Designation: E 1139 – 02

Standard Practice for Continuous Monitoring of Acoustic Emission from Metal Pressure Boundaries[1]

This standard is issued under the fixed designation E 1139; 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 provides guidelines for continuous monitoring of acoustic emission (AE) from metal pressure boundaries in industrial systems during operation. Examples are pressure vessels, piping, and other system components which serve to contain system pressure. Pressure boundaries other than metal, such as composites, are specifically not covered by this document.

1.2 The functions of AE monitoring are to detect, locate, and characterize AE sources to provide data to evaluate their significance relative to pressure boundary integrity. These sources are those activated during system operation, that is, no special stimulus is applied to produce AE. Other methods of nondestructive testing (NDT) may be used, when the pressure boundary is accessible, to further evaluate or substantiate the significance of detected AE sources.

1.3 *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 specific precautionary statements, see Section 6.

2. Referenced Documents

2.1 *ASTM Standards:*

E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing[2]

E 569 Practice for Acoustic Emission Monitoring of Structures During Controlled Stimulation[2]

E 650 Guide for Mounting Piezoelectric Acoustic Emission Sensors[2]

E 750 Practice for Characterizing Acoustic Emission Instrumentation[2]

E 976 Guide for Determining the Reproducibility of Acoustic Emission Sensor Response[2]

E 1316 Terminology for Nondestructive Examinations[2]

2.2 *Aerospace Industries Association*

NAS-410 Certification and Qualification of Nondestructive Testing Personnel

2.3 *Other Documents:*

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

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

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this practice, refer to Terminology E 1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *continuous monitoring*—the process of monitoring a pressure boundary continuously to detect acoustic emission during system operation and also during system shut-down testing such as hydrostatic testing.

3.2.2 *raw data*—data values determined directly from measurement of analog inputs. These could include emission count or emission event count, or both, relative time of signal arrival at different sensors (delta time), signal rise time, peak signal amplitude, RMS signal level, pressure system pressure and temperature, and the like.

3.2.3 *processed data*—data resulting from analysis of raw data. Included would be AE source location coordinates, AE versus time from a given source area, AE signal amplitude versus time, and the like.

4. Summary of Practice

4.1 This practice describes the use of a passive monitoring system to detect, locate, and characterize AE sources, in order to evaluate their significance to the integrity of metal pressure boundaries.

4.2 The practice provides guidelines for selection, qualification, verification, and installation of the AE monitoring system. Qualification of personnel is also addressed.

4.3 The practice provides guidelines for using the AE information to estimate the significance of a detected AE source with respect to continued pressure system operation.

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[2] *Annual Book of ASTM Standards*, Vol 03.03.

[3] Available from American Society for Nondestructive Testing, 1711 Arlingate Plaza, PO Box 28518, Columbus, Ohio 43228-0518.

5. Significance and Use

5.1 Acoustic emission examination of a structure requires application of a mechanical or thermal stimulus. In this case, the system operating conditions provide the stimulation. During operation of the pressurized system, AE from active discontinuities such as cracks or from other acoustic sources such as leakage of high-pressure, high-temperature fluids can be detected by an instrumentation system using sensors mounted on the structure. The sensors are acoustically coupled to the surface of the structure by means of a couplant material or pressure on the interface between the sensing device and the structure. This facilitates the transmission of acoustic energy to the sensor. When the sensors are excited by acoustic emission energy, they transform the mechanical excitations into electrical signals. The signals from a detected AE source are electronically conditioned and processed to produce information relative to source location and other parameters needed for AE source characterization and evaluation.

5.2 AE monitoring on a continuous basis is a currently available method for continuous surveillance of a structure to assess its continued integrity. The use of AE monitoring in this context is to identify the existence and location of AE sources. Also, information is provided to facilitate estimating the significance of the detected AE source relative to continued pressure system operation.

5.3 In addition to immediate evaluation of the AE sources, a permanent record of the total data collected (AE plus pressure system parameters measured) provides an archival record which can be re-evaluated.

