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Standard Test Method for Primary Calibration of Acoustic Emission Sensors[1]

This standard is issued under the fixed designation E1106; 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 test method covers the requirements for the absolute calibration of acoustic emission (AE) sensors. The calibration yields the frequency response of a transducer to waves, at a surface, of the type normally encountered in acoustic emission work. The transducer voltage response is determined at discrete frequency intervals of approximately 10 kHz up to 1 MHz. The input is a given well-established dynamic displacement normal to the mounting surface. The units of the calibration are output voltage per unit mechanical input (displacement, velocity, or acceleration).

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E114 Practice for Ultrasonic Pulse-Echo Straight-Beam Contact Testing

E494 Practice for Measuring Ultrasonic Velocity in Materials by Comparative Pulse-Echo Method

E650 Guide for Mounting Piezoelectric Acoustic Emission Sensors

E1316 Terminology for Nondestructive Examinations

3. Terminology

3.1 Refer to Terminology E1316 for terminology used in this test method.

4. Significance and Use

4.1 *Transfer Standards*—One purpose of this test method is for the direct calibration of displacement transducers for use as secondary standards for the calibration of AE sensors for use in nondestructive evaluation. For this purpose, the transfer standard should be high fidelity and very well behaved and understood. If this can be established, the stated accuracy should apply over the full frequency range up to 1 MHz.

NOTE 1—The stated accuracy applies only if the transfer standard returns to quiescence, following the transient input, before any wave reflected from the boundary of the calibration block returns to the transfer standard (~100 µs). For low frequencies with periods on the order of the time window, this condition is problematical to prove.

4.2 *Applications Sensors*—This test method may also be used for the calibration of AE sensors for use in nondestructive evaluation. Some of these sensors are less well behaved than devices suitable for a transfer standard. The stated accuracy for such devices applies in the range of 100 kHz to 1 MHz and with less accuracy below 100 kHz.

5. General Requirements

5.1 A primary difficulty in any calibration of a mechanical/electrical transduction device is the determination of the mechanical-motion input to the device. To address this difficulty, this calibration procedure uses *(i)* a standard transducer whose absolute sensitivity is known from its design and physical characteristics; and also *(ii)* a source that produces motion that approximates a waveform calculable from theory. The use of two independent sources of information confers a degree of redundancy that is employed to confirm the validity of the measurements and quantify the experimental errors. Briefly stated, the sensitivity of the transfer standard (or other sensor under test) is determined by comparison with the standard transducer, while knowledge of a part of the theoretical waveform is used as a check.

5.2 *Test Block and Mechanical Input*—The mechanical input to the sensors is obtained by pressing a glass capillary

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[1] This test method 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.

down onto the surface of a large test block until it breaks. The reasons for selecting this approach are: *(a)* capillary breaks are localized and short in duration, like natural acoustic emission events; and *(b)* use of a large block simplifies wave propagation and makes sensor output less dependent on arbitrary features of block geometry.

5.2.1 Prior to the fracture of the glass capillary, the force it exerts on the surface is distributed over an area on the order of 2 mm × 0.3 mm.[3] When the glass capillary breaks, the force it was applying to the surface is abruptly relieved, within a time on the order of 0.2 to 0.3 µs. Within the limitations arising from these finite dimensions, the breaking of the capillary approximates a step force function at a point on the surface of the block. Theoretical solutions for the idealized response of a half-space to a normal point-force step function in time applied to the surface are available.[4,5] The outputs of flat-response transducers have been found to be a good match (except for the infinite amplitude part) to the theoretical waveforms, supporting the use of this theory as a check on the primary calibration of sensors. An example with a flat response transducer is shown in Figure 9. The vertical component of the theoretical waveform comprises three parts: *(a)* a low-amplitude response beginning at time d/c_L, where d is the distance from the source and c_L is the longitudinal wave velocity; *(b)* a short impulsive response between times d/c_S and d/c_R, where c_S is the shear wave velocity and c_R the Rayleigh wave velocity; *(c)* a step function beginning at d/c_R. It is the last of these that is salient for checking the sensor calibration. The theoretical height[6] (shelf value [see Figure 9 for determination of the shelf value], relative to zero displacement) of this displacement step u_3 is:

$$u_3 = F_0 A / 4\pi\mu d(A - 1)$$

where F_0 is the applied force (which is measured), µ is the shear modulus (calculated by use of the shear wave velocity) of the test block, $A = (c_L/c_S)^2$ and d is the distance from the source to the transducer.

