Designation: E 750 – 98

Standard Practice for Characterizing Acoustic Emission Instrumentation[1]

This standard is issued under the fixed designation E 750; 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 is recommended for use in testing and measuring operating characteristics of acoustic emission electronic components or units. (See Appendix X1 for a description of components and units.) It is not intended that this practice be used for routine checks of acoustic emission instrumentation, but rather for periodic calibration or in the event of a malfunction. The sensor is not addressed in this document other than suggesting methods for standardizing system gains (equalizing them channel to channel) when sensors are present.

1.2 Where the manufacturer provides testing and measuring details in an operating and maintenance manual, the manufacturer's methods should be used in conjunction with the methods described in this practice.

1.3 Difficult or questionable instrumentation measurements should be referred to electronics engineering personnel.

1.4 The methods set forth in this practice are not intended to be either exclusive or exhaustive.

1.5 The methods (techniques) used for testing and measuring the components or units of acoustic emission instrumentation, and the results of such testing and measuring should be documented. Documentation should consist of photographs, charts or graphs, calculations, and tabulations where applicable.

1.6 AE systems that use mini or micro computers to control the collection, storage, display, and analysis of data are in common use. Features of the computer-based systems include a wide selection of measurement parameters relating to the AE event. This selection, however, is usually made after the data have been acquired. This implies that the AE signals are individually recorded for later analysis, or that all the available parameters are measured on every AE signal that exceeds the selected threshold. The latter is usually the case. The manufacturer provides a specification for each system that specifies the operating range and conditions for the system. All calibration and acceptance testing of computer-based AE systems must use the manufacturer's specification as a guide. This practice does not cover testing of the computer or computer peripherals.

1.7 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 1316 Terminology for Nondestructive Examinations[2]

2.2 *ANSI Standard:*

ANSI/IEEE 100-1984 Dictionary of Electrical and Electronic Terms[3]

2.3 *Other Documents:*

Manufacturer's Operating and Maintenance Manuals pertinent to the specific instrumentation or component

3. Terminology

3.1 *Definitions*—For definitions of additional terms relating to acoustic emission, refer to Terminology E 1316.

4. Apparatus

4.1 The basic test instruments required for measuring the operating characteristics of acoustic emission instrumentation include:

4.1.1 *Variable Sine Wave Generator*,

4.1.2 *True RMS Voltmeter*,

4.1.3 *Oscilloscope*,

4.1.4 *Variable Attenuator, graduated in decibels*, and

4.1.5 *Tone Burst Generator*.

4.2 Additional test instruments should be used for more specialized measurements of acoustic emission instrumentations or components. They are as follows:

4.2.1 *Variable-Function Generator*,

4.2.2 *Time Interval Meter*,

4.2.3 *Frequency Meter, or Counter*,

4.2.4 *Random Noise Generator*,

4.2.5 *Spectrum Analyzer*,

4.2.6 *D-C Voltmeter*,

4.2.7 *Pulse-Modulated Signal Generator*,

4.2.8 *Variable Pulse Generator*, and

[1] This practice is under the jurisdiction of ASTM Committee E-7 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 03.03.

[3] Available from American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

4.2.9 *Phase Meter*,

4.2.10 *Electronic AE Simulator*.

4.3 An electronic AE simulator is necessary to evaluate the operation of computer-based AE instruments. A detailed example of the use of an electronic AE simulator is given in 5.5.3 under dead time measurement. The instruction manual for the electronic AE simulator provides details on the setup and adjustment of the simulator. Control of pulse frequency, rise time, decay, repetition rate, and peak amplitude in the simulator makes it possible to simulate a wide range of AE signal conditions.

5. Tests and Measurements

5.1 *Required Measurements*:

5.1.1 Tests and measurements should be performed to determine the instrumentation bandwidth, frequency response, gain, noise level, threshold level, dynamic range, signal overload point, dead time, and counter accuracy.

5.1.2 Where acoustic emission test results depend upon the reproduced accuracy of the temporal, spatial, or spectral histories, additional measurements of instrumentation parameters should be performed to determine the specific limits of instrumentation performance. Examples of such measurements may include amplifier slew rate, gate window width and position, and spectral analysis.

5.1.3 Tests and measurements should be performed to determine the loss in effective sensor sensitivity resulting from the capacitive loading of the cable between the preamplifier and the sensor. The cable and preamplifier should be the same as that used for the acoustic emission tests without substitution. (See also Appendix X2.)

5.1.3.1 Important tests of a computer-based AE system include the evaluation of limits and linearity of the available parameters such as:

(a) Amplitude,
(b) Duration,
(c) Rise Time,
(d) Energy, and
(e) Source Location.

