Designation: ~~E2905/E2905M – 12~~ E2905/E2905M – 13

Standard Practice for Examination of Mill and Kiln Girth Gear Teeth—Electromagnetic Methods[1]

This standard is issued under the fixed designation E2905/E2905M; 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~~ Scope*

1.1 This practice describes a two-part procedure for electromagnetic evaluation on gear teeth on mill and kiln gear drives and pinions. The first part of this practice details the ability to detect 100 % of surface-breaking discontinuities only in the addendum, dedendum, and root area on both the drive side and non-drive side of the gear ~~tooth.~~ tooth using an eddy current array. The second part of the examination is to ~~have the ability to~~ size or measure accurately the length and depth of any cracks found in these ~~areas. No existing~~areas using electromagnetic methods. No other practice addresses the use of ~~eddy current array~~ electromagnetic methods for the detection and sizing of surface-breaking discontinuities on mill and kiln ~~gear teeth combined with alternating current field measurement to size accurately any cracks found, length and depth.~~ring gear teeth.

1.2 This practice is used only for crack ~~detection~~ detection, alignment issues, wear patterns, and early signs of macro-pitting. It will not illustrate a full gear tooth analysis. Visual examination by an experienced gear technician is the only way to analyze fully gear teeth wear patterns and potential failure.

1.3 Two ~~technicians are~~ technicians, or one technician and a technical assistant, are typically required for this practice. One technical assistant guides the probe and the ~~other~~ technician operates the computer/software and analyzes the gear teeth condition.

1.4 It is important that the appropriate method standards, such as Guide E709 and Practice E2261 ~~and Guides~~, if the ~~E709~~alternating current field measurement approach is used for crack sizing, accompany the technician when performing the examination.

1.5 It is recommended that the technician reviews the appendixes in this practice ~~well~~ in advance of starting the job.

1.6 A clean gear is recommended for a complete gear analysis. Depending on the lubrication used, the technician, in discussion with the client, shall determine ~~what cleaning procedure should be used. If a non-asphaltic lubricant~~ the appropriate cleaning procedure, if cleaning is required. If an oil bath lubrication system is used, ensure the gear teeth surface is clean. If an asphaltic-based or synthetic-based lubricant is used, refer to the annexes and ~~appendixes~~appendices in this practice.

1.7 *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.

1.8 *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:*[2]

E709 Guide for Magnetic Particle Testing
E1316 Terminology for Nondestructive Examinations
E2261 Practice for Examination of Welds Using the Alternating Current Field Measurement Technique
E2884 Guide for Eddy Current Testing of Electrically Conducting Materials Using Conformable Sensor Arrays

[1] This test method is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.07 on Electromagnetic 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**

2.2 *AIA Standard:*[3]
NAS 410 Certification and Qualification of Nondestructive Test Personnel
2.3 *ANSI/AGMA Standards:*[4]
AGMA 912-A04 Mechanisms of Gear Tooth Failures—Information Sheet
ANSI/AGMA 1010 E-95 Standard for Appearance of Gear Teeth—Terminology of Wear and Failure
ANSI/AGMA 1012 G-05 Gear Nomenclature, Definition of Terms
2.4 *ANSI/ASNT Standards:*[4]
ANSI/ASNT-CP-189 Qualification and Certification of Nondestructive Testing Personnel
SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

3. Terminology

3.1 *Definitions*—~~The~~For definitions of ~~general~~ terms relating to ~~gear examinations can be found in Guide~~ this guide refer to ~~E709,~~ Terminology E1316, Practice E2261, and Guide E2884. For definitions of general terms relating to gear examinations refer to Guide E709, ANSI/AGMA 1012 G-05, and ANSI/AGMA 1010 E-95.

NOTE 1—Different equipment manufacturers may use slightly different terminology. Reference should be made to the equipment manufacturer's documentation for clarification.

