Designation: E 976 – 00

Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response[1]

1. Scope

1.1 This guide defines simple economical procedures for testing or comparing the performance of acoustic emission sensors. These procedures allow the user to check for degradation of a sensor or to select sets of sensors with nearly identical performances. The procedures are not capable of providing an absolute calibration of the sensor nor do they assure transferability of data sets between organizations.

1.2 *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. Significance and Use

2.1 Acoustic emission data is affected by several characteristics of the instrumentation. The most obvious of these is the system sensitivity. Of all the parameters and components contributing to the sensitivity, the acoustic emission sensor is the one most subject to variation. This variation can be a result of damage or aging, or there can be variations between nominally identical sensors. To detect such variations, it is desirable to have a method for measuring the response of a sensor to an acoustic wave. Specific purposes for checking sensors include: (*1*) checking the stability of its response with time; (*2*) checking the sensor for possible damage after accident or abuse; (*3*) comparing a number of sensors for use in a multichannel system to ensure that their responses are adequately matched; and (*4*) checking the response after thermal cycling or exposure to a hostile environment. It is very important that the sensor characteristics be always measured with the same sensor cable length and impedance as well as the same preamplifier or equivalent. This guide presents several procedures for measuring sensor response. Some of these procedures require a minimum of special equipment.

3. Principles of Application

3.1 The procedures given in this guide are designed to measure the response of an acoustic emission sensor to an arbitrary but repeatable acoustic wave. These procedures in *no* way constitute a calibration of the sensor. The absolute calibration of a sensor requires a complete knowledge of the characteristics of the acoustic wave exciting the sensor or a previously calibrated reference sensor. In either case, such a calibration is beyond the scope of this guide.

3.2 The fundamental requirement for comparing sensor responses is a source of repeatable acoustic waves. The characteristics of the wave do not need to be known as long as the wave can be reproduced at will. The sources and geometries given in this guide will produce primarily compressional waves. While the sensors will respond differently to different types of waves, changes in the response to one type of wave will imply changes in the responses to other types of waves.

3.3 These procedures all use a test block or rod. Such a device provides a convenient mounting surface for the sensor and when appropriately marked, can ensure that the source and the sensor are always positioned identically with respect to each other. The device or rod also provides mechanical loading of the sensor similar to that experienced in actual use. Care must be taken when using these devices to minimize resonances so that the characteristics of the sensor are not masked by these resonances.

3.4 These procedures allow comparison of responses only on the same test setup. No attempt should be made to compare responses on different test setups, whether in the same or separate laboratories.

4. Apparatus

4.1 The essential elements of the apparatus for these procedures are: (*1*) the acoustic emission sensor under test; (*2*) a block or rod; (*3*) a signal source; and (*4*) measuring and recording equipment.

4.1.1 Block diagrams of some of the possible experimental setups are shown in Fig. 1.

---

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

Current edition approved Dec. 10, 2000. Published February 2001. Originally published as E 976 – 84. Last previous edition E 976 – 99.

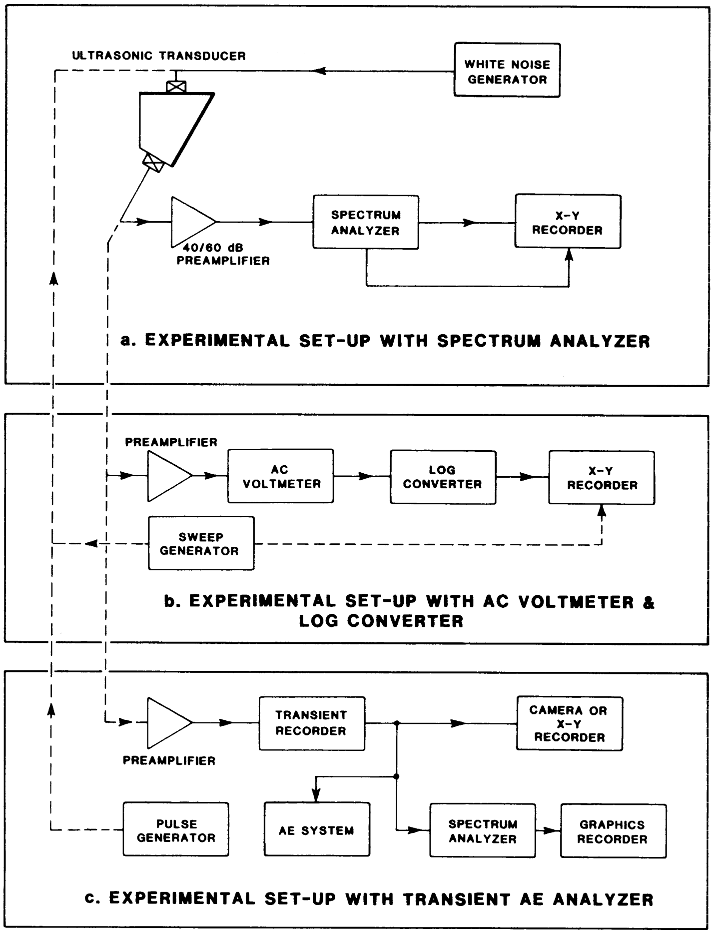


FIG. 1 Block Diagrams of Possible Experimental Setups

4.2 *Blocks*—The design of the block is not critical. However, the use of a "nonresonant" block is recommended for use with an ultrasonic transducer and is required when the transducer drive uses any form of coherent electrical signal.