5.1.3.2 The processing speed of these data should be measured as described in 5.5.3 for both single- and multiple-channel operation.

5.1.3.3 The data storage capability should be tested against the specification for single- and multiple-channel operation. Processing speed is a function of number of channels, parameters being measured, event duration, front-end filtering, storage and display (RAM, disk, plots) and printout requirements.

5.2 *Frequency Response and Bandwith*:

5.2.1 The instrumentation, shown in Fig. 1, includes the preamplifier, wave filters, secondary amplifier, and interconnecting cables. All measurements and tests should be documented. The preamplifier should be terminated with the normal working load.

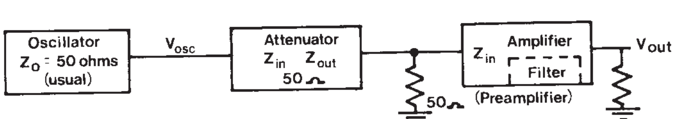

FIG. 1 Component Configuration Used for Testing and Measuring the Frequency Response, Amplification, Noise, Signal Overload, Recovery Time, and Threshold of Acoustic Emission Instrumentation

5.2.2 An acceptable frequency response between cutoff frequencies is within 3 dB of the reference frequency. The reference frequency is the geometric mean of the nominal bandwidth of the instrumentation. The mean frequency is calculated as follows:

$$f_M = (f_L f_H)^{\frac{1}{2}}$$

where:
f_M = mean frequency,
f_L = nominal lower cutoff, and
f_H = nominal upper cutoff.

5.2.3 The bandwidth should include all contiguous frequencies with amplitude variations as specified by the manufacturer. Instruments that include signal processing of amplitude as a function of frequency should have bandwidth amplitude variations as specified by the manufacturer.

5.2.4 With the instrumentation connected as shown in Fig. 1 and the sine wave oscillator set well within the instrumentation's specified dynamic range, the frequency response should be measured between frequency limits specified in 5.2.2. The oscillator is maintained at a fixed amplitude and the frequency is swept through the frequency limits. The secondary amplifier, or final filter, output is monitored with an rms voltmeter. Values of amplitude are recorded for each of several frequencies within and beyond the nominal cutoff frequencies. The recorded values are plotted on chart paper. The amplitude scale may be converted to decibels. The frequency scale may be plotted either linearly or logarithmically. Appendix X2 provides further discussion of wave shaping components.

5.2.5 A spectrum analyzer may be used in conjunction with a white noise source or an oscilloscope may be used in conjunction with a sweep frequency oscillator to determine bandwidth. With a white noise source connected to the input, a spectrum analyzer connected to the output will record the frequency response.

5.2.6 The measured bandwidth is the difference between the frequencies at which the response is 3 dB less than the response at the reference frequency.

5.3 *Gain*:

5.3.1 The electronic amplification is comprised of the preamplifier gain, the secondary amplifier gain, and the wave filters insertion gains or losses. (See Appendix X2 for an explanation of gain measurements.)

5.3.2 The electronic amplification may be measured with the instrumentation shown in Fig. 1. The sine wave oscillator is set to the reference frequency. The oscillator amplitude is set well within the dynamic range of the instrumentation to avoid distortion due to overload. With the voltmeter at V_{osc}, oscillator amplitude is set to 1 V. The attenuator is set for a value greater than the anticipated electronic amplification. Next, the voltmeter is moved to V_{out}. The attenuator is now adjusted until the voltmeter again reads 1 V. The electronic amplification is equal to the new setting on the attenuator. A white noise generator or sweep generator and spectrum analyzer may be used in place of the oscillator and RMS voltmeter.

NOTE 1—If the input impedance of the preamplifier is not both resistive and equal to the required load impedance of the attenuator, proper compensation should be made.

5.4 *Dynamic Range*:

5.4.1 The criterion used for establishing dynamic range should be documented as the signal overload point, referenced to the instrumentation noise amplitude. Alternatively, the reference amplitude may be the threshold level if the instrumentation includes a voltage comparator for signal detection. In addition, dynamic range relative to instrumentation damage may also be documented. The total harmonic distortion criterion should be used for signal processing involving spectrum analysis. All other signal processing may be performed with the signal overload point criterion.

5.4.2 The dynamic range (DR) in decibels should be determined as follows:

$$DR = 20 \log_{10} \frac{\text{maximum rms output}}{\text{rms noise output}}$$

5.4.2.1 The dynamic range of instrumentation exclusive of threshold or voltage comparator circuits, is a ratio of the rms signal overload level to the rms noise amplitude. (A brief description of noise sources appears in Appendix X4). An oscilloscope is usually required as an adjunct to determine the characteristics of noise and to monitor the signal overload point.

