INTERNATIONAL

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Standard Practice for ~~Ultrasonic Testing Using~~ Measuring thickness by Pulse-Echo Electromagnetic Acoustic Transducer (EMAT) ~~Techniques~~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 covers procedures for the use of electromagnetic acoustic transducers (EMATs) for specific ultrasonic examination applications. Recommendations are given for specific applications for using EMAT techniques to detect flaws through both surface and volumetric examinations as well as to measure thickness.~~

1.1 ~~These procedures recommend technical details and~~ This practice provides guidelines for ~~the reliable and reproducible ultrasonic detection of flaws and thickness measurements using electromagnetic acoustic transducers for both the pulsing and receiving of ultrasonic waves. The EMAT techniques described herein can be used as a basis for assessing the serviceability of various components nondestructively, as well as for process control in manufacturing.~~ 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].

~~1.3 These procedures cover noncontact techniques for coupling ultrasonic energy into materials through the use of electromagnetic fields. Surface, Lamb, longitudinal, and shear wave modes are discussed.~~

~~1.4 These procedures are intended to describe specific EMAT applications. These procedures are intended for applications in which the user has determined that the use of EMAT techniques can offer substantial benefits over conventional piezoelectric search units. It is not intended that EMAT techniques should be used in applications in which conventional techniques and applications offer superior benefits (refer to Guide E1774).~~

1.2 ~~These procedures are~~This practice is applicable to any ~~material in which acoustic waves can be introduced electromagnetically. This includes any material that is either electrically conductive or ferromagnetic.~~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.

~~1.6 The procedures outlined in this practice address proven EMAT techniques for specific applications; they do not purport to address the only variation or all variations of EMAT techniques to address the given applications. Latitude in application techniques is offered where options are considered appropriate.~~

1.3 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as ~~the~~ standard. The values ~~given in parentheses are for information only.~~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~~ safety, health, and ~~health~~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

[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.

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

E494 Practice for Measuring Ultrasonic Velocity in Materials
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.

~~3.2.3 *lift-off effect*—refer to Terminology E1316, Section C.~~

3.2.4 *Lorentz forces*—forces ~~applied to~~ 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.

~~3.2.7 *pancake (spiral) coil*—an EMAT coil consisting of spirally wound, usually evenly spaced conductors.~~

4. Summary of Practice

4.1 ~~*Surface Examination:*~~ 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.

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

~~4.1.1 The generation of Rayleigh or surface waves in the material to be examined allows for sensitivity to surface flaws and discontinuities. Flaws can be detected by reflections of acoustic waves from the discontinuity interfaces or by acoustic wave attenuation in traversing across the surface of the component. Either pulse-echo or pitch-catch ultrasonic techniques can be used.~~

~~4.1.2 Fig. 1 shows a typical EMAT setup for the transduction of Rayleigh or Lamb waves. As shown, an external magnetic induction B is applied parallel to the surface of an electrically conductive or ferromagnetic material. A meander coil is used. The coil is oriented in the same plane as the surface of the material and is excited by an electrical radio frequency (RF) pulse. A surface current is produced in the material by transformer action. The surface current, in the presence of the magnetic field, experiences Lorentz forces that produce oscillating stress waves perpendicular to the surface of the material to produce surface acoustic waves. Basic EMAT designs generate bidirectional surface waves. Specialized designs can be used to generate unidirectional waves, as with conventional ultrasonic examination.~~

~~4.1.3 Surface flaws or discontinuities lead to reflections or attenuation of the surface waves. Upon approach to the receiver EMAT, the reflected or attenuated ultrasonic waves produce oscillations within the conductor in the presence of the magnetic field and thus produce a voltage induction in the coil, allowing for detection.~~

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[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] ~~Nondestructive Testing Handbook,~~Available from International ~~2nd ed., Vol 7,~~Organization for Standardization (ISO), ~~Ultrasonic Testing,~~ISO Central ~~A. S. Birks, R. E. Green, and P. McIntire, eds., American Society for Nondestructive Testing, Columbus, OH, 1991.~~Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

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

4.2.1 Sensitivity to flaws or discontinuities within a part requires the use of bulk acoustic wave modes to interrogate the volume of the material. As with surface examinations, reliance on the reflection or attenuation of acoustic waves from discontinuity interfaces forms the basis for the detection of flaws.