4.2.1 *Conical "Nonresonant" Block*—The Beattie block, shown in Fig. 2, can be machined from a 10-cm (4-in.) diameter metal billet. The preferred materials are aluminum and low-alloy steel. After the bottom is faced and the taper cut, the block is clamped at a 10° angle and the top face is milled. The dimensions given will provide an approximate circle just over 2.5 cm (1 in.) in diameter for mounting the sensor. The acoustic excitation should be applied at the center of the bottom face. The conic geometry and lack of any parallel surfaces reduce the number of mechanical resonances that the block can support. A further reduction in possible resonances of the block can be achieved by roughly machining all surfaces except where the sensor and exciter are mounted and coating them with a layer of metal-filled epoxy.

4.2.2 *Gas-Jet Test Block*—Two gas-jet test blocks are shown in Fig. 3. The block shown in Fig. 3(*a*) is used for opposite surface comparisons, which produce primarily compressional waves. That shown in Fig. 3(*b*) is for same surface comparisons which produce primarily surface waves. The "nonresonant" block described in 4.2.1 can also be used with a gas jet in order to avoid exciting many resonant modes. The blocks in Fig. 3 have been used successfully but their design is not critical. However it is suggested that the relative positions of the sensor and the jet be retained.

4.2.3 *Acrylic Polymer Rod*—A polymethylmethacrylate rod is shown in Fig. 4. The sensor is mounted on the end of the rod and the acoustic excitation is applied by means of pencil lead break, a consistent distance from the sensor end of the rod. See Appendix X1 for additional details on this technique.

4.3 *Signal Sources*—Three signal sources are recommended: an electrically driven ultrasonic transducer, a gas jet, and an impulsive source produced by breaking a pencil lead.

4.3.1 *Ultrasonic Transducer*—Repeatable acoustic waves can be produced by an ultrasonic transducer permanently bonded to a test block. The transducer should be heavily damped to provide a broad frequency response and have a center frequency in the 2.25 to 5.0-MHz range. The diameter of the active element should be at least 1.25 cm (0.5 in.) to provide measurable signal strength at the position of the sensor under test. The ultrasonic transducer should be checked for adequate response in the 50 to 200-kHz region before permanent bonding to the test block.

4.3.1.1 *White Noise Generator*—An ultrasonic transducer driven by a white noise generator produces an acoustic wave that lacks coherent wave trains of many wave lengths at one frequency. This lack of coherent wave trains greatly reduces the number and strength of the mechanical resonances excited in a structure. Therefore, an ultrasonic transducer driven by a

