



Standard Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels¹

This standard is issued under the fixed designation E 1067; 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 0.44 MPa absolute (65 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 0.06 MPa (0 and 9 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 The values stated in SI units are to be regarded as standard. The inch-pound units in parentheses may be approximate.

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:

- D 883 Terminology Relating to Plastics²
- E 543 Practice for Agencies Performing Nondestructive Testing³
- E 650 Guide for Mounting Piezoelectric Acoustic Emission Sensors³
- E 750 Practice for Characterizing Acoustic Emission Instrumentation³
- E 1316 Terminology for Nondestructive Examinations³

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.

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² *Annual Book of ASTM Standards*, Vol 08.01.

³ *Annual Book of ASTM Standards*, Vol 03.03.

2.2 ANSI/ASNT Standards:

- SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification⁴
- ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel⁴

2.3 Military Standard:

- MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification⁵

3. Terminology

3.1 Complete definitions of terms related to plastics and acoustic emission will be found in Terminology D 883 and E 1316.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *count value* N_c —an evaluation criterion based on the total number of AE counts. (See A2.4 of Annex A2.)

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

3.2.3 *high-amplitude threshold*—a threshold for large amplitude AE events. (See A2.3 of Annex A2.)

3.2.4 *low-amplitude threshold*—the threshold above which AE counts (N) are measured. (See A2.2 of Annex A2.)

3.2.5 *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.

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

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

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

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

⁴ Available from American Society for Nondestructive Testing, 1711 Arlington Plaza, P.O. Box 28518, Columbus, OH 43228-0518.

⁵ Available from Standardization Documents Order Desk, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

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 having an internal operating pressure exceeding 0.2 MPa absolute (30 psia), will normally be tested to $1.5 \times$ operating pressure. Atmospheric storage vessels will normally be tested under maximum operating conditions. Pressure vessels having an internal pressure between 0.1 and 0.2 MPa absolute (15 and 30 psia), and vacuum vessels having an external differential pressure between 0 and 0.06 MPa (0 and 9 psi), will normally be tested to pressures in the range from 1.0 to $1.5 \times$ operating pressure.

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 Flaws 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 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, MIL-STD-410, NAS-410, 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 specified in the contractual agreement between the using parties.

6.2 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated in accordance with Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

6.3 *Procedures and Techniques*—The procedures and techniques to be utilized shall be in accordance with this practice unless otherwise specified. Specific techniques may 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 E 750.

7.2 Instrumentation shall be capable of recording AE counts and AE hits above the low-amplitude threshold, AE hits above the high-amplitude threshold within specific frequency ranges, and having 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 count, 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 $\pm 2\%$ of the maximum test value.

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.

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

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 E 650 for additional information on sensor mounting. Location and spacing of the sensors are discussed in 9.5. 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.

9.3 *High-Frequency Sensor*—(See Annex A1.) Several high-frequency channels are used for zone location of emission sources. Greater attenuation of stress waves at higher frequencies result in smaller zones of sensitivity for high-frequency sensors.

9.4 *Low-Frequency Sensor*—(See Annex A1.) Low-frequency channels are less affected by attenuation; therefore, they can be used to identify flaws in a large zone. If significant activity is detected on the low-frequency channels, and not on high-frequency channels, consideration should be given to relocating high-frequency sensors. It should be noted, however, that low-frequency channels are more susceptible to background noise.

9.5 *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.

9.5.1 *Attenuation Characterization*—Typical signal propagation losses shall be determined according to one of the following procedures. These procedures provide 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. In both cases the attenuation characterization should be made above the liquid line.

9.5.1.1 For acoustic emission instrumentation with amplitude analysis: Select a representative region of the vessel away from manways, nozzles, etc. Mount a high-frequency 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 leads⁶ 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.

9.5.1.2 *For Systems Without Amplitude Analysis*—Select a representative region of the vessel away from manways, nozzles, etc. Mount a high-frequency AE sensor and break 0.3 mm 2H leads along a line parallel to one of the principal directions of the surface fibers.

9.5.1.3 Record the distances from the center of the sensor to the points at which the high-amplitude threshold and low-amplitude threshold are no longer detected (see Annex A2). Repeat this procedure along a line inclined 45° to the direction

⁶ Pentel 0.3 (2H) lead or its equivalent has been found satisfactory for this purpose.

of the original line. The data shall be retained as part of the original experimental record.

9.5.2 *Sensor Spacings*—The recommended high-frequency sensor spacing on the vessel shall be not greater than $3 \times$ the distance at which detected signals from the attenuation characterization equal the low-amplitude threshold.

9.5.3 *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.

9.5.3.1 *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.

9.5.3.2 *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.

9.5.3.3 *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.

9.5.3.4 *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.

9.5.3.5 *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.

9.5.3.6 *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 hookup. The response of each sensor-preamplifier combination to a repeatable simulated acoustic emission source should be taken prior to the examination.

