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Standard Practice for Measuring thickness by Pulse-Echo Electromagnetic Acoustic Transducer (EMAT) Methods[1]

This standard is issued under the fixed designation E1816; 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 measuring the thickness of materials using Electromagnetic Acoustic Transducers (EMAT), a non-contact pulse-echo method, at temperatures not to exceed 1200°F [650°C].

1.2 This practice is applicable to any electrically conductive or ferromagnetic material, or both, in which ultrasonic waves will propagate at a constant velocity throughout the part, and from which back reflections can be obtained and resolved.

1.3 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.4 *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.*

1.5 *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

E543 Specification for Agencies Performing Nondestructive Testing

E587 Practice for Ultrasonic Angle-Beam Contact Testing

E797 Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method

E1316 Terminology for Nondestructive Examinations

E1774 Guide for Electromagnetic Acoustic Transducers (EMATs)

2.2 *ASNT Standards:*[3]

SNT-TC-1A Recommended Practice for Personnel Qualifications and Certification in Nondestructive Testing

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

2.3 *Aerospace Industries Association Standard:*

NAS 410 Certification and Qualification of Nondestructive Test Personnel[4]

2.4 *International Standards Organization (ISO):*[5]

ISO 9712 Qualification and Certification of NDT Personnel

3. Terminology

3.1 *Definitions:* Related terminology is defined in Terminology E1316.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bulk wave*—an ultrasonic wave, either longitudinal or shear horizontal mode, used in nondestructive testing to interrogate the volume of a material.

3.2.2 *butterfly (double elongated racetrack) coil*—an EMAT coil consisting of two coils wound on an elongated racetrack shape, placed side by side, and connected so the current on the conductors in the middle section flows in only one direction.

3.2.3 *electromagnetic acoustic transducer (EMAT)*—an electromagnetic device for converting electrical energy into acoustical energy in the presence of a magnetic field.

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.06 on Ultrasonic 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.

[3] Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.

[4] Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org.

[5] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

3.2.4 *Lorentz forces*—forces exerted on a charged particle by electric currents when placed in a magnetic field. Lorentz forces are perpendicular to both the direction of the magnetic field and the current direction. Lorentz forces are the forces responsible behind the principle of electric motors.

3.2.5 *magnetostrictive forces*—forces arising from magnetic domain wall movements within a magnetic material during magnetization.

3.2.6 *meander coil*—an EMAT coil consisting of periodic, winding, nonintersecting, and usually evenly spaced conductors.

4. Summary of Practice

4.1 Determining the thickness (T) of a material, when measured by the pulse-echo ultrasonic method, is a product of the velocity of sound in the material (V) and the transit time (t) divided by two due to round trip through the material.

$$T = Vt/2 \tag{1}$$

4.2 The pulse-echo ultrasonic instrument measures the transit time of the ultrasonic pulse travelling through the part.

4.3 The velocity in the material being measured is a function of the material physical properties. It is usually assumed to be uniform for a given class of materials and its approximate value can be obtained from Table X3.1 in Practice E494, from other references, or can be estimated experimentally. Different alloys of steel, aluminum, or other metals can have differences in velocity enough to make your reading outside of its accuracy requirements. Extreme care must be taken when selecting calibration block materials.

4.4 One or more reference blocks are required having known velocity or, preferably, being of the same alloy material as that being examined, and having thicknesses accurately measured, and which are in the range of thicknesses to be measured. It is generally desirable that the thicknesses be "round numbers" rather than miscellaneous odd values. One block should have a thickness value near the maximum thickness of the range of interest and another block near the minimum thickness.

4.5 Thickness measurements of materials at high-temperature can be performed with specially designed search units with high temperature compensation. Normalization of apparent thickness readings for elevated temperatures is required. A rule of thumb mentioned in Practice E797 and often used is as follows: The apparent thickness reading obtained from steel walls having elevated temperatures is high (too thick) by a factor of about 1 % per 100°F (55°C). Thus, if the instrument was standardized on a piece of similar material at 68°F (20°C), and if the reading was obtained with a surface temperature of 860°F (460°C), the apparent reading should be reduced by 8 %. This correction is an average one for many types of steel. Other corrections would have to be determined empirically for other materials.

4.6 The display element (A-scan display, meter, or digital display) of the instrument must be adjusted to present convenient values of thickness dependent on the range being used. The control for this function may have different names on different instruments, including range, sweep, material standardize, or velocity.

4.7 The timing circuits in different instruments use various conversion schemes. A common method is the so-called time/analog conversion in which the time measured by the instrument is converted into a proportional d-c voltage which is then applied to the readout device. Another technique uses a very high-frequency oscillator that is modulated or gated by the appropriate echo indications, the output being used either directly to suitable digital readouts or converted to a voltage for other presentation.

5. Significance and Use

5.1 The methods described provide indirect measurement of the thickness of sections of materials not exceeding temperatures of 1200°F [650°C]. Measurements are made from one side of the object, without requiring access to the rear surface.

5.2 Ultrasonic thickness measurements are used extensively on basic shapes and products of many materials, on precision machined parts, and to determine wall thinning in process equipment caused by corrosion and erosion.

5.3 Recommendations for determining the capabilities and limitations of ultrasonic thickness gages for specific applications can be found in the cited references (**1**,**2**).[6]

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this standard.