6. Hazards

6.1 **Warning**—Application of this practice will inherently involve work in an operating plant. This may involve potential exposure to hazardous materials and equipment and, in the case of nuclear power plants, exposure to nuclear radiation. A written safety plan shall be prepared for each monitoring installation which defines requirements to be observed to protect personnel safety, safety of the plant system, and to meet administrative and legal needs. This plan shall be approved by all parties prior to start of work on the plant.

7. Basis of Application

7.1 *Personnel Qualification*

7.1.1 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, 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.

7.2 *Qualification of Nondestructive Agencies*

7.2.1 If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

7.3 *Timing of Examination*

7.3.1 The timing of examination shall be continuous, in accordance with 1.1 unless otherwise specified.

7.4 *Extent of Examination*

7.4.1 The extent of examination shall be that part of the pressure boundary in the coverage range of the mounted acoustic emission sensors, unless otherwise specified.

7.5 *Reporting Criteria/Acceptance Criteria*

7.5.1 Reporting criteria for the examination results shall be in accordance with Section 15 unless otherwise specified. Since acceptance criteria (for example, for reference radiographs) are not specified in this standard, they shall be specified in the contractual agreement.

7.6 *Reexamination of Repaired/Reworked Items*

7.6.1 Reexamination of repaired/reworked items is not addressed in this standard and if required shall be specified in the contractual agreement.

7.7 Routine operation of the acoustic emission system for collection and interpretation of the data may be performed by a competent plant engineer not necessarily specialized in acoustic emission. However, acoustic emission system operation and data interpretation should be verified by a qualified acoustic emission specialist on approximately six-month intervals or sooner if the system appears to be malfunctioning or the data appear unusual.

8. Monitoring System Functional Requirements and Qualification

8.1 *Functional Requirements*:

8.1.1 The monitoring system must include the functional capabilities shown in Fig. 1 which also shows a suggested sequence of monitoring system functions.

8.1.2 *Signal Detection*—The AE sensor together with the acoustic coupling to the structure must have sensitivity sufficient to detect AE signals while the pressure system is operating. In most cases, this determination must be performed when the pressure system is not operating. AE system response to normal operational noise, which must be considered here, is discussed in 9.1. One method of performing the required evaluation is to use a pencil lead break as a signal source. With

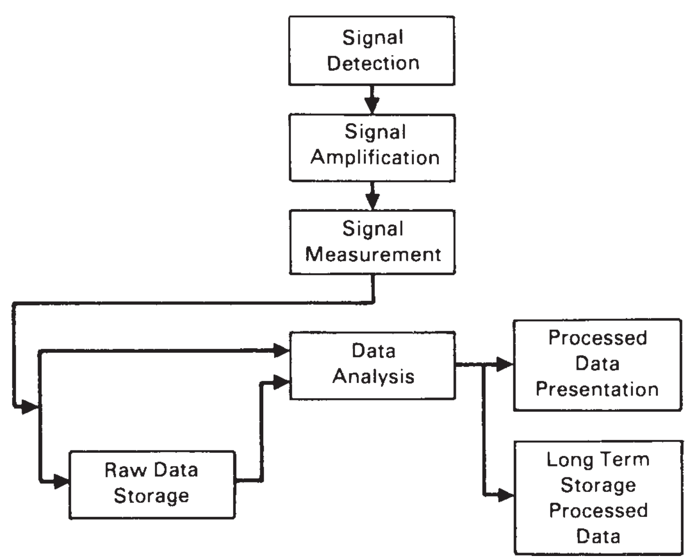

FIG. 1 Functional Flow Diagram—Continuous AE Monitoring System

the sensor in place and connected to the amplifier(s), the response at the amplifier output to fracturing a 0.3-mm pencil lead against the surface being monitored, at a distance of 150 to 300 mm (6 to 12 in.) from the sensor should show a minimum signal-to-noise (electronic plus process noise) ratio of 4 to 1 in a frequency range suitable for the planned monitoring environment. A differential sensor should be considered to minimize interference from electronic transients. The sensor must be capable of withstanding the monitoring environment (temperature, moisture, nuclear radiation, mechanical vibration, and the like) for an extended period of continuous exposure. The minimum length of this period will be dictated by accessibility to the location to change sensors, and by economic considerations.

