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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*

NOTE 1—Throughout the standard, "gear" means gear or pinion unless the gear is specifically identified.

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,~~ flank and root area on both the drive side and non-drive (coast) side of the gear tooth using an eddy current array. The second part of the examination is to size or measure accurately the length and depth of any cracks found in these areas using electromagnetic methods. No other practice addresses the use of electromagnetic methods for the detection and sizing of surface-breaking discontinuities on mill and kiln ring gear teeth. For reference, Fig. 1 contains a schematic diagram labeling the areas of the gear teeth.

1.2 This practice is used only for ~~crack detection, scuffing, wear patterns, and early signs of macro-pitting.~~ the detection of surface breaking discontinuities including cracking, macropitting, and certain scuffing and wear patterns. It will not provide a full gear tooth analysis. Visual examination by an experienced gear specialist is the ~~only~~best way to characterize fully the failure modes ~~present, their severity, and consequences.~~ present. It is imperative that the analysis of the gear teeth is completed at the time of examination. Sending data offsite for analysis later is not recommended, as potential failure modes could be missed from lack of in-situ visual examination.

1.3 Two technicians, one ~~gear specialist,~~lead technician, and a gear technician, are typically required for this practice. One technician 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~~Practice ~~E709~~E3024 and Practice E2261, ~~if the alternating current field measurement approach is used for crack sizing, accompany the technician when performing the examination.~~accompany the technician when performing the examination. If crack sizing is performed, then it shall be performed using an electromagnetic testing method such as the alternating current field measurement approach of Practice E2261.

1.5 It is recommended that the technician review the appendixes in this practice 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 the appropriate cleaning procedure. If an oil bath lubrication system is used, ensure the gear teeth surfaces are clean. If an asphaltic-based or synthetic-based lubricant is used, refer to the annexes and appendices in this practice.

[1] This practice 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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*A Summary of Changes section appears at the end of this standard

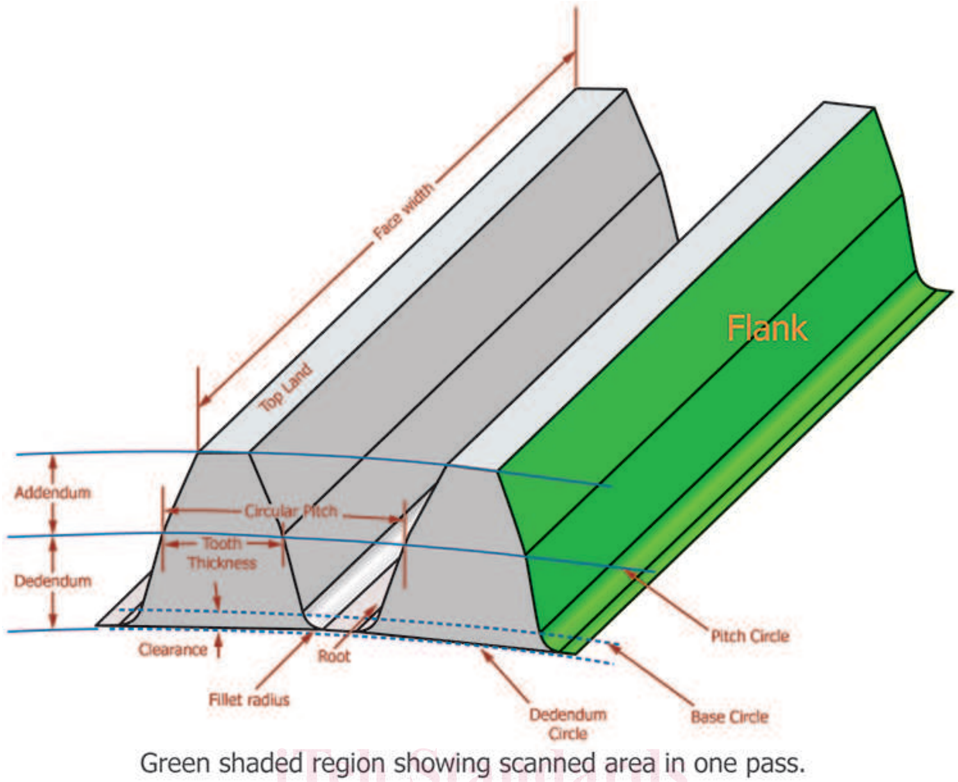

FIG. 1 Schematic Image Labeling the Regions of the Gear Teeth and the Area (Shown in Green Shading) That is Scanned in One Pass With the Eddy Current Array Probe

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 are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.9 *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]

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
E3024 Practice for Magnetic Particle Testing for General Industry

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
AGMA 919-1-A14 Condition Monitoring and Diagnostics of Gear Units and Open Gears

[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 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.

ASNI/AGMA 1010-F14 Standard for Appearance of Gear Teeth—Terminology of Wear and Failure
ANSI/AGMA 1012 G-05 Gear Nomenclature, Definition of Terms
ANSI+AGMA+6014-B15 Annex G

2.4 *ANSI/ASNT Standards:*
ANSI/ASNT-CP-189 Qualification and Certification of Nondestructive Testing Personnel[4]
ISO 9712 Qualification and Certification of NDT Personnel[4]
SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing[5]

3. Terminology

3.1 *Definitions*—For definitions of terms relating to this practice, refer to 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, ANSI/AGMA 1010-F14, AGMA 919-1-A14, and ANSI+AGMA+6014-B15.