6.2 *Personnel Qualification:*

6.2.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally- or internationally-recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, ISO 9712, 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. Instruments with direct read thickness displays, including automated thickness measurement, may be used by personnel only trained in the thickness measurement procedure if initial programing of the instrument is done by personnel trained in accordance with one of the standards mentioned above.

6.3 *Qualification of Nondestructive Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Specification E543. The applicable edition of Specification E543 shall be specified in the contractual agreement.

6.4 *Procedures and Techniques*—The procedures and techniques to be used shall be as described in this practice unless otherwise specified. Specific techniques may be specified in the contractual agreement.

[6] The boldface numbers in parentheses refer to a list of references at the end of this standard.

7. Apparatus

7.1 *Instruments*—Most instruments capable of thickness-measurement using EMATs are flaw detectors with an A-scan display and direct thickness readout.

7.1.1 Flaw detectors with A-scan display readouts display time/amplitude information. Thickness determinations are made by reading the distance between the zero-corrected initial pulse and first-returned echo (back reflection), or between multiple-back reflection echoes, on a standardized baseline of the A-scan display. The baseline of the A-scan display should be adjusted for the desired thickness increments.

7.1.2 Some flaw detectors have thermocouple inputs in order to acquire the material's temperature, which is then used to apply a temperature correction algorithm (See Practice E797).

7.1.3 Automated EMAT thickness measurement systems may have a variety of displays including direct read, color coded mapping, line scans, point maps, etc.

8. Standardization

8.1 EMAT transducers and instrumentation are available from several manufacturers. In addition to custom designs for specific applications, there are off-the-shelf SH and L wave EMAT transducers offered for the most common ultrasonic frequencies (typically 1.5 MHz, 2.5 MHz, 5 MHz, 7.5 MHz) and transducer dimensions (ranging from 0.25 to 2 in. (6 to 50 mm)). The characteristics of the different transducers (dimensions, center frequency, bandwidth, beam profile) should be made available by the transducer manufacturer.

8.2 Prior to examination, the EMAT system should be standardized by means of appropriate reference blocks, described in 4.4, 8.9.1, or as specified in the contractual specification. If the instrument is capable of storing different velocities based on Alloy programs, a program for a specific alloy can be loaded and a verification step performed instead of a standardization. If the verification step shows that the instrument reads outside of tolerance a standardization must be performed before use.

8.3 Reference standards should have ultrasonic characteristics similar to the material being examined.

8.4 As in conventional ultrasonic application, attenuation correction should be completed if the amplitude of a reference reflector (for example, backwall) in the reference standard does not match that of the sample.

8.5 Reference standards should be rechecked following any system or operator changes to maintain standardization.

8.6 If the EMATs are being operated in a scan mode of operation, it should be verified that the scan rates are optimum to ensure ultrasonic resolution adequate to the specified contract.

8.7 Unless otherwise specified, the EMAT system should always provide an A-scan display. As a minimum, the initial pulse and one back wall reflection should be present on the oscilloscope trace. The total number of visible reflections depends on operator preference.

8.8 Specific standardization procedures should be generated for specific applications. Generic procedures for thickness applications are outlined as follows.

8.9 *Thickness Applications:*

8.9.1 *Reference Block Selection*—The requirements for appropriate reference blocks are given in 4.4, Appendix XI in Practice E797. It is recommended that reference blocks also be available representing thicknesses between the maximum and minimum values. The EMATs are placed on the selected reference block and the instrumentation parameters adjusted until appropriate thicknesses are displayed.

8.9.2 Since the major difference between examinations with EMATs and those with conventional ultrasonics lies in the coupling mechanism, standardization guidance from conventional ultrasonic thickness procedures should be used, as appropriate (for example, Practice E797).

8.9.3 *Back Reflection Amplitude*—The amplitude of the back wall reflection should be monitored to ensure that adequate signal strength is available for accurate thickness measurements and to ensure that adequate electromagnetic coupling is being maintained.

8.9.4 *Back Reflection Gating*—Gating for the back wall reflection should be verified prior to examining and periodically thereafter to ensure that the proper gating location and length are being maintained to ensure the accuracy of examination.

9. Procedure

9.1 *Case I – Magnetic Materials (Spiral coil – Radially polarized shear horizontal wave, or butterfly coil – Linearly polarized shear horizontal).*

9.1.1 The procedure outlined herein describes one EMAT technique for the application of measuring material thickness in magnetic components. starting from 0.02 in. (0.5 mm) to 4 in. (101.6 mm) with accuracy of 0.0005 in. (12 µm). Thicker components can be measured with custom designed units that may operate at lower frequencies and have larger coils, depending on material properties such as conductivity and grain size. While it is not purported to be the only applicable technique, it does describe a field-tested proven methodology for application to fast scanning of plates and tubes.

9.1.2 All surfaces of the examination components should be relatively free of scale, dirt, burrs, slag, spatter, or other conditions that could interfere with the examination results or damage the EMAT probe.

9.1.3 To make a thickness measurement or scan, the operator places the EMAT probe head on the object to be examined. A large current spike pulse or multi-cycle tone burst is generated in the EMAT coil, which, in the presence of the applied magnetic field, launches an ultrasonic shear horizontal wave.

9.1.4 The shear horizontal wave is reflected at the back surface interface, which is then detected by the same EMAT coil.

9.1.5 The voltage from the receiver EMAT coil is amplified by a low-noise preamplifier and sent to the receiver section in the signal processing electronics, where it is further amplified,