ARTICLE 8
EDDY CURRENT EXAMINATION

T-810 SCOPE

When specified by the referencing Code Section, the eddy current examination method and techniques described in this Article shall be used.

(a) This Article describes the techniques to be used when performing eddy current examinations on conductive-nonferromagnetic and coated ferromagnetic materials.

(b) The requirements of Article 1, General Requirements, also apply when eddy current examination, in accordance with Article 8, is required by a referencing Code Section.

(c) Definitions of terms for eddy current examination appear in Article 1, Mandatory Appendix I, I-121.5, ET — Electromagnetic (Eddy Current).

(d) Mandatory Appendix II, Eddy Current Examination of Nonferromagnetic Heat Exchanger Tubing, provides the requirements for bobbin coil multifrequency and multiparameter eddy current examination of installed nonferromagnetic heat exchanger tubing.

(e) Mandatory Appendix III, Eddy Current Examination on Coated Ferromagnetic Materials, provides eddy current requirements for eddy current examination on coated ferromagnetic materials.

(f) Mandatory Appendix IV, External Coil Eddy Current Examination of Tubular Products, provides the requirements for external coil eddy current examination of seamless copper, copper alloy, austenitic stainless steel, Ni-Cr-Fe alloy, and other nonferromagnetic tubular products.

(g) Mandatory Appendix V, Eddy Current Measurement of Nonconductive-Nonferromagnetic Coating Thickness on a Nonferromagnetic Metallic Material, provides the requirements for surface probe eddy current examination for measuring nonconductive-nonferromagnetic coating thicknesses.

(h) Mandatory Appendix VI, Eddy Current Detection and Measurement of Depth of Surface Discontinuities in Nonferromagnetic Metals With Surface Probes, provides the requirements for surface probe eddy current examination for detection of surface connected discontinuities and measuring their depth.

(i) Mandatory Appendix VII, Eddy Current Examination of Ferromagnetic and Nonferromagnetic Conductive Metals to Determine If Flaws Are Surface Connected, provides the requirements for eddy current examination with a surface probe to determine if flaws are surface connected in both ferromagnetic and nonferromagnetic metals.

(j) Mandatory Appendix VIII, Alternative Technique for Eddy Current Examination of Nonferromagnetic Heat Exchanger Tubing, Excluding Nuclear Steam Generator Tubing, provides the requirements for an alternative technique for bobbin coil multifrequency and multiparameter eddy current examination of installed nonferromagnetic heat exchanger tubing, excluding nuclear steam generator tubing.

(k) Mandatory Appendix IX, Eddy Current Array Examination of Ferromagnetic and Nonferromagnetic Materials for the Detection of Surface-Breaking Flaws, provides the requirements for eddy current array (ECA) surface probe examination of coated and noncoated ferromagnetic and nonferromagnetic materials for the detection of surface-breaking flaws.

(l) Mandatory Appendix X, Eddy Current Array Examination of Ferromagnetic and Nonferromagnetic Welds for the Detection of Surface-Breaking Flaws, provides the requirements for ECA surface probe examination of coated and noncoated ferromagnetic and nonferromagnetic welds for the detection of surface-breaking flaws.

MANDATORY APPENDIX II
EDDY CURRENT EXAMINATION OF NONFERROMAGNETIC HEAT EXCHANGER TUBING

II-810 SCOPE

This Appendix provides the requirements for bobbin coil, multifrequency, multiparameter, eddy current examination for installed nonferromagnetic heat exchanger tubing, when this Appendix is specified by the referencing Code Section.

II-820 GENERAL

This Appendix also provides the methodology for examining nonferromagnetic, heat exchanger tubing using the eddy current method and bobbin coil technique. By scanning the tubing from the boreside, information will be obtained from which the condition of the tubing will be determined. Scanning is generally performed with a bobbin coil attached to a flexible shaft pulled through tubing manually or by a motorized device. Results are obtained by evaluating data acquired and recorded during scanning.

II-821 WRITTEN PROCEDURE REQUIREMENTS

II-821.1 Requirements. Eddy current examinations shall be conducted in accordance with a written procedure which shall contain, as a minimum, the requirements listed in Table II-821. The written procedure shall establish a single value, or range of values, for each requirement.

II-821.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table II-821 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

II-822 PERSONNEL REQUIREMENTS

The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with the requirements of this Appendix and the referencing Code Section.

II-830 EQUIPMENT

II-831 DATA ACQUISITION SYSTEM

II-831.1 Multifrequency-Multiparameter Equipment. The eddy current instrument shall have the capability of generating multiple frequencies simultaneously or multiplexed and be capable of multiparameter signal combination. In the selection of frequencies, consideration shall be given to optimizing flaw detection and characterization.

(a) The outputs from the eddy current instrument shall provide phase and amplitude information.

(b) The eddy current instrument shall be capable of operating with bobbin coil probes in the differential mode or the absolute mode, or both.

(c) The eddy current system shall be capable of real time recording and playing back of examination data.

(d) The eddy current equipment shall be capable of detecting and recording dimensional changes, metallurgical changes and foreign material deposits, and responses from imperfections originating on either tube wall surface.

II-832 ANALOG DATA ACQUISITION SYSTEM

II-832.1 Analog Eddy Current Instrument.

(a) The frequency response of the outputs from the eddy current instrument shall be constant within 2% of full scale from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-s/mm) times maximum probe travel speed in./sec (mm/s).

(b) Eddy current signals shall be displayed as two-dimensional patterns by use of an X-Y storage oscilloscope or equivalent.

(c) The frequency response of the instrument output shall be constant within 2% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-sec/mm) times maximum probe travel speed.

II-832.2 Magnetic Tape Recorder.

(a) The magnetic tape recorder used with the analog equipment shall be capable of recording and playing back eddy current signal data from all test frequencies and shall have voice logging capability.

Table II-821
Requirements of an Eddy Current Examination Procedure

Requirements as Applicable	Essential Variable	Nonessential Variable
Tube material	X	...
Tube diameter and wall thickness	X	...
Mode of inspection — differential or absolute	X	...
Probe type and size	X	...
Length of probe cable and probe extension cables	X	...
Probe manufacturer, part number, and description	X	...
Examination frequencies, drive voltage, and gain settings	X	...
Manufacturer and model of eddy current equipment	X	...
Scanning direction during data recording, i.e., push or pull	X	...
Scanning mode — manual, mechanized probe driver, remote controlled fixture	X	...
Fixture location verification	X	...
Identity of calibration reference standard(s)	X	...
Minimum digitization rate	X	...
Maximum scanning speed during data recording	X	...
Personnel requirements	...	X
Data recording equipment manufacturer and model	...	X
Scanning speed during insertion or retraction, no data recording	...	X
Side of application — inlet or outlet	...	X
Data analysis parameters	...	X
Tube numbering	...	X
Tube examination surface preparation	...	X

(b) The frequency response of the magnetic tape recorder outputs shall be constant within 10% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-s/mm) times maximum probe travel speed.

(c) Signal reproducibility from input to output shall be within 5%.

II-832.3 Strip Chart Recorder.

(a) Strip chart recorders used with analog equipment shall have at least 2 channels.

(b) The frequency response of the strip chart recorder shall be constant within 20% of full scale from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-s/mm) times maximum probe travel speed.

II-833 DIGITAL DATA ACQUISITION SYSTEM

II-833.1 Digital Eddy Current Instrument.

(a) At the scanning speed to be used, the sampling rate of the instrument shall result in a minimum digitizing rate of 30 samples per in. (25 mm) of examined tubing, use dr = sr/ss, where dr is the digitizing rate in samples per in., sr is the sampling rate in samples per sec or Hz, and ss is the scanning speed in in. per sec.

(b) The digital eddy current instrument shall have a minimum resolution of 12 bits per data point.

(c) The frequency response of the outputs of analog portions of the eddy current instrument shall be constant within 2% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-s/in. (0.4 Hz-sec/mm) times maximum probe travel speed.

(d) The display shall be selectable so that the examination frequency or mixed frequencies can be presented as a Lissajous pattern.

(e) The Lissajous display shall have a minimum resolution of 7 bits full scale.

(f) The strip chart display shall be capable of displaying at least 2 traces.

(g) The strip chart display shall be selectable so either the X or Y component can be displayed.

(h) The strip chart display shall have a minimum resolution of 6 bits full scale.

II-833.2 Digital Recording System.

(a) The recording system shall be capable of recording and playing back all acquired eddy current signal data from all test frequencies.

(b) The recording system shall be capable of recording and playing back text information.

(c) The recording system shall have a minimum resolution of 12 bits per data point.

II-834 BOBBIN COILS

II-834.1 General Requirements.

(a) Bobbin coils shall be able to detect artificial discontinuities in the calibration reference standard.

(b) Bobbin coils shall have sufficient bandwidth for operating frequencies selected for flaw detection and sizing.

II-835 DATA ANALYSIS SYSTEM

II-835.1 Basic System Requirements.