5.4.2.2 A field measurement of dynamic range may produce substantially different results when compared with a laboratory measurement. This difference is caused by an increase in the reference voltage output, and may result from noise impulses of electrical origin, or ground faults.

5.4.2.3 For an amplifier that has a threshold comparator as its output device, the dynamic range is the ratio of maximum threshold level to input noise level. Excess amplitude range in the amplifier contributes to overload immunity but not to the dynamic range. The following measurement will give the effective dynamic range:

$$DR_e = 20\log_{10}(\text{MaxTh}/\text{MinTh})$$

where:

DR_e = the effective dynamic range of the system,
MaxTh = the threshold value that just passes the largest undistorted peak signal input, and
MinTh = the threshold value that passes less than 1 count/s with no input signal.

This dynamic range is the difference between the largest and the smallest AE input that can be counted by the system.

5.4.3 Measurement of instrument electronic noise is accomplished by replacing the oscillator/attenuator of Fig. 1, with the sensor that will be used, including its cable (or with a lumped equivalent capacitance). A lumped capacitance represents the electrical characteristic of the sensor and cable combination without adding mechanical noise interference. The rms voltage is measured at the instrumentation output (V_{out}).

5.4.4 The signal overload level is measured by replacing the sensor with a sine wave oscillator as shown in Fig. 1. The frequency is set to the mid-band frequency of the instrumentation. The oscillator amplitude is fixed at 1 V peak to peak monitored at V_{osc}. The attenuator is adjusted to increase the signal level to the preamplifier until the instrumentation output (V_{out}) is 3 dB less than the computed output.

5.4.5 Should the peak amplitude of acoustic emission events exceed the dynamic range, several deleterious effects may be produced; these include clipping, saturation, and overload recovery time-related phenomena. (See Appendix X2 for a discussion of overload recovery.) The instrumentation gain should be adjusted to limit these effects to an absolute minimum in order to increase the reliability of the data.

5.5 *Dead Time*:

5.5.1 The instrumentation dead time may include variable and fixed components depending on the instrumentation design for handling the routine of the input and output data processing. The components included in dead time are process time and lock-out time. Process time varies from system to system and usually depends on the number of parameters processed for each event. Lock-out time, which may be operator controlled, is used to force a time delay before accepting new events.

5.5.2 Dead time measurement in a counter type AE instrument should be conducted as follows: Set the instrument to the count rate mode. Set the oscillator frequency to the mid-band frequency of the instrument. Set the oscillator amplitude to achieve a count rate equal to the oscillator frequency. Increase the oscillator frequency until the count rate ceases to equal the oscillator frequency. Record the frequency as the maximum count rate. (If the frequency is equal to or greater than the specified upper frequency limit of the instrument, the dead time of the counter is zero.) Dead time (*Td*) is given by:

$$Td = 1/Fm - 1/Fu$$

where:

Fm = the measured frequency, and
Fu = the upper bandwidth limit of the instrument.

5.5.3 Where the dead time in question is related to AE event processing such as measurement of source location, energy, duration, or amplitude, the measurement is best accomplished by using an electronic AE simulator as follows:

5.5.3.1 Select an event parameter to evaluate the dead time.

5.5.3.2 Set the electronic AE simulator frequency, rise, decay, duration, and repetition rate such that the observed event rate in the selected parameter equals the repetition rate of the simulator.

5.5.3.3 Increase the repetition rate of the simulator until the observed event rate falls below the simulator rate.

5.5.3.4 Record this value as maximum event rate (processing speed) for the selected parameter.

5.5.4 The dead time (*Td*) is given by:

$$Td = 1/R_p - D_p$$

where:

D_p = the selected pulse duration, and
R_p = the repetition rate of the simulator where the limit was found.

This dead time measurement procedure should be performed for each event-based parameter of the AE system.

5.6 *Threshold Level* (*Threshold of Detection*):

5.6.1 Various acoustic emission signal processing instruments rely upon the signal exceeding a comparator voltage level to register a hit. This level may be fixed, adjustable, floating and fixed, or floating and adjustable. The floating threshold may be called automatic threshold. Signal recognition (or hit) does not occur until the threshold is exceeded.