3.2 *Eddy Current Array Method:*

3.2.1 *basic concepts of eddy current array, ECA, n*—eddy current array (ECA) technology provides the ability to ~~drive~~measure electronically multiple eddy current sensing coils placed side by side in the same probe assembly. ~~Data acquisition is performed by multiplexing the eddy current coils in a special~~ Example eddy current arrays have distinct drive coils associated with each sense coil or a drive coil with a linear conductor that is parallel to a linear array of sense coils. Depending upon the instrumentation, the response for each sense element can be measured in parallel or a multiplexer can be used to switch between one or more of the sense coils. Typically, a multiplexer is used when the number of sense coils is greater than the number of data acquisition channels for impedance measurement. When using eddy current sensor arrays with multiple drive coils and multiple sensing coils, undesired coupling between the individual coils is likely to take place. It may be necessary to use a multiplexer with a special multiplexing pattern to avoid ~~mutual inductance between the individual coils.~~ such undesired coupling. Most conventional eddy current flaw detection techniques can be reproduced with an ECA examination. With the benefits of single-pass coverage, and enhanced imaging capabilities, ECA technology provides a remarkably powerful tool and significant time savings during ~~inspections.~~ inspections compared to raster scanning with a single coil probe. (See Fig. 1.)

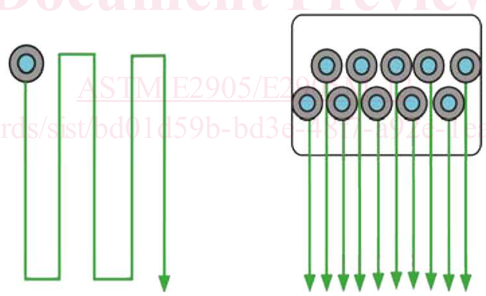

FIG. 1 Eddy Current ~~Single-Probe~~Single Coil Probe Compared to Eddy Current Array Probe Coils

[3] Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org.
[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3.2.1.1 *Discussion*—

~~The~~ In this standard, the use of the eddy current array is for crack ~~detection and~~ detection, early signs of macro-pitting ~~only. Limitations—eddy~~ alignment issues, and wear patterns. Although ECA will show wear patterns, the proper method for interpreting contact and wear patterns should be used. Refer to AGMA 912-A04, section 3.3.3.2. Limitations—The eddy current array will not reveal ~~alignment issues,~~ backlash problems, lubrication issues, tip to root interface, and so forth. Visual interpretation is the typical method used to analyze ~~gear teeth condition.~~ these conditions. It is also very important that the technician has an education in gear analysis. ~~Simple~~Basic eddy current experience does not provide the knowledge required to interpret gear teeth issues or the understanding of ECA. The knowledge of the defect type helps in determining the root causes and the potential solutions, resulting in a higher standard of examination.

~~3.2.2 *depth of penetration, n*—eddy current density does not remain constant across the depth of a material. The density is greatest at the surface and decreases exponentially with depth (the "skin effect"). The standard depth of penetration equation is used to explain the penetration capability of eddy current testing, which decreases with increasing frequency, conductivity, or~~

~~permeability. For a material that is both thick and uniform, the standard depth of penetration is the depth at which the eddy current density is 37 % of the material surface value. To detect very shallow defects in a material, very high frequencies are used.~~

3.2.2 *eddy current array probes, n*—probes can be designed to detect a specific type of discontinuity and to conform to the shape of the part under examination (see Fig. 2).