5.3 *Absolute Displacement Measurement*—An absolute measurement of the dynamic normal surface displacement of the block is required for this calibration test method. The transducer used for this measurement is a standard transducer against which the device under test is compared. The standard transducer should meet or exceed the performance of the capacitive transducer described by Breckenridge and Greenspan.[7] The important characteristics of the standard transducer include high fidelity, high sensitivity, and operating characteristics amenable to theoretical calculation. It should also present no appreciable dynamic loading to the surface it is measuring.

5.3.1 For a calibration, the standard transducer and the device to be calibrated are both placed on the same surface of the block as the mechanical input and equidistant in opposite directions from it. This guarantees that both experience the same displacement-time history. Comparison of the output of the transfer standard or AE sensor with the output of the standard transducer yields a calibration of the device under test.

5.3.2 Other relative geometries for the input and transducers are possible, but results from other geometries should only be used to supplement results from the "same surface" geometry. AE waves in structures are most frequently dominated by surface wave phenomena, and the calibration should be based on the transducer's response to such waves.

5.4 *Units for the Calibration*—An AE sensor may be considered to respond to either stress or strain at its front face. The actual stress and strain at the front face of a mounted sensor depend on the interaction between the mechanical impedance of the sensor (load) and that of the mounting block (driver). Neither the stress nor the strain is amenable to direct measurement at this location. However, the free displacement that would occur at the surface of the block in the absence of the sensor can be inferred from measurements made elsewhere on the surface. Also, the ideal displacement (except at the point where the displacement becomes infinite) for an ideal source is known from theory. Since AE sensors are used to monitor motion at a free surface of a structure and interactive effects between sensor and structure are generally of no interest, the free surface motion is the appropriate input variable. It is, therefore, recommended that the units of calibration should be voltage per unit of free motion; for example, volts per metre.

5.5 *Block Material:*

5.5.1 Since the calibration depends on the interaction of the mechanical impedance of the block and that of the AE sensor, a calibration procedure must specify the material of the block. Calibrations performed on blocks of different materials will yield transducer sensitivity versus frequency curves that are different in shape and in average magnitude. The amount by which such averages differ may be very large. A transducer calibrated on a glass or aluminum block will have an average sensitivity that may be from 50 to 100 % of the value obtained on steel, and will have an average sensitivity that may be as little as 3 % of the value obtained on steel if calibrated on a polymethyl methacrylate block. In general, the sensitivity will be less if the block is made of a less rigid or less dense material.

5.5.2 The Rayleigh speed in the material of the block affects surface wave calibrations. For a sensor having a circular aperture (mounting face) with uniform sensitivity over the face, the aperture effect predicts nulls at the zeroes of J_1 (ka), where $k = 2\pi f/c_R$, and f = frequency, c_R = Rayleigh speed, and a = radius of the sensor face (active element). Hence, the frequencies at which the nulls occur are dependent upon the Rayleigh speed.

[3] Burks, Brian, "Re-Examination of NIST Acoustic Emission Sensor Calibration: Part I – Modeling the Loading from Glass Capillary Fracture," *Journal of Acoustic Emission*, Vol. 29, pp. 167–174.

[4] Breckenridge, F. R., "Acoustic Emission Transducer Calibration by Means of the Seismic Surface Pulse," *Journal of Acoustic Emission* Vol 1, pp. 87–94.

[5] Hsu, N. N., and Breckenridge, F. R., "Characterization and Calibration of Acoustic Emission Sensors," *Materials Evaluation,* Vol 39, 1981, pp. 60–68.

[6] Paul G. Richards, "Elementary Solutions to Lamb's Problem for a Point Source and their Relevance to Three- Dimensional Studies of Spontaneous Crack Propagation," *Bull. of the Seismological Society of America*, Vol 69, No. 4, 1979, pp. 947–956.

[7] Breckenridge, F. R., and Greenspan, M., "Surface-Wave Displacement: Absolute Measurements Using a Capacitive Transducer," *Journal,* Acoustic Society of America, Vol 69, pp 1177–1185.