10.1.1 When using systems with amplitude analysis, 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.

10.1.2 When using systems without amplitude analysis, verification is accomplished by recording the distance from each sensor at which the response from the repeated simulated source falls below the low-amplitude threshold. This distance should not vary more than 30 cm (12 in.) from the average of all sensors. Any sensor-preamplifier combination failing this check should be investigated and replaced or repaired as necessary.

10.2 *Background Noise Check*—Recommended to identify and determine 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 10 to 30 min.

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 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 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.

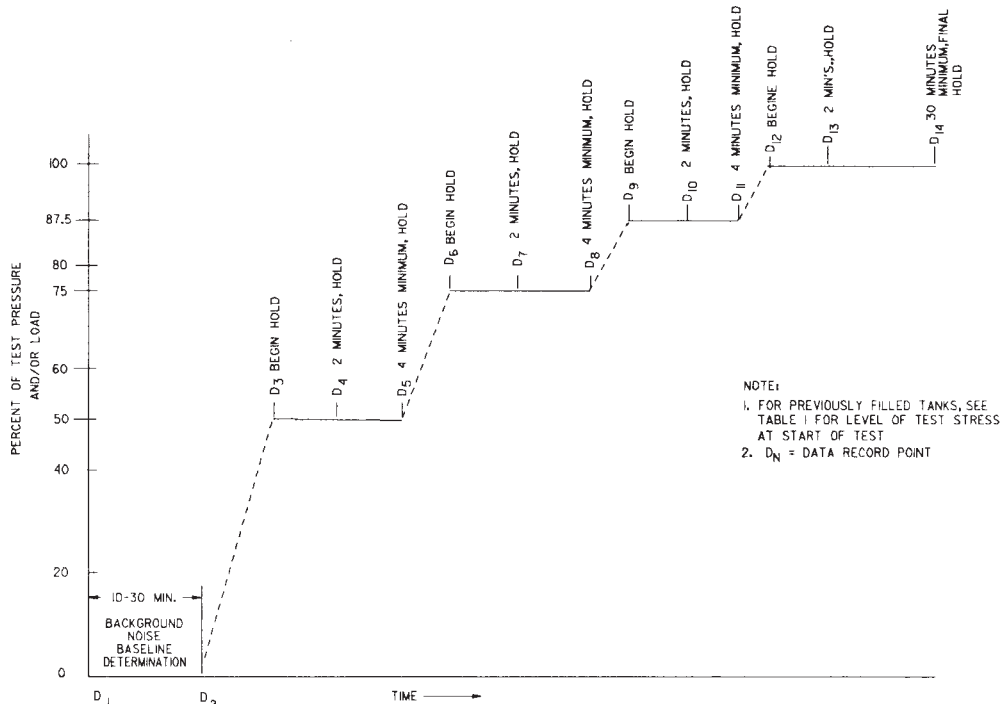


FIG. 1 Atmospheric Tank Examination, Stressing Sequence

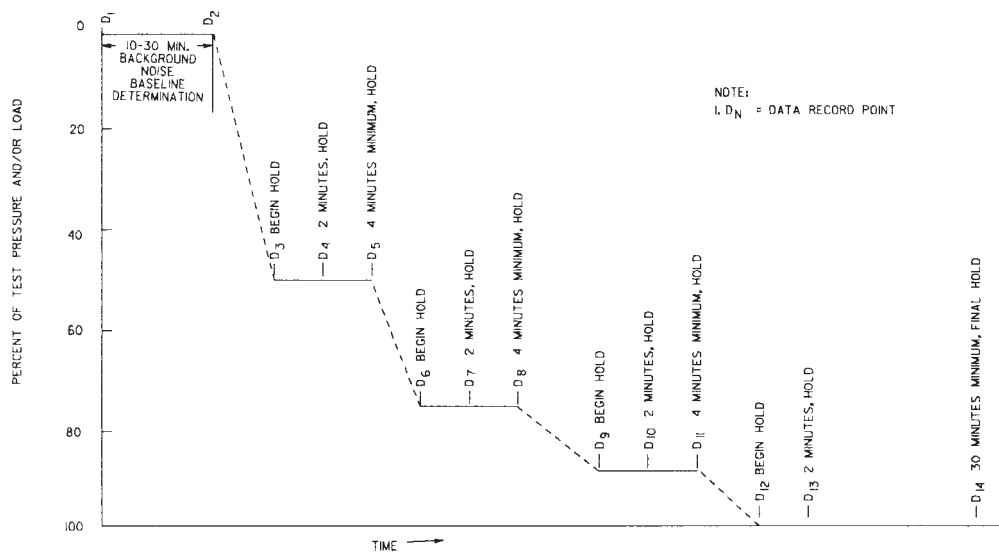


FIG. 2 Vacuum Tank Examination, Stressing Sequence

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

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 9.5.

