groups of channels. Hit detection is required for each channel. An AE hit amplitude measurement is recommended for sensitivity verification (see Annex A2). Amplitude distributions are recommended for flaw characterization. It is preferred that AE instrumentation acquire and record duration hit and amplitude information on a per channel basis. The AE instrumentation is further described in Annex A1.

7.3 Capability for measuring parameters such as time and pressure shall be provided. The pressure-vacuum in the vessel should be continuously monitored to an accuracy of ±2 % of the maximum test value.

7.4 *Lockouts and Guard Sensors*—These techniques shall not be used.

7.5 *Instrument Displays*—- The instrumentation shall be capable of providing the following real time displays:

7.5.1 *Bar Chart by Channel of Cumulative Signal Strength*—Enables the inspector to identify which channel is recording the most data.

7.5.2 *Amplitude per Hit Versus Time*—Provides the inspector with early warning of an impending failure.

7.5.3 *Duration per Hit Versus Time*—Useful for identifying rubbing or sliding.

7.5.4 *Log Duration (or Counts) per Hit Versus Amplitude per Hit*—Helps the inspector determine the presence of false emission signals

7.5.5 *Cumulative Signal Strength per Channel Versus Time*—Useful for identifying certain types of instrument malfunctions.

7.6 *Cumulative Amplitude Distribution,* or a tabular listing by channel number of total hits equal to and greater than defined amplitude values. Tabular amplitude values shall be in increments of not greater than 5 dB and shall be for at least a 35 dB range beginning at the threshold. These displays are used to provide warning of significant fiber breakage of the type that can lead to sudden structural failure. The displays also provide information about the micromechanisms giving rise to the emission and warn of potential instrument malfunction.

## 8. Examination Preparations

8.1 *Safety*—All plant safety requirements unique to the examination location shall be met.

8.1.1 Protective clothing and equipment that is normally required in the area in which the examination is being conducted shall be worn.

8.1.2 A fire permit may be needed to use the electronic instrumentation.

8.1.3 Precautions shall be taken to protect against the consequences of catastrophic failure when pressure testing, for example, flying debris and impact of escaping liquid. Pressurizing under pneumatic conditions is not recommended except when normal service loads include either a superposed gas pressure or gas pressure only. Care shall be taken to avoid overstressing the lower section of the vessel when liquid test loads are used to simulate operating gas pressures.

8.1.4 Special safety precautions shall be taken when pneumatic testing is required; for example, safety valves, etc.

8.2 *Vessel Conditioning*—The operating conditions for vessels that have been stressed previously shall be reduced prior to examining in accordance with the schedule shown in Table 1. The maximum operating pressure or load in the vessel during the past year must be known in order to conduct the AE examination properly.

8.3 *Vessel Stressing*—Arrangements should be made to stress the vessel to the operating pressure-load where possible. The stress rate shall be sufficient to expedite the examination with minimum extraneous noise. Holding stress levels is a key aspect of an acoustic emission examination. Accordingly, provision must be made for holding the pressure-load at designated check points.

8.3.1 *Atmospheric Tanks*—Process liquid is the preferred fill medium for atmospheric tanks. If water must replace the process liquid, the designer and user shall be in agreement on the procedure to achieve acceptable stress levels.

8.3.2 *Vacuum-Tank Stressing*—A controllable vacuum-pump system is required for vacuum tanks.

8.3.3 *Pressure-Vessel Stressing*—Water is the preferred medium for pressure tanks. Safe means for hydraulically increasing the pressure under controlled conditions shall be provided.

8.4 *Tank Support*—The tank shall be examined in its operating position and supported in a manner consistent with good installation practice. Flat-bottomed tanks examined in other than the intended location shall be mounted on a pad (for example, rubber on a concrete base or equivalent) to reduce structure-borne noise between the tank and base.

8.5 *Environmental*—The normal minimum acceptable vessel wall temperature is 4°C [40°F].

8.6 *Noise Reduction*—Noise sources in the examination frequency and amplitude range, such as rain, spargers, and foreign objects contacting the tank, must be minimized since they mask the AE signals emanating from the structure. The inlet should be at the lowest nozzle or as near to the bottom of the vessel as possible, that is, below the liquid level. Liquid falling, swirling, or splashing can invalidate data obtained during the filling phase.

8.7 *Power Supply*—A stable grounded power supply, meeting the specification of the instrumentation, is required at the examination site.

8.8 *Instrumentation Settings*—Settings will be determined as described in Annex A2.

## 9. Sensors

9.1 *Sensor Mounting*—Refer to Practice E650 for additional information on sensor mounting. Location and spacing of the sensors are discussed in 9.3. Sensors shall be placed in designated locations with a couplant between the sensor and examination article. One recommended couplant is silicone-stopcock grease. Care must be exercised to assure that adequate couplant is applied. Sensors shall be held in place utilizing methods of attachment which do not create extraneous signals. Methods of attachment using crossed strips of pressure-sensitive tape or suitable adhesive systems, may be considered. Suitable adhesive systems are those whose bonding and acoustic coupling effectiveness have been demonstrated. The attachment method should provide support for the signal cable (and preamplifier) to prevent the cable(s) from stressing the sensor or pulling the sensor away from the examination article causing loss of coupling.

9.2 *Surface Contact*—Reliable coupling between the sensor and tank surface shall be assured and the surface of the vessel in contact with the sensor shall be clean and free of particulate matter. Sensors should be mounted directly on the tank surface unless integral waveguides shown by test to be satisfactory are used. Preparation of the contact surface shall be compatible with both sensor and structure modification requirements. Possible causes of signal loss are coatings such as paint and encapsulants, surface curvature, and surface roughness at the contact area.

**TABLE 1 Requirements for Reduced Operating Pressure-Load Immediately Prior to Examining**

| % of Operating Pressure or Load, or Both | Time at Reduced Pressure or Load, or Both |
|---|---|
| 10 or less | 12 h |
| 20 | 18 h |
| 30 | 30 h |
| 40 | 2 days |
| 50 | 4 days |
| 60 | 7 days |

9.3 *Locations and Spacings*—Locations on the vessel shell are determined by the need to detect structural flaws at critical sections; for example, high-stress areas, geometric discontinuities, nozzles, manways, repaired regions, support rings, and visible flaws. Spacings are governed by the attenuation of the FRP material.

9.3.1 *Attenuation Characterization*—Typical signal propagation losses shall be determined in accordance with the following procedure. This procedure provides a relative measure of the attenuation, but may not be representative of genuine AE activity. It should be noted that the peak amplitude from a mechanical pencil lead break may vary with surface hardness, resin condition, and cure. The attenuation characterization should be made above the liquid line.

9.3.1.1 Select a representative region of the vessel away from manways, nozzles, etc. Mount an AE sensor and locate points at distances of 150 mm [6 in.] and 300 mm [12 in.] from the center of the sensor along a line parallel to one of the principal directions of the surface fiber (if applicable). Select two additional points on the surface of the vessel at 150 mm [6 in.] and 300 mm [12 in.] along a line inclined 45° to the direction of the original points. At each of the four points, break 0.3 mm 2H leads[5] and record peak amplitude. All lead breaks shall be done at an angle of approximately 30° to the surface with a 2.5 mm [0.1 in.] lead extension. The data shall be retained as part of the original experimental record.

9.3.2 *Sensor Spacings*—The recommended sensor spacing on the vessel shall not be greater than 3 × the distance at which detected signals from the attenuation characterization equal the threshold setting.