8.1.3 *Signal Amplification*—A total signal amplification of 80 to 90 dB is usually required to achieve an adequate AE signal level for measurement of signal parameters. Due to the very small magnitude of energy involved in an AE source, it is desirable to locate the first stage of signal amplification as near as possible to the output of the sensor. This is beneficial in controlling noise interference and AE signal transmission loss. The amplifiers must have low inherent electronic background noise. This should not exceed 20 µV peak (Note 1) referred to the input. Resistance of the amplifier circuits to the environment (temperature, moisture, nuclear radiation, mechanical vibration, and the like) must be considered and appropriate steps taken to protect them.

NOTE 1—When used herein, peak means zero to peak voltage.

8.1.4 *Monitoring Frequency Band*—The frequency response of the sensor or amplifier combination must be selected for the given application. The AE signal being a transient pulse is detectable over a broad range of frequencies. Because the acoustic attenuation in engineering materials is frequency dependent, it is desirable to use a low monitoring frequency (50 to 100 kHz) to maximize the distance from the AE source over which the AE event can be detected. The low end of the monitoring frequency will usually be controlled by the background noise present in the monitoring environment. In some applications such as operating nuclear reactors, the background noise may require a low frequency cut-off point of 400 to 500 kHz. In cases of severe continuous background noise, inductive tuning of the sensor at the preamplifier input may be effective. The high end of the frequency response band may be limited to 1.0 MHz to help reduce amplifier electronic noise.

8.1.5 *Signal Measurement*:

8.1.5.1 The signal measurement section will receive the fully-amplified analog signal. Generally its operation will be controlled by a voltage threshold circuit which will limit accepted data to that exceeding the voltage amplitude threshold. AE parameters measured may include AE count, AE event count, signal amplitude, time from threshold crossing to signal peak, signal duration, difference in time of signal arrival at various sensors making up a source location array, clock time, data, and the value of any process system parameters (temperature, pressure, strain, and the like) available to the AE monitoring system. If the AE monitoring system is to perform detection of pressure system leaks, it must measure the average signal level or AE rms voltage for each sensing channel.

8.1.5.2 It is desirable that the signal measurements include a function to assess the characteristics of an acoustic emission signal to determine if it matches those originating from crack growth. The function should provide a "flag" for those signals which have characteristics similar to those known to originate from crack growth as determined by an AE specialist.

8.1.5.3 The output from the signal measurement subsystem should be in digital form to facilitate storage of large quantities of data.

8.1.6 *Raw Data Storage*—The AE monitoring system must include a raw digital data storage feature to facilitate retention of the output from the signal measurement subsystem. This serves as a backup in the event that the data analysis process malfunctions, for example, incorrect operation of the data analyzer or loss of power which might destroy data in a computer memory. The raw data storage device must be compact with a high capacity and be nonvolatile. The data retention period will be governed by the operating characteristics of the pressure system and by plant procedures. The storage device should include provision to play back the recorded information directly to the data analysis subsystem or to a peripheral computer.

8.1.7 *Data Analysis*:

8.1.7.1 One of the major functions of the data analysis section is to determine the source of AE signals. There are two primary methods used to locate discrete AE signals:

(a) Calculate the source point using the difference in time of signal arrival at the sensors (Δt) in a given source location array.

(b) Utilize the Δt information to enter a "look-up" table which will define an area including the specific Δt location. Either approach is acceptable. The "look-up" table area resolution must be examined in light of the accuracy requirements of the application. Neither approach can be expected to yield location accuracies closer than ± one wall thickness of the pressure system component being monitored.