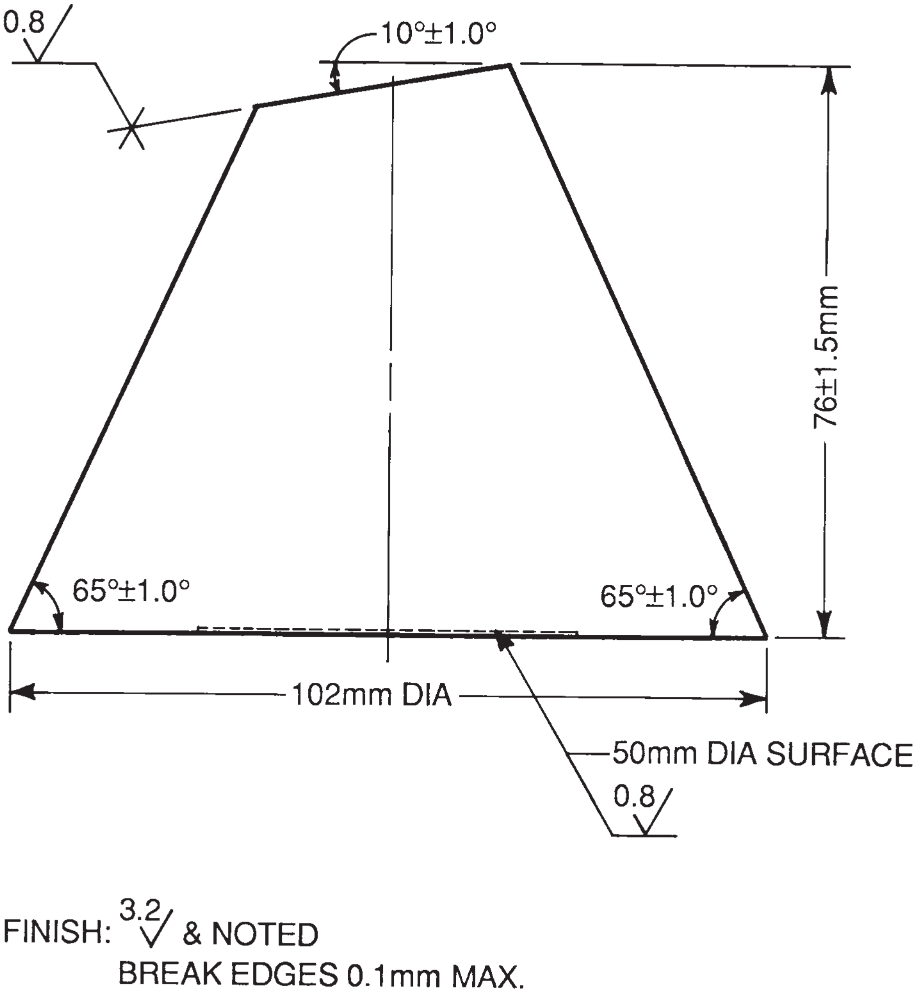


FIG. 2 The Beattie Block

white-noise generator can be used with a resonant block having parallel sides. However, the use of a "nonresonant" block such as that described in 4.2.1 is strongly recommended. The generator should have a white-noise spectrum covering at least the frequency range from 10 kHz to 2 MHz and be capable of an output level of 1 V rms.

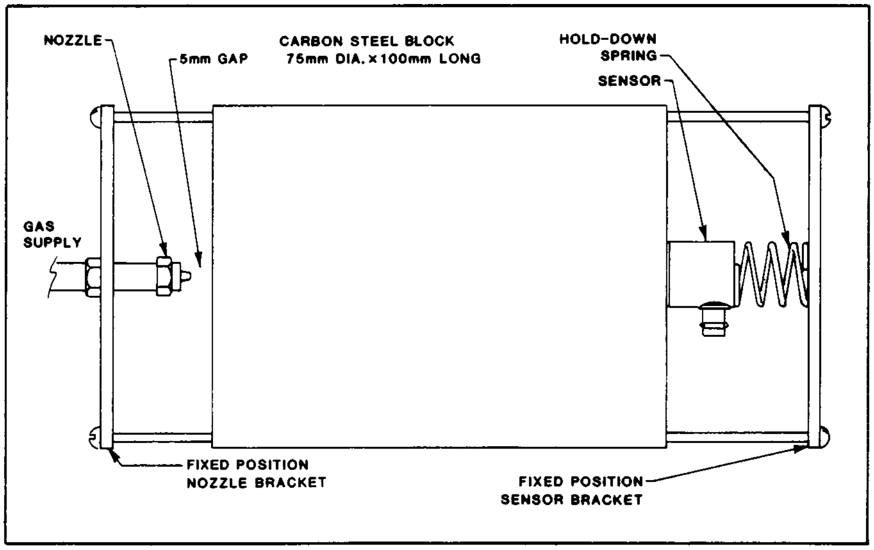
4.3.1.2 *Sweep Generator*—The ultrasonic transducer can be driven by a sweep generator in conjunction with a "nonresonant" block. Even with this block, some resonances will be produced that may partially mask the response of the sensor under test. The sweep generator should have a maximum frequency of at least 2 MHz and the sweep speed should be compatible with the XY recorder used. It is recommended that a sweep generator be used with an a-c voltmeter with a logarithmic output.

4.3.1.3 *Pulse Generator*—The ultrasonic transducer may be excited by a pulse generator. The pulse width should be either slightly less than one-half the period of the center frequency of the transducer (≤0.22 µs for a 2.25 MHz transducer) or longer than the damping time of the sensor, block, and transducer (typically >10 ms). The pulse repetition rate should be low (<100 pulses/s) so that each acoustic wave train is damped out before the next one is excited.

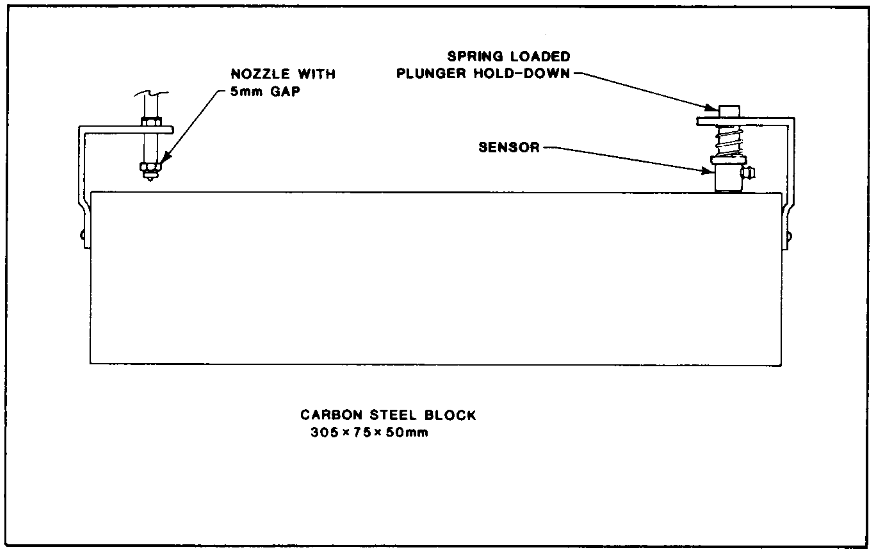
4.3.1.4 The pulse generator should be used with an oscilloscope and camera or, in single-pulse mode, with the counter in an acoustic emission system. Not enough energy is generated above 200 kHz for effective use with a spectrum analyzer.