4.2.2 Depending on the particular application, either longitudinal or shear wave modes may be desirable. While straight beam applications using pulse-echo techniques are the most straightforward, angle beam pitch-catch techniques could be desirable, depending on such factors as expected flaw location and orientation.

4.2.3 Fig. 2 shows one typical EMAT setup for the transduction of bulk waves. As shown, an external magnetic induction B is applied normal to the surface of an electrically conductive or ferromagnetic material. A spiral EMAT coil is used for this example. The coil is positioned in a plane parallel to the surface of the material and is excited by an electrical current pulse. A surface current is produced in the material by transformer action. The surface current, in the presence of the magnetic field, experiences Lorentz forces that produce oscillating stress waves originating in the surface of the material. Radially polarized shear waves are generated for this example. Depending on the design characteristics of the magnetic field, the excitation of either radially polarized or planar-polarized shear waves, propagating normal to the surface, can be introduced. Longitudinal wave modes can also be generated and used effectively in non-ferromagnetic materials. Longitudinal wave generation in ferromagnetic materials is impractical due to unacceptably low coupling efficiency. Mode-converted longitudinal waves can be used effectively. Paragraph 7.2 and the subparagraphs of 7.2 give a more in-depth discussion of the various EMAT/magnet configurations for producing various bulk wave modes.

4.3 *Thickness Gaging:* 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.

4.3.1 Determining the thickness of a material by ultrasonic means is a matter of coupling an ultrasonic wave into the material, allowing the sound wave to propagate through the material, reflect from the backwall boundary interface of the material, and propagate back to the front surface. The thickness of the material can be calculated by measuring the transit time of the ultrasonic wave and the knowledge of the ultrasonic wave velocity. Thickness measurements can also be extrapolated for a given material through standardizations of transit time as a function of thickness as derived from a reference block (see Practice E797 and 7.3.1).

4.3.2 The ultrasonic velocity of the material under examination is a function of the physical properties of the material, namely, stiffness and density. It is usually assumed to be constant for a given class of materials. Approximate velocity values are available in tabular format from numerous sources, including the ASNT *Nondestructive Testing Handbook*.[5] Velocity values can also be determined empirically (see Practice E494).

4.3.3 Determination of the transit time of an acoustic wave through a material requires the use of bulk acoustic wave modes. While longitudinal waves can be used, it is often desirable to use shear waves since their slower propagation velocities lend themselves to more accurate measurements of thin materials. While straight beam applications using pulse-echo techniques are the most straightforward and popular, angle beam pitch-catch techniques could be desirable, especially in applications in which fast scan rates are needed or high resolution is desired for thin material. The generation of bulk waves by means of the EMAT technique is discussed in 4.2.3 and depicted in Fig. 2.

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 Since EMAT techniques are noncontacting, they should be considered for ultrasonic examinations in which applications involve automation, high-speed examinations, moving objects, applications in remote or hazardous locations, and applications to objects at elevated temperatures or objects with rough surfaces. This practice describes procedures for using EMAT techniques as associated with the ultrasonic method to detect flaws for both surface and volumetric examinations as well as to measure thickness.

5.2 The uniqueness of the electromagnetic acoustic transducer technique for ultrasonic examination basically lies in the generation and reception of the ultrasonic waves. Otherwise, conventional ultrasonic techniques and methodologies generally apply.