11.4.1 During an examination, the sum of counts above the low-amplitude threshold from all low-frequency channels shall be monitored and the sum of counts above the low-amplitude threshold from all the high-frequency channels shall be separately monitored and recorded. The number of hits from all

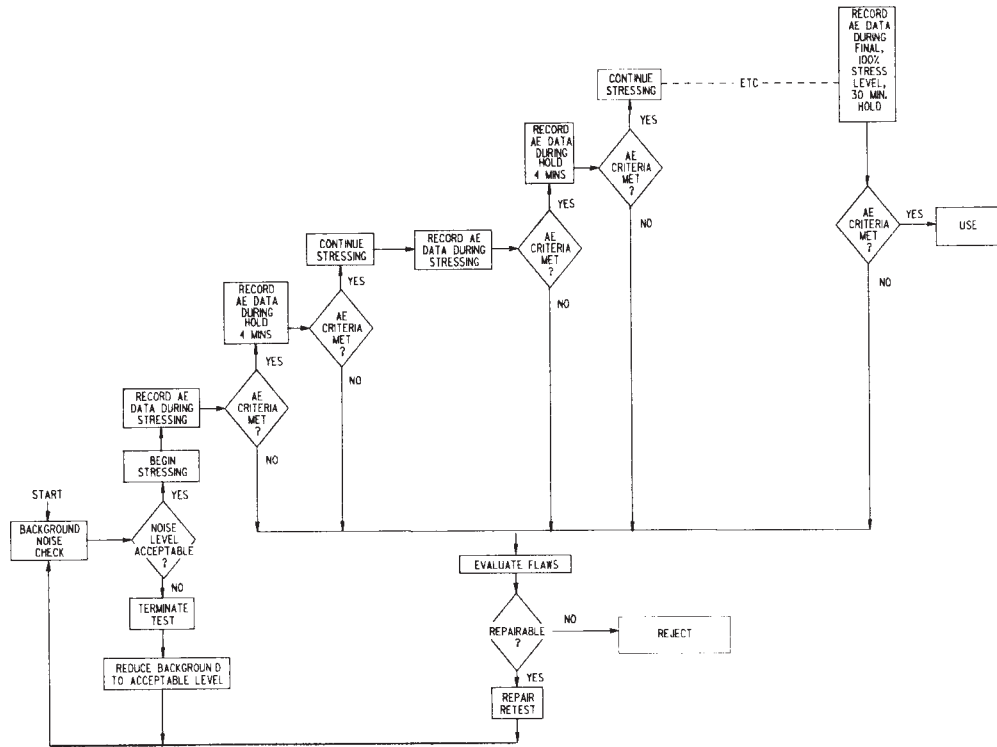


FIG. 3 AE Examination Algorithm—Flow Chart Atmospheric-Vacuum Tanks (See Fig. 1 and Fig. 2.)

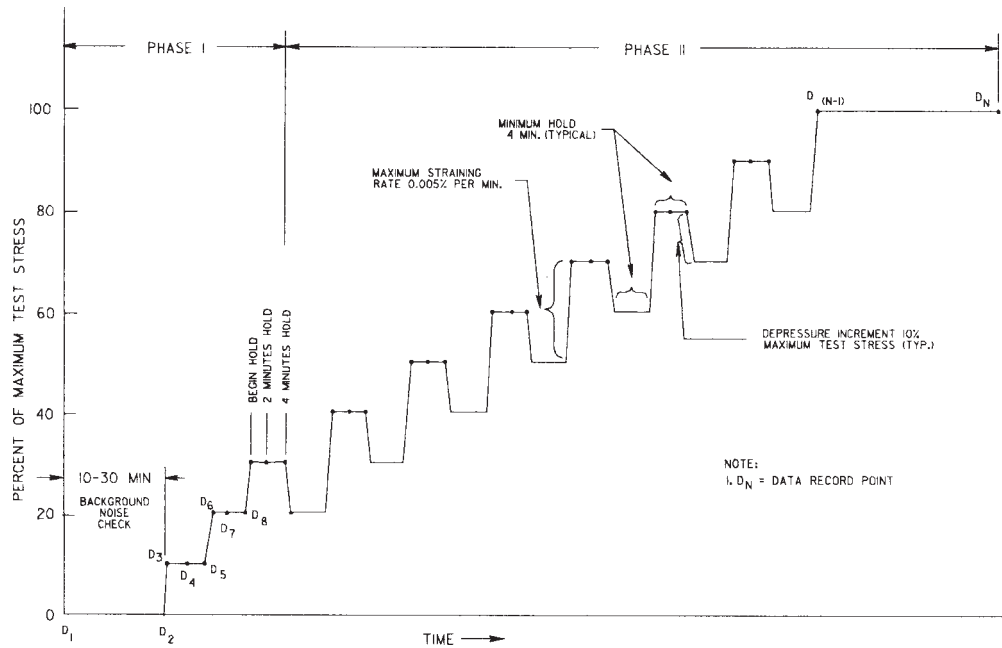


FIG. 4 Pressure Tank Examination, Stressing Sequence

high-frequency channels whose amplitude exceeds the high-amplitude threshold shall also be recorded (see Annex A2). Channels that are active during load holds should be noted.