4.3.2 *Gas Jet*—Suitable gases for this apparatus are extra dry air, helium, etc. A pressure between 150 and 200 kPa (20 to 30 psi) is recommended for helium or extra dry air. Once a pressure and a gas has been chosen, all further tests with the apparatus should use that gas and pressure. The gas jet should be permanently attached to the test block (see Fig. 3(*a*) and 3 (*b*)).

4.3.3 *Pencil Lead Break*—A repeatable acoustic wave can be generated by carefully breaking a pencil lead against the test block or rod. When the lead breaks, there is a sudden release of the stress on the surface of the block where the lead is touching. This stress release generates an acoustic wave. The Hsu pencil source uses a mechanical pencil with a 0.3-mm diameter lead (0.5-mm lead is also acceptable but produces a larger signal). The Nielsen shoe, shown in Fig. 5 can aid in



(*a*) Opposite Surface Comparison Setup



(*b*) Same Surface Comparison Test

FIG. 3 Gas-Jet Test Blocks

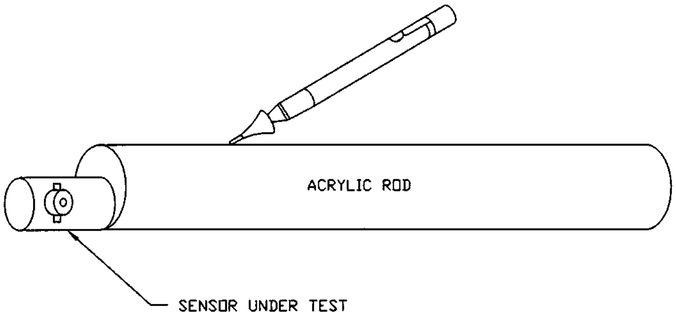


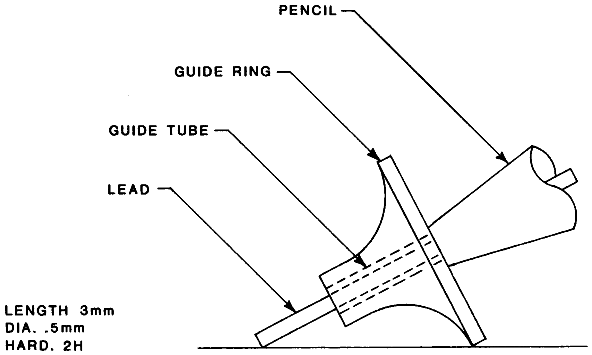
FIG. 4 Acrylic Polymer Rod

breaking the lead consistently. Care should be taken to always break the same length of the same type of lead (lengths between 2 and 3 mm are preferred).[2] The lead should always be broken at the same spot on the block or rod with the same angle and orientation of the pencil. Spacing between the lead break and sensor should be at least 10 cm (4 in.). With distances shorter than that, it is harder to get consistent results. The most desirable permanent record of a pencil lead break is the wave form captured by a transient recorder or oscilloscope.

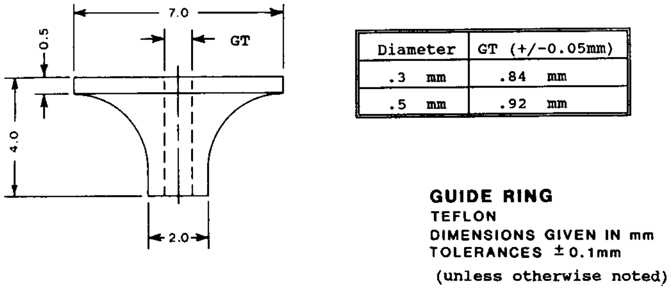
4.4 *Measuring and Recording Equipment*— The output of the sensor under test must be amplified before it can be measured. After the measurement, the results should be stored in a form that allows an easy comparison, either with another sensor or with the same sensor at a different time.

---

[2] Pentel 2H lead has been found satisfactory for this purpose.



(*a*) Nielsen Shoe on Hsu Pencil Source



(*b*) Nielsen Shoe

FIG. 5 Guide Ring for Impulsive SourceⒶP

4.4.1 *Preamplifier*—The preamplifier, together with the sensor to preamp coaxial cable, provides an electrical load for the sensor, amplifies the output, and filters out unwanted frequencies. The electrical load on the sensor can distort the low-frequency response of a sensor with low inherent capacitance. To prevent this from occurring, it is recommended that short sensor cables (<2 m) be used and the resistive component of the preamplifier input impedance be 20 kΩ or greater. The preamplifier gain should be fixed. Either 40 to 60-dB gains are suitable for most sensors. The bandpass of the preamplifier should be at least 20 to 1200 kHz. It is recommended that one preamplifier be set aside to be used exclusively in the test setup. However, it may be appropriate at times to test a sensor with the preamplifier assigned to it in an experiment.

