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Standard Guide for Electromagnetic Acoustic Transducers (EMATs)¹

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1. Scope*

1.1 This guide is intended primarily for tutorial purposes. It provides an overview of the general principles governing the operation and use of electromagnetic acoustic transducers (EMATs) for ultrasonic examination.

1.2 This guide describes a non-contact technique for coupling ultrasonic energy into an electrically conductive or ferromagnetic material, or both, through the use of electromagnetic fields. This guide describes the theory of operation and basic design considerations as well as the advantages and limitations of the technique.

1.3 This guide is intended to serve as a general reference to assist in determining the usefulness of EMATs for a given application as well as provide fundamental information regarding their design and operation. This guide provides guidance for the generation of longitudinal, shear, Rayleigh, and Lamb wave modes using EMATs.

1.4 This guide does not contain detailed procedures for the use of EMATs in any specific applications; nor does it promote the use of EMATs without thorough testing prior to their use for examination purposes. Some applications in which EMATs have been applied successfully are outlined in Section 9.

1.5 *Units*—The values stated in inch-pound units are to be regarded as the standard. The SI values given in parentheses are for information only.

1.6 *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.*

1.7 *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.*

¹ This guide 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. Referenced Documents

2.1 ASTM Standards:²

E127 Practice for Fabrication and Control of Flat Bottomed Hole Ultrasonic Standard Reference Blocks

E428 Practice for Fabrication and Control of Metal, Other than Aluminum, Reference Blocks Used in Ultrasonic Testing (Withdrawn 2019)³

E543 Specification for Agencies Performing Nondestructive Testing

E1065 Practice for Evaluating Characteristics of Ultrasonic Search Units

E1316 Terminology for Nondestructive Examinations

2.2 ASNT Documents:⁴

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

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

2.3 Aerospace Industries Association Standard:⁵

NAS-410 Certification and Qualification of Nondestructive Test Personnel

2.4 ISO Standard:⁶

ISO 9712 Non-Destructive Testing: 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 mode, used in nondestructive testing to interrogate the volume of a material.

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 The last approved version of this historical standard is referenced on www.astm.org.

⁴ Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, <http://www.asnt.org>.

⁵ Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, <http://www.aia-aerospace.org>.

⁶ 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>.

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

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 Lorentz forces—forces applied to electric currents when placed in a magnetic field. Lorentz forces are perpendicular to the direction of both the magnetic field and the current direction.

3.2.4 magnetostrictive forces—forces arising from magnetic domain wall movements within a magnetic material during magnetization, where magnetostrictive materials will undergo a strain in the presence of a magnetic field.

3.2.5 meander coil—an EMAT coil consisting of periodic, winding, non-intersecting, and usually evenly-spaced conductors.

3.2.6 pancake coil (spiral)—an EMAT coil consisting of spirally-wound, usually evenly-spaced conductors.

4. Significance and Use

4.1 General—Ultrasonic testing is a widely used nondestructive method for the examination of a material. The majority of ultrasonic examinations are performed using transducers that directly convert electrical energy into acoustic energy through the use of piezoelectric crystals. This guide describes an alternate technique in which electromagnetic energy is used to produce acoustic energy inside an electrically conductive or ferromagnetic material. EMATs have unique characteristics when compared to conventional piezoelectric ultrasonic search units, making them a significant tool for some ultrasonic examination applications.

4.2 Principle—An electromagnetic acoustic transducer (EMAT) generates and receives ultrasonic waves without the need to contact the material in which the acoustic waves are traveling. The use of an EMAT requires that the material to be examined be electrically conductive or ferromagnetic, or both. There are two basic components of an EMAT system, a magnet and a coil. The magnet may be an electromagnet or a permanent magnet, which is used to produce a magnetic field in the material under test. The coil is driven using alternating current at the desired ultrasonic frequency. The coil and AC current also induce a surface magnetic field in the material under test. In the presence of the static magnetic field, the surface current experiences Lorentz forces that produce the desired ultrasonic waves. Upon reception of an ultrasonic wave, the surface of the conductor oscillates in the presence of a magnetic field, thus inducing a voltage in the coil. The transduction process occurs within an electromagnetic skin depth. The EMAT forms the basis for a very reproducible noncontact system for generating and detecting ultrasonic waves.

4.3 Specific Advantages—Since an EMAT technique does not have to be in contact with the material under examination, no fluid couplant is required. Important consequences of this include applications to moving objects, in remote or hazardous locations, to objects at elevated temperatures, or to objects with rough surfaces. The EMAT technique is environmentally safe since it does not use potentially polluting or hazardous chemicals. The technique facilitates the rapid scanning of compo-

nents having complex geometries. EMAT signals are highly reproducible as a consequence of the manner in which the acoustic waves are generated. EMATs can also produce horizontally polarized shear (SH) waves without mode conversion and can accommodate scanning while using SH waves. (Note that in order to produce this wave mode by conventional ultrasonic techniques, either an epoxy or a highly viscous couplant is required. Thus, conventional ultrasonic techniques do not lend themselves easily to scanning when using SH wave modes.) Additionally, EMATs can allow the user to electronically steer shear waves.

4.4 Specific Limitations—EMATs have very low efficiency as compared with conventional ultrasonic methods, with insertion losses of 40 dB or more. The EMAT technique can be used only on materials that are electrical conductors or are ferromagnetic. Highly corroded surfaces, especially inner surfaces, may render EMAT unsuitable for use if the surface disturbs the generation of the Lorentz forces. The design of EMAT probes is usually more complex than comparable piezoelectric search units, and are usually relatively large in size. Due to their low efficiency, EMATs usually require more specialized instrumentation for the generation and detection of ultrasonic signals. High transmitting currents, low-noise receivers, and careful electrical matching are imperative in system design. In general, EMAT probes are application-specific, in the same way as are piezoelectric transducers.

5. Basis of Application

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

5.2 Personnel Qualification:

5.2.1 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.

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

5.4 Procedures and Techniques—The procedures and techniques to be utilized shall be as specified in the contractual agreement.

5.5 Surface Preparation—The pre-examination surface preparation criteria shall be as specified in the contractual agreement.

5.6 Timing of Examination—The timing of examination shall be as specified in the contractual agreement.

5.7 Extent of Examination—The extent of the examination shall be as specified in the contractual agreement.