12. Interpretation of Results

12.1 *Examination Termination*—Departure from a linear count-load relationship should signal caution. If the AE count

rate increases rapidly with load, the vessel shall be unloaded and the examination terminated. A rapidly (exponentially) increasing count rate indicates uncontrolled, continuing damage and is indicative of impending failure.

12.2 Significance of Data:

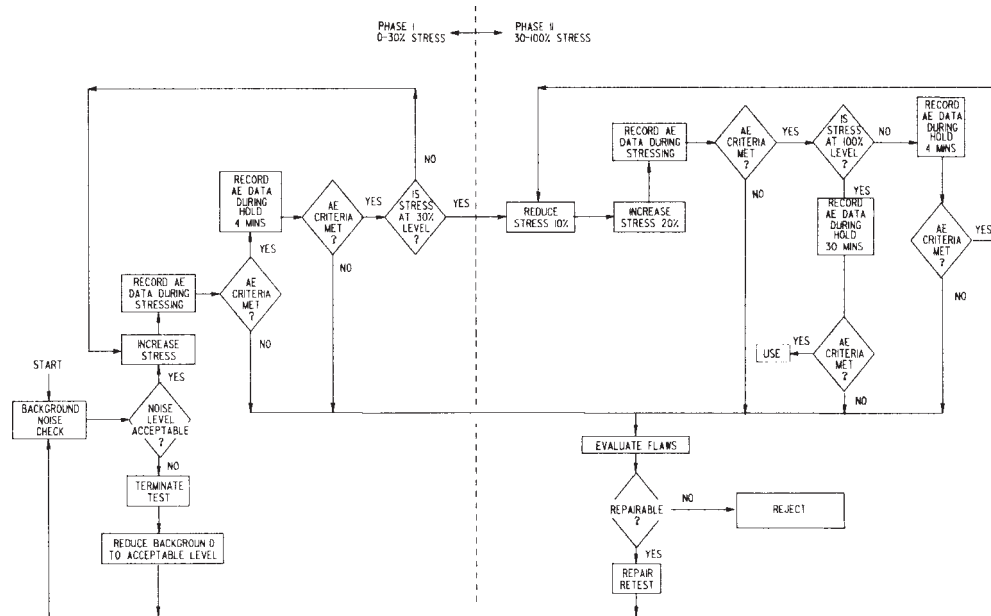


FIG. 5 AE Examination Algorithm—Flow Chart Pressure Tanks (See Fig. 4.)

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. Emissions continuing 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 $N_c/25$ counts during a 10 % increase in load, where N_c is the count value defined in Annex A2, Section A2.4.

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 (above the high amplitude threshold) is a condition on which acceptance criteria may be based.

12.2.4 Evaluation based on total counts is valuable for atmospheric and vacuum tanks. Pressure vessels, particularly on first loading, tend to be noisy and it is not possible to define a specific number of counts. Because emissions on first loading of pressure vessels may be of minor structural significance, trends in count data rather than fixed numbers are generally

used for evaluation. Total counts is a condition on which acceptance criteria may be based.

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 above the high-amplitude threshold versus time for zones of interest, total counts above the low-amplitude threshold versus time, emissions during load holds, and signal propagation loss (see 9.5).

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 *High-Frequency Sensors*—These 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.

A1.1.3 *Low-Frequency Sensors*—These sensors shall have a resonant response between 25 and 75 kHz. Minimum sensitivity will be comparable to, or greater than, commercially available high-sensitivity accelerometers with resonant response in that frequency range. In service, these sensors may be wrapped or covered with a sound absorbing medium to limit interference by airborne noise.

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 or high-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 from high-frequency sensors is not less than 100 kHz, and for low-frequency sensors not less than 25 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 have a minimum of two active data-processing circuits through which high-frequency and low-frequency sensor data will be processed independently. If independent channels are used, the processor shall be capable of processing hits and counts on each channel. No more than two sensors may be connected in common to a single preamplifier.

A1.8.1.1 If a summing amplifier is used, it shall provide a minimum processing capability for hit detection on eight channels (preamplifier inputs). Provisions to sum or exclude any of the channel inputs will be within real-time manual control.

A1.8.1.2 Low-frequency channel information will be processed for emission activity. Total counts will be processed from the high-frequency channels only. Hits accumulated above a high-amplitude threshold will be processed from the high-frequency channels only. The high-amplitude signal threshold may be established through signal-gain reduction, threshold increase, or peak-amplitude detection.

A1.8.2 *Peak-Amplitude Detection*—If peak-amplitude detection is practiced, 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 total counts above the low-amplitude threshold, and total hits above the high-amplitude threshold for high-frequency channels and hits by channel (zone location). A sample schematic is shown in Fig. A1.1.