9.3.3 *Sensor Location*—Sensor location guidelines for the following tank types are given in the Annex. Other tank types require an agreement among the owner, manufacturer, or examination agency, or combinations thereof.

9.3.3.1 *Case I: Atmospheric Vertical Tank*—flat bottom, flanged and dished head, typical nozzle and manway configuration, cylindrical shell fabricated in two sections with secondary bond-butt joint, dip pipe.

9.3.3.2 *Case II: Atmospheric Vertical Tank*—flat bottom, 2:1 elliptical head, typical nozzle and manway configuration, agitator with baffles, cylindrical shell fabricated in one section.

9.3.3.3 *Case III: Atmospheric-Pressure Vertical Tank*—flanged and dished heads top and bottom, typical nozzle and manway configuration, packing support, legs attached to cylindrical shell, cylindrical shell fabricated in one section.

9.3.3.4 *Case IV: Atmospheric-Pressure Vertical Tank*—cone bottom, 2:1 elliptical head, typical nozzle and manway configuration, cylindrical shell fabricated in two sections, body flange, dip pipe, support ring.

9.3.3.5 *Case V: Atmospheric-Vacuum Vertical Tank*—flanged and dished heads top and bottom, typical nozzle and manway configuration, packing support, stiffening ribs, support ring, cylindrical shell fabricated in two sections with secondary bond-butt joint.

9.3.3.6 *Case VI: Atmospheric-Pressure Horizontal Tank*—flanged and dished heads, typical nozzle and manway configuration, cylindrical shell fabricated in two sections with secondary bond-butt joint, saddle supports.

## 10. Instrumentation System Performance Check

10.1 *Sensor Coupling and Circuit Continuity Verification*—Verification shall be performed following sensor mounting and system setup. The response of each sensor-preamplifier combination to a repeatable simulated acoustic emission source should be recorded and evaluated prior to the examination (see Guide E2374).

10.1.1 The peak amplitude of the simulated event at a specific distance from each sensor should not vary more than 6 dB from the average of all the sensors. Any sensor-preamplifier combination failing this check should be investigated and replaced or repaired as necessary.

10.2 *Background Noise Check*—A background noise check is recommended to identify and determine the level of spurious signals. This is done following the completion of the verification described in 10.1 and prior to stressing the vessel. A recommended time period is 20 minutes.

## 11. Examination Procedure

11.1 *General Guidelines*—The tank-vessel is subjected to programmed increasing pressure-load levels to a predetermined maximum while being monitored by sensors that detect acoustic emission (stress waves) caused by growing structural flaws.

11.1.1 Fill and pressurization rates shall be controlled so as not to exceed a strain rate of 0.005 %/min based on calculated values or actual strain gage measurements of principal strains. Normally, the desired pressure will be attained with a liquid (see 8.1.3 and 8.1.4). Pressurization with a gas (air, $N_2$ etc.) is not recommended. A suitable manometer or other type gage shall be used to monitor pressure.

11.1.2 Vacuum should be attained with a suitable vacuum source. A quick release valve shall be provided to handle any imminent catastrophic failure condition.

11.1.3 Background noise shall be minimized and identified (see also 8.6). Excessive background noise is cause for suspension of the pressurization. In the analysis of examination results, background noise should be properly discounted. Sources of background noise include the following: liquid splashing into a tank, a fill rate that is too high, pumps, motors, agitators and other mechanical devices, electromagnetic interference, and environmental factors, such as rain, wind, etc.

11.2 *Loading*—Atmospheric tanks that operate with liquid head and pressures of 0.2 MPa [30 psia] or less, and vacuum vessels that operate at pressures below atmospheric, shall be loaded in a series of steps. Recommended load procedures are shown in Fig. 1 and Fig. 2. The algorithm flow chart for this class of tanks is given in Fig. 3.

11.2.1 For tanks that have been stressed previously, the examination can begin with the liquid level as high as 60 % of the operating or maximum test level (see 8.2). Fig. 1 should be modified for vessels that are partially full at the beginning of an examination. The background noise baseline determination is important for this class of examination and should be provided

[5] Pentel 0.3-mm (2H) lead or its equivalent has been found satisfactory for this purpose.

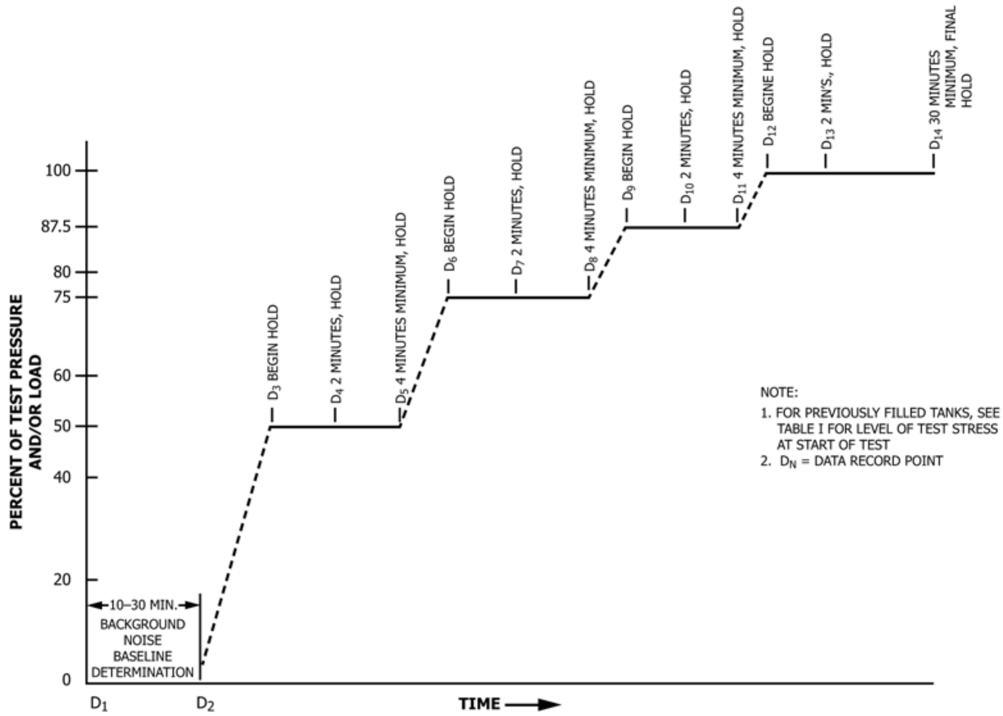



FIG. 1 Atmospheric Tank Examination, Stressing Sequence

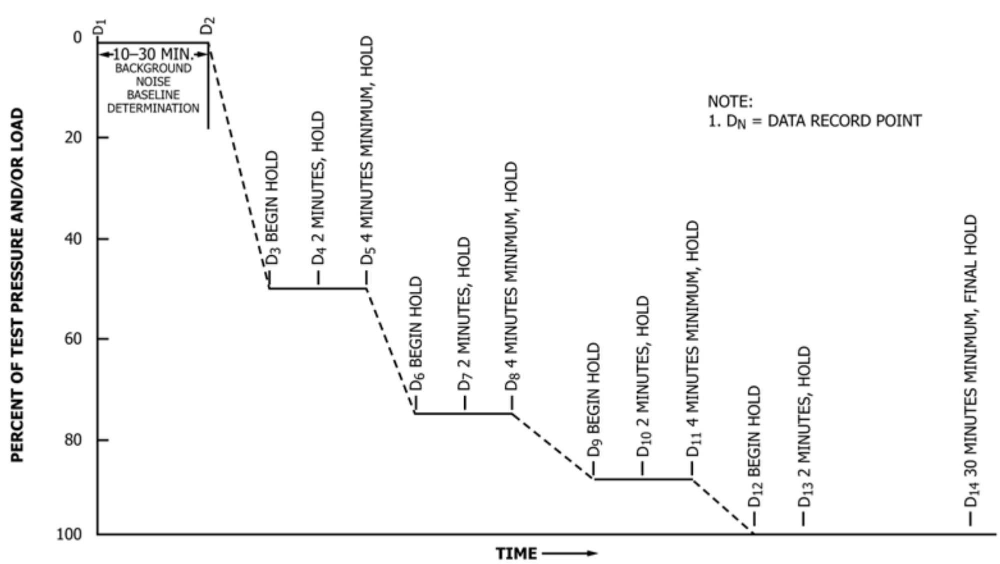



FIG. 2 Vacuum Tank Examination, Stressing Sequence

for. Many vessels operate with liquid contents and partial vacuum; however, vacuum vessels are normally examined empty.