4.4.2 *Spectrum Analyzers*—A very useful instrument for testing sensor response is the spectrum analyzer. Spectrum analyzers can be used with acoustic signals generated by ultrasonic transducers that are driven by either white-noise generators or tracking-sweep generators, by gas-jet sources or by acoustic signals, produced by any source, that are captured on a transient recorder and replayed into the spectrum analyzer. A suitable spectrum analyzer should be capable of displaying a spectrum covering the frequency range from 20 kHz to 1.2 MHz. The amplitude should be displayed on a logarithmic scale covering a range from at least 50 dB in order to display the entire dynamic range of the sensor. The spectrum can be recorded photographically from an oscilloscope. However, the most useful output is an XY plot of the spectrum as shown in Fig. 6.

4.4.3 *Voltmeters*—An a-c voltmeter can be used to measure sensor outputs produced by signals generated by an ultrasonic transducer driven by a sweep generator. The response of the voltmeter should be flat over the frequency range from 10 kHz to 2 MHz. It is desirable that the voltmeter either have a logarithmic output or be capable of driving a logarithmic converter. The output of the voltmeter or converter is recorded on an XY recorder as a function of frequency.

4.4.3.1 The limited dynamic range of an rms voltmeter makes it less desirable than an a-c averaging voltmeter when used with a sweep generator. However, a rough estimate of a sensor performance can be obtained by using an rms or a-c voltmeter to measure the output of a sensor driven by a wide band source such as a white-noise generator or a gas jet.

4.4.4 *Acoustic Emission System*—A sensor can be characterized by using an acoustic emission system and an impulsive source such as a pencil lead break, an ultrasonic (or AE) transducer driven by a pulse generator, or the impulsive source that is built into many AE systems with automated pulsing capabilities. One or more of several significant AE signal features (such as amplitude, counts or energy) can be used to characterize the sensor response. The acoustic emission features from each signal pulse should be measured for multiple pulses (at least three). Data recorded should be the individual

---

ⒶP Editorially corrected.

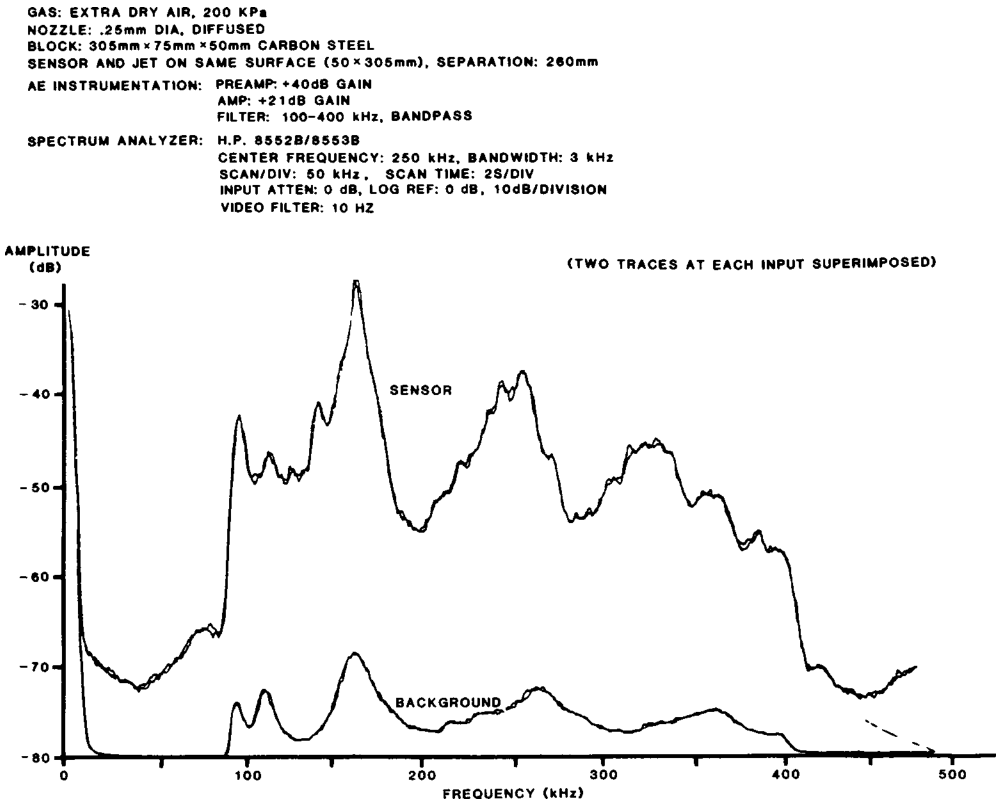


FIG. 6 Example of an X-Y Recorder Plot from a Spectrum Analyzer (150 kHz Resonant Sensor)

AE feature values (for repeatability determination) and average value of the readings (for sensitivity determination). In addition, the system gain, preamplifier gain, filtering, and any other significant settings of acoustic emission system should be recorded.