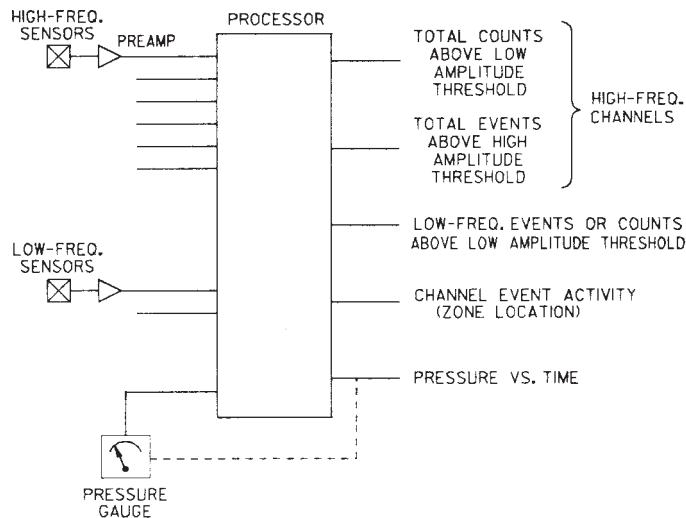


FIG. A1.1 Sample Schematic of AE Instrumentation for Vessel Testing

A2. INSTRUMENT CALIBRATION

A2.1 *General*—The performance and threshold definitions vary for different types of acoustic emission equipment. Parameters such as counts, amplitude, energy, ASL, RMS, and TMS vary from manufacturer to manufacturer, and from model to model by the same manufacturer. This annex defines procedures for determining the low-amplitude threshold, high-amplitude threshold, and count value N_c .

A2.1.1 The procedures defined in this annex are intended for baseline instrument calibration at 15° to 27°C (60° to 80°F). It is recommended that instrumentation users develop calibration techniques, along the lines outlined in this annex. For field use, small portable FRP, or similar, samples can be carried with the equipment and used for periodic checking of sensor, preamplifier, and channel sensitivity.

A2.2 *Low-Amplitude Threshold*—The low-amplitude threshold shall be determined using 120 cm by 180 cm by 1.3 cm (4 ft by 6 ft by 1/2 in.) 99 % pure lead sheet. The sheet shall be suspended clear of the floor. The low-amplitude threshold is defined as the average measured amplitude of ten events generated by a 0.3 mm pencil (2H) lead break at a distance of 130 cm (4 ft 3 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 15 cm (6 in.) from the 120 cm (4 ft) side and mid-distance between 180 cm (6 ft) sides.

A2.3 *High-Amplitude Threshold*—For large amplitude events, the high-amplitude threshold shall be determined using a 300 cm by 5 cm by 2 cm (10 ft by 2 in. by 3/4 in.) clean, mild steel bar. The bar shall be supported at each end on elastomeric, or similar, isolating pads. The high-amplitude threshold is

defined as the average measured amplitude of ten events generated by a 0.3 mm pencil (2H) lead break at a distance of 210 cm (7 ft) 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 *Count Value N_c* —The count value N_c shall be determined either before or after the examination using a 0.3 mm pencil (2H) lead broken on the surface of the vessel. 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. Calibration points shall be chosen so as to be representative of different constructions and thicknesses and should be performed above and below the liquid line (if applicable), and away from manways, nozzles, etc.

A2.4.1 A sensor shall be mounted at each calibrator point and two calibrations shall be carried out at each location. One calibration shall be in the principal direction of the surface fibers (if applicable), and the second calibration shall be carried out along a line at 45° to the direction of the first calibration.

A2.4.2 For systems with amplitude analysis, lead⁴ breaks shall be at a distance from the calibration point so as to provide an amplitude decibel value A_m midway between the low-amplitude threshold (see A2.2) and high-amplitude threshold (see A2.3).

A2.4.3 For systems without amplitude analysis, lead breaks shall be at a distance from the calibration point equal to 0.5 times the distance measured for the low-amplitude threshold.

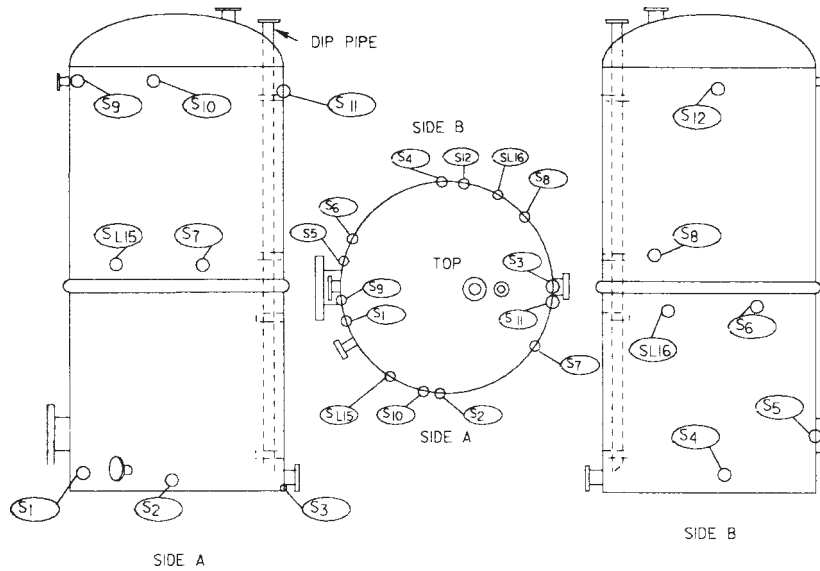
A2.4.4 The count value N_c for a particular examination setup is defined as the counts recorded from 5 × the sum of the

total counts from 13 of 0.3-mm (2H) lead pencil breaks for each of the two lead break locations.