11.2.2 Pressure vessels that operate with superimposed pressures greater than 0.2 MPa [30 psia] shall be loaded as shown in Fig. 4. The algorithm flow chart for this class of tanks is given in Fig. 5.

11.2.3 The initial hold period is used to determine a baseline of the background noise. This data provides an estimate of the total background noise contribution during the examination. Background noise shall be discounted in the final data analysis.

11.2.4 Intermittent load holds shall be for 4 min. As shown in Fig. 4, pressure vessels shall be loaded in steps up to 30 % of the maximum test pressure. Thereafter, the pressure shall be

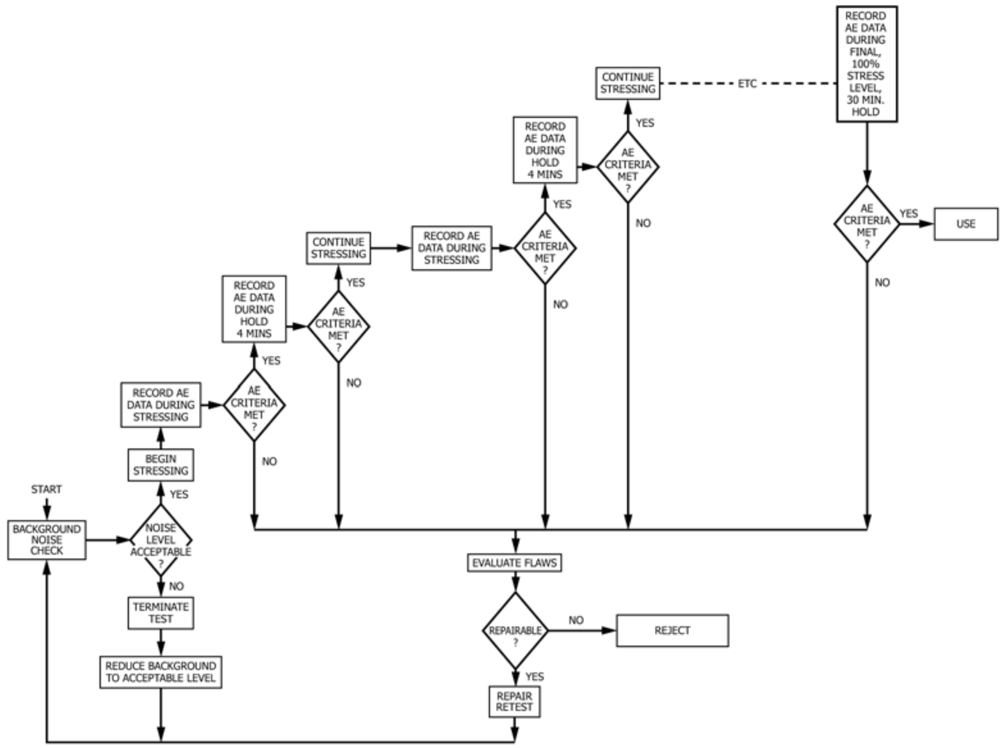



FIG. 3 AE Examination Algorithm—Flow Chart Atmospheric-Vacuum Tanks (See Fig. 1 and Fig. 2.)

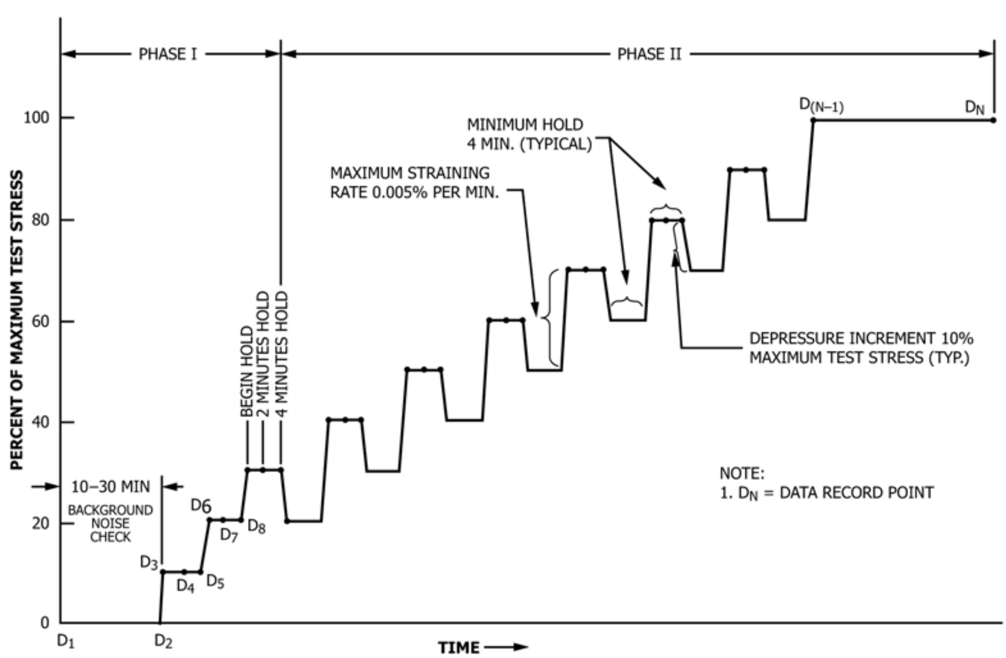



FIG. 4 Pressure Tank Examination, Stressing Sequence

decreased by 10 % of the maximum test pressure before proceeding to the next hold level. Following a decrease in pressure, the load shall be held for 4 min before reloading.

11.2.5 For all vessels, the final load hold shall be for 30 min. The vessel should be monitored continuously during this period.