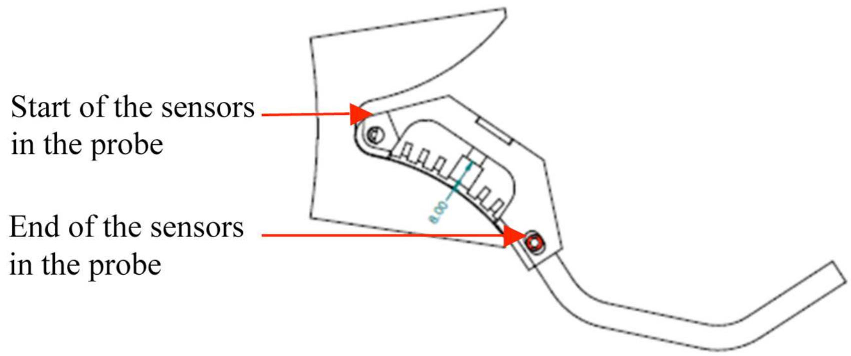

FIG. 2 Coverage of a Flexible Probe—Root, Dedendum, and Addendum

3.2.2.1 *Discussion—*

Probes can be designed to detect a specific type of discontinuity and conform to the shape of the gear tooth under examination. Also notice that the center of the root would actually be scanned twice. In this examination, there is no saturation performed. Surface probes are made with coils designed to be driven at relatively high frequencies (typically 50 to 500 kHz). Using higher frequencies results in less penetration of the eddy current field into the test part allowing full coverage of any surface-breaking discontinuities of the component to be examined. In addition, the higher frequencies provide a higher resolution for the detection of smaller defects. For this practice, a surface array probe, with the ability of detecting all surface discontinuities—including cracks, is required for a successful examination.

3.2.3 *reference standard, n*—shall contain at least one long reference indicator to standardize all the channels of the array at once and also representative defects for ~~flaws~~flaw characterization during the examination.

3.2.4 *set screws, n*—conformable and substantially nonconducting set screws on the probe that are used to allow small ~~liftoff~~lift-off adjustments or excursions on surface response.

3.2.5 *system performance verification, n*—use of a measurement of one or more response values, typically physical property values for a reference ~~part~~standard to confirm that the ~~property~~response values are within specified tolerances to validate the system standardization and verify proper instrument operation.

3.2.5.1 *Discussion—*

Probe quality—Probe life varies depending on the environmental conditions within the work area. Some of these environmental factors are temperature, moisture, cleanliness, and the main factor being surface roughness.

FIG. 3 Two ~~Cracks on Tooth Just Above the Root~~cracks on a tooth just above the root that were only observed visually after being revealed by the ECA examination. In this example, the cracks were not apparent visually until MT was performed.

~~3.2.6.2 *Discussion—*~~

~~Different equipment manufacturers may use slightly different terminology. Reference should be made to the equipment manufacturer's documentation for clarification.~~

~~3.2.7 *Practice E2261*—The terminology, procedure, and definition of terms are used in this practice.~~

~~NOTE 1—Different equipment manufacturers may use slightly different terminology. Reference should be made to the equipment manufacturer's documentation for clarification.~~

~~3.3 *ANSI/AGMA 1012 G-05*—The terminology used in ANSI/AGMA 1012 G-05 is used throughout this practice.~~

~~3.4 *ANSI/AGMA 1010 E-95*—The terminology used in ANSI/AGMA 1010 E-95 is used throughout this practice.~~