(a) The data analysis system shall be capable of displaying eddy current signal data from all test frequencies.

(b) The system shall have multiparameter mixing capability.

(c) The system shall be capable of maintaining the identification of each tube recorded.

(d) The system shall be capable of measuring phase angles in increments of one degree or less.

(e) The system shall be capable of measuring amplitudes to the nearest 0.1 volt.

II-836 ANALOG DATA ANALYSIS SYSTEM

II-836.1 Display. Eddy current signals shall be displayed as Lissajous patterns by use of an X-Y storage display oscilloscope or equivalent. The frequency response of the display device shall be constant within 2% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-s/mm) times maximum probe travel speed.

II-836.2 Recording System.

(a) The magnetic tape recorder shall be capable of playing back the recorded data.

(b) The frequency response of the magnetic tape recorder outputs shall be constant within 10% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-s/mm) times maximum probe travel speed in./sec (mm/s).

(c) Signal reproducibility input to output shall be within 5%.

II-837 DIGITAL DATA ANALYSIS SYSTEM

II-837.1 Display.

(a) The analysis display shall be capable of presenting recorded eddy current signal data and test information.

(b) The analysis system shall have a minimum resolution of 12 bits per data point.

(c) The Lissajous pattern display shall have a minimum resolution of 7 bits full scale.

(d) The strip chart display shall be selectable so either the X or Y component of any examination frequency or mixed frequencies can be displayed.

(e) The strip chart display shall have a minimum resolution of 6 bits full scale.

II-837.2 Recording System.

(a) The recording system shall be capable of playing back all recorded eddy current signal data and test information.

(b) The recording system shall have a minimum resolution of 12 bits per data point.

II-838 HYBRID DATA ANALYSIS SYSTEM

(a) Individual elements of hybrid systems using both digital elements and some analog elements shall meet specific sections of II-830, as applicable.

(b) When analog to digital or digital to analog converters are used, the frequency response of the analog element outputs shall be constant within 5% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-sec/in. (0.4 Hz-s/mm) times maximum probe travel speed.

II-840 REQUIREMENTS

II-841 RECORDING AND SENSITIVITY LEVEL

(a) The eddy current signal data from all test frequencies shall be recorded on the recording media as the probe traverses the tube.

(b) The sensitivity for the differential bobbin coil technique shall be sufficient to produce a response from the through-wall hole(s) with a minimum vertical amplitude of 50% of the full Lissajous display height.

II-842 PROBE TRAVERSE SPEED

The traverse speed shall not exceed that which provides adequate frequency response and sensitivity to the applicable calibration discontinuities. Minimum digitization rates must be maintained at all times.

II-843 FIXTURE LOCATION VERIFICATION

(a) The ability of the fixture to locate specific tubes shall be verified visually and recorded upon installation of the fixture and before relocating or removing the fixture. Independent position verification, e.g., specific landmark location, shall be performed and recorded at the beginning and end of each unit of data storage of the recording media.

(b) When the performance of fixture location reveals that an error has occurred in the recording of probe verification location, the tubes examined since the previous location verification shall be reexamined.

II-844 AUTOMATED DATA SCREENING SYSTEM

When automated eddy current data screening systems are used, each system shall be qualified in accordance with a written procedure.

II-860 CALIBRATION

II-861 EQUIPMENT CALIBRATION

II-861.1 Analog Equipment. The following shall be verified by annual calibration:

(a) the oscillator output frequency to the drive coil shall be within 5% of its indicated frequency

(b) the vertical and horizontal linearity of the cathode ray tube (CRT) display shall be within 10% of the deflection of the input voltage

(c) the CRT vertical and horizontal trace alignment shall be within 2 deg of parallel to the graticule lines

(d) the ratio of the output voltage from the tape recorder shall be within 5% of the input voltage for each channel of the tape recorder

(e) the chart speed from the strip chart recorder shall be within 5% of the indicated value

(f) amplification for all channels of the eddy current instrument shall be within 5% of the mean value, at all sensitivity settings, at any single frequency

(g) the two output channels of the eddy current instrument shall be orthogonal within 3 deg at the examination frequency

II-861.2 Digital Equipment. Analog elements of digital equipment shall be calibrated in accordance with II-861.1. Digital elements need not be calibrated.

II-862 CALIBRATION REFERENCE STANDARDS

II-862.1 Calibration Reference Standard Requirements. Calibration reference standards shall conform to the following:

(a) Calibration reference standards shall be manufactured from tube(s) of the same material specification and nominal size as that to be examined in the vessel.

(b) Tubing calibration reference standard materials heat treated differently from the tubing to be examined may be used when signal responses from the discontinuities described in II-862.2 are demonstrated to the Inspector to be equivalent in both the calibration reference standard and tubing of the same heat treatment as the tubing to be examined.

(c) As an alternative to (a) and (b), calibration reference standards fabricated from UNS Alloy N06600 shall be manufactured from a length of tubing of the same material specification and same nominal size as that to be examined in the vessel.

(d) Artificial discontinuities in calibration reference standards shall be spaced axially so they can be differentiated from each other and from the ends of the tube. The as-built dimensions of the discontinuities and the applicable eddy current equipment response shall become part of the permanent record of the calibration reference standard.

(e) Each calibration reference standard shall be permanently identified with a serial number.

II-862.2 Calibration Reference Standards for Differential and Absolute Bobbin Coils.

(a) Calibration reference standards shall contain the following artificial discontinuities:

(1) One or four through-wall holes as follows:

(-a) A 0.052 in. (1.3 mm) diameter hole for tubing with diameters of 0.750 in. (19 mm) and less, or a 0.067 in. (1.70 mm) hole for tubing with diameters greater than 0.750 in. (19 mm).

(-b) Four holes spaced 90 deg apart in a single plane around the tube circumference, 0.026 in. (0.65 mm) diameter for tubing with diameters of 0.750 in. (19 mm) and less and 0.033 in. (0.83 mm) diameter for tubing with diameters greater than 0.750 in. (19 mm).

(2) A flat-bottom hole 0.109 in. (2.7 mm) diameter, 60% through the tube wall from the outer surface.

(3) Four flat-bottom holes 0.187 in. (5 mm) diameter, spaced 90 deg apart in a single plane around the tube circumference, 20% through the tube wall from the outer surface.

(b) The depth of the artificial discontinuities, at their center, shall be within 20% of the specified depth or 0.003 in. (0.08 mm), whichever is less. All other dimensions shall be within 0.003 in. (0.08 mm).

(c) All artificial discontinuities shall be sufficiently separated to avoid interference between signals, except for the holes specified in (a)(1)(-b) and (a)(3).

II-863 ANALOG SYSTEM SETUP AND ADJUSTMENT

II-863.1 Differential Bobbin Coil Technique.

(a) The sensitivity shall be adjusted to produce a minimum peak-to-peak signal of 4 V from the four 20% flat-bottom holes or 6 V from the four through-wall drilled holes.

(b) The phase or rotation control shall be adjusted so the signal response due to the through-wall hole forms down and to the right first as the probe is withdrawn from the calibration reference standard holding the signal response from the probe motion horizontal. See Figure II-863.1.

(c) Withdraw the probe through the calibration reference standard at the nominal examination speed. Record the responses of the applicable calibration reference standard discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

II-863.2 Absolute Bobbin Coil Technique.

(a) The sensitivity shall be adjusted to produce a minimum origin-to-peak signal of 2 V from the four 20% flat-bottom holes or 3 V from the four through-wall drilled holes.

(b) Adjust the phase or rotation control so that the signal response due to the through-wall hole forms up and to the left as the probe is withdrawn from the calibration reference standard holding the signal response from the probe motion horizontal. See Figure II-863.2.