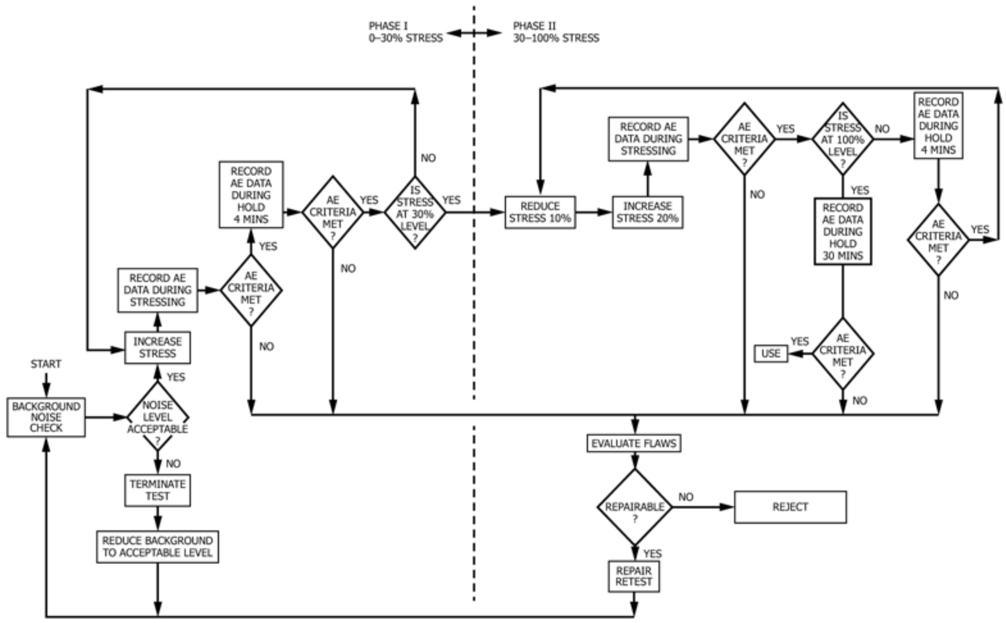



**FIG. 5 AE Examination Algorithm—Flow Chart Pressure Tanks (See Fig. 4.)**

11.3 *Felicity Ratio Determination*—The Felicity ratio is not measured during the first loading of atmospheric tanks and vacuum vessels. The Felicity ratio is obtained directly from the ratio of the stress at the emission source at onset of significant emission and the maximum prior stress at the same point.

11.3.1 The Felicity ratio is measured from the unload-reload cycles during the first loading of pressure vessels. For subsequent loadings, the Felicity ratio is obtained directly from the ratio of the stress at the emission source at onset of emission and the previous maximum stress at the same point. A secondary Felicity ratio is determined from the unload-reload cycles.

11.4 *Data Recording*—Prior to an examination, the signal propagation loss (attenuation) data, that is, amplitude as a function of distance from the signal source, shall be recorded in accordance with the procedure detailed in 9.3.

11.4.1 The number of hits from all channels whose amplitude exceeds the threshold setting shall be recorded. Channels that are active during load holds should be noted.

## 12. Interpretation of Results

12.1 *Examination Termination*—The real-time instrument displays shall be continuously monitored during the test. If any of these displays indicate approaching failure, the vessel shall be unloaded and the test terminated. If the inspector judges background noise to be excessive during the test, the test shall be terminated. "Excessive" background noise is a matter of judgment based on experience.

12.2 *Significance of Data:*

12.2.1 Evaluation based on emissions during load hold is particularly significant. Continuing emissions indicate continuing damage. Fill and other background noise will generally be at a minimum during a load hold. Continuing emission during hold periods is a condition on which acceptance criteria may be based.

12.2.2 Evaluation based on Felicity ratio is important for in-service vessels. The Felicity ratio provides a measure of the severity of previously induced damage. The onset of "significant" emission for determining measurement of the Felicity ratio is a matter of experience. The following are offered as guidelines to determine if emission is significant:

12.2.2.1 More than five bursts of emission during a 10 % increase in load.

12.2.2.2 More than $N_d/2$ duration during a 10 % increase in load, where $N_d$ is the total duration value defined in Annex A2.

12.2.2.3 Emission continues at a load hold. For purposes of this guideline, a short (1 min or less) nonprogrammed load hold can be inserted in the procedure.

12.2.2.4 Felicity ratio is a condition on which acceptance criteria may be based.

12.2.3 Evaluation based on high-amplitude events is important for new vessels. These events are often associated with fiber breakage and are indicative of major structural damage. This condition is less likely to govern for in-service and previously loaded vessels where emissions during a load hold and Felicity ratio are more important. High-amplitude events is a condition on which acceptance criteria may be based.

12.2.4 Evaluation based on total duration is valuable for atmospheric and vacuum tanks. Pressure vessels, particularly on first loading, tend to be noisy and therefore evaluation for pressure vessels is based on reloading only. Total duration is a condition on which acceptance criteria may be based.

12.2.5 Indications located with AE should be examined by other techniques; for example, visual, ultrasonics, dye penetrant, etc.

## 13. Report

13.1 The report shall include the following:

13.1.1 Complete identification of equipment, including material type, source, method of fabrication, manufacturer's name and code number, date and pressure-load of previous tests, and previous history.

13.1.2 Equipment sketch or manufacturer's drawing with dimensions of equipment and sensor location.

13.1.3 Test liquid employed.

13.1.4 Test liquid temperature.

13.1.5 *Test Sequence*—filling rate, hold times, and hold levels.

13.1.6 Comparison of examination data with specified acceptance criteria.

13.1.7 Show on sketch or manufacturer's drawing the location of any suspect areas found that require further evaluation.

13.1.8 Any unusual effects or observations during or prior to the examination.

13.1.9 Dates of examination.

13.1.10 Name(s) of examiner(s).

13.1.11 *Instrumentation Description*—complete description of AE instrumentation including manufacturer's name, model number, sensor type, system gain, serial numbers or equivalent, software title and version number, etc.

13.1.12 *Permanent Record of AE Data,* for example, AE hits versus time for zones of interest, total duration above the threshold setting versus time, emissions during load holds, and signal propagation loss.

## 14. Keywords

14.1 felicity effect; felicity ratio; fiber debonding; fiber pullout; resin cracking; source characterization; source location

# ANNEXES

**(Mandatory Information)**

## A1. INSTRUMENTATION PERFORMANCE REQUIREMENTS

A1.1 *AE Sensors:*

A1.1.1 *General*—AE sensors shall be temperature-stable over the range of use which may be 4° to 93°C [40° to 200° F], and shall not exhibit sensitivity changes greater than 3 dB over this range. Sensors shall be shielded against radio frequency and electromagnetic noise interference through proper shielding practice or differential (anticoincident) element design, or both. Sensors shall have omnidirectional response in the plane of contact with variations not exceeding 4 dB from the peak response.

A1.1.2 *Sensors*—Sensors shall have a resonant response between 100 and 200 kHz. Minimum sensitivity shall be −80 dB referred to 1 volt per microbar, determined by face-to-face ultrasonic test.

NOTE A1.1—This method measures approximate sensitivity of the sensor. AE sensors used in the same examination should not vary in peak sensitivity more than 3 dB from the average.

A1.2 *Signal Cable*—The signal cable from sensor to preamp shall not exceed a length that will cause more than 3 dB of signal loss (typically 2 m [6 ft]) and shall be shielded against electromagnetic interference. This requirement is omitted where the preamplifier is mounted in the sensor housing, or a line-driving (matched impedance) sensor is used.

A1.3 *Couplant*—Commercially available couplants for ultrasonic flaw detection may be used. Frangible wax or quick-setting adhesives may be used, provided couplant sensitivity is not significantly lower than with fluid couplants. Couplant selection should be made to minimize change in coupling sensitivity during an examination. Consideration should be given to testing time and the surface temperature of the vessel.

A1.4 *Preamplifier*—The preamplifier should be mounted in the vicinity of the sensor, or may be in the sensor housing. If the preamplifier is of differential design, a minimum of 40 dB of common-mode noise rejection shall be provided. The preamplifier bandpass shall be consistent with the frequency range of the sensor and shall not attenuate the resonant frequency of the sensor.