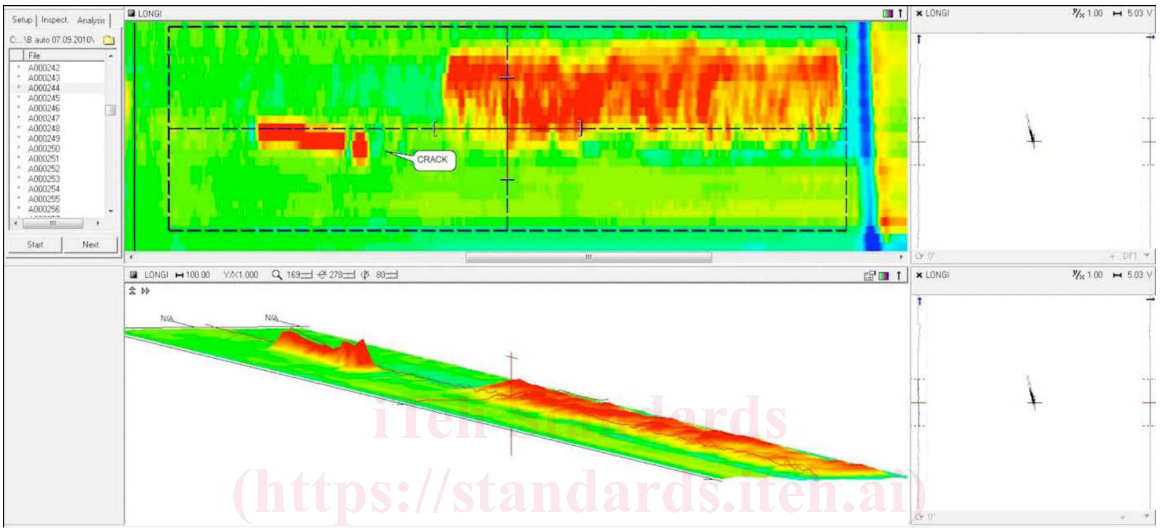

FIG. 4 Two- and Three-Dimensional View

4. Summary of Practice

4.1 *Gear-Cleaning Procedure*—Typically, mill operations does the cleaning or supervises the cleaning. ~~Maintenance~~ Mill maintenance removes the guards for access to the gear. Nondestructive evaluation (NDE) mill girth gear examinations are provided for maintenance. ~~As visual~~ Visual interpretation is ~~the~~ also a common method used to analyze gear teeth condition, such as contact patterns and wear ~~patterns,~~ patterns. For visual inspection, a cleaned gear is mandatory. Another reason for a cleaned gear tooth is that it is very hard for the ECA probe to maintain the geometry of a gear tooth that is covered with ~~lubrication,~~lubricant, especially if the ~~lubrication is asphaltic based.~~ lubricant is asphaltic-based or synthetic. If asphaltic or sythetic lubrication is used, refer to Appendix X2 for cleaning procedures.

4.1.1 *ECA*—ECA is used for nondestructively locating and characterizing surface-breaking discontinuities in conducting materials to electrically conductive materials. For use in this practice, the properly designed ECA probe has proven to detect all surface-breaking discontinuities from 0.76 mm (0.03 in.) and larger on the addendum, dedendum, and root of girth gear teeth. The examination is performed by scanning a conformable ~~eddy-current~~ eddy current sensor array over the surface of the addendum, dedendum, and root of the gear tooth being examined in one pass. The drive side of the tooth is referred to as the A side and the nondrive side of the tooth is referred to as the B side of the tooth. The measured responses and location information are then used, typically in the form of a displayed image (C-scan), to determine the presence and characteristics of discontinuities.

4.1.2 *Alternating Current Field Measurement Method*—Alternating current field measurement is ~~only to be~~ used if a crack is found. Alternative electromagnetic methods can also be used for sizing cracks.

4.1.3 *Alternating Current Field Measurement for Nondestructive Testing Detection and Sizing of Surface-Breaking Cracks*—It works on all metals, ferrous or nonferrous. A sensor probe is placed on the surface to be examined and an alternating current is induced into the surface. When no defects are present the alternating current produces a uniform magnetic field above the surface. Any defect present will perturb the current, forcing it to flow around and underneath the defect; this causes the magnetic field to become non-uniform and sensors in the alternating current field measurement probe measure these field variations. Two components of this magnetic field are measured—one provides information about the depth or aspect ratio of the defect(s) and the other shows the positions of the defects' ends. The two signals are used to confirm the presence of a defect and, together with a sizing algorithm, measure its length and depth. The main ~~advantage~~advantages of alternating current field measurement for this practice ~~is~~ are the speed of sizing cracks and that it provides both depth and length information. Defects up to 25 mm (1 in.) in depth can be sized accurately.

4.1.4 *Magnetic Particle Examination*—Magnetic particle is used when a crack is found. It is used to illustrate the crack for the picture in the report. (See Fig. 3.) It is also used when excessive lift-off prevents the ECA probe from receiving a signal.

5. Significance and Use

5.1 Visual interpretation of gear teeth condition is different from examining for cracks or early signs of macro-pitting. Visual interpretation is referred to ANSI/AGMA 1010 E-95.

5.1.1 The purpose of using ~~eddy-current~~ an eddy current array for mill girth gear teeth examination is it drastically reduces the examination time; covers a large area in one single pass; provides real-time cartography of the examined region, facilitating data interpretation; and improves reliability and probability of detection (POD). One tooth can be examined in less than 30 seconds.

NOTE 2—In this standard, ECA is used as a discontinuity finding tool (see Fig. 3) and a presentation aid as support once problems are discovered and photographed. ~~As presentation is everything and so is visualization, colors and~~ Colors and three-dimensional (3D) images (see Fig. 4) that help with visualization are ~~absolutely~~ invaluable in such circumstances.