8.1.7.2 A third method used largely for processing "continuous" signals produced by a pressure system leak to approximate the source of AE is to compare the amplitude of response from various sensors. This will permit estimating a signal attenuation pattern which will, in turn, indicate the approximate source location.

8.1.7.3 Generally, information in addition to source location will be required. Another function of data analysis is to provide a display, or plot, or both of selected AE information (AE rate, AE from a given source area, AE energy, etc.) versus time, pressure system strain, temperature, etc. for the purpose of correlation evaluations.

8.1.7.4 If the AE monitoring system is to perform pressure system leak detection, a function of data analysis is to provide a continuous assessment of the AE rms signal level. This information can indicate the presence of pressure boundary leakage.

8.1.8 *Processed Data Presentation*:

8.1.8.1 The monitoring system must provide a means of presenting analyzed data on demand. This may take the form of a computer printout alone or a printout in conjunction with a video display. The operator should have the option of specifying the time period of the displayed information.

8.1.8.2 AE rms signal level information must be presented if the AE monitoring system is to perform pressure system leak detection. When the AE rms value exceeds a predetermined level, an operator alert should be activated which will also indicate the sensor producing the high rms value.

8.1.9 *Long Term Storage of Processed Data*—Orderly storage of processed or analyzed data is a key element in the sequence of continuous AE monitoring to assure pressure system integrity. The volume of information to be stored will be inherently large. Digital tape or other digital media plus selected printouts or plots of analyzed information is a suggested approach. The time period for storage will be influenced by two considerations: (1) legal requirements for maintaining records, and (2) the need for engineering data base information.

8.2 *General System Requirements*:

8.2.1 Data processing rate of the total monitoring system is a very important consideration. This will vary with the purpose of the pressure system surveillance. If the objective is solely to indicate impending failure, data rate requirements for processing discrete signals may exceed 100/s for periods of several minutes or more. If the objective is to identify and evaluate crack growth in the early stages, sustained data rate requirements for processing discrete signals may be less than 10/s.

8.2.2 Another general consideration of importance is the capability of the monitoring system to operate continuously over long time periods (one year or greater). Components need to be well suited to such long sustained operation without frequent attention.

9. Monitoring System Performance Verification and Functional Tests

9.1 Various measurements of the acoustic emission monitoring system shall be performed before and after installation on the pressure system to ensure adequate performance. These measurements are described in Practice E 750. In addition, the following must be evaluated:

9.1.1 *System Response to Process Background Noise*—It is critical that the process background noise be characterized in terms of acoustic emission monitoring system response to the noise excitation. This will be the primary factor in determining acoustic emission system frequency response limitations necessary to avoid noise-masking acoustic emission signals. As a guideline, acoustic emission system response to continuous process background noise should not exceed 35 dBae (approximately 1.5 V peak output after 90 dB electronic amplification).

9.1.2 *Prior to Installation*—The operating characteristics of the acoustic emission monitoring system shall be evaluated prior to installation on the pressure system. The evaluation shall specifically include:

9.1.2.1 Frequency response characteristics of each data channel including the sensor and all associated amplifiers to determine if the frequency response is suitable for the intended use. Gas jet excitation of the sensor as defined in Guide E 976 is suitable for this. See also 9.1.3.1 of this document.

9.1.2.2 Determine if the dynamic range is large enough to accommodate the planned analysis method. Determine if the system saturates first in the preamplifier(s) or amplifier and if it recovers rapidly.

9.1.2.3 Determine the rate at which the AE monitoring system can acquire and record raw data and to acquire and process data from *one sensor array* for a continuous input over a 1-h period. The rate should be no less than 10 AE events per second. Also, the data rate capability for short intermittent periods of 30 s should be at least 100 AE events per second.

9.1.2.4 Determine the accuracy of AE parameter measurements (rise time, amplitude, and the like) of the AE monitoring system using a known signal input.