A1.5 *Filters*—Filters shall be of the band pass type, and shall provide a minimum of 24 dB per octave signal attenuation. Filters may be located in preamplifier or post-preamplifier circuits, or may be integrated into the component design of the sensor, preamplifier, or processor to limit frequency response. Filters or integral design characteristics, or both, shall ensure that the principal processing frequency is between 100 and 200 kHz.

A1.6 *Power-Signal Cable*—The cable providing power to the preamplifier and conducting the amplified signal to the main processor shall be shielded against electromagnetic noise. Signal loss shall be less than 1 dB/30 m [100 ft] of cable length at 150 kHz. The recommended maximum cable length to avoid excessive signal attenuation is 150 m [500 ft]. Digital or radio transmission of signals is allowed consistent with practice in transmitting those signal forms.

A1.7 *Main Amplifier*—The main amplifier, if used, shall have signal response with variations not exceeding 3 dB over the frequency range of 25 to 200 kHz, and temperature range of 4 to 52°C [40 to 125°F]. The main amplifier shall have adjustable gain, or an adjustable threshold for hit detection and counting.

A1.8 *Main Processor:*

A1.8.1 *General*—The main processor(s) shall be capable of processing hits, peak amplitude, signal strength, and duration on each channel.

A1.8.2 *Peak-Amplitude Detection*—Comparative calibration must be established in accordance with the requirements of Annex A2. Usable dynamic range shall be a minimum of 60 dB with 2 dB resolution. Not more than 2-dB variation in peak-detection accuracy shall be allowed over the stated temperature range. Amplitude values may be stated in volts or dB, but must be referenced to a fixed gain output of the system (sensor or preamplifier).

A1.8.3 *Signal Outputs and Recording*—The processor as a minimum shall provide outputs for permanent recording of duration, amplitude, signal strength, and hits above the threshold setting by channel (zone location) and hits. A sample system schematic is shown in Fig. A1.1.

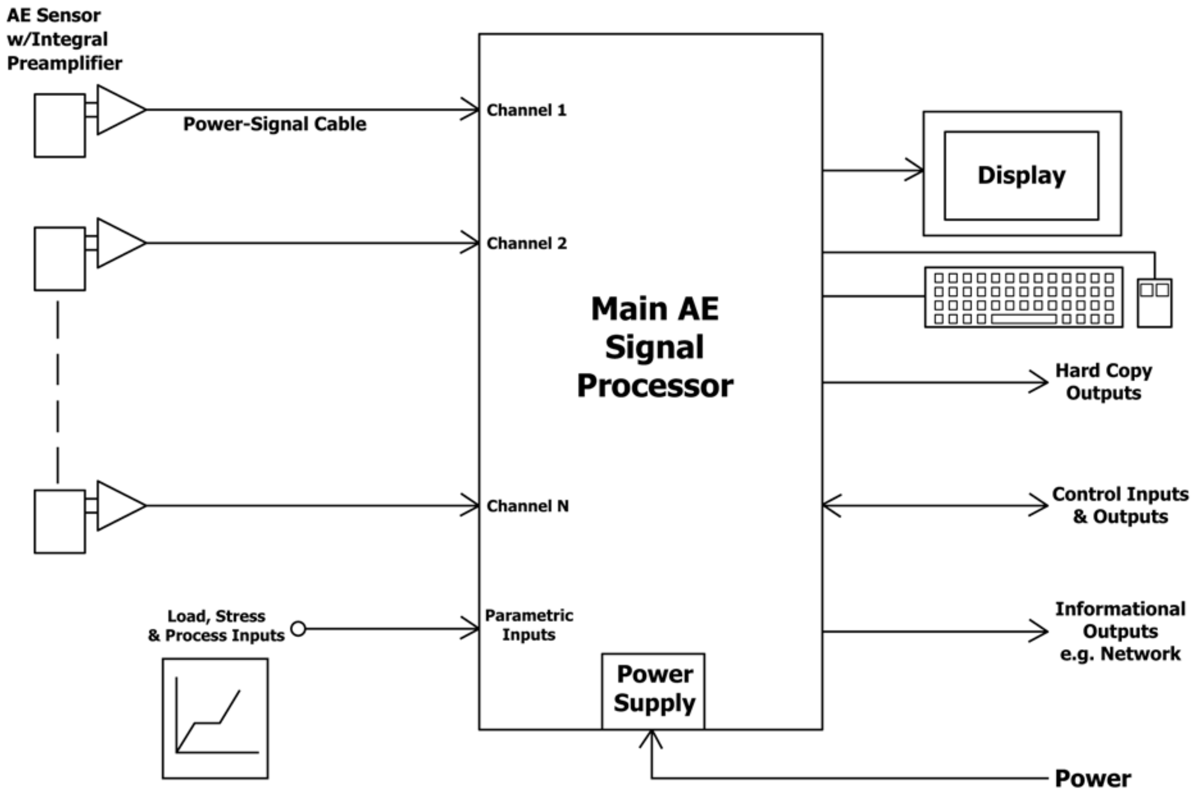



FIG. A1.1 Sample Schematic of AE Instrumentation for Vessel Testing

## A2. INSTRUMENT SETTINGS

A2.1 *General*—The performance and threshold definitions vary for different types of acoustic emission instrumentation. Parameters such as signal strength and amplitude may vary from manufacturer to manufacturer and from model to model by the same manufacturer. This annex describes techniques for generating common baseline levels for the different types of instrumentation. Through the use of these procedures the test sensitivity can be effectively the same regardless of instrumentation manufacturer or equipment nomenclature.

A2.1.1 The procedures described in A2.2 and A2.3 should be performed at a temperature of 15 to 27°C [60 to 80°F]. It is intended that this be a one-time determination of threshold values for data acquisition, or evaluation, or both. For field use, a portable acrylic rod (see Practice E2075) can be carried with the equipment and used for periodic checking of sensor, preamplifier, and channel sensitivity.

A2.2 *Threshold of Detectability (aka Detection Threshold)*—To determine the detection threshold for AE examinations on fiberglass vessels, a sensor of the applicable type is mounted on one end of a 788 mm [31 in.] long, 38.1 mm [1.5 in.] diameter rod of cast acrylic material conforming to Specification D5436. Rod setup and sensor mounting shall be as specified in Practice E2075 (however the reference marks specified in Practice E2075 will not be used in this application). The detection threshold is 12 dB lower than the average measured amplitude of ten hits generated by a 0.3 mm [0.012 in.] Pentel pencil (2H) lead break at a distance of 610 mm [24 in.] from the sensor. All lead breaks shall be done at an angle of approximately 30° to the surface with a 2.5 mm [0.1 in.] lead extension. This determination may be repeated with additional sensors, remounts as appropriate to confirm its reliability.

A2.3 *Reference Amplitude Threshold*—For large amplitude hits, the reference amplitude threshold shall be determined using a 300 by 5 by 2 cm [118 by 2 in. by 0.8 in.] clean, mild steel bar. The bar shall be supported at each end on elastomeric, or similar, isolating pads. The reference amplitude threshold is defined as the average measured amplitude of ten hits generated by a 0.3 mm [0.012 in.] Pentel pencil (2H) lead break at a distance of 210 cm [83 in.] from the sensor. All lead breaks shall be done at an angle of approximately 30° to the surface with a 2.5 mm [0.1 in.] lead extension. The sensor shall be mounted 30 cm [12 in.] from the end of the bar on the 5 cm [2 in.] wide surface.