(c) Withdraw the probe through the calibration reference standard at the nominal examination speed. Record the responses of the applicable calibration reference

Figure II-863.1
Differential Technique Response From Calibration Reference Standard

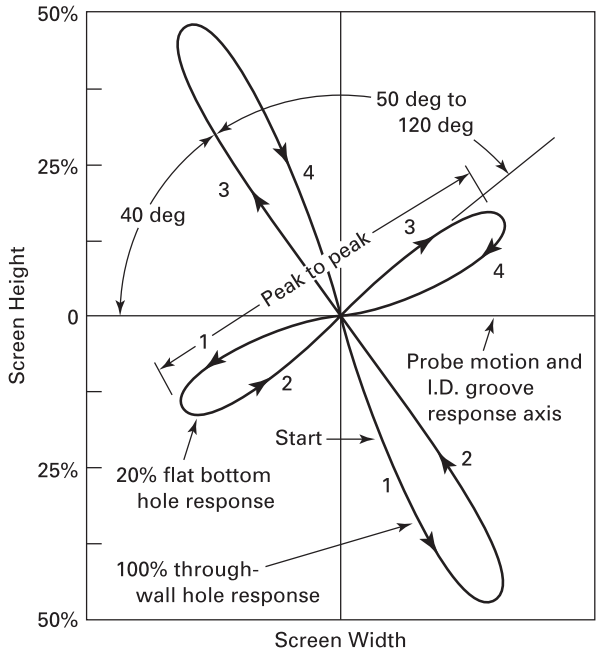
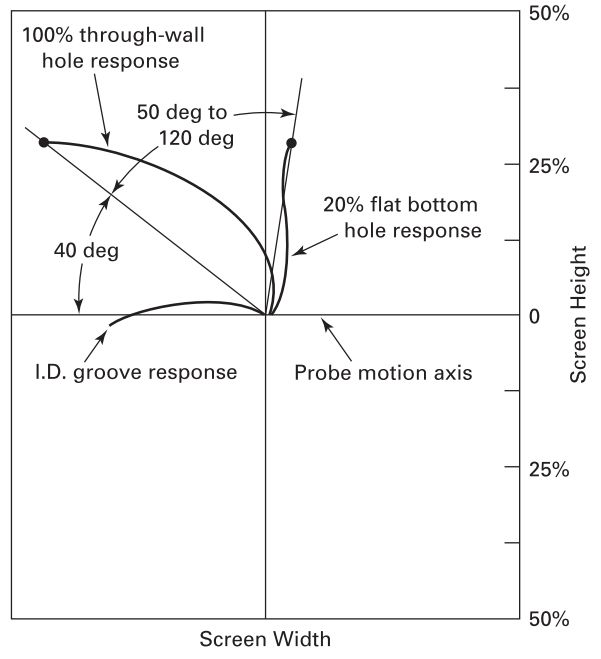


Figure II-863.2
Absolute Technique Response From Calibration Reference Standard



standard discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

II-864 DIGITAL SYSTEM OFF-LINE CALIBRATION

The eddy current examination data is digitized and recorded during scanning for off-line analysis and interpretation. The system setup of phase and amplitude settings shall be performed off-line by the data analyst. Phase and amplitude settings shall be such that the personnel acquiring the data can clearly discern that the eddy current instrument is working properly.

II-864.1 System Calibration Verification.

(a) Calibration shall include the complete eddy current examination system. Any change of probe, extension cables, eddy current instrument, recording instruments, or any other parts of the eddy current examination system hardware shall require recalibration.

(b) System calibration verification shall be performed and recorded at the beginning and end of each unit of data storage of the recording media.

(c) Should the system be found to be out of calibration (as defined in II-863), the equipment shall be recalibrated. The recalibration shall be noted on the recording. All tubes examined since the last valid calibration shall be reexamined.

II-870 EXAMINATION

Data shall be recorded as the probe traverses the tube.

II-880 EVALUATION

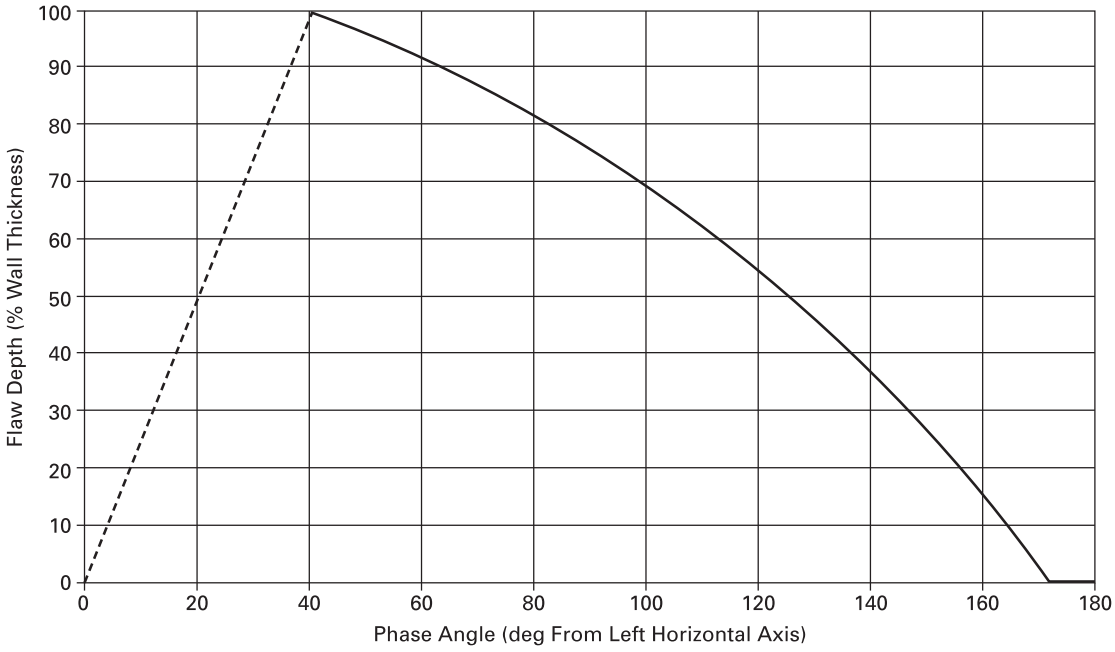
II-881 DATA EVALUATION

Data shall be evaluated in accordance with the requirements of this Appendix.

II-882 MEANS OF DETERMINING INDICATION DEPTH

For indication types that must be reported in terms of depth, a means of correlating the indication depth with the signal amplitude or phase shall be established. The means of correlating the signal amplitude or phase with the indication depth shall be based on the basic calibration standard or other representative standards that have been qualified. This shall be accomplished by using curves, tables, or software. Figure II-880 illustrates the relationship of phase angle versus flaw depth for a nonferromagnetic thin-walled tube examined at a frequency selected to optimize flaw resolution.

Figure II-880
Flaw Depth as a Function of Phase Angle at 400 kHz [Ni–Cr–Fe 0.050 in. (1.24 mm) Wall Tube]



II-883 FREQUENCIES USED FOR DATA EVALUATION

All indications shall be evaluated. Indication types, which must be reported, shall be characterized using the frequencies or frequency mixes that were qualified.

II-890 DOCUMENTATION

II-891 REPORTING

II-891.1 Criteria. Indications reported in accordance with the requirements of this Appendix shall be described in terms of the following information, as a minimum:

(a) location along the length of the tube and with respect to the support members

(b) depth of the indication through the tube wall, when required by this Appendix

(c) signal amplitude

(d) frequency or frequency mix from which the indication was evaluated

II-891.2 Depth. The maximum evaluated depth of flaws shall be reported in terms of percentage of tube wall loss. When the loss of tube wall is determined by the analyst to be less than 20%, the exact percentage of tube wall loss need not be recorded, i.e., the indication may be reported as being less than 20%.

II-891.3 Nonquantifiable Indications. A nonquantifiable indication is a reportable indication that cannot be characterized. The indication shall be considered a flaw until otherwise resolved.

II-891.4 Support Members.

II-891.4.1 Location of Support Members. The location of support members used as reference points for the eddy current examination shall be verified by fabrication drawings or the use of a measurement technique.

II-892 RECORDS

II-892.1 Record Identification. The recording media shall contain the following information within each unit of data storage:

(a) Owner

(b) plant site and unit

(c) heat exchanger identification

(d) data storage unit number

(e) date of examination

(f) serial number of the calibration standard

(g) operator's identification and certification level

(h) examination frequency or frequencies

(i) mode of operation including instrument sample rate, drive voltage, and gain settings

(j) lengths of probe and probe extension cables

(k) size and type of probes

(l) probe manufacturer's name and manufacturer's part number or probe description and serial number

(m) eddy current instrument serial number

(n) probe scan direction during data acquisition
(o) application side — inlet or outlet
(p) slip ring serial number, as applicable
(q) procedure identification and revision

II-892.2 Tube Identification.

(a) Each tube examined shall be identified on the applicable unit of data storage and

(b) The method of recording the tube identification shall correlate tube identification with corresponding recorded tube data.

II-892.3 Reporting.

(a) The Owner or his agent shall prepare a report of the examinations performed. The report shall be prepared, filed, and maintained in accordance with the referencing Code Section. Procedures and equipment used shall be identified sufficiently to permit comparison of the examination results with new examination results run at a later date. This shall include initial calibration data for each eddy current examination system or part thereof.

(b) The report shall include a record indicating the tubes examined (this may be marked on a tubesheet sketch or drawing), any scanning limitations, the location and depth of each reported flaw, and the identification and certification level of the operators and data evaluators that conducted each examination or part thereof.

(c) Tubes that are to be repaired or removed from service, based on eddy current examination data, shall be identified.

II-892.4 Record Retention. Records shall be maintained in accordance with requirements of the referencing Code Section.

MANDATORY APPENDIX III
EDDY CURRENT EXAMINATION ON COATED FERROMAGNETIC MATERIALS

III-810 SCOPE

(a) This Appendix provides the eddy current examination methodology and equipment requirements applicable for performing eddy current examination on coated ferromagnetic materials.