NOTE 2—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 measure electronically multiple eddy current sensing coils placed side by side in the same probe assembly.~~ a sensor configuration with multiple sensing coils that respond to a local magnetic field created by at least one proximate drive coil.

3.2.1.1 *Discussion*—
The eddy current array technology provides the ability to measure electronically multiple eddy current sensing coils placed side by side in the same probe assembly. 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 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 examinations compared to raster scanning with a single coil probe. (See Fig. ~~1~~2.)

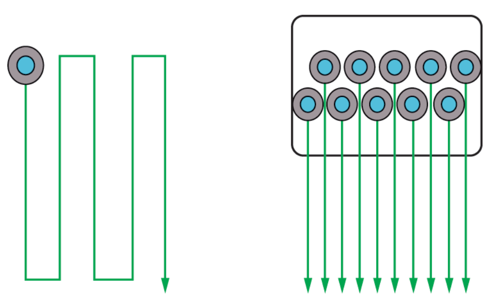

FIG. ~~1~~2 Eddy Current Single Coil Probe Compared to Eddy Current Array Probe Coils

3.2.1.2 *Discussion*—
In this ~~standard,~~practice, the eddy current array is used for ~~crack detection, early signs of macro-pitting, scuffing, and~~ the detection of surface breaking discontinuities including cracking, macro-pitting, and certain scuffing and wear patterns. Although ECA will show the effects of certain types of wear patterns, the proper method for interpreting contact and wear patterns should be used. Refer to ANSI/AGMA 1010-F14. It describes the appearance of gear tooth failure modes and discusses their mechanisms, with the sole intent of facilitating identification of gear wear and failure. ~~Limitations—The eddy current array will not reveal backlash problems, lubrication issues, tip to root interface, and so forth. Visual interpretation by an expert is the typical method used to analyze these conditions. It is very important that the technician has a clear understanding of analyzing gear teeth failure modes~~

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

~~that may be present. 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 *eddy current array probes, n*—~~probes can be~~ mechanical fixtures designed to detect a specific type of discontinuity with an eddy current array and to conform to the shape of the part under examination (see Fig. ~~2~~3).

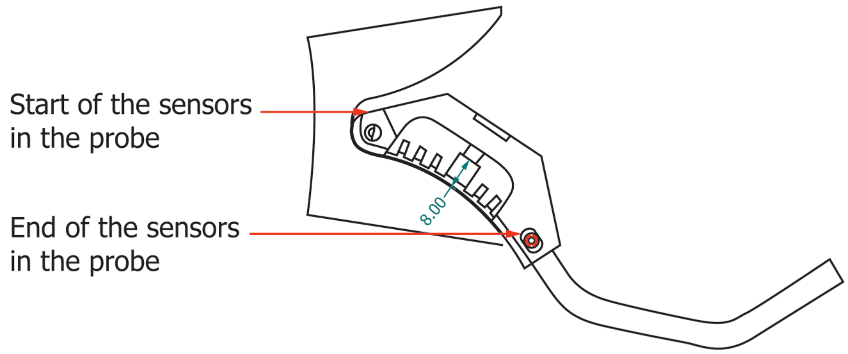

FIG. ~~2~~3 Coverage of a Flexible Probe—Root, Dedendum, and Addendum

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~~ cracks—is required for a successful examination.

3.2.2.2 *Discussion*—
Probe Quality—Probe operational 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.

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 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 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 standard to confirm that the 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.~~

4. Summary of Practice

4.1 *Gear-Cleaning Procedure*—Typically, mill operations performs the gear tooth cleaning. However, in some cases, the technicians performing the examination may be required to clean the gear as per Appendix X2. Mill maintenance personnel are responsible for removing the guards for access to the gear teeth. Nondestructive examination (NDE) for mill and kiln girth gear ~~examinations~~teeth are provided for maintenance and as a part of an overall ~~Reliability Centered Maintenance Program.~~ predictive maintenance plan. Visual interpretation is the common method used by gear specialists to analyze gear tooth condition in-situ, such as contact patterns, scuffing, and wear patterns. However, visual examination is not recommended for crack detection. For a thorough visual examination, proper cleaning of the gear teeth is considered mandatory. ~~Another reason~~Other reasons for a cleaned gear tooth ~~is~~ are to prevent lift-off and that it is very hard for the ECA probe to maintain the geometry of a gear tooth that ~~is covered~~

FIG. ~~3~~4 Two 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

~~with lubricant,~~ has lubricant present, especially if the lubricant is asphaltic-based or synthetic. If asphaltic or synthetic 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,~~ flank and root of girth gear teeth. The examination is performed by scanning a conformable eddy current sensor array over the surface of the ~~addendum, dedendum,~~ flank 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~~non-drive 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 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 advantages of alternating current field measurement for this practice 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. See Practice E2261 for additional information regarding the alternating current field measurement method.