A2.4 *Typical Attenuation*—Table A2.1 shows signal amplitude values for various distances along a cast acrylic rod of the kind described in A2.2 and Practice E2075. These are values for a sensor containing a piezoelectric crystal often used for

**TABLE A2.1 Decibel Calibration Values**

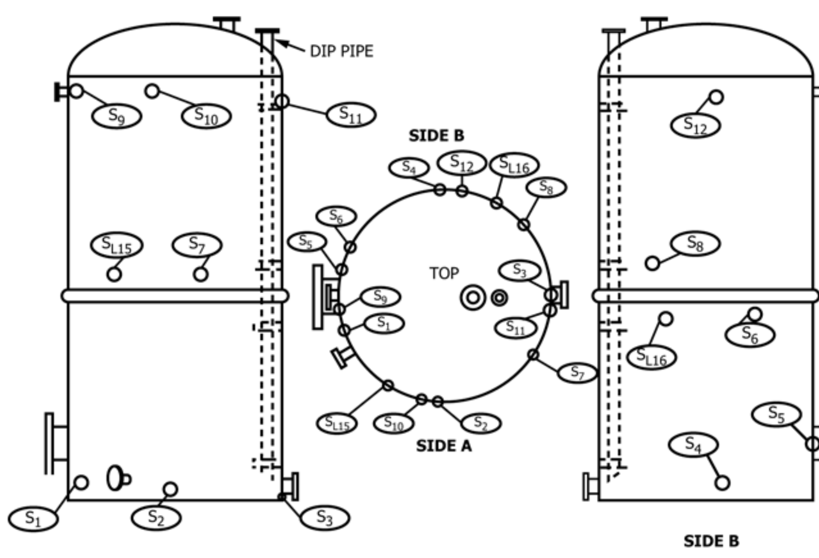
| Distance of Pentel Break from Sensor | Typical Decibel Value |
|---|---|
| 100 mm [4 in.] | 82.5 |
| 150 mm [6 in.] | 80.5 |
| 300 mm [12 in.] | 73.5 |
| 450 mm [18 in.] | 66.5 |
| 600 mm [24 in.] | 60.0 |

this kind of test. The decibel numbers in Table A2.1 are $dB_{AE}$ as defined in Terminology E1316. The numbers in this table are indicative of what may be expected when using the cast acrylic rod in accordance with A2.2, but these numbers shall not be taken as a substitute for performing the procedure.

A2.5 *Duration Criterion $N_D$—The Duration Criterion $N_D$ shall be determined either before or after the examination using a 0.3 mm [0.012 in.] Pentel pencil (2H) lead broken on the surface of the vessel. This determination is made separately on each vessel examined. All lead breaks shall be done at an angle of approximately 30° to the test surface with a 2.5 mm [0.1 in.] lead extension. Measurement points shall be chosen so as to be representative of different constructions and thicknesses and should be performed above and below the liquid (if applicable) and away from manways, nozzles, etc. A sensor shall be mounted at each measurement point and two measurements shall be carried out at each location. One measurement shall be in the principal direction of the surface fibers (if applicable), and the second calibration shall be carried out along a line 45° to the direction of the first measurement. Lead breaks shall be at a distance from the measurement point so as to provide an amplitude decibel value Am midway between the threshold of detectability and the Reference Amplitude Threshold. The Duration Criterion at each measurement point is defined as one hundred and thirty times the average duration per lead break from ten 0.3 mm [0.012 in.] Pentel pencil (2H) lead breaks at each of the two lead break locations. When applying the Duration Criterion, the value which is representative of the region where activity is observed should be used.*

## A3. SENSOR PLACEMENT GUIDELINES

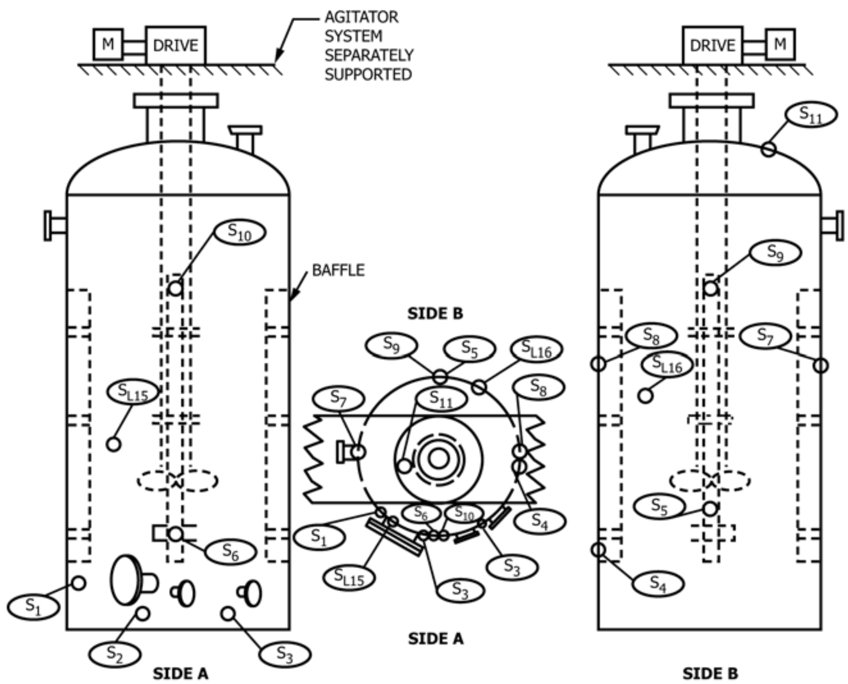
See Figs. A3.1-A3.6.




NOTE 1—The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, for example, approximately every 90° and 150 to 300 mm [6 to 12 in.] away from knuckle on shell.

NOTE 2—The secondary bond joint areas are suspect, for example, nozzles, manways, shell-butt joint, etc. For nozzles and manways, the preferred sensor location is 75 to 150 mm [3 to 6 in.] from intersection with shell and below. The shell-butt joint region is important. Locate the two high-frequency sensors up to 180° apart—one above and one below the joint.

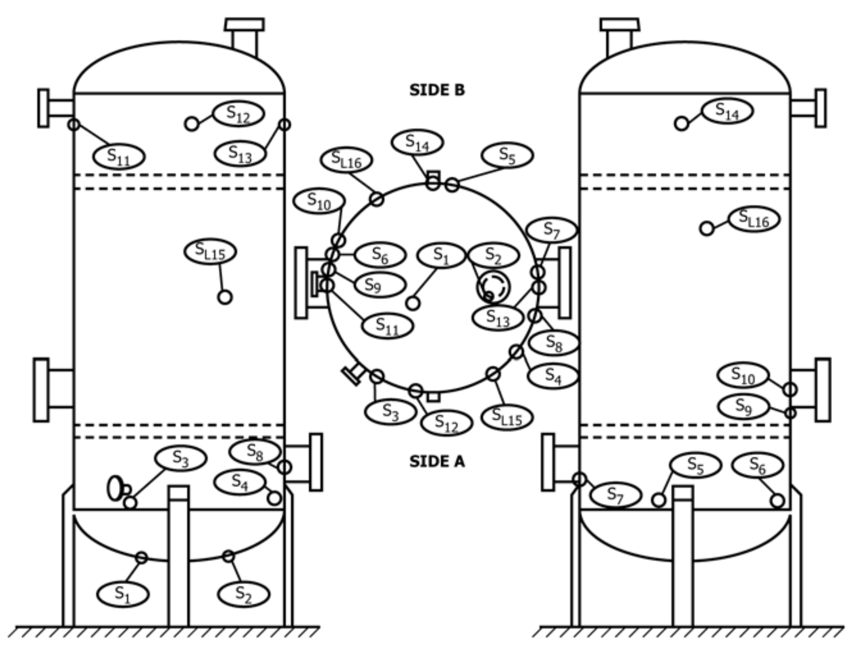
**FIG. A3.1 Case I—Atmospheric Vertical Tank**




NOTE 1—The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, for example, approximately every 90° and 150 to 300 mm [6 to 12 in.] away from knuckle on shell. In this example, sensors are so placed that the bottom nozzles, manways, and baffle areas plus the knuckle region are covered.