(b) Article 1, General Requirements, also applies when eddy current examination of coated ferromagnetic materials is required. Requirements for written procedures, as specified in Article 8, shall apply, as indicated.

(c) SD-7091, Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals, may be used to develop a procedure for measuring the thickness of nonferromagnetic and conductive coatings.

III-820 GENERAL

III-821 PERSONNEL QUALIFICATION

The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with requirements of this Appendix and the referencing Code Section.

III-822 WRITTEN PROCEDURE REQUIREMENTS

The requirements of IV-823 shall apply. The type of coating and maximum coating thickness also shall be essential variables.

III-823 PROCEDURE DEMONSTRATION

The procedure shall be demonstrated to the satisfaction of the Inspector in accordance with requirements of the referencing Code Section.

III-830 EQUIPMENT

The eddy current system shall include phase and amplitude display.

III-850 TECHNIQUE

The performance of examinations shall be preceded by measurement of the coating thickness in the areas to be examined. If the coating is nonconductive, an eddy current technique may be used to measure the coating thickness. If the coating is conductive, a ferromagnetic coating thickness technique may be used in accordance with SD-7091. Coating thickness measurement shall be used in accordance with the equipment manufacturer's instructions. Coating thickness measurements shall be taken at the intersections of a 2 in. (50 mm) maximum grid pattern over the area to be examined. The thickness shall be the mean of three separate readings within 0.250 in. (6 mm) of each intersection.

III-860 CALIBRATION

(a) A qualification specimen is required. The material used for the specimen shall be the same specification and heat treatment as the coated ferromagnetic material to be examined. If a conductive primer was used on the material to be examined, the primer thickness on the procedure qualification specimen shall be the maximum allowed on the examination surfaces by the coating specification. Plastic shim stock may be used to simulate nonconductive coatings for procedure qualification. The thickness of the coating or of the alternative plastic shim stock on the procedure qualification specimen shall be equal to or greater than the maximum coating thickness measured on the examination surface.

(b) The qualification specimen shall include at least one crack. The length of the crack open to the surface shall not exceed the allowable length for surface flaws. The maximum crack depth in the base metal shall be between 0.020 in. and 0.040 in. (0.5 mm and 1.0 mm). In addition, if the area of interest includes weld metal, a 0.020 in. (0.5 mm) maximum depth crack is required in an as-welded and coated surface typical of the welds to be examined. In lieu of a crack, a machined notch of 0.010 in. (0.25 mm) maximum width and 0.020 in. (0.5 mm) maximum depth may be used in the as-welded surface.

(c) Examine the qualification specimen first uncoated and then after coating to the maximum thickness to be qualified. Record the signal amplitudes from the qualification flaws.

(d) Using the maximum scanning speed, the maximum scan index, and the scan pattern specified by the procedure, the procedure shall be demonstrated to consistently detect the qualification flaws through the maximum coating thickness regardless of flaw orientation (e.g., perpendicular, parallel, or skewed to the scan direction). The

signal amplitude from each qualification flaw in the coated qualification specimen shall be at least 50% of the signal amplitude measured on the corresponding qualification flaw prior to coating.

III-870 EXAMINATION

(a) Prior to the examination, all loose, blistered, flaking, or peeling coating shall be removed from the examination area.

(b) When conducting examinations, areas of suspected flaw indications shall be confirmed by application of another surface or volumetric examination method. It may be necessary to remove the surface coating prior to performing the other examination.

Material de Estudo
Não Divulgar

III-890 DOCUMENTATION

III-891 EXAMINATION REPORT

The report of examination shall contain the following information:

(a) procedure identification and revision

(b) examination personnel identity and, when required by the referencing Code Section, qualification level

(c) date of examination

(d) results of examination and related sketches or maps of rejectable indications

(e) identification of part or component examined

III-893 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

MANDATORY APPENDIX IV
EXTERNAL COIL EDDY CURRENT EXAMINATION OF TUBULAR PRODUCTS

IV-810 SCOPE

This Appendix describes the method to be used when performing eddy current examinations of seamless copper, copper alloy, and other nonferromagnetic tubular products. The method conforms substantially with the following Standard listed in Article 26 and reproduced in Subsection B: SE-243, Standard Practice for Electromagnetic (Eddy Current) Examination of Copper and Copper-Alloy Tubes.

IV-820 GENERAL

IV-821 PERFORMANCE

Tubes may be examined at the finish size, after the final anneal or heat treatment, or at the finish size, prior to the final anneal or heat treatment, unless otherwise agreed upon between the supplier and the purchaser. The procedure shall be qualified by demonstrating detection of discontinuities of a size equal to or smaller than those in the reference specimen described in IV-833. Indications equal to or greater than those considered reportable by the procedure shall be processed in accordance with IV-880.

IV-822 PERSONNEL QUALIFICATION

The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with requirements of this Appendix and the referencing Code Section.

IV-823 WRITTEN PROCEDURE REQUIREMENTS

IV-823.1 Requirements. Eddy current examinations shall be performed in accordance with a written procedure, which shall contain, as a minimum, the requirements listed in Table IV-823. The written procedure shall establish a single value, or range of values, for each requirement.

IV-823.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table IV-823 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

IV-830 EQUIPMENT

Equipment shall consist of electronic apparatus capable of energizing the test coil or probes with alternating currents of suitable frequencies and shall be capable of sensing the changes in the electromagnetic properties of the material. Output produced by this equipment may be processed so as to actuate signaling devices and/or to record examination data.

IV-831 TEST COILS AND PROBES

Test coils or probes shall be capable of inducing alternating currents into the material and sensing changes in the electromagnetic characteristics of the material. Test coils should be selected to provide the highest practical fill factor.

Table IV-823
Requirements of an External Coil Eddy Current Examination Procedure

Requirements (as Applicable)	Essential Variable	Nonessential Variable
Frequency(ies)	X	...
Mode (differential/absolute)	X	...
Minimum fill factor	X	...
Probe type	X	...
Maximum scanning speed during data recording	X	...
Material being examined	X	...
Material size/dimensions	X	...
Reference standard	X	...
Equipment manufacturer/model	X	...
Data recording equipment	X	...
Cabling (type and length)	X	...
Acquisition software	X	...
Analysis software	X	...
Scanning technique	...	X
Scanning equipment/fixtures	...	X
Tube scanning surface preparation	...	X

IV-832 SCANNERS

Equipment used should be designed to maintain the material concentric within the coil, or to keep the probe centered within the tube and to minimize vibration during scanning. Maximum scanning speeds shall be based on the equipment's data acquisition frequency response or digitizing rate, as applicable.

IV-833 REFERENCE SPECIMEN

The reference specimen material shall be processed in the same manner as the product being examined. It shall be the same nominal size and material type (chemical composition and product form) as the tube being examined. Ideally, the specimen should be a part of the material being examined. Unless specified in the referencing Code Section, the reference discontinuities shall be transverse notches or drilled holes as described in Standard Practice SE-243, Section 8, Reference Standards.

IV-850 TECHNIQUE

Specific techniques may include special probe or coil designs, electronics, calibration standards, analytical algorithms and/or display software. Techniques, such as channel mixes, may be used as necessary to suppress signals produced at the ends of tubes. Such techniques shall be in accordance with requirements of the referencing Code Section.

IV-860 CALIBRATION

IV-861 PERFORMANCE VERIFICATION

Performance of the examination equipment shall be verified by the use of the reference specimen as follows:

(a) As specified in the written procedure

(1) at the beginning of each production run of a given diameter and thickness of a given material

(2) at the end of the production run

(3) at any time that malfunctioning is suspected

(b) If, during calibration or verification, it is determined that the examination equipment is not functioning properly, all of the product tested since the last calibration or verification shall be reexamined.

(c) When requalification of the written procedure as required in IV-823.2.

IV-862 CALIBRATION OF EQUIPMENT

(a) Frequency of Calibration. Eddy current instrumentation shall be calibrated at least once a year, or whenever the equipment has been subjected to a major electronic repair, periodic overhaul, or damage. If equipment has not been in use for a year or more, calibration shall be done prior to use.

(b) Documentation. A tag or other form of documentation shall be attached to the eddy current equipment with dates of the calibration and calibration due date.

IV-870 EXAMINATION

Tubes are examined by passing through an encircling coil, or past a probe coil with the apparatus set up in accordance with the written procedure. Signals produced by the examination are processed and evaluated. Data may be recorded for post-examination analysis or stored for archival purposes in accordance with the procedure. Outputs resulting from the evaluation may be used to mark and/or separate tubes.

IV-880 EVALUATION

Evaluation of examination results for acceptance shall be as specified in the written procedure and in accordance with the referencing Code Section.

IV-890 DOCUMENTATION

IV-891 EXAMINATION REPORTS

A report of the examination shall contain the following information:

(a) tube material specification, diameter, and wall thickness condition

(b) coil or probe manufacturer, size and type

(c) mode of operation (absolute, differential, etc.)