5.1 An EMAT generates and receives acoustic waves in a material by electromagnetic means; electrically conductive or ferromagnetic materials can be examined. In its simplest form, an EMAT as a generator of ultrasonic waves is basically a coil of wire, excited by an alternating current, and placed in a uniform magnetic field near the surface of a material. For conductive materials, eddy currents are induced as a result of the alternating current. Due to the magnetic field, these eddy currents experience Lorentz forces that in turn are transmitted to the solid by collisions with the lattice or other microscopic processes. These forces are alternating at the frequency of the driving current and act as a source of ultrasonic waves. If the material is ferromagnetic, additional coupling mechanisms play a part in the generation of ultrasonic waves. Interactions between the dynamic magnetic field generated by the alternating currents and the magnetization associated with the material offer a source of coupling, as do the associated magnetostrictive influences. Reciprocal processes exist whereby all of these mechanisms lead to detection. 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 Fig. 3 depicts the mechanisms (forces), along with associated direction, for electromagnetic ultrasound generation. the rear surface.

5.2 The EMAT can be used to generate all ultrasonic modes of vibration. As with conventional ultrasonic techniques, material types, probable flaw locations, and flaw orientations determine the selection of beam directions and modes of vibration. The use of EMATs and selection of the proper wave mode presuppose a knowledge of the geometry of the object; the probable location, size, orientation, and reflectivity of the expected flaws; the allowable range of EMAT lift-off; and the laws of physics governing the propagation of ultrasonic waves. 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 The EMAT techniques show benefits and advantages over conventional piezoelectric ultrasonic techniques in special applications in which flexibility in the type of wave mode generation is desired. The EMATs are highly efficient in generating surface waves. The EMATs lend themselves to horizontally polarized shear wave (SH) generation more easily than do conventional ultrasonic search units. This is important since SH shear waves produce no mode conversions at interfaces and their angle of introduction can be varied from 0 to 90° simply by sweeping through various frequency RF generation. The EMATs can also be configured to produce Lamb wave modes whose use can provide the full circumferential examination Recommendations for determining the capabilities and limitations of ultrasonic thickness gages for specific applications can be found in the cited references (**1**of ,**2**tubular).products[6] or volumetric examination of thin plate material. The EMATs also lend themselves easily to the repeatability of sensor fabrication, and hence the associated sensor response is highly reproducible.

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 practicesstandard 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.

6.5 *Reporting Criteria and Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with Section 11 unless otherwise specified. Acceptance criteria shall be specified in the contractual agreement.

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

6.6 *Reexamination of Repaired and Re-Worked Items*—The reexamination of repaired and reworked items is not addressed in this practice and, if required, shall be specified in the contractual agreement.

7. Apparatus

7.1 *Surface Examinations:*

7.1.1 *Base Material Applications:*

7.1.1.1 *EMAT Coil Design*—Fig. 4 shows a typical meander EMAT coil design for Rayleigh wave transduction. The mode of operation can be either pulse-echo or pitch-catch.

7.1.1.2 *Coil Excitation*—A high-power, specialized RF generator is necessary to provide excitation to the coil in the form of a toneburst of several cycles.

7.1.1.3 *Magnetization*—Fig. 5 shows a typical electromagnet configuration for producing an external magnetic induction for the meander coil. A pulsed magnetic induction is produced parallel to the examination surface for the particular design shown. An accompanying magnet pulser and power supply unit are needed to supply the current pulse to the pulsed magnet. It should be noted that magnetization could be supplied from a permanent magnet or from a dc magnet with power supply.

7.1.1.4 *Instrumentation*—The following is a description of a typical instrumentation package for data acquisition and analysis of the EMAT signals. The signal processing and data acquisition electronics should consist of a receiver section to provide for adjustable gain and filtering for the EMAT signals. Conventional ultrasonic instruments can be used for this purpose. The user has several options to capture and analyze the EMAT signals. A personal computer housing any of several commercially available analog-to-digital converter boards with associated dedicated ultrasonics software provides for an effective configuration. However, as with conventional ultrasonics, configurations as simple as analog output to oscilloscope can provide for acceptable results. In either case, pulser/receiver synchronization circuitry will be necessary to provide adequate triggering for signal acquisition.