4.4.5 *Transient Recorders and Storage Oscilloscopes*—The waveform generated by a sensor in response to a single pulse or a pencil lead break can be measured and stored by a transient recorder, digital oscilloscope, or a waveform-based acoustic emission system. This waveform can be recorded on computer media, displayed on a computer screen or printed out on a printer or X-Y recorder. Digitization rates should be at least 10 samples per highest frequency period in the waveform. Lower rates might result in distortion or loss of amplitude accuracy of the wave shape. When comparing waveforms, emphasis should be placed on the initial few cycles and on the large amplitude features. Small variations late in the waveform are often produced by slight changes in the coupling or position of the sensor under test. The waveform can also be converted into the frequency domain by means of a fast fourier transform (FFT) for amplitude versus frequency response analysis.

5. Procedure

5.1 Place the sensors under test on the test block or rod in as near to identical positions as possible. Use identical forces to hold the sensor and block (or rod) together. A low-viscosity couplant is desirable to ensure reproducible and thin couplant thicknesses. For all setups, take several measurements before the final data is recorded to ensure reproducibility. During the initial measurements, display the preamplifier output on an oscilloscope to see that the signals are not being clipped by overdriving the preamplifier. Establish written procedures and follow them to ensure reproducibility over long periods of time.

6. Interpretation of Results

6.1 Short-term reproducibility of results, covering such actions as removing and remounting the sensor, should be better than 3 dB if the test is conducted under normal working conditions. Long-term reproducibility of the test system should be checked periodically by the use of a reference sensor that is not exposed to the risk of environmental damage. Variations of sensor response greater than 4 dB indicates damage or degradation, and the cause of the discrepancy should be further investigated. While there are no set criteria for acceptable limits on sensor degradation, a sensor whose sensitivity had fallen by more than 6 dB would generally be considered unfit for further service in acoustic emission measurements.

APPENDIX

(Nonmandatory Information)

X1. VERIFYING THE CONSISTENCY OF AE SENSOR RESPONSE USING AN ACRYLIC ROD

X1.1 Scope

X1.1.1 This procedure is recommended for routinely checking the sensitivity of acoustic emission (AE) sensors. It is intended to provide a reliable, precisely specified way of comparing a set of sensors and/or telling whether an individual sensor's sensitivity is degrading during its service life. This procedure is not a "calibration" nor does it give frequency response information. It is simply a way of verifying consistency of sensor peak amplitude response. The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

X1.2 Referenced Documents

X1.2.1 *ASTM Standards*:

E 650 Guide for Mounting Piezoelectric Acoustic Emission Sensors[3]

E 750 Practice for Characterizing Acoustic Emission Instrumentation[3]

X1.3 Significance and Use

X1.3.1 Degradation in sensor performance can occur due to dropping, mechanical shock while mounted on the test structure, temperature cycles, etc. It is necessary and desirable to have a simple measurement procedure that will check the consistency of sensor response, over time or within a batch, while holding all other variables constant. While test blocks of many different kinds have been used for this purpose for many years, an acrylic polymer rod offers the best all-round combination of suitable acoustic properties, practical convenience, ease of procurement, and low cost.

X1.3.2 Since the acoustic properties of the acrylic rod are known to depend on temperature, this procedure requires that the rod, sensors, and couplant be stabilized at the same working temperature, prior to application of the practice.

X1.3.3 Properly applied and with proper record keeping, this procedure can be used in many ways. The user organization must determine the context for its use, the acceptance standards and the actions to be taken based on the lead break results. The following uses are suggested:

X1.3.3.1 To determine when a sensor is no longer suitable for use.

X1.3.3.2 To check sensors that have been exposed to high-risk conditions such as dropping, overheating, etc.

X1.3.3.3 To get an early warning of sensor degradation with time. This can lead to identifying conditions of use which are damaging sensors, and thus to better equipment care and lower replacement costs.

X1.3.3.4 To obtain matched sets of sensors, preamplifiers, and/or instrumentation channels for more uniform performance of the total system.

X1.3.3.5 To save time and money, by eliminating the installation of bad sensors.

X1.3.3.6 To verify sensors quickly but consistently in the field and to assist trouble-shooting when a channel does not pass a performance check.

X1.3.4 All the above uses are recommended for consideration. The purpose of this document is not to call out how these uses are to be implemented, but only to state how the test itself is to be performed so that the results obtained will be accurate and reliable.

X1.4 Apparatus

X1.4.1 The following apparatus are required in order to carry out this procedure:

X1.4.1.1 An acrylic polymer cylindrical rod (Fig. X1.1) should be used. The actual material of the acrylic polymer rod is polymethylmethacrylate. Some of the generic brand names of this material include, but are not limited to; Lucite PMMA, plexiglass, perspex, etc.

(1) Dimensions of the rod should be 78.74 cm (31 in.) long by 3.81 cm (1.5 in.) diameter, sensor end cut true and smooth with a surface finish of 0.4µm RMS (0.16 µin.).

(2) Other lengths of rod are acceptable, provided that there is sufficient distance to attenuate and prevent reflected signals from the non-sensor end of the rod reaching the sensor.