5.6.2 The nonautomatic threshold level should be measured with the instrumentation assembled as shown in Fig. 1 and the signal processors attached to the point V_{out}. The signal processors are frequently digital electronic counters that may follow the secondary amplifier. Increasing the oscillator amplitude will result in an increasing signal level at V_{out}. The counters will begin counting when the signal at the comparator reaches the preset threshold level. This level measured with an oscilloscope connected to V_{out} multiplied by the gain of the secondary amplifier is equal to the threshold voltage. Some counters and other signal processors utilizing threshold detection are frequency sensitive. Therefore, the threshold level should be measured over the instrumentation bandwidth.

5.6.3 The automatic threshold cannot be measured with a continuous-wave generator because the automatic threshold level is usually derived from the rectified and averaged input signal. The tone burst generator provides an adjustable burst amplitude duration and repetition rate that may be used to establish the threshold level using the same technique that is used in 5.6.2. The automatic threshold level's affected by the tone burst amplitude, duration, and repetition rate.

5.7 *Counter Accuracy*:

5.7.1 Counters are of two types: summation counters and rate counters. Counters that tally signals for fixed repetitive periods of time during an acoustic emission test are known as rate counters. The tallied signals may be a count of acoustic emission signals, loading cycles, or amplitude levels.

5.7.2 The accuracy of the counting function of the instrumentation should be measured using a tone burst generator set as follows: (1) the amplitude should be well above the threshold level, but well within the dynamic range of the instrumentation; (2) the tone burst frequency should be within the instrumentation nominal bandwidth; (3) the tone burst duration should be at least one cycle, but fewer cycles than would cause the automatic threshold to take effect; (4) the tone burst repetition rate should be adjusted for a period that does not cause the automatic threshold to interfere with the count function. The counting accuracy is assured by comparing the emission count with the tone burst count.

5.8 *Computer-Measured Parameters*:

5.8.1 The limits and linearity of AE parameters recorded by computer-based systems may be measured by means of an electronic AE simulator. The electronic AE simulator provides individually adjustable amplitude, duration, rise time, and relative arrival time. Burst energy from the AE simulator may be calculated from the parameters given.

5.8.2 The limits or dynamic range and linearity of each parameter should be measured as follows for amplitude, duration, and rise time:

5.8.2.1 Connect the AE simulator to the preamplifier input of the channel to be tested.

5.8.2.2 Set up the AE system to record and display the parameter to be tested.

5.8.2.3 Adjust the AE simulator to produce a mid range simulated AE signal where the displayed amplitude, duration, and rise time are 10 % of their maximum value as specified by the AE system manufacturer.

5.8.2.4 Record the value of each parameter at the electronic AE simulator output and at the AE system display.

5.8.2.5 To measure upper limits for each parameter, increase the measured input in equal increments (for example, 10 % of maximum) and record the displayed value for that parameter until the output differs from the input by 10 % or the specified maximum value is exceeded.

5.8.2.6 To measure lower limits for each parameter, adjust input-output condition as in 5.8.2.3, then decrease the input in equal increments (for example, 10 % of the initial value) and record the displayed value until the output differs from the input by 10 % or the minimum value specified by the AE system manufacturer is reached.

5.8.2.7 To test the computer-derived energy per event parameter, it is necessary to calculate the input energy from the electronic AE simulator in accordance with the method used by the AE system. For example, one method used in some AE systems computes approximate burst pulse AE event energy (E) as follows:

$$E \cong DV^2/2$$

where:
D = burst duration, and
V = peak amplitude.

5.8.2.8 Set the initial conditions as in 5.8.2.3. Increment input amplitude to obtain approximately 10 % of full scale change in energy input. Record the displayed energy per event value at each increment until the output differs from the input by 10 % or the maximum value specified by the AE system manufacturer is exceeded. Repeat this process with amplitude fixed at the initial value while incrementing pulse duration.

5.8.2.9 Again repeat the process with amplitude and pulse duration except decrease each parameter until the minimum value specified by the manufacturer is reached or no further change in the output is produced.

5.8.3 The source location computational algorithm is a complex computer process not covered by this document. However, a multichannel electronic AE simulator may be used to check the locational accuracy of systems that rely on the constancy of sound velocity to calculate location. For anisotropic materials where velocity is not constant, other source location algorithms exist such as area location based on first hit sensor.

5.8.3.1 Set up the AE system for source location in accordance with the operator's manual.

5.8.3.2 Set up the multichannel electronic AE simulator to provide simulated AE inputs to the appropriate number of channels.

5.8.3.3 Using the appropriate velocity of sound for the simulated structure, compute the times of flight from the simulated AE source position to each sensor of the source location array. The differences between the times of flight give relative arrival times (delta T) for the simulated AE sensor positions.

5.8.3.4 Record the displayed location coordinates for this initial simulated input. Compute and input a new delta T set for