5.1.2 The purpose of using alternating current field measurement is ~~its ability~~ to size ~~accurately~~ surface-breaking ~~cracks.~~cracks electronically.

5.1.3 This practice is a useful tool for a condition-based monitoring program.

5.2 The examination results may then be used by qualified personnel or organizations to assess remaining service life or other engineering characteristics (beyond the scope of this practice). This practice is not intended for the examination of non-surface-breaking discontinuities.

6. Basis of Application

6.1 The following item is subject to contractual agreement between the parties using or referencing this practice.

6.1.1 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this practice 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, 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.

7. Interferences—ECA

7.1 *Curvature of Examination Surface*—For helical gears with a helix angle of 1° or more, a flexible probe is required and needs to be flexible enough to adjust its curvature to the various helix angles. System performance verification tests should be run to verify ~~liftoff~~lift-off sensitivity by adjusting the set screws in the face of the array probe.

7.2 *Surface Conditions*—Micropitting, macropitting, spalling, and so forth of gear teeth surfaces can be ~~easily~~readily scanned with the ECA probe by adjusting the set screws allowing for ~~liftoff.~~lift-off. Gear teeth surfaces shall be clean and free of any asphaltic ~~lubrication.~~or synthetic lubricant that could interfere with sliding of the ECA probe along the gear tooth surface.

7.3 *Pressure of the Probe against Surface under Examination*—Sliding the probe across the gear tooth is all the pressure that is required.

NOTE 3—The array probe has two set screws that allow for adjusting ~~liftoff.~~lift-off.

7.4 *Temperature*—~~Eddy-current~~ Eddy current measurements are generally affected by temperature variations of the material under examination. For this practice, once the gear has been cleaned, the temperature of the gear teeth is ready for examination.

7.5 *Scanning Speed*—~~Depending on~~ The length of the C-scan image may depend upon how fast a gear tooth is ~~scanned, C-scans will be more or less long, which means that they will contain also more or less acquisitions points.~~ scanned if a position encoder is not used. This means that the number of acquisition points in the images may vary with the scan speed. As the technician applies a filter with a given number of points on the C-scan, this filter could cut or modify some indications. Scanning speed should be at the same speed that is set in the scan parameters.

7.6 *Residual Magnetism*—In magnetic materials, residual magnetism may affect the measurement and appear as a local property change. In this application, eddy current is induced in the ~~material, then~~ material by the applied alternating magnetic field. With a probe configuration as in this application, the magnetism is very weak. Residual magnetism would be detected if the gear was previously examined using magnetic particle. Gears of this nature are usually examined every year or two, so any residual magnetism would be minimal. This application reduces the noise level by an optimal probe ~~configuration (transmit receive configuration instead of absolute or differential).~~configuration.

8. Apparatus—ECA

8.1 *Instrumentation*—The electronic instrumentation shall be capable of energizing the eddy current surface array with alternating current of one or more suitable frequencies and shall be capable of measuring changes in the impedance of each element in the surface array. The equipment shall include a capability to correlate the impedance variations with physical property changes for the material under examination.

8.2 ~~*Instrumentation—*~~*Eddy Current Surface Array—*The ~~electronic instrumentation~~ eddy current surface array shall be capable of ~~energizing the eddy-current surface array with alternating current of one or more suitable frequencies and shall be capable of measuring~~ inducing currents in the material under examination and sensing changes in the ~~impedance of each element in the surface array. The equipment shall include a capability to correlate the impedance variations with physical property changes for the material under~~ physical characteristics of the material under examination. Eddy current array (ECA) technology provides the ability to measure electronically multiple eddy current coils placed side by side in the same probe assembly. The surface probe array shall have at least two rows of coils offset by one-half coil and covering the entire length of the surface to be examined. Such coils configuration, whichever the exciting mode (absolute, transmit-receive, differential, and so forth), will allow good coverage all along the array and also to avoid dead zones. The ECA data responses can be displayed as an image spanning the surface of the examined region of the gear or as individual coil channels for analysis after examination.