(3) A permanent reference mark (for example an "X") is placed on the rod at a distance of 10.16 cm (4 in.) from one

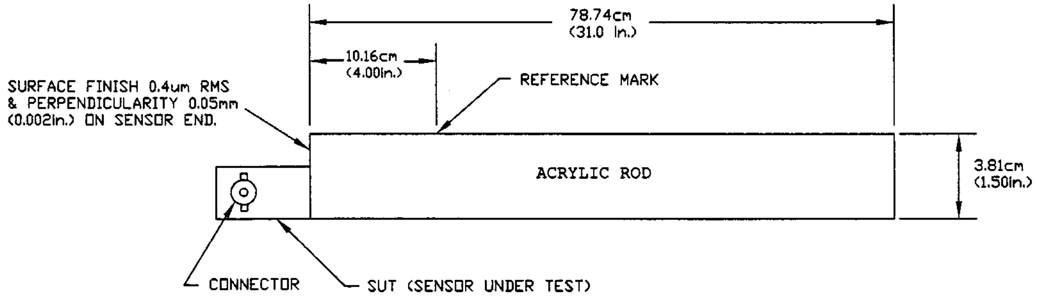


FIG. X1.1 Acrylic Rod Description

---

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

end; this marks the spot where the lead is to be broken. It is convenient to provide a very small spotface, for example, 0.5 mm (0.02 in.) in size at this reference mark point, to rest the tip of the pencil lead to avoid slippage during the lead break process.

NOTE X1.1—The surface finish of the cylindrical rod section could produce reflections that affect AE response. The surface finish should be maintained in a clean, undamaged condition.

X1.4.2 A 0.3 or 0.5 mm Hsu-Nielsen pencil lead break source, with Nielsen shoe as described earlier in this guide, with 2H pencil lead.

X1.4.3 Sensor(s) to be tested.

X1.4.4 Acoustic emission equipment, with amplitude measurement capability, for recording sensor response. (Operating familiarity with the apparatus is assumed).

X1.4.5 Couplant, to be standardized and documented by the user of this guide.

X1.5 Procedure

X1.5.1 Assure that the acrylic rod, sensors and couplant have been allowed to stabilize to the working temperature of the examination environment.

X1.5.2 Place the prepared acrylic rod horizontally on a suitable hard, flat surface (such as a benchtop) with the 10.16 cm (4.0 in.) reference mark facing vertically up (12 o'clock). It may be secured with tape or other means no closer than 12 in. from the reference mark.

X1.5.3 Prepare and power-up the AE measurement system including preamplifier (if used) and connecting cables; allow warm up time as necessary; verify the system's performance. Verification may be accomplished on the rod using a reference sensor that is dedicated to this purpose and not exposed to the hazards of field use; or it may be accomplished by electronic procedures such as those described in Practice E 750.

X1.5.4 Mount the sensor to be tested on the flat end of the rod using the prescribed couplant. Wipe off any old couplant before mounting and do not let couplant from previous sensors accumulate under the rod. Mount the sensor in the 6 o'clock position so that it is resting on the same surface supporting the acrylic rod. This will prevent slipping of the sensor during sensor verification.

X1.5.5 Using the Hsu-Nielsen pencil lead source, break lead with the end of the 0.3 (or 0.5) mm lead in the center of the reference mark, with a lead extension of 2.5mm ± 0.5mm (0.1 in. ± 0.20 in.). Use the Nielsen shoe to obtain a consistent 30° angle between the lead and the surface. Hold the pencil pointing towards the sensor but with its axis approximately 22° (a quarter of a right angle) off from the axis of the rod, so that the lead flies off to one side and does not hit the sensor. Fingers may be rested on the rod on the side away from the sensor to steady the pencil, but there must be no finger contact or other materials in contact with the rod between pencil and sensor, except for the hard surfrace on which the acrylic rod is resting.

X1.5.6 Maintaining instrument settings, make three consistent lead breaks for each sensor, recording amplitude responses on a "Sensor Performance Verification Form", for example, similar to that shown in Fig. X1.2. Determine the average sensor amplitude response and proceed to the next sensor.

X1.5.7 Acceptance criteria (which should be assigned prior to conducting this practice by the testing organization) should be documented, for example as shown in Fig. X1.2, and applied to the sensor data recorded. Sensors failing the criteria should not be used during the examination, and should be returned for a more comprehensive analysis, repaired, or discarded.

X1.6 Precision and Bias

X1.6.1 Temperature variations are known to affect the acoustic absorption properties of the acrylic rod. However, since this is a comparative technique rather than an absolute one, this practice can be carried out with good results if all component parts used in the practice have been allowed to stabilize to the examination (environmental) temperature prior to application.

