Designation: E976 – 15

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

This standard is issued under the fixed designation E976; 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 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 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E750 Practice for Characterizing Acoustic Emission Instrumentation

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

E2374 Guide for Acoustic Emission System Performance Verification

3. Significance and Use

3.1 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.

3.2 It is not the intent of this guide to evaluate AE system performance. Refer to Practice E750 for characterizing acoustic instrumentation and refer to Guide E2374 for AE system performance verification.

3.3 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.

3.4 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.

3.5 These procedures 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

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[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 Method.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

be taken when using these devices to minimize resonances so that the characteristics of the sensor are not masked by these resonances.

3.6 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.

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 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 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 Practice E2075 for additional details on this technique.

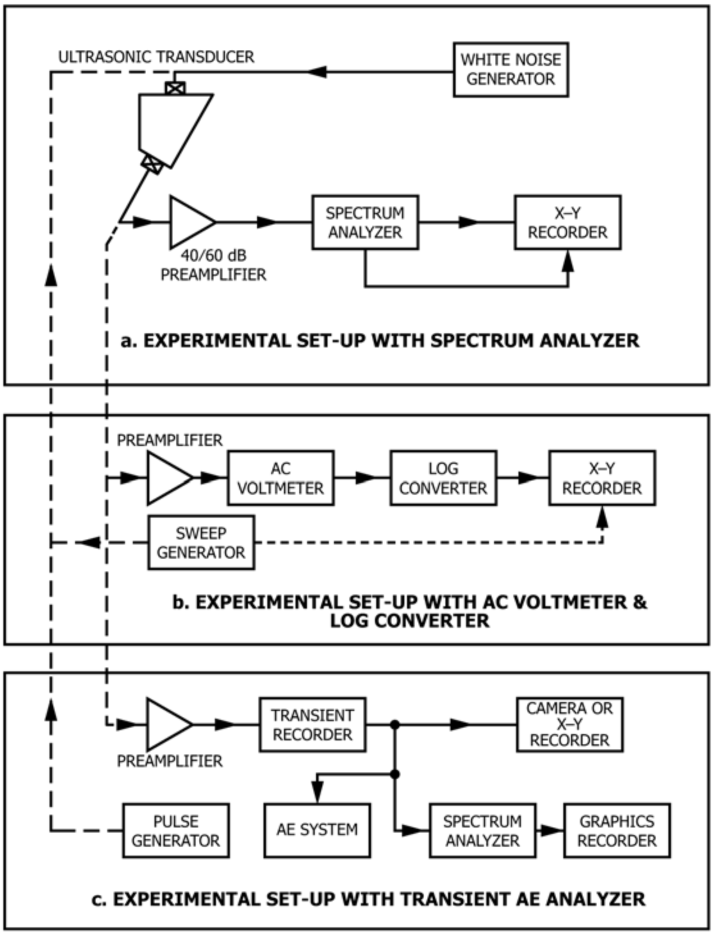


FIG. 1 Block Diagrams of Possible Experimental Setups

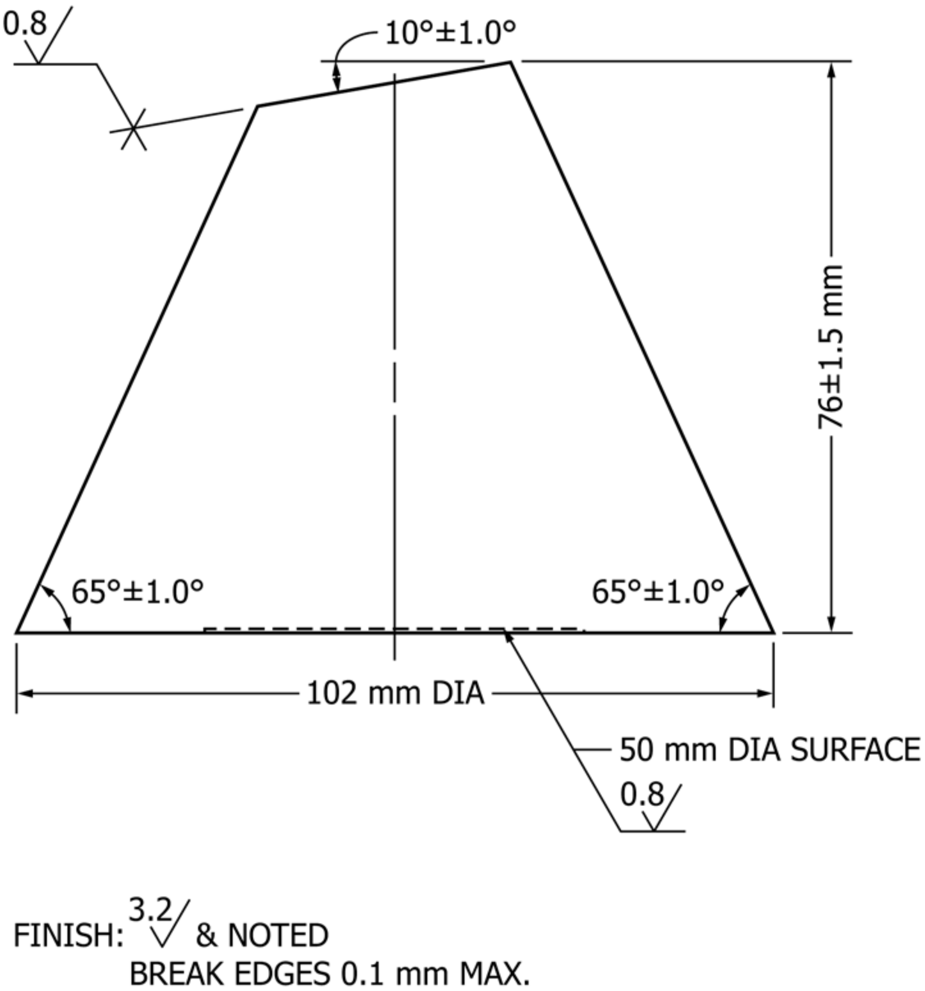


FIG. 2 The Beattie Block

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.

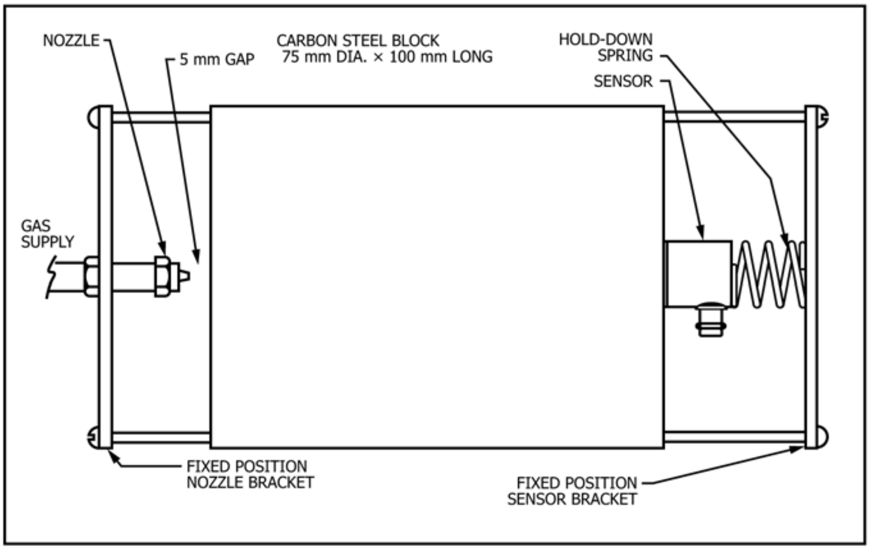
4.3.1 *Ultrasonic Transducer*—Repeatable acoustic waves can be produced by an ultrasonic transducer permanently bonded to a test block, or attached face-to-face to the AE sensor under test. The transducer should be heavily damped to provide a broad frequency response and have a center frequency in the 2.25 to 5.0-MHz range. The diameter of the active element should be at least 1.25 cm 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 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.

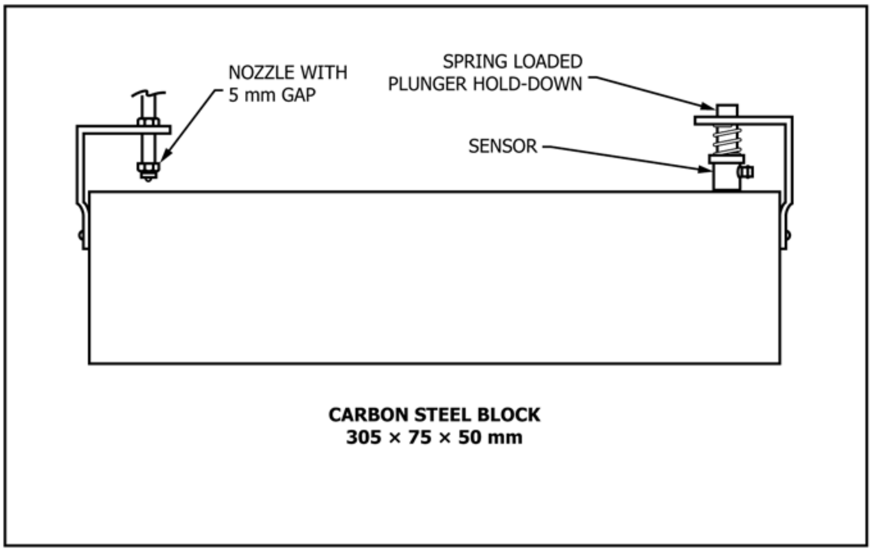
4.3.1.2 *Sweep Generator*—The ultrasonic transducer can be driven by a sweep generator (or swept wave burst) in conjunction with a "nonresonant" block. Even with this block, some resonances will be produced that may partially mask the response of the sensor under test. The sweep generator should have a maximum frequency of at least 2 MHz and should be used with a digital oscilloscope or waveform based data acquisition system with frequency analysis (FFT) capabilities to analyze the resulting response of the sensor under test.