NOTE 2—The secondary bond joint areas are suspect, for example, nozzles, manways, and baffle attachments to shell. See the last sentence of one above for bottom region coverage in this example. Note sensor adjacent to agitator shaft-top manway. This region should be checked with agitator on.

**FIG. A3.2 Case II—Atmospheric Vertical Tank**

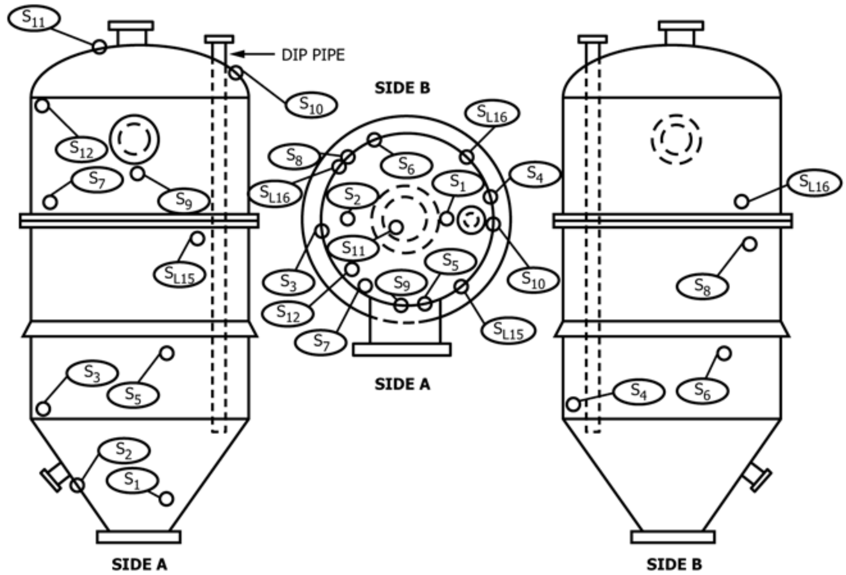



NOTE 1—The bottom head is highly stressed. Locate two sensors approximately as shown.

NOTE 2—The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, for example, approximately every 90° and 150 to 300 mm [6 to 12 in.] away from knuckle on shell. The top knuckle region is similarly treated.

NOTE 3—The secondary bond areas are suspect, that is, nozzles, manways, and leg attachments. For nozzles and manways, the preferred sensor location is 75 to 150 mm [3 to 6 in.] from the intersection with shell and below. For leg attachments, therefore should be a sensor within 300 mm [12 in.] of the shell-leg interface.

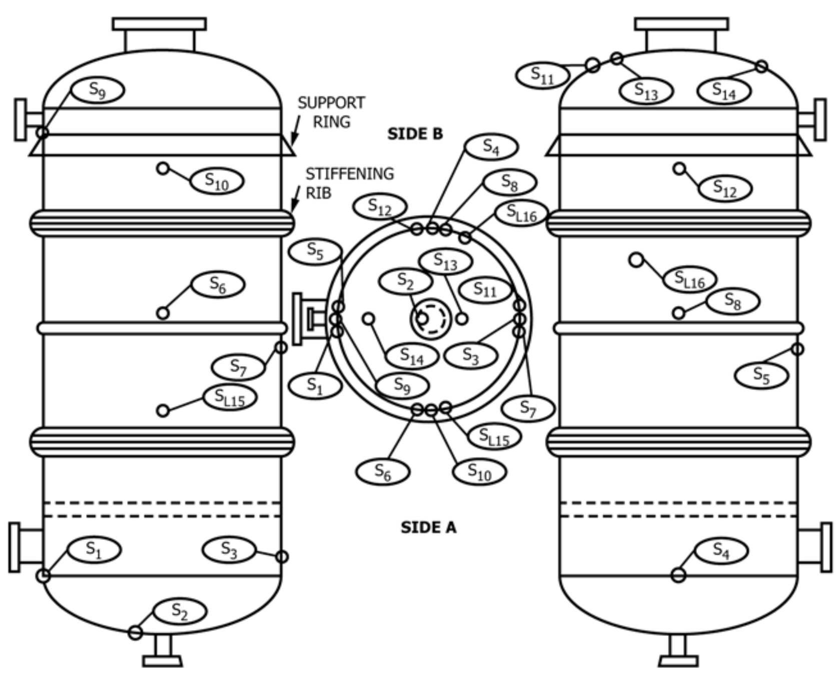
**FIG. A3.3 Case III—Atmospheric-Pressure Vessel Tank**




Note 1—The secondary bond-joint areas are suspect, that is, nozzles, manways, and body flanges. Particularly critical in this tank are the bottom manway and nozzle. For nozzles and manways, the preferred sensor location is 75 to 150 mm [3 to 6 in.] from intersection with shell and below. The bottom flange in this example is covered by a sensor 75 to 150 mm [3 to 6 in.] above the manway.

Note 2—The knuckle regions are suspect due to discontinuity stresses. Locate sensors to provide adequate coverage, that is, approximately every 90° and 75 to 150 mm [6 to 12 in.] away from knuckle on shell.

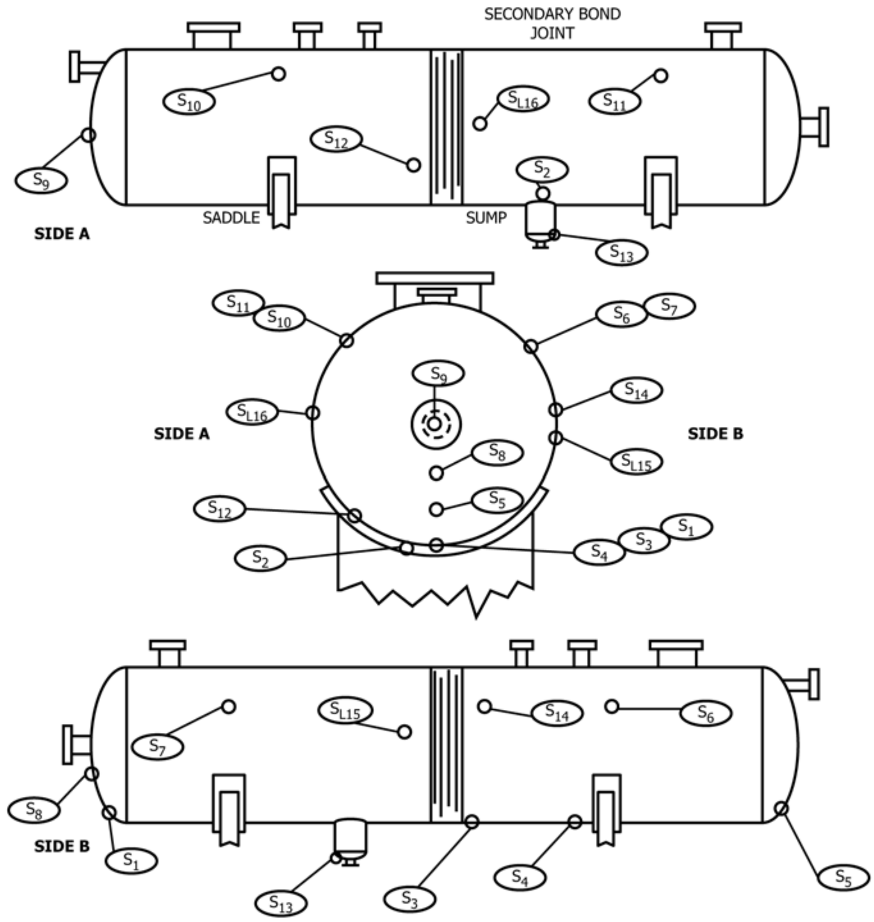
**FIG. A3.4 Case IV—Atmospheric-Pressure Vertical Tank**




Note 1—The knuckle regions are suspect due to discontinuity stresses. Locate sensors to provide adequate coverage, that is, approximately every 90° and 150 to 300 mm [6 to 12 in.] away from knuckle on shell.