A2.4.5 When applying the count evaluation, the count value, which is representative of the region where activity is observed, should be used.

A3. SENSOR PLACEMENT GUIDELINES

See Figs. A3.1-A3.6.

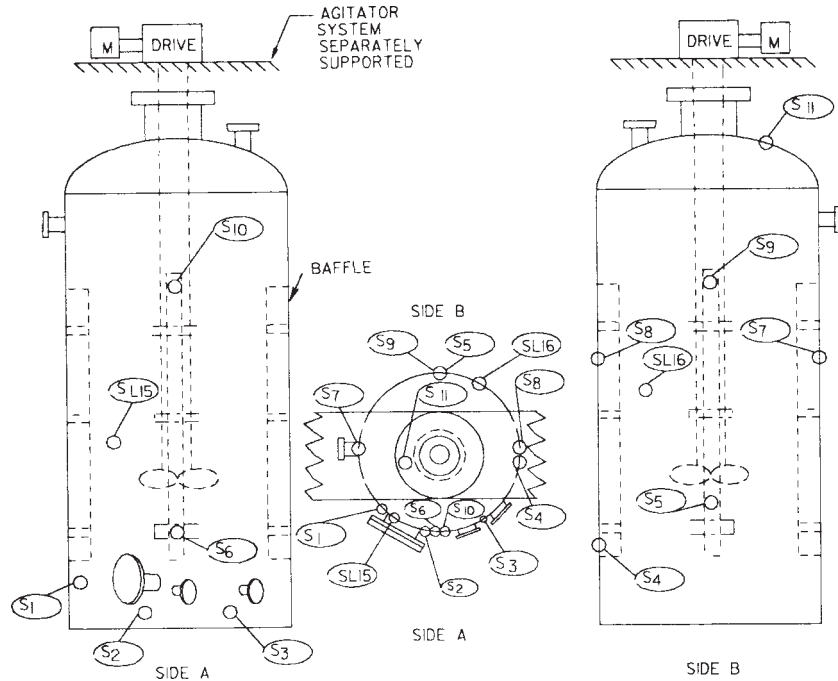


NOTE 1—The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, for example, approximately every 90° and 150 to 300 mm (6 to 12 in.) away from knuckle on shell.

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.

NOTE 3—The low-frequency sensors shown as SL15 and SL16 should be located at tank mid-height—one above and one below the joint. Space as far apart as possible—up to 180° and at 90° to the high-frequency pair.

FIG. A3.1 Case I—Atmospheric Vertical Tank

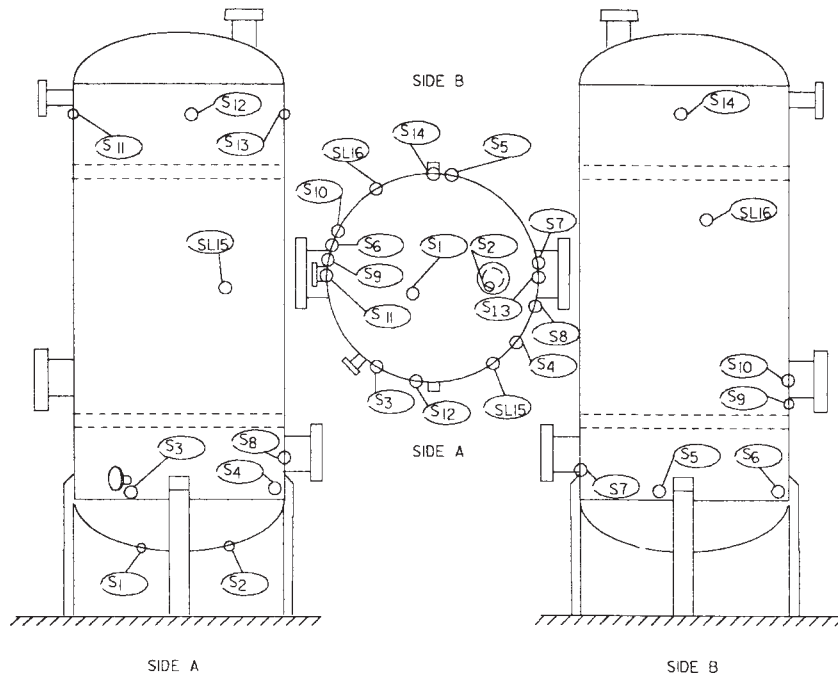


NOTE 1—The bottom knuckle region is critical due to discontinuity stresses. Locate sensors to provide adequate coverage, for example, approximately every 90° and 150 to 300 mm (6 to 12 in.) away from knuckle on shell. In this example, sensors are so placed that the bottom nozzles, manways, and baffle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

NOTE 3—The low-frequency sensors shown as SL15 and SL16 should be located at tank mid-height, one above and one below mid-height. They should be spaced as far apart as possible—up to 180°.