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 a digital oscilloscope or waveform based data acquisition system (such as a waveform based AE system) or, in single-pulse mode, with the counter in an acoustic emission system.



(*a*) Opposite Surface Comparison Setup



(*b*) Same Surface Comparison Test

FIG. 3 Gas-Jet Test Blocks

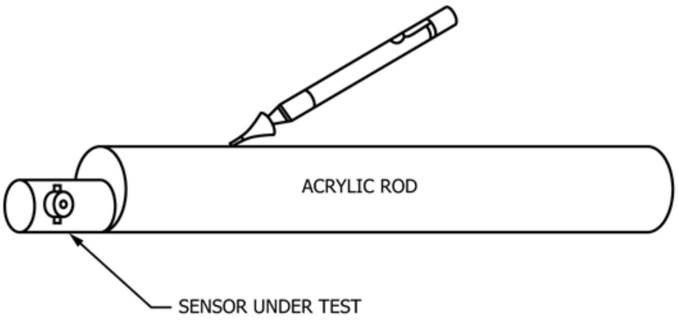


FIG. 4 Acrylic Polymer Rod

4.3.2 *Gas Jet*—Suitable gases for this apparatus are extra dry air, helium, etc. A pressure between 150 and 200 kPa 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. Care should be taken to always break the same length of the same type of lead. The normal lead diameter is 0.3 mm. The normal lead length is 2.5 ± 0.5 mm. The lead hardness is 2H. Space permitting, the pencil is held at an angle of 30 degrees to the surface of the test block or rod. 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 the center of the sensor should be at least 100 mm and must be documented. With distances shorter than 100 mm, it is harder to get consistent results. The spacing between the lead break and sensor must be large enough to avoid saturating the electronics, which would invalidate comparisons of amplitude response. The most desirable permanent record of a pencil lead break is the waveform captured by a waveform-based data acquisition system (such as an AE waveform-based instrument) with frequency analysis (FFT) capabilities.

4.3.3.1 The Nielsen shoe, shown in Fig. 5, is a polytetrafluoroethylene guide ring that can aid in breaking lead consistently. When the guide ring is constructed to the dimensions of Fig. 5, an angle of 30 degrees between pencil and structure will be obtained for a 2.5 mm lead extension. The dimension GT is representative of the diameter of the pencil ferrule; typically it is 0.84 mm for a 0.3 mm pencil, but it depends on the brand and model of pencil. The length of the guide ring should be matched to the length of the pencil ferrule.

4.3.3.2 The pencil lead break technique has other uses in addition to determining the reproducibility of sensor response, and it is not limited to use on blocks or rods. For some of these other uses, larger lead diameters (which produce larger signals) may be appropriate and simple measurements of signal amplitude may suffice in lieu of full waveform capture.

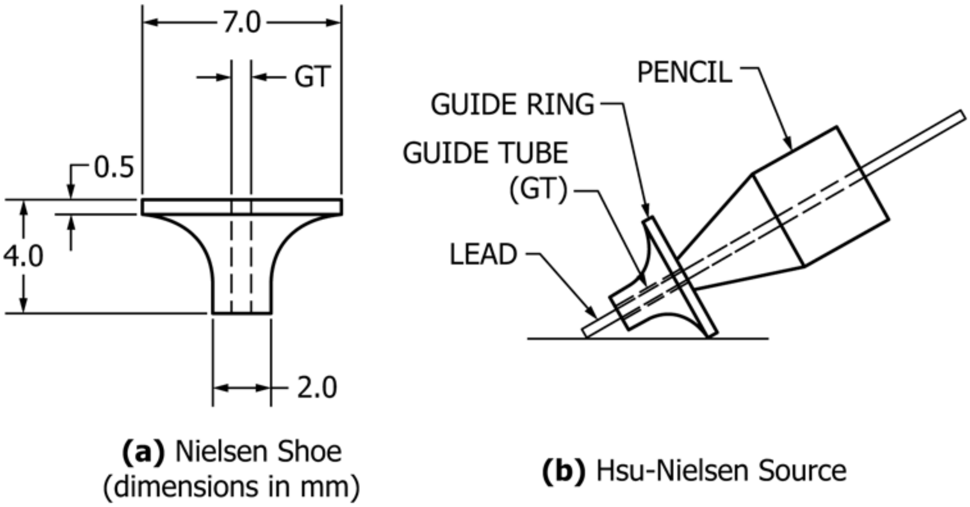
4.4 *Measuring and Recording Equipment*—The output of the sensor under test must be amplified before it can be measured. After the measurement, the results should be stored in a form that allows an easy comparison, either with another sensor or with the same sensor at a different time.