7.1.1.5 *Reference Standard*—A reference standard for verification of the system standardization should be prepared from a component of the same material, thickness, surface finish, and nominal heat treatment as the material to be examined. The material should be free of discontinuities or other abnormal conditions other than those reference reflectors exemplifying the necessary sensitivity. Flaw dimensions of length, depth, and width must be decided upon by the using party or parties and should be consistent with the acceptance criteria.

7.1.2 *Weld Applications:*

7.1.2.1 *EMAT Coil Design*—In most cases, the EMAT coil/magnet design for base material applications (7.1.1) can be used effectively for weld applications. In certain applications, however, the examination of welds for surface discontinuities presents unique challenges. A problem arises in that the root and crown of the weld can produce reflections that are prominent enough to interfere with, or even obscure, any flaw signals. Through the use of a proven diffraction technique, signals reflected as a result of weld geometry effects can be eliminated while flaw indications can be shown clearly. Fig. 6 shows a specially designed pitch-catch EMAT coil configuration consisting of a collinear set of focused EMAT search units that, when scanned, are rotated at an angle with respect to the weld centerline. The frequency is chosen so that the wavelength of the Rayleigh wave is comparable to the dimensions of the critical surface discontinuities that must be detected. As a result, the surface discontinuities can be detected by diffraction over a wide range of angles, but the root and crown signals are reflected away as specular reflectors.

7.1.2.2 *Coil Excitation*—See 7.1.1.2.

7.1.2.3 *Magnetization*—Fig. 5 shows a typical magnet configuration for producing an external magnetic induction for the specialized coil configuration described in 7.1.2.1. The particular design shown provides for a magnetic induction parallel to the examination surface. Again, permanent or dc electromagnets can also be used to supply the magnetic induction.

7.1.2.4 *Instrumentation*—See 7.1.1.4.

7.1.2.5 *Reference Standard:* (*1*) A reference standard for verification of the system standardization should be prepared from a length of weldment of the same material, welding magnetic properties, thickness, surface finish, and nominal heat treatment as the material to be examined. The weldment should be free of discontinuities or other abnormal conditions that could cause interference with detection of the reference reflectors. The reference reflectors should be selected to ensure uniform coverage of the weld at the sensitivity levels prescribed. The reference reflectors most commonly used will consist of machined notches or flat-bottom holes.

(*2*) Reference reflectors may be placed in the weld seam, in the base material heat-affected zone of the weld, or in the material parallel to the weld seam, as specified in the weld acceptance criteria.

(*3*) The machined notch dimensions of length, depth, and width must be decided upon by the using party or parties and should be consistent with the weld acceptance criteria.

(*4*) The notch depth should be measured from the adjacent surface to its maximum and minimum penetration. Measurements may be made by optical, replicating, mechanical, or other techniques. Notch depth is commonly specified as a percent of nominal material thickness.

7.2 *Volumetric Examination:*

7.2.1 *Base Material Applications:*

7.2.1.1 *EMAT Coil Design*—For volumetric examinations, the use of bulk acoustic waves is appropriate for interrogation of the volume of a material. Fig. 7 shows various EMAT coil/magnet configurations for bulk wave transduction. Modes of operation can be either pulse-echo or pitch-catch, as with conventional ultrasonics. Coil excitation is provided by an RF pulse. As shown, magnetic induction can be either parallel or normal to the sample surface, depending on the desired wave mode.

7.2.1.2 *Coil Excitation*—A high-power, specialized RF generator is necessary to provide coil excitation. If the specific EMAT coil is of the meander type, a toneburst of several cycles is the required RF pulse type. A high-power spike pulse or short-duration toneburst is required if the spiral coil is used.

7.2.1.3 *Instrumentation*—See 7.1.1.4.

7.2.1.4 *Reference Standard*—See 7.1.1.5.