(d) examination frequency or frequencies

(e) manufacturer, model, and serial number of eddy current equipment

(f) scanning speed

(g) procedure identification and revision

(h) calibration standard and serial number

(i) identity of examination personnel, and, when required by the referencing Code Section, qualification level

(j) date of examination

(k) list of acceptable material

(l) date of procedure qualification

(m) results of procedure requalification (as applicable)

IV-893 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

MANDATORY APPENDIX V
EDDY CURRENT MEASUREMENT OF NONCONDUCTIVE-NONFERROMAGNETIC COATING THICKNESS ON A NONFERROMAGNETIC METALLIC MATERIAL

V-810 SCOPE

This Appendix provides requirements for absolute surface probe measurement of nonconductive-nonferromagnetic coating thickness on a nonferromagnetic metallic material.

V-820 GENERAL

This Appendix provides a technique for measuring nonconductive-nonferromagnetic coating thicknesses on a nonferromagnetic metallic substrate. The measurements are made with a surface probe with the lift-off calibrated for thickness from the surface of the test material. Various numbers of thickness measurements can be taken as the probe's spacing from the surface is measured. Measurements can be made with various types of instruments.

V-821 WRITTEN PROCEDURE REQUIREMENTS

V-821.1 Requirements. Eddy current examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table V-821. The written procedure shall establish a single value, or range of values, for each requirement.

V-821.2 Procedure Qualification/Technique Validation. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table V-821 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement, identified as a nonessential variable, does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

V-822 PERSONNEL QUALIFICATION

The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with requirements of this Appendix and the referencing Code Section.

V-823 PROCEDURE/TECHNIQUE DEMONSTRATION

The procedure/technique shall be demonstrated to the satisfaction of the Inspector in accordance with the requirements of the referencing Code Section.

V-830 EQUIPMENT

The eddy current instrument may have a storage type display for phase and amplitude or it may contain an analog or digital meter. The frequency range of the instrument shall be adequate for the material and the coating thickness range.

Table V-821
Requirements of an Eddy Current Examination Procedure for the Measurement of Nonconductive-Nonferromagnetic Coating Thickness on a Metallic Material

Requirement	Essential Variable	Nonessential Variable
Examination frequency	X	...
Absolute mode	X	...
Size and probe type(s), manufacturer's name and description	X	...
Substrate material	X	...
Equipment manufacturer/model	X	...
Cabling (type and length)	X	...
Nonconductive calibration material (nonconductive shims)	...	X
Personnel qualification requirements unique to this technique	...	X
Reference to the procedure qualification records	...	X
Examination surface preparation	...	X

V-831 PROBES

The eddy current absolute probe shall be capable of inducing alternating currents into the material and sensing changes in the separation (lift-off) between the contact surface of the probe and the substrate material.

V-850 TECHNIQUE

A single frequency technique shall be used with a suitable calibration material such as nonconductive shim(s), paper, or other nonconductive nonferromagnetic material. The shims or other material thicknesses shall be used to correlate a position on the impedance plane or meter reading with the nonconductive material thicknesses and the no thickness position or reading when the probe is against the bare metal. If the thickness measurement is used only to assure a minimum coating thickness, then only a specimen representing the minimum thickness need be used.

V-860 CALIBRATION

The probe frequency and gain settings shall be selected to provide a suitable and repeatable examination. The probe shall be nulled on the bare metal.

(a) Impedance Plane Displays. For instruments with impedance plane displays, gains on the vertical and horizontal axes shall be the same value. The phase or rotation control and the gain settings shall be adjusted so that the bare metal (null) and the air point are located at diagonally opposite corners of the display. A typical coating thickness calibration curve is illustrated in Figure V-860.

(b) Meter Displays. For instruments with analog meter displays, the phase and gain controls shall be used to provide near full scale deflection between the bare metal and maximum coating thickness.

(c) All Instruments. For all instruments, the difference in meter readings or thickness positions on the screen shall be adequate to resolve a 10% change in the maximum thickness.

(d) Calibration Data. The screen positions or meter readings and the shim thicknesses shall be recorded along with the bare metal position or meter reading.

(e) Verification of Calibration. Calibration readings shall be verified every two hours. If, during recalibration, a reading representing a coating thickness change greater than ±10% from the prior calibration is observed, examinations made after the prior calibration shall be repeated.

V-870 EXAMINATION

Coating thickness measurements shall be taken at individual points as indicated in the referencing Code Section. If it is desired to measure the minimum coating thickness or maximum coating thickness on a surface, a suitable grid pattern shall be established and measurements shall be taken at the intersections of the grid pattern. Measurements shall be recorded.

V-880 EVALUATION

Coating thicknesses shall be compared with the acceptance standards of the referencing Code Section.

V-890 DOCUMENTATION

V-891 EXAMINATION REPORT

The report of the examination shall contain the following information:

(a) procedure identification and revision

(b) examination personnel identity, and, when required by the referencing Code Section, qualification level

(c) date of examination

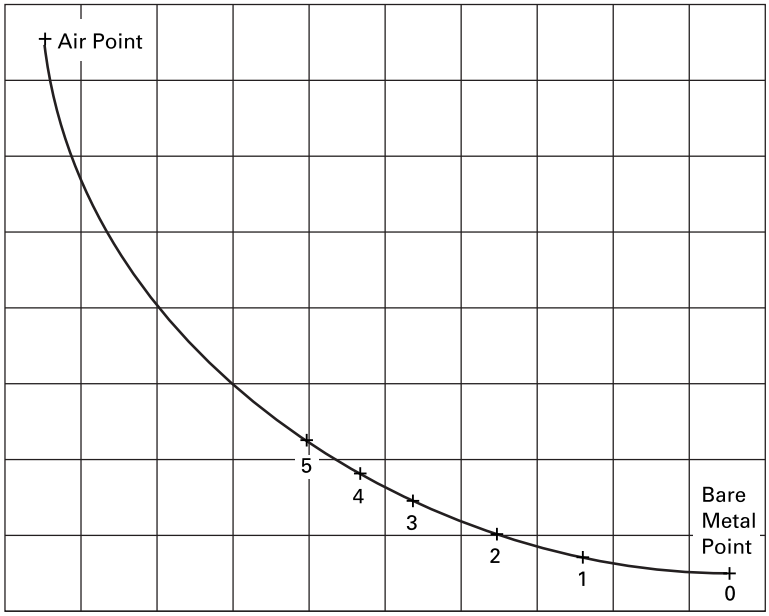
(d) results of examination and related sketches or maps of thickness measurements

(e) identification of part or component examined

V-893 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

Figure V-860
Typical Lift-off Calibration Curve for Coating Thickness Showing Thickness Calibration Points Along the Curve



MANDATORY APPENDIX VI
EDDY CURRENT DETECTION AND MEASUREMENT OF DEPTH OF SURFACE DISCONTINUITIES IN NONFERROMAGNETIC METALS WITH SURFACE PROBES

VI-810 SCOPE

This Appendix provides the requirements for the detection and measurement of depth for surface discontinuities in nonferromagnetic-metallic materials using an absolute surface probe eddy current technique.

VI-820 GENERAL

This Appendix provides a technique for the detection and depth measurement of cracks and other surface discontinuities in nonferromagnetic metal components. An absolute surface probe containing a single excitation coil is scanned over the surface of the examination object. When a surface discontinuity is encountered by the magnetic field of the probe, eddy currents generated in the material change their flow and provide a different magnetic field in opposition to the probe's magnetic field. Changes in the eddy current's magnetic field and the probe's magnetic field are sensed by the instrument and are presented on the instrument's impedance plane display. These instruments generally have capability for retaining the signal on the instrument's display where any discontinuity signal can be measured and compared to the calibration data.

VI-821 WRITTEN PROCEDURE REQUIREMENTS

VI-821.1 Requirements. Eddy current examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table VI-821. The written procedure shall establish a single value, or range of values, for each requirement.

VI-821.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table VI-821 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

VI-822 PERSONNEL QUALIFICATION

The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with requirements of this Appendix and the referencing Code Section.

VI-823 PROCEDURE/TECHNIQUE DEMONSTRATION

The procedure/technique shall be demonstrated to the satisfaction of the Inspector in accordance with the requirements of the referencing Code Section.

Table VI-821
Requirements of an Eddy Current Examination Procedure for the Detection and Measurement of Depth for Surface Discontinuities in Nonferromagnetic Metallic Materials

Requirement	Essential Variable	Nonessential Variable
Examination frequency	X	...
Size and probe type(s), manufacturer's name and description	X	...
Material	X	...
Equipment manufacturer/model	X	...
Cabling (type and length)	X	...
Reference specimen and notch depths	X	...
Personnel qualification, when required by the referencing Code Section	X	...
Personnel qualification requirements unique to this technique	...	X
Reference to the procedure qualification records	...	X
Examination surface preparation	...	X

VI-830 EQUIPMENT

The eddy current instrument may have a storage type display for phase and amplitude on an impedance plane. The frequency range of the instrument shall be adequate to provide for a suitable depth of penetration for the material under examination.