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 *Waveform Based Instruments 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. Digitization rates should be at least ten 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.

4.4.3 *Spectrum Analyzers*—Spectrum (FFT) 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 graph showing the sensor amplitude response or power versus frequency as shown in Fig. 6.

4.4.4 *Acoustic Emission System*—A sensor can be characterized by using an acoustic emission system and an impulsive



(a) Nielsen Shoe
(dimensions in mm)

(b) Hsu-Nielsen Source

FIG. 5 Nielsen Shoe Used in Conjunction with Hsu Pencil

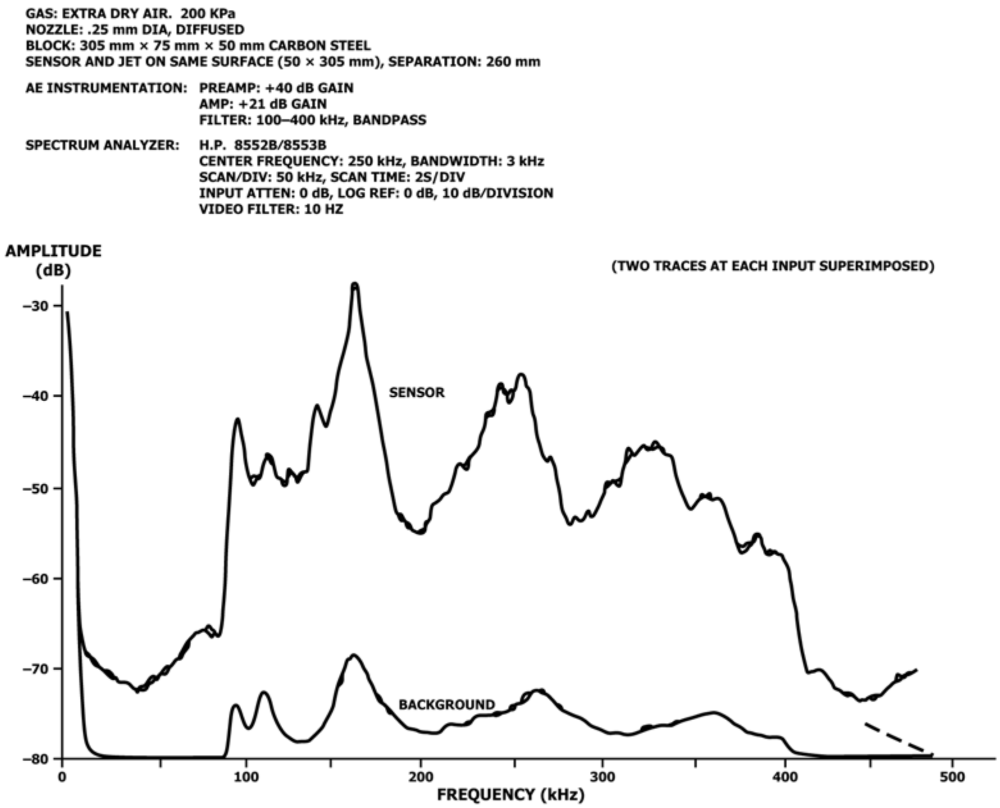


FIG. 6 Example of an Amplitude vs. Frequency Plot of a 150 kHz Resonant Sensor

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 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 the acoustic emission system should be recorded.

4.4.5 *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.

4.4.5.1 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.

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 minimum 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 or waveform based instrument 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.

7. Keywords

7.1 AE sensor; Beattie Block; Gas-Jet test blocks; Nielson shoe

SUMMARY OF CHANGES

Committee E07 has identified the location of selected changes to this standard since the last issue (E976-10) that may impact the use of this standard.

(1) Replaced Fig. 5.
(2) Made subsection 4.3.3 (pencil lead break technique) more definitive to encourage uniform PLB practice across ASTM and other standards.
(3) Added section 4.3.3.1 to describe the Nielsen Shoe.
(4) Added section 4.3.3.2 to describe other applications and the use of different lead diameters.

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