9.1.3 *After Installation*—The following measurements should be performed after the acoustic emission monitoring system is installed on the pressure boundaries to be monitored. All results should be documented and incorporated in a report on the functional capability of the installed acoustic emission monitoring system. These data are of special importance because they form a baseline reference for acoustic emission system performance. The following measurements should be performed:

9.1.3.1 The AE system response sensitivity versus frequency for each data channel should be measured. This can be accomplished using a helium jet excitation applied from a 210 kPa (30 psi) gage pressure source through a #18 hypodermic needle and impinged on the structure surface at a 3-mm (⅛-in.) standoff distance, 40 mm (1½ in.) from the mounted sensor. In the case of metal waveguide sensors in particular, care must be exercised to shield the waveguide from impingement of the gas on the waveguide either directly or indirectly. Using the helium jet excitation as described, the peak response at the desired monitoring frequency should be at least 80 dBae (1.0 mV peak output from the sensor). Any data channel showing less than an equivalent of 75 dBae (approximately 0.6 mV peak output) from the sensor should be investigated and the sensor remounted or replaced as necessary to improve sensitivity.

9.1.3.2 Source location accuracy for each sensor array shall be measured using simulated acoustic emission signals injected on the structure surface at known points. At least 10 different points dispersed within each sensor array shall be examined. The location where signals are being injected shall be surrounded with a material such as duct putty to damp out energy propagation by surface wave directly from the signal source. This is particularly important in structures where the energy must cross one or more welds to reach the sensors. Lower attenuation of surface waves by the weld compared to that for longitudinal or shear waves, or both may produce misleading results. Location accuracy should be within a maximum of two wall thicknesses of the structure or 5 % of the sensor spacing distance from the actual point of signal injection, whichever is greater. A suggested method of simulating acoustic emission signals is by use of pencil lead breaks as described in Guide E 976.

9.1.3.3 A source of simulated acoustic emission signals should be provided to test the response of the AE monitoring system during pressure system operation. In those cases where access to the sensor locations is impossible during pressure system operation, a remotely controlled source(s) of simulated acoustic emission signals capable of exciting all sensors should be installed on the structure as a permanent part of the installation. This will provide a means of periodically checking the acoustic emission sensors for relative change in sensitivity during the monitoring period. Response of the acoustic emission system to this signal source should be documented as part of the acoustic emission monitoring information. One versatile signal source which can be utilized is an ultrasonic transducer capable of withstanding the pressure system temperature. This has the advantage of being effective over a wide frequency range. Another possible source is a mechanical impactor. However, this device has limited effectiveness at frequencies above approximately 250 kHz.

10. Monitoring System Installation

10.1 Special requirements for installation of acoustic emission monitoring system components imposed by pressure system requirements must be considered and an examination plan prepared and approved in advance of the installation. Some of the major considerations are:

10.1.1 *Sensor mounting*—Guide E 650 provides general guidance in this area. The use of drilled and tapped holes in the pressure boundary surface is generally not acceptable. Use of any bonding or acoustic coupling agent, or both shall be supported by chemical analysis of the material to assure that it does not contain elements harmful to the pressure boundary material. Pressure coupling the sensors to the structure surface through the use of magnetic mounts or fixtures secured in place by steel bands are generally acceptable methods. The sensor should be electrically isolated from the structure to minimize electrical interference.

10.1.2 Penetration of protective barriers with signal leads must be approached with care to avoid compromising the protection barrier and to avoid incurring noise or loss of AE signal, or both.

10.1.3 *Signal lead routing inside of protective barriers*—in the case of nuclear plants, signal leads will generally need to be routed through metal conduit.

10.1.4 *Seismic qualification*—in nuclear plants, all components will have to be evaluated for safety from a seismic stand-point.

10.2 This is not intended to be an all inclusive list of considerations. It is the responsibility of those applying this practice to independently evaluate each installation.

11. Procedure

11.1 Procedural guidelines for continuous monitoring are limited because it is a passive function which will not control operation of the pressure system. It is, thus, very important that a written procedure be prepared for each installation to recognize unique requirements. Items to be addressed in the procedure are discussed in this section.