7.2.2 *Weld Applications:*

7.2.2.1 *EMAT Coil Design*—The EMAT coil design for volumetric weld examinations is basically the same as that used for volumetric examinations of the base material, and, therefore, the EMAT coil/magnet configurations shown in Fig. 7 apply. Again, the mode of operation can be either pulse-echo or pitch-catch. Coil excitation is provided by an RF pulse. Magnetization can be either parallel or normal to the sample surface, depending on the particular wave modes desired.

7.2.2.2 *Coil Excitation*—See 7.2.1.2.

7.2.2.3 *Instrumentation*—See 7.1.1.4.

7.2.2.4 *Reference Standard:* (*1*) A reference standard for verification of the system standardization should be prepared from a length of weldment of the same material, thickness, surface finish, and nominal heat treatment as the material to be examined. The weldment should be free of discontinuities or other abnormal conditions that could cause interference with detection of the reference reflectors. The reference reflectors should be selected to ensure uniform coverage of the weld at the sensitivity levels prescribed. The reference reflectors most commonly used will consist of machined notches or drilled flat-bottom holes.

(*2*) Reference reflectors may be placed in the weld seam, in the base material heat-affected zone of the weld, or in the material parallel to the weld seam, as specified in the weld acceptance criteria.

(*3*) The machined notch dimensions of length, depth, and width, or hole diameter and depth, must be decided upon by the using party or parties and should be consistent with the weld acceptance criteria.

(*4*) The notch or hole depth should be measured from the adjacent surface to its maximum and minimum penetration. Measurements may be made by optical, replicating, mechanical, or other techniques. Notch or hole depth is commonly specified as a percent of nominal material thickness.

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

7.1.1 *Thin Components*—The following EMAT procedure is recommended for measuring the thickness in components ranging from 0.100 to 0.500 in. (2.54 to 12.7 mm) and expressly for components exhibiting relatively rough back surfaces.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.

7.3.1.1 *EMAT Design*—Fig. 8 shows an effective EMAT coil design for measuring thickness in thin components. The particular design shown incorporates a pitch-catch configuration. It is used to introduce a shear wave into the component and receive a reflected longitudinal mode from the back surface. Coil excitation is from a large current spike pulse. This particular design offers advantages over typical pulse-echo techniques. The angularly reflected and mode-converted longitudinal wave effectively introduces a delay that reduces or eliminates problems with "main-bang spill-over" into the first reflection and simultaneously allows the use of lower-frequency analysis (that is, roughly 1 MHz), which is less sensitive to any back surface irregularities. This technique effectively allows the use of the first back wall reflection, a procedure that is imperative to ensure accurate results for applications in which the back surface is irregular (for example, steam or distribution tubing).

7.3.1.2 *Coil Excitation*—A high-power, specialized RF generator is necessary to provide excitation to the coil in the form of a spike pulse or short-duration toneburst.

7.3.1.3 *Magnetization*—Fig. 5 depicts a pulsed electromagnet design that can be used to produce the magnetic field for the coil described in 7.3.1.1. The pulsed magnet generates tangential magnetic fields in the surface of the component. An accompanying magnet pulser and power supply unit are necessary to supply the current pulse to the pulsed magnet. Permanent or dc electromagnets could also be used to produce the magnetic induction.

7.3.1.4 *Instrumentation*—The following is a description of a field-tested instrumentation package associated with the thickness gaging application described above. The signal processing and data acquisition electronics consist of a receiver section, a ruggedized personal computer (PC), a waveform digitizing board, and synchronization circuitry. A receiver section from a commercially available ultrasonic testing device can be used to provide adjustable gain and filtering for the EMAT signals. A PC section using any of several commercially available analog-to-digital (A/D) boards can be used to capture the received EMAT signals. Commercially available, or slightly modified commercially available, software can provide the necessary programming capability to measure the time of arrivals and amplitude of the EMAT signals as well as display the A-scan and thickness data. Any conventional ultrasonic thickness measurement instrumentation, properly configured, should also produce adequate results.