8.2.1 Depending upon the instrumentation, the response for each sense element can be measured in parallel or a multiplexer can be used to switch between one or more of the sensing coils. Typically, a multiplexer is used when the number of sense elements is greater than the number of data acquisition channels for impedance measurement. When using eddy current sensor arrays with multiple drive coils and multiple sensing coils, undesired coupling between the individual coils is likely to take place. It may be necessary to use a multiplexer with a special multiplexing pattern to avoid such undesired coupling. An undesirable effect known as mutual inductance (magnetic coupling between coils in close proximity) can be minimized with the use of an internal multiplexing system to program carefully the exact time that each coil is excited to transmit its eddy current signal. The signals are then reassembled before being displayed.

8.2.2 ~~*Eddy-Current Surface Array*—The eddy-current surface array shall be capable of inducing currents in the material under examination and sensing changes in the physical characteristics of the material under examination. Eddy current array (ECA) technology provides the ability to drive electronically multiple eddy current coils placed side by side in the same probe assembly. Data acquisition is performed by multiplexing the eddy current coils in a special pattern to avoid mutual inductance between the individual coils. The surface probe array shall have at least two rows of coils offset by one-half coil and covering the entire length of the surface to be examined. Such coils configuration, whichever the exciting mode (absolute, transmit-receive, differential, and so forth), will allow to assure a good coverage all along the array and also to avoid dead zones. An undesirable effect known as mutual inductance (magnetic coupling between coils in close proximity) is minimized with the use of an internal multiplexing system to program carefully the exact time that each coil is excited to transmit its eddy current signal. The signals are then reassembled before being displayed as an image. In addition to the enhanced imaging capabilities of multiplexed data, multiplexing allows any individual coil (data) channel to be analyzed after examination. Multiplexing allows an increased channel resolution, increased coil sensitivity (through the reduction of mutual inductance), and a reduced noise level. This ultimately leads to an improved signal-to-noise ratio.~~ To achieve the best results for examination performance, there are several important parameters to consider when designing an effective ECA probe. Key factors include examination coverage, sensitivity, frequency, and, of course, cost. To optimize performance, it is important to balance the various probe parameters carefully. For example, high-sensitivity probes require small, high-frequency coils (providing less coverage); probes capable of greater coverage require larger, lower-frequency coils (resulting in decreased sensitivity to small defects). As is the case with conventional eddy current examinations, choosing the correct probe characteristics is essential to a successful examination. The array can be in contact with the material being tested or offset by an intended ~~liftoff~~lift-off distance (for noncontact scanning) with two set screws in the face of the array probe.

8.3 An important consideration affecting the choice of instrumentation, eddy current array, and operational parameters is the depth of penetration of the sensor fields into the material under examination. The eddy current density does not remain constant with depth into the material. The eddy current density is greatest at the surface and decreases exponentially with depth (i.e., the "skin effect"). The standard depth of penetration decreases with increasing frequency, electrical conductivity, or magnetic permeability of the material. For a material that is both thick and uniform, the standard depth of penetration is the depth at which the eddy current density is 37 % of the material surface value. To detect shallow defects in a material, relatively high frequencies are used. Refer to E2884 for additional information.

9. Standardization—ECA

9.1 The ~~eddy-current~~ eddy current unit is a precision instrument and should be calibrated annually or at periodic intervals after a repair or when a malfunction is suspected.

9.1.1 ~~*Reference Part*~~ *Standardization—*~~Reference part standardization is to standardize~~ Standardization is performed to adjust the sensitivity for an ECA probe. To do this, the operator scans a reference ~~block~~standard containing a reference notch to generate the same eddy current signal for each channel. To do this, the operator needs to adjust signal amplitude and phase for each channel to achieve it. After the standardization, other defects can be scanned, such as three different long transversal notches at depths from 1 to 3 to 5 mm (0.04 to 0.1 to 0.2 in.) long to 30 mm (1.2 in.) long. Also six holes ranging from 0.76 to 6 mm (0.03 to 0.24 in.) in diameter can be used for characterization purposes. Using the reference ~~block,~~standard, the operator adjusts the gain and rotation of each channel so that the same phase and amplitude response is obtained for all channels. To validate the standardization, ~~baseline~~a system performance verification should be performed.