Note 2—The secondary bond-joint areas are critical, for example, nozzles, manways, and shell-butt joint. For nozzles and manways, the preferred sensor location is 75 to 150 mm [3 to 6 in.] from the intersection with the shell (or head) and below, where possible. The shell butt joint region is important. Locate sensors up to 180° apart where possible and alternately above and below joint.

**FIG. A3.5 Case V—Atmospheric-Vacuum Vertical Tank**




NOTE 1—The discontinuity stresses at the intersection of the heads and the shell in the bottom region are important. Sensors should be located to detect structural problems in these areas.

NOTE 2—The secondary bond-joint areas are suspect, for example, shell-butt joint, nozzles, manways, and sump. The preferred sensor location is 75 to 150 mm [3 to 6 in.] from intersecting surfaces of revolution. The shell butt-joint region is important. Locate the two high-frequency sensors up to 180° apart—one on either side of the joint.

**FIG. A3.6 Case VI—Atmospheric-Pressure Horizontal Tank**

## APPENDIX

**(Nonmandatory Information)**

### X1. RATIONALE

X1.1 This practice was rewritten from the "Recommended Practice for Acoustic Emission Testing of Fiberglass Tanks/Vessels," which was developed by the Committee on Acoustic Emission from Reinforced Plastics (CARP) and published by the Reinforced/Composites Institute of the Society of the Plastics Industry (SPI).

X1.2 The CARP Recommended Practice has been used successfully on numerous applications.

X1.3 Criteria for evaluating the condition of FRP tanks and the need for secondary inspection were established while working with AE equipment, characteristics, and setup conditions listed in Table X1.1.

X1.4 Acceptance criteria are found in Table X1.2.

**TABLE X1.1 Acoustic Emission Equipment, Characteristics, and Setup Conditions**

| | |
|---|---|
| Sensors | –77 dBV ref. 1V/ubar, at approximately 150 kHz |
| Couplant | silicone grease |
| Preamplifier gain | 40 dB (X100) |
| Preamplifier filter | 100 to 300 kHz bandpass |
| Power/signal cable length | <150 m [500 ft] |
| Low-amplitude threshold | 46 $dB_{AE}$ |
| High-amplitude threshold | 76 $dB_{AE}$ |
| Signal processor filter | 100 to 300 kHz bandpass |
| Dead time | 10 ms |
| Background noise | <40 $dB_{AE}$ |
| Sensitivity check | >80 $dB_{AE}$ |

**TABLE X1.2 Acceptance Criteria**

NOTE 1—An acceptable vessel must meet all of the following criteria. Underlined criteria carry the greatest weight. Background noise must be properly discounted when applying acceptance criteria.

| | Tanks (internal pressure no greater than 0.1 MPa absolute [14.5 psia] above the static pressure due to internal contents, or vacuum with differential pressure no greater than 0.1 MPa [14.5 psi]) | | Pressure Vessels (internal pressure no greater than 1.73 MPa absolute [250 psia] above the static pressure due to internal contents)$^A$ | Significance of Criterion |
|---|---|---|---|---|
| | First Filling | Subsequent Fillings | Subsequent Loadings | |
| Emissions during hold | No hits having an amplitude greater than $A_m$ beyond 2 min$^B$ | None beyond 2 min | None beyond 2 min | Measure of continuing permanent damage$^C$ |
| Felicity ratio | Not applicable | Greater than 0.95 | Greater than 0.95 | Measure of severity of previously induced damage |
| Cumulative Duration, $N_D$$^D$ | Less than $N_D$ | Less than $N_D/2$ | Less than $N_D/2$ | Measure of overall damage during a load cycle |
| High amplitude hits | Less than 5 | None | Less than 5 | Measure of high energy microstructural failures. This criterion is often associated with fiber breakage. |

$^A$ Above the static pressure due to the internal contents.
$^B$Decibel value $A_m$ as defined in A2.5.
$^C$ Permanent damage may include microcracking, debonding, and fiber pull-out.
$^D$ Varies with instrumentation manufacturer. See A2.5 for functional definition of $N_D$.

## SUMMARY OF CHANGES

Committee E07 has identified the location of selected changes to this standard since the last issue (E1067 - 07) that may impact the use of this standard. (July 1, 2011)

*(1)* Changed 1.5 to reflect the change to a combined standard.
*(2)* Added Practice E2075 as a reference in 2.1.
*(3)* Removed *count value* $N_c$, *high amplitude threshold*, and *low amplitude threshold* from Section 3 and renumbered subsequent subsections appropriately.
*(4)* Updated instrument requirements in Section 7 in terms more current with AE instruments, as noted in changes of 7.2, and added 7.4, 7.5, and 7.6.
*(5)* Removed the need for "High Frequency Sensors" and "Low Frequency Sensors" from Section 9, subsections 9.3 and 9.4 and elsewhere in the document.
*(6)* Deleted 9.5.1.2 and 10.1.2 since all current AE instruments have amplitude analysis.
*(7)* Deleted 9.5.1.3 since high and low amplitude thresholds are no longer specified.
*(8)* Deleted parts of 11.4.1 that specified counts and low and high amplitude thresholds and low and high frequency channels.
*(9)* Rewrote 12.1 which describes examination termination using current AE instruments.
*(10)* Removed high and low amplitude thresholds in old subsection 13.1.12.

*(11)* Removed High Frequency sensor reference in A1.1.2.
*(12)* Removed subsection A1.1.3 to remove Low Frequency sensors from the standard.
*(13)* Removed low and high frequency sensor discussion from A1.5.
*(14)* Removed parts of the A1.8.1 dealing with low and high frequency channels.
*(15)* Removed subsection A1.8.1.1 since this is not used in current AE instrumentation.
*(16)* Removed subsection A1.8.1.2 as low and high frequency channels are used in this examination.
*(17)* Modified paragraph to reflect the use of current day AE instruments.
*(18)* Replaced Fig. A1.1 with current AE system block diagram.
*(19)* Each section in Annex A2 has been replaced with a new paragraph reflecting the use of current AE instruments, the new procedure that eliminates a hazardous lead sheet to establish common baseline levels, and the new examination procedure based on duration criterion.
*(20)* An attenuation versus distance reference table has been added as Table A2.1.
*(21)* Note 3 has been removed from Fig. A3.1, Fig. A3.2, Fig. A3.5, and Fig. A3.6.
*(22)* Note 4 has been removed from Fig. A3.3,
*(23)* The last sentence in Note 1 of Fig. A3.4 has been removed.