VI-831 PROBES

The eddy current absolute probe shall be capable of inducing alternating currents into the material and sensing changes in the depth of the notches in the reference specimen. The probe and instrument at the frequency to be used in the examination shall provide a signal amplitude for the smallest reference notch of a minimum of 10% full screen height (FSH). With the same gain setting for the smallest notch, the signal amplitude on the largest notch shall be a minimum of 50% FSH. If the amplitudes of the signals cannot be established as stated, other probe impedances or geometries (windings, diameters, etc.) shall be used.

VI-832 REFERENCE SPECIMEN

A reference specimen shall be constructed of the same alloy as the material under examination. Minimum dimensions of the reference specimen shall be 2 in. (50 mm) by 4 in. (100 mm) and shall contain a minimum of two notches. Notch length shall be a minimum of 0.25 in. (6 mm) and notch depth shall be the minimum to be measured and the maximum depth allowed. If smaller length notches are required to be detected by the referencing Code Section, the reference specimen shall contain a smaller length notch meeting the referencing Code requirements. The depth shall have a tolerance of +10% and −20% of the required dimensions. A typical reference specimen for measuring flaw depths in the range of 0.01 in. (0.25 mm) through 0.04 in. (1 mm) is shown in Figure VI-832.

When curvature of the examination object in the area of interest is not flat and affects the lift-off signal, a reference specimen representing that particular geometry with the applicable notches shall be used.

VI-850 TECHNIQUE

A single frequency technique shall be used. The frequency shall be selected to result in an impedance plane presentation that will result in a 90 deg phase shift between the lift-off signal and the flaw signals. The resulting signals will be displayed using an impedance plane presentation with one axis representing the lift-off signal and the other axis representing the reference notch and flaw signal responses. The gain control on each axis displaying the flaw signals shall be adjusted to present amplitude for the flaw signal from the deepest notch to be at least 50% of the vertical or horizontal display it is presented on. Typical responses of the calibrated instrument are shown in Figure VI-850. Note that the display may be rotated to show these indications in accordance with the procedure. Typically, the gain setting on the axis displaying the discontinuity signal will have a gain setting higher than the axis displaying lift-off. Discontinuity indications will be mostly vertical or horizontal (at 90 deg to lift-off). Any surface discontinuities in the examination specimen would provide similar indications.

VI-860 CALIBRATION

The probe frequency and gain settings shall be selected to provide a suitable depth of penetration within the material so that the depth of the deepest notch is distinguishable from the next smaller notch. The gain settings on the vertical and horizontal axis shall be set so that there is a dB difference with the discontinuity depth gain being higher. The probe shall be nulled on the bare metal away from the notches. The X-Y position of the null point shall be placed on one corner of the screen. The phase or rotation control shall be adjusted so that when the probe is lifted off the metal surface, the display point travels at 90 deg to the discontinuity depth. Increase the vertical or horizontal gain, as applicable, if the smallest indication or the largest indication from the notches do not make 10% or 50% FSH, respectively. Maximum response from the notches is achieved when the probe is scanned perpendicular to the notch and centered on the notch. Differences in the vertical and horizontal gain may have to be adjusted. The screen indication lengths from the baseline (lift-off line) for each of the notch depths shall be recorded.

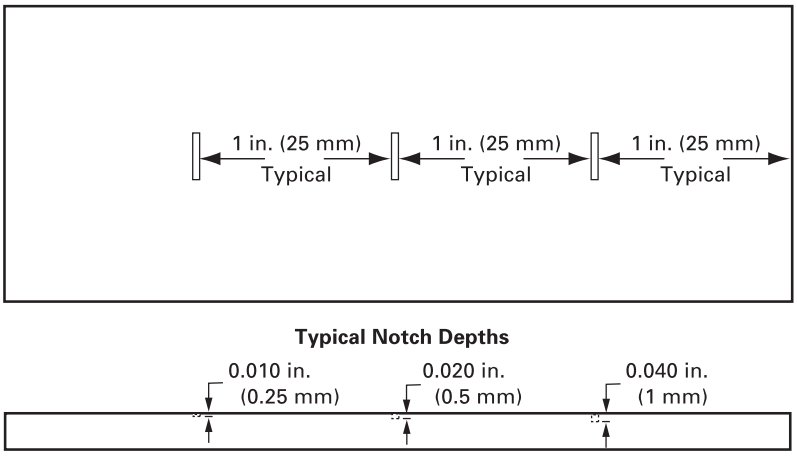
VI-870 EXAMINATION

The area of interest shall be scanned with overlap on the next scan to include at least 10% of the probe diameter. If the direction of suspected discontinuities are known, the scan direction shall be perpendicular to the long axis of the discontinuity. The object shall be scanned in two directions, 90 deg to each other. During the examination, the maximum scanning speed and lift-off distance shall not be greater than those used for calibration.

VI-880 EVALUATION

The discontinuity shall be scanned perpendicular to its long axis to determine its maximum depth location and value. The maximum depth of any discontinuity detected shall be compared with the appropriate response of the reference specimen as specified in the referencing Code Section.

Figure VI-832
Reference Specimen



GENERAL NOTES:
(a) Typical notch dimensions are 0.25 in. (6 mm) length × 0.010 in. (0.25 mm) width.
(b) Tolerances on notch dimensions are ±10% for length and width, and +10% and −20% for depth.

VI-890 DOCUMENTATION

VI-891 EXAMINATION REPORT

The report of the examination shall contain the following information:

(a) procedure identification and revision

(b) examination personnel identity, and, when required by the referencing Code Section, qualification level

(c) date of examination

(d) results of examination and related sketches or maps of indications exceeding acceptance standard

(e) identification of part or component examined

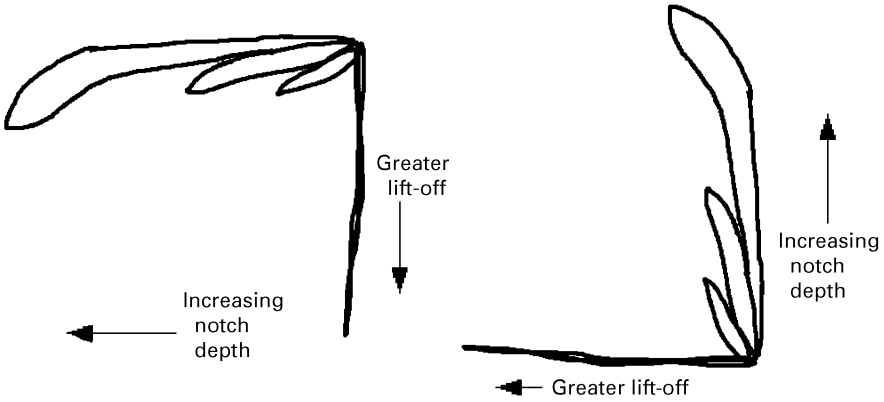
(f) identification of reference specimen

(g) calibration results, minimum and maximum discontinuity depth measured

VI-893 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

Figure VI-850
Impedance Plane Representations of Indications From Figure VI-832



MANDATORY APPENDIX VII
EDDY CURRENT EXAMINATION OF FERROMAGNETIC AND NONFERROMAGNETIC CONDUCTIVE METALS TO DETERMINE IF FLAWS ARE SURFACE CONNECTED

VII-810 SCOPE

This Appendix provides the requirements for using an eddy current examination (ET) procedure to determine if flaws are surface connected (i.e., open to the surface being examined). With appropriate selection of parameters, the method is applicable to both ferromagnetic and nonferromagnetic conductive metals.

VII-820 GENERAL

VII-821 PERFORMANCE

This Appendix provides requirements for the evaluation of flaws, detected by other nondestructive examinations, utilizing a surface probe operating at a suitable test frequency or combination of frequencies. The resultant phase and amplitude responses are used to determine if flaws are surface connected.

VII-822 PERSONNEL QUALIFICATION

The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with requirements of this Appendix or the referencing Code Section.

VII-823 WRITTEN PROCEDURE REQUIREMENTS

VII-823.1 Requirements. Eddy current examinations shall be performed in accordance with a written procedure, which shall contain, as a minimum, the requirements listed in Table VII-823. The written procedure shall establish a single value or range of values, for each requirement.

VII-823.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table VII-823 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of or an addendum to the written procedure.

VII-830 EQUIPMENT

VII-831 SYSTEM DESCRIPTION

The eddy current system shall consist of an eddy current instrument, surface probe, and cable connecting the instrument and the probe.

VII-832 SURFACE PROBES

The eddy current probes shall be either differential or absolute type. They shall be capable of inducing alternating currents in the material being examined and be capable of sensing changes in the resultant electromagnetic field.

VII-833 CABLES

Cables connecting the eddy current instrument and probes shall be designed and assembled to operate with these components.

Table VII-823
Requirements of an Eddy Current Surface Examination Procedure

Requirement (as Applicable)	Essential Variable	Nonessential Variable
Frequencies	X	...
Mode (differential/absolute)	X	...
Probe type	X	...
Maximum scanning speed	X	...
Material being examined	X	...
Material surface condition	X	...
Reference specimen material and simulated flaws	X	...
ET instrument manufacturer/model	X	...
Data presentation — display	X	...
Cabling (type and length)	X	...
Use of saturation	X	...
Analysis method	X	...
Scanning technique	...	X
Surface preparation	...	X

VII-834 INSTRUMENTATION

The eddy current instrument shall be capable of driving the probes selected for this examination with alternating current over a suitable range of frequencies. The eddy current instrument shall be capable of sensing and displaying differences in phase and amplitude correlated to the depth of discontinuities. The instrument shall be capable of operating in either the absolute or differential mode. The persistence shall be adjusted to display the phase and amplitude responses of the reference specimen notches and flaws in the material under examination.

VII-835 REFERENCE SPECIMEN

The reference specimen shall be constructed of the same alloy and product form as the material being examined. The reference specimen shall be as specified in Figure VII-835. Calibration references consist of two surface-connected notches and two bridged notches, representing both surface-connected and subsurface flaws.

The specimen shall be a minimum of 5.0 in. (125 mm) long, 1.5 in. (38 mm) wide, and ¼ in. (6 mm) thick. Additional notches and bridged notches may be added and block lengthened when additional information or higher precision is required. Surface conditions and finish of both the reference specimen and the material being examined shall be similar.

VII-850 TECHNIQUE

A single or multiple frequency technique may be used. The frequency(s) shall be selected to result in an impedance plane presentation of 90 deg to 180 deg phase shift between the surface and subsurface notch indications.

VII-860 CALIBRATION

VII-861 GENERAL

The probe frequency(s) and gain settings shall be selected to provide a suitable phase spread while providing sufficient penetration to ensure that the shallowest subsurface bridged notch indication is detected. Display gain of the vertical and horizontal axis shall be set to provide equal signal response. The ET instrument shall be adjusted to rotate the phase for the lift-off response to be positioned at the 270 deg horizontal plane. Scanning shall be conducted perpendicular to the length of the notches. The gain shall be set to display the 0.020 in. (0.5 mm) deep surface notch at 100% full screen height. At this gain setting, the 0.010 in. (0.24 mm) deep surface notch should be displayed at approximately 25% full screen height. The gain settings for these two reference notches may be accomplished on separate frequencies. Balancing the instrument will be conducted with the probe situated on the space between notches. Scanning speed shall be adjusted to allow the display to be formed for evaluation. The persistence of the screen shall be adjusted to allow a comparison of the responses from each notch. The screen shall be cleared to prevent the display to become overloaded. The presentation shall be balanced prior to making initial and final adjustments of phase and amplitude. Responses in terms of amplitude and phase angle resulting from scanning the surface notches and notch bridges shall be recorded.

VII-862 CALIBRATION RESPONSE

Typical responses from carbon steel and stainless steel calibration specimens are shown in Figure VII-862. Note that responses from ferromagnetic materials and nonferromagnetic materials provide significantly different displays.

VII-870 EXAMINATION

The flaw of interest shall be scanned with an overlap on the adjacent scan to include approximately 50% of the probe diameter. Scanning shall be conducted perpendicular to the flaw length. The identity of the flaw will be determined from the phase and amplitude of the displayed response. The phase and amplitude of flaws and their location will be recorded. During the examination the maximum scanning speed and lift-off distance shall not be greater than those used for calibration. The surface finish of areas scanned shall be comparable to the reference specimen.

VII-880 EVALUATION

Discrimination of surface-connected flaw responses from those of subsurface flaws shall be determined by comparable phase and amplitude responses obtained from similar surface-connected notches and subsurface, bridged notches contained in the reference specimen.

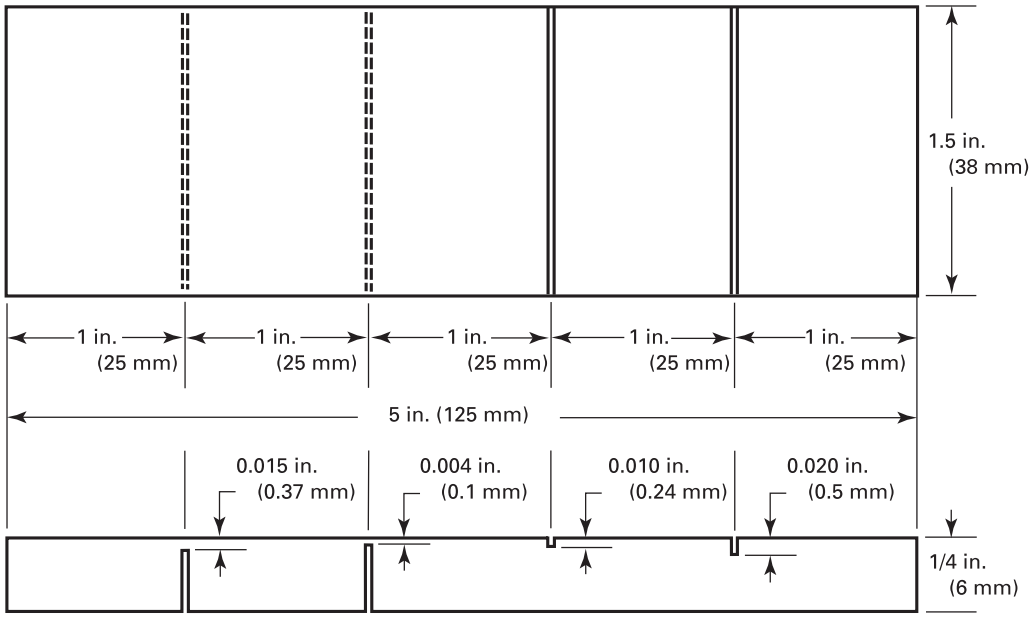
VII-890 DOCUMENTATION

VII-891 EXAMINATION REPORT

The report of the examination shall contain the following information:

(a) procedure identification and revision
(b) identification of examination personnel
(c) qualification of personnel, when required by the referencing Code Section
(d) date of examination
(e) identification of component or material examined
(f) scan plan including frequency(s) and gain
(g) flaw identity (e.g., surface connected or not surface connected)
(h) identification and drawing of reference calibration specimen
(i) calibration results (display) showing the indications of the bridged (subsurface) notches and surface notches detected

Figure VII-835
Eddy Current Reference Specimen



GENERAL NOTES:
(a) Drawing not to scale.
(b) Typical notch length may vary from 1 in. (25 mm) to full block width. Full width notches will require welding at the ends or filling the notch with epoxy to prevent block breakage.
(c) Maximum notch widths 0.010 in. (25 mm).
(d) Tolerance on notch bottoms +0/–10% from the examination surface.
(e) Block length, width, and thickness are as shown.
(f) Notch spacing and distance from ends of block are as shown.

(j) ET equipment manufacturer, model, type, and serial number

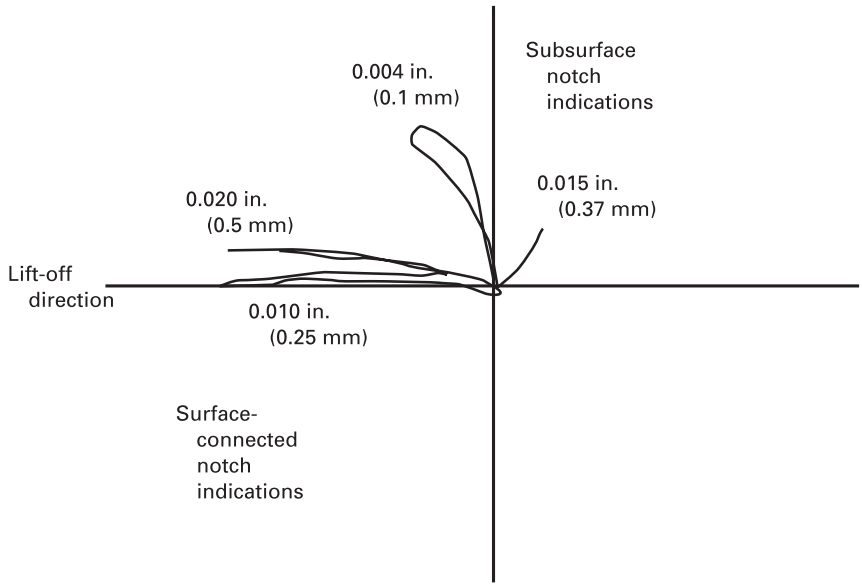
(k) probe manufacturer, model, type, and serial number