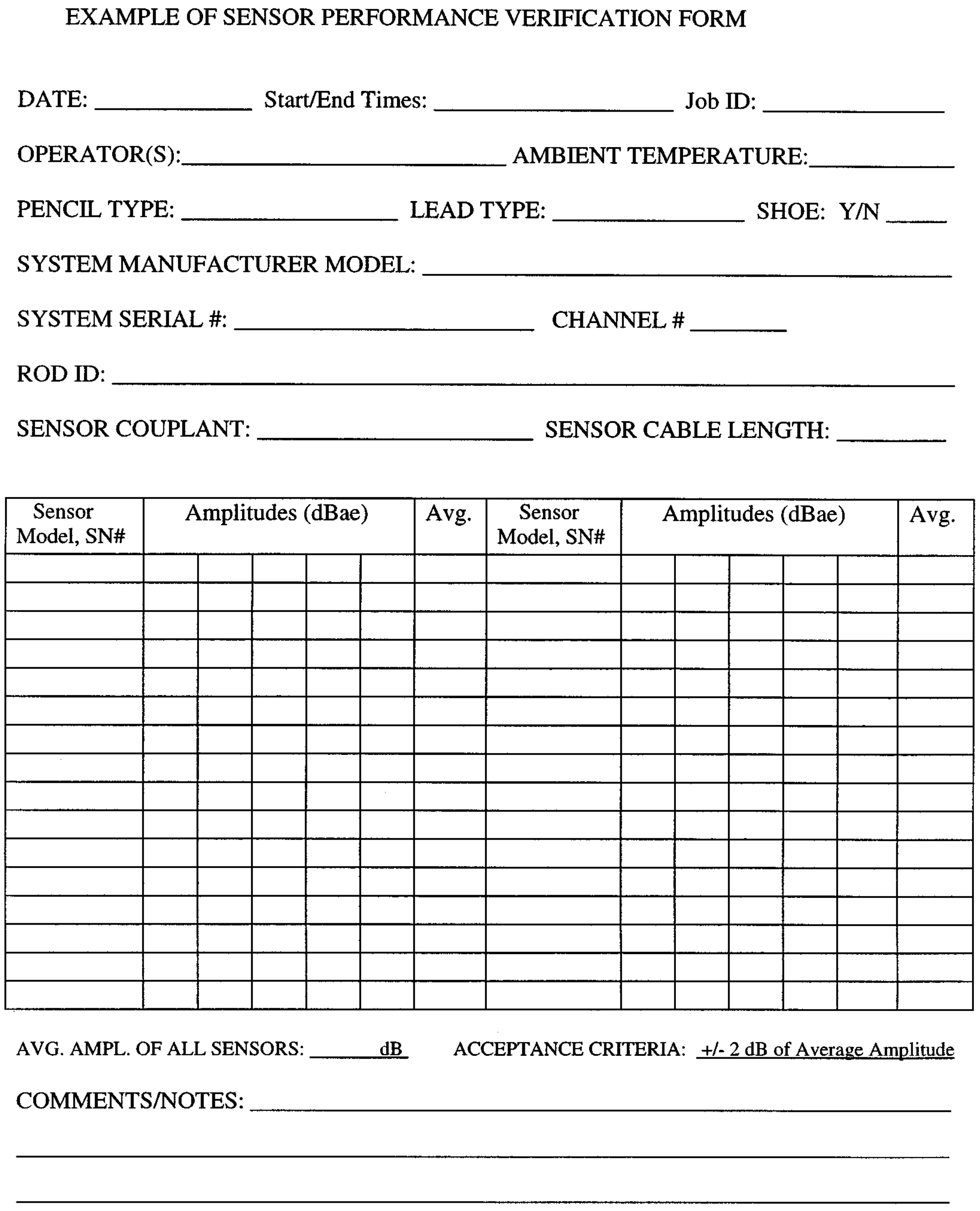
X1.6.2 Rod-to-rod variations of several dB have been reported, but it is not certain whether these came truly from the rods or from some other source of variation.

X1.6.3 Person-to-person variations can be reduced to a range of 1 dB by proper technique and training.

X1.6.4 Variations in fracture performance within a lead and between leads are possible. With experience, occasional bad breaks can often be identified by the operator, even without reference to the results of the measurement.

X1.6.5 Bad breaks are relatively common as the pencil is about to run out of lead.

X1.6.6 Uniformity of material is a major quality goal of the lead manufacturer, but even so, runs of bad lead can occur due to manufacturing variations.



EXAMPLE OF SENSOR PERFORMANCE VERIFICATION FORM

DATE: ____________ Start/End Times: ___________________ Job ID: ______________

OPERATOR(S):_________________________ AMBIENT TEMPERATURE:___________

PENCIL TYPE: _________________ LEAD TYPE: _______________ SHOE: Y/N _____

SYSTEM MANUFACTURER MODEL: ____

SYSTEM SERIAL #: ________________________ CHANNEL # ________

ROD ID: ____

SENSOR COUPLANT: ______________________ SENSOR CABLE LENGTH: _________

Sensor Model, SN#	Amplitudes (dBae)					Avg.	Sensor Model, SN#	Amplitudes (dBae)					Avg.

AVG. AMPL. OF ALL SENSORS: _______dB ACCEPTANCE CRITERIA: +/- 2 dB of Average Amplitude

COMMENTS/NOTES: ____

____

____

FIG. X1.2 Sensor Performance Verification Form

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org).