FIG. A3.2 Case II—Atmospheric Vertical Tank



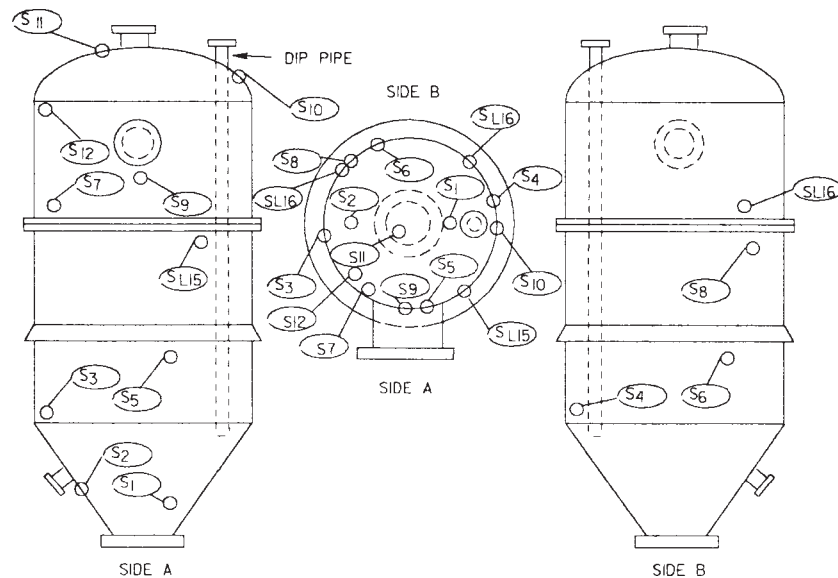
NOTE 1—The bottom head is highly stressed. Locate two sensors approximately as shown.

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, there should be a sensor within 300 mm (12 in.) of the shell-leg interface.

NOTE 4—The low-frequency sensors shown as SL15 and SL16 should be located at tank mid-height—one above and one below mid-height. They should be spaced as far apart as possible up to 180°.

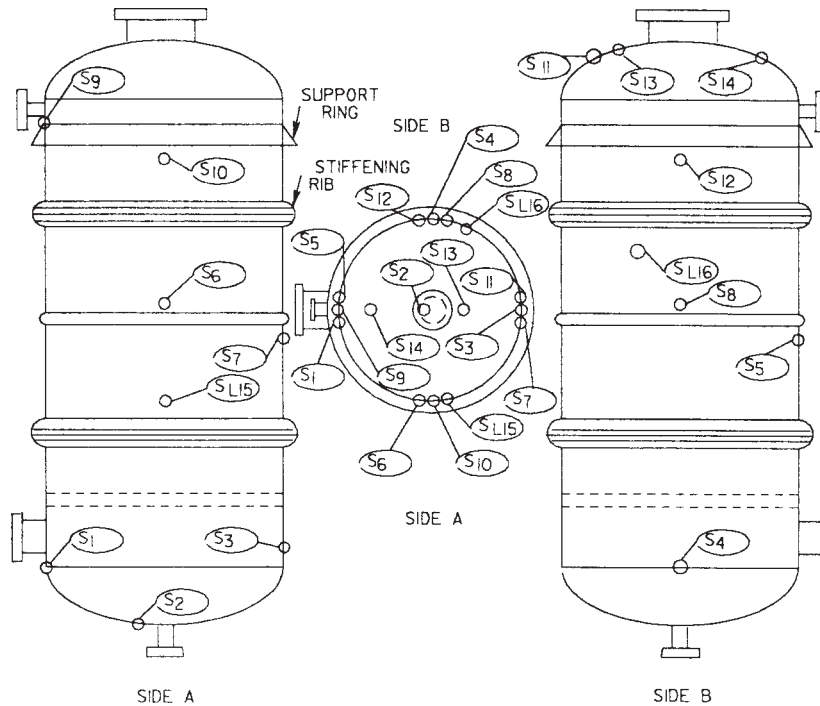
FIG. A3.3 Case III—Atmospheric-Pressure Vessel Tank



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. The body flange is covered by low-frequency sensors SL15 and SL16—one above and one below the body flange and spaced as far apart as possible up to 180°. Displaced approximately 90° from this pair and spaced up to 180° apart are the two high-frequency sensors—one above and one below the flange.