11.1.1 *Pressure System Startup*—Pressure system startup may be the most critical period of an operating cycle for flaw growth due to a combination of pressure stresses and thermal stresses. During this period, acoustic emission count and source location information shall be closely observed for any indication of flaw growth. The rms signal level shall also be observed for indications of leaks in the pressure system.

11.1.2 *Normal Pressure System Operation*:

11.1.2.1 Analysis and summary of acoustic emission data on a weekly basis is suggested during normal plant operation. Acoustic emission count and source location should be examined for trends or build up or both of data at a given location.

11.1.2.2 Response of the acoustic emission system to the installed acoustic signal source (see 9.1.3.3) shall be evaluated on a monthly basis. Indication of deterioration of sensitivity of any sensor must be noted and the sensor(s) shall be replaced at the earliest opportunity.

12. Interpretation of Monitoring Results

12.1 Criteria for interpretation of acoustic emission information from continuous monitoring of a pressure boundary during pressure system operation are both qualitative and quantitative.

12.1.1 The first indication of a significant condition will be a consistent clustering of data source locations within an area approximately 3 times the wall thickness or 10 % of the sensor spacing distance in surface dimensions, whichever is greater. When this condition occurs, thorough analysis must be initiated. The condition should first be evaluated in light of other available plant operating information to determine if the source can be definitely associated with an innocuous cause. If this is not the case, the condition must be considered as a growing flaw.

12.1.2 Given an indication of a growing flaw, the data should be filtered to obtain a measure of acoustic emission events versus time for the localized area of the data source location cluster. If this is a linear curve, it indicates that the flaw is growing in a stable manner and is not yet a serious condition but requires careful surveillance. If the acoustic emission events versus time becomes an exponentially increasing curve, it indicates that the flaw growth rate is rapidly increasing and represents a serious condition. Also, the data should be analyzed relative to plant operating parameters such as temperature, pressure, and the like. This may provide information on the driving force which will aide in assessing significance.

12.1.3 For those acoustic emission monitoring systems which have the analytical capability to assess if a detected signal originates from crack growth, changes in crack growth rate can be estimated with useful accuracy from acoustic emission event rate. An assessment of change in crack growth rate with time by this technique can provide an indication of crack significance.

12.1.4 In cases where it is feasible during pressure system operation or in all cases during pressure system shutdown, acoustic emission indications should be examined with other nondestructive examination methods to provide added definition of AE source significance.

12.1.5 Interpretation of acoustic emission data obtained during hydrostatic testing of the pressure system should be in accordance with Practice E 569.

12.1.6 A sudden, sustained increase in the AE rms signal level from the sensors in one or more sensor arrays is indicative of a leak in the pressure system. In this case, the AE rms signal level from all sensors should be examined to determine the relative level of response to the leak. This will provide an indication of the location of the leak.

13. Precision and Bias

13.1 Location accuracy is influenced by factors that affect elastic wave propagation, by sensor coupling, and by signal processor settings.

13.2 It is possible to measure AE and produce AE source locations that cannot be verified by other NDT methods. If such emissions are measured, and are produced by flaws, such flaws are small and are not of structural significance.

14. Data Record Requirements

14.1 The safety and examination plan documents shall be retained as permanent records.

14.2 Installed acoustic emission system characterization and calibration results shall be retained on record until such time that the acoustic emission system is recalibrated.

14.3 Raw data records shall be retained until acoustic emission indications can be independently verified as a minimum.

14.4 Retention period for processed data records shall be determined by the pressure system owner or operator.

15. Administrative Record Requirements

15.1 A summary of acoustic emission monitoring results shall be prepared at the end of each pressure system operating cycle. This should be a brief, concise report suitable for management review.

15.2 Reporting requirements in the event of unusual acoustic emission indications shall be defined by the pressure system owner or operator.

16. Keywords

16.1 acoustic emission; acoustic emission source location; continuous monitoring; leak detection; metal piping; metal pressure vessels; pressure systems