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# Standard Practice for Ultrasonic Examinations Using Electromagnetic Acoustic Transducer (EMAT) Techniques[1]

This standard is issued under the fixed designation E 1816; 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.

1.2 These procedures recommend technical details and 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.

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 E 1774).

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

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.

1.7 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.8 *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:*

E 114 Practice for Ultrasonic Pulse-Echo Straight-Beam Examination by the Contact Method[2]

E 494 Practice for Measuring Ultrasonic Velocity in Materials[2]

E 587 Practice for Ultrasonic Angle-Beam Examination by the Contact Method[2]

E 797 Practice for Measuring Thickness by Manual Ultrasonic Pulse-Echo Contact Method[2]

E 1316 Terminology for Nondestructive Examinations[2]

E 1774 Guide to Electromagnetic Acoustic Transducers (EMATs)[2]

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 *Military Standard:*

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification[4]

## 3. Terminology

3.1 *Definitions*—Related terminology is defined in Terminology E 1316.

3.2 *Definitions of Terms Specific to This Standard:*

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

[3] Available from American Society for Nondestructive Testing, 1711 Arlingate Plaza, P.O. Box 28518, Columbus, OH 43228-0518.

[4] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

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

3.2.2 *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 E 1316, Section C.

3.2.4 *Lorentz forces*—forces applied to 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*:

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.

4.2 *Volumetric Examination*:

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*:

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

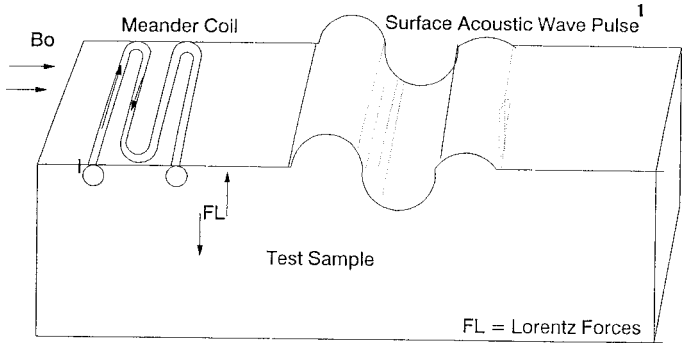


**FIG. 1 Typical EMAT Configuration for Rayleigh or Lamb Wave Generation**



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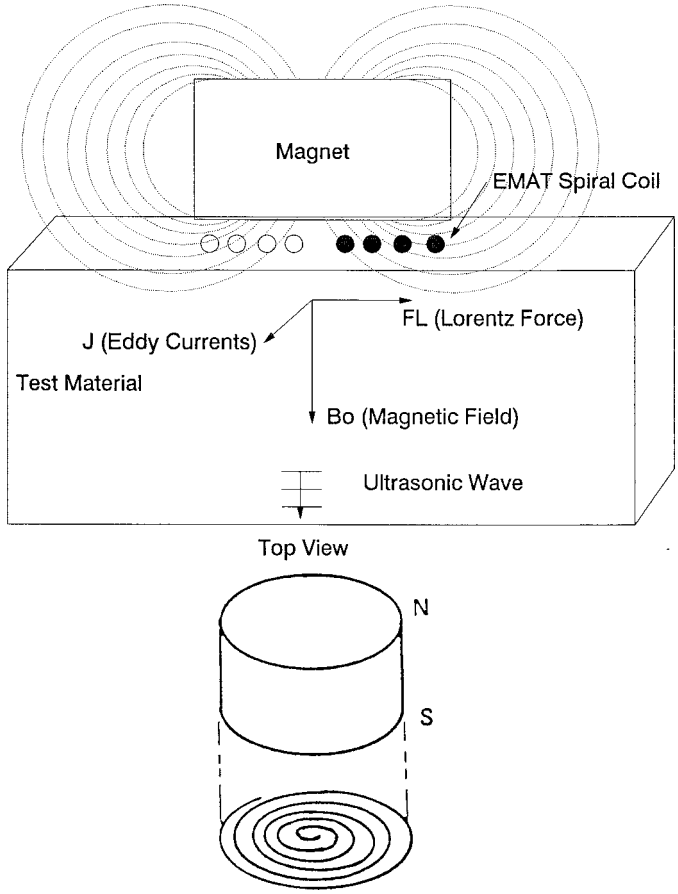



**FIG. 2 Typical EMAT Configuration for Bulk Wave Generation**

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 through 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 standardization block (see Practice E 797 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 E 494).

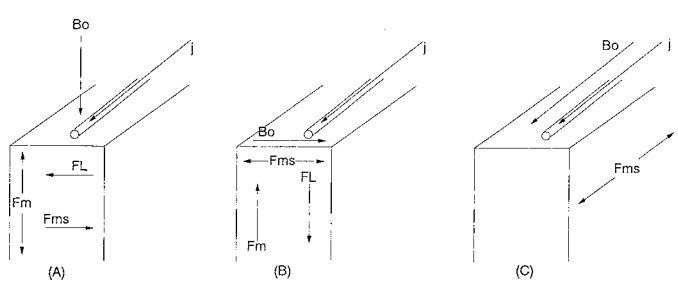
4.3.3 Determination of the transit time of an acoustic wave through a material requires the use of bulk acoustic wave modes. While longitudinal waves can be used, it is often desirable to use shear waves since their slower propagation velocities lend themselves to more accurate measurements of thin materials. 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.

## 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.

5.3 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. Fig. 3 depicts the mechanisms (forces), along with associated direction, for electromagnetic ultrasound generation.




NOTE 1—j = current in a single conductor, Bo = magnetization from external magnet, Fm = magnetic force (ferromagnetic material), Fms = magnetostrictive force (ferromagnetic material), and FL = Lorentz force (conductive material).

**FIG. 3 Mechanisms of Electromagnetic Ultrasound Generation**

[5] *Nondestructive Testing Handbook*, 2nd ed., Vol 7, *Ultrasonic Testing*, A. S. Birks, R. E. Green, and P. McIntire, eds., American Society for Nondestructive Testing, Columbus, OH, 1991.



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