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

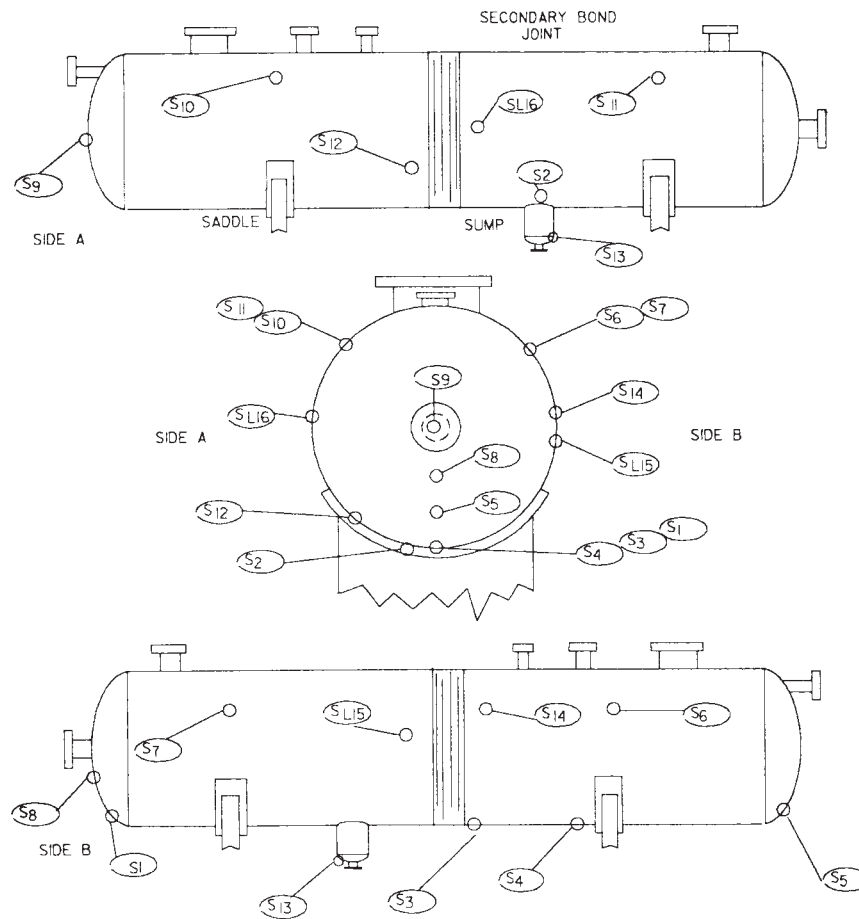


NOTE 1—The knuckle regions are suspect due to discontinuity stresses. Locate sensors to provide adequate coverage, that is, approximately every 90° and 150 to 300 mm (6 to 12 in.) away from knuckle on shell.

NOTE 2—The secondary bond-joint areas are critical, for example, nozzles, manways, and shell-but 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.

NOTE 3—The low-frequency sensors shown as SL15 and SL16 should be located at tank mid-height—one above and one below joint. They should be spaced as far apart as possible, up to 180° and at 90° to other pair.

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.

NOTE 3—The low-frequency sensors shown as SL15 and SL16 should be located in the middle of the tank—one on either side of the joint. They should be spaced as far apart as possible, that is, up to 180° and at 90° to high-frequency pair.

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	<500 ft (152.4 m)
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.

	Atmospheric (Liquid Head) and Additional Superimposed Pressure of Up to 0.1 MPa (14.7 psig) and Vacuum		Pressure Vessels (Additional ^A Superimposed Pressure of 0.1 to 0.34 MPa (14.750 psig))		Significance of Criterion
	First Filling	Subsequent Fillings	First Loading	Subsequent Loadings	
Emissions during hold	No hits having an amplitude greater than A_m beyond 2 min ^B	None beyond 2 min	Fewer than 5 hits/min having an amplitude greater than A_m beyond 2 min ^B	None beyond 2 min	Measure of continuing permanent damage ^C
Felicity ratio	Not applicable	Greater than 0.95	Greater than 0.95	Greater than 0.95	Measure of severity of previously induced damage
Total counts ^D	Less than N_c	Less than $N_c/2$	Not excessive ^E	Less than N_c	Measure of overall damage during a load cycle
No. of hits greater than high-amplitude threshold	Fewer than 10	Fewer than 5	Fewer than 10	Fewer than 5	Measure of high energy microstructural failures. This criterion is often associated with fiber breakage.

^A Above atmospheric.

^B A_m is defined as $\frac{1}{2}$ (high-amplitude threshold + low-amplitude threshold). See Annex A2 for definitions of high-amplitude threshold and low-amplitude threshold.

^C Permanent damage may include microcracking, debonding, and fiber pull-out.

^D Varies with instrumentation manufacturer. See A2.4 for functional definition of N_c .

^E Excessive counts are defined as a significant increase in the rate of emission as a function of load. On a plot of counts against load, excessive counts will show as a departure from linearity.

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