4.1.4 *Magnetic Particle Examination*—~~Magnetic particle is used when an indication is found. It is used to visualize the indication for the technician to make an assessment and document~~ The magnetic particle method produces a direct visual indication which can assist the technician/inspector in further analyzing and identifying the discontinuity for documentation in the report. (See Fig. ~~3~~4.) 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 ASNI/AGMA 1010-F14.

5.1.1 The purpose of using an eddy current array for mill girth gear tooth 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 3—In this ~~standard,~~practice, ECA is used as a discontinuity finding tool (see Fig. ~~3~~4) and a presentation aid as support once problems are discovered and photographed. Colors and three-dimensional (3D) images (see Fig. ~~4~~5) that help with visualization are invaluable in such circumstances.

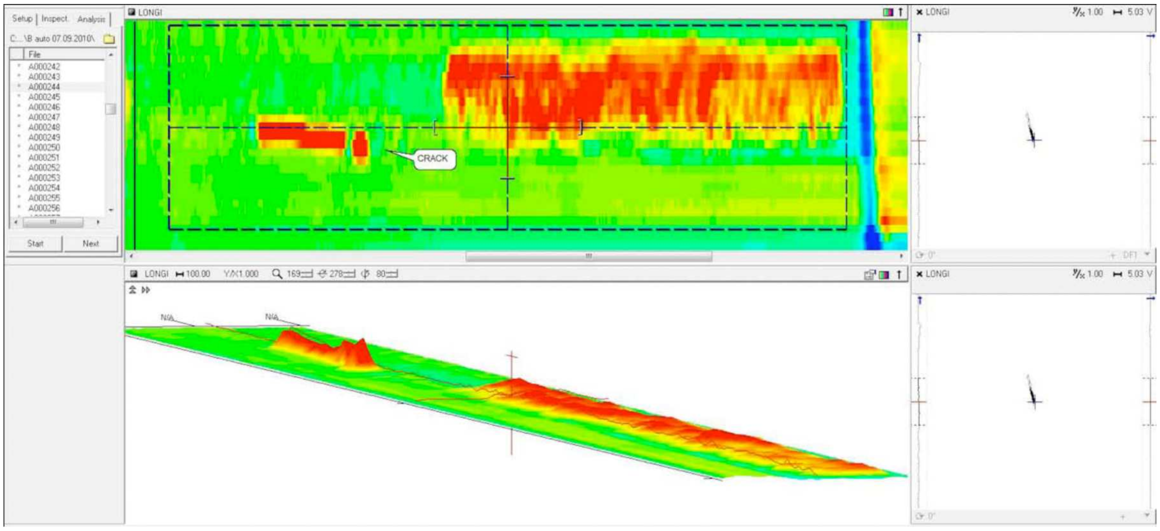

FIG. ~~4~~5 Two- and Three-Dimensional View

5.1.2 The purpose of using alternating current field measurement is to size surface-breaking 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 ~~criticality or probability of failure, or both, or other engineering characteristics (beyond the scope of this practice).~~ the severity and potential consequences of the failure modes identified. This practice is not intended for the examination of non-surface-breaking discontinuities. Other methods ~~are available~~ should be considered to address ~~this if required.~~examination for 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, 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.

7. ~~Interferences—ECA~~Interferences

7.1 *Curvature of Examination Surface*—For the examination of gears or pinions with ~~a~~ pronounced ~~involute profile,~~ profiles, a flexible probe is required that can adjust its curvature to the various ~~involute~~ profiles. System performance verification tests should be run to verify 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~~ The gear tooth flanks and roots can be readily scanned with the ECA probe by adjusting the set screws to set a proper lift-off. Gear tooth surfaces shall be clean and free of any asphaltic or synthetic lubricant that could interfere with ~~sliding~~ proper lift-off of the ECA probe ~~along~~against 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 4—The array probe has two set screws that allow for adjusting lift-off.

7.4 *Temperature*—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*—The length of the C-scan image may depend upon how fast a gear tooth is 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 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.

7.7 *Limitations*—The eddy current array will not detect all scuffing conditions, wear patterns, backlash problems, lubrication issues, tip to root interference, and similar conditions. Visual interpretation by an expert is the typical method used to analyze these conditions. It is advised that the technician also be a girth gear specialist who understands how to properly identify and characterize gear tooth failure modes. Basic eddy current experience does not provide the knowledge required to interpret gear tooth 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.

8. ~~Apparatus—ECA~~Apparatus

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~~ the impedance or variations in the impedance of each element in the surface array. The equipment shall include a capability to correlate the impedance ~~variations~~ variations, or property values derived from the impedance values, with physical property changes for the material under examination.

8.2 *Eddy Current Surface Array*—The eddy current surface array shall be capable of inducing currents in the material under examination and sensing ~~changes~~variations in the 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~~ sense coils that cover the entire length of the surface to be examined. This could include two rows of coils offset by one half between the two rows. 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~~ Similarly, the undesirable effect ~~known as~~ of 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 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 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 (that is, the "skin effect"). The standard depth of penetration decreases with increasing frequency, electrical conductivity, or magnetic permeability