(l) extension cable, if used, manufacturer, type, and length

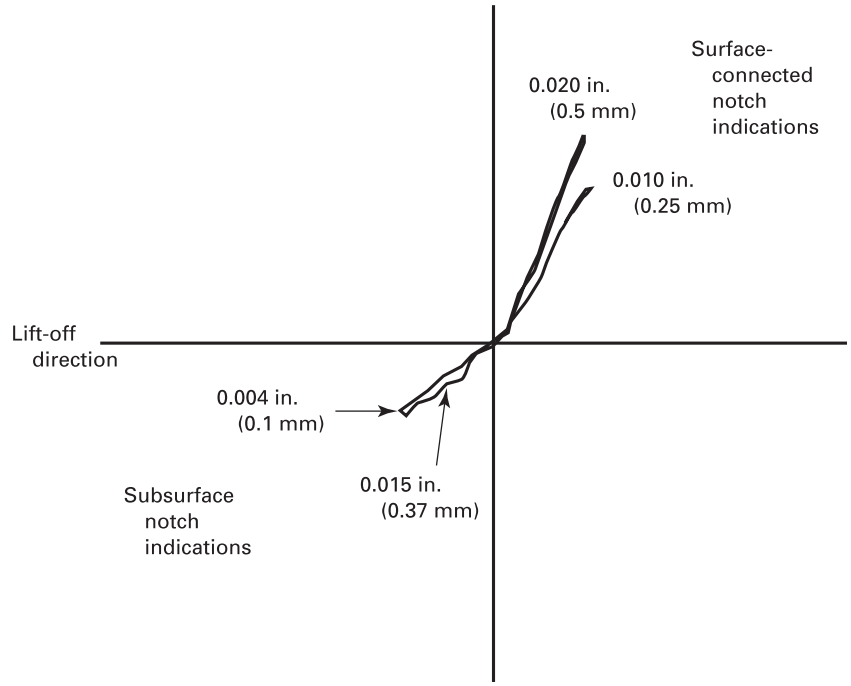
VII-892 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

Figure VII-862
Impedance Plane Responses for Stainless Steel and Carbon Steel Reference Specimens



(a) Stainless Steel at Examination Frequency of 800 kHz



(b) Carbon Steel at Examination Frequency of 800 kHz

MANDATORY APPENDIX VIII
ALTERNATIVE TECHNIQUE FOR EDDY CURRENT EXAMINATION OF NONFERROMAGNETIC HEAT EXCHANGER TUBING, EXCLUDING NUCLEAR STEAM GENERATOR TUBING

VIII-810 SCOPE

This Appendix provides the requirements for bobbin coil, multifrequency, multiparameter, eddy current examination for installed nonferromagnetic heat exchanger tubing, excluding nuclear steam generator tubing, when this Appendix is specified by the referencing Code Section.

VIII-820 GENERAL

This Appendix also provides the technique requirements for examining nonferromagnetic heat exchanger tubing using the electromagnetic method known as near field eddy current testing (the coil that generates the magnetic field also senses changes in the magnetic field). The method may employ one or more bobbin wound coils. By scanning the tubing from the boreside, information will be obtained from which the condition of the tubing will be determined. Scanning is generally performed with the bobbin coil(s) attached to a flexible shaft pulled through tubing manually or by a motorized device. Results are obtained by evaluating data acquired and recorded during scanning. This Appendix does not address tubing with enhanced heat transfer surfaces or saturation eddy current testing.

VIII-821 WRITTEN PROCEDURE REQUIREMENTS

VIII-821.1 Requirements. Eddy current examinations shall be conducted in accordance with a written procedure, which shall, as a minimum, contain the requirements listed in Table VIII-821. The written procedure shall establish a single value, or range of values, for each requirement.

VIII-821.2 Procedure Qualification. When procedure qualification is specified by the referencing Code Section, a change of a requirement in Table VIII-821 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

VIII-821.3 Personnel Requirements. The user of this Appendix shall be responsible for assigning qualified personnel to perform eddy current examination in accordance with requirements of the referencing Code Section.

VIII-830 EQUIPMENT

VIII-831 DATA ACQUISITION SYSTEM

VIII-831.1 Multifrequency-Multiparameter Equipment. The eddy current instrument shall have the capability of generating multiple frequencies simultaneously or multiplexed and be capable of multiparameter signal combination. In the selection of frequencies, consideration shall be given to optimizing flaw detection and characterization.

(a) The outputs from the eddy current instrument shall provide phase and amplitude information.

(b) The eddy current instrument shall be capable of operating with bobbin coil probes in the differential mode or the absolute mode, or both.

(c) The eddy current system shall be capable of real time recording.

(d) The eddy current equipment shall be capable of sensing and recording discontinuities, dimensional changes, resistivity/conductivity changes, conductive/magnetic deposits, and responses from imperfections originating on either tube wall surface.

VIII-832 ANALOG DATA ACQUISITION SYSTEM

VIII-832.1 Analog Eddy Current Instrument.

(a) The frequency response of the outputs from the eddy current instrument shall be constant within 2% of full scale from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-s/in. (0.4 Hz-s/mm) times maximum probe travel speed [in./sec (mm/s)].

(b) Eddy current signals shall be displayed as two-dimensional patterns by use of an X-Y storage oscilloscope or equivalent.

VIII-832.2 Magnetic Tape Recorder.

(a) The magnetic tape recorder used with the analog equipment shall be capable of recording and playing back eddy current signal data from all test frequencies and shall have voice logging capability.

Table VIII-821
Requirements of an Eddy Current Examination Procedure

Requirements (as Applicable)	Essential Variable	Nonessential Variable
Tube material, size (outside diameter), and wall thickness	X	...
Mode of inspection — differential and/or absolute	X	...
Probe type and size(s)	X	...
Probe manufacturer, part or serial number, and description	X	...
Examination frequencies, drive voltage, and gain settings	X	...
Manufacturer and model of eddy current equipment	X	...
Maximum scanning speed	X	...
Scanning mode — manual, mechanized probe driver, remote controlled fixture	X	...
Identity of calibration reference standard(s) including drawing	X	...
Minimum digitization rate/samples per second	X	...
Procedure qualification	X	...
Personnel qualifications	...	X
Data recording equipment manufacturer and model	...	X
Data analysis parameters	...	X
Tube numbering	...	X
Tube examination surface preparation	...	X
Scanning equipment, extension cable, and fixtures	...	X

(b) The frequency response of the magnetic tape recorder outputs shall be constant within 10% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-s/in. (0.4 Hz-s/mm) times maximum probe travel speed [in./sec (mm/s)].

(c) Signal reproducibility from input to output shall be within 5%.

VIII-832.3 Strip Chart Recorder.

(a) Strip chart recorders used with analog equipment shall have at least 2 channels.

(b) The frequency response of the strip chart recorder shall be constant within 20% of full scale from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-s/in. (0.4 Hz-s/mm) times maximum probe travel speed [in./sec (mm/s)].

VIII-833 DIGITAL DATA ACQUISITION SYSTEM

VIII-833.1 Digital Eddy Current Instrument.

(a) At the scanning speed to be used, the sampling rate of the instrument shall result in a minimum digitizing rate of 30 samples per in. (1.2 samples per mm) of examined tubing, use dr = sr/ss, where dr is the digitizing rate in samples per in., sr is the sampling rate in samples per sec or Hz, and ss is the scanning speed [in./sec (mm/sec)].

(b) The digital eddy current instrument shall have a minimum resolution of 12 bits per data point.

(c) The frequency response of the outputs of analog portions of the eddy current instrument shall be constant within 2% of the input value from dc to F_{max}, where F_{max} (Hz) is equal to 10 Hz-s/in. (0.4 Hz-s/mm) times maximum probe travel speed [in./sec (mm/s)].

(d) The display shall be selectable so that the examination frequency or mixed frequencies can be presented as a Lissajous pattern as shown in Figure VIII-864.1.

(e) The Lissajous display shall have a minimum resolution of 7 bits full scale.

(f) The strip chart display shall be capable of displaying at least 2 traces.

(g) The strip chart display shall be selectable so either the X or Y component can be displayed.

(h) The strip chart display shall have a minimum resolution of 6 bits full scale.

VIII-833.2 Digital Recording System.

(a) The recording system shall be capable of recording and playing back all acquired eddy current signal data from all test frequencies.

(b) The recording system shall be capable of recording and playing back text information.

(c) The recording system shall have a minimum resolution of 12 bits per data point.

VIII-834 BOBBIN COILS

VIII-834.1 General Requirements.

(a) Bobbin coils shall be able to detect artificial discontinuities in the calibration reference standard.

(b) Bobbin coils shall have sufficient bandwidth for operating frequencies selected for flaw detection and sizing.

(c) The probe fill factor [(probe diameter)^2/(tube inside diameter)^2 × 100] shall be a minimum of 80%.

(d) If the 80% fill factor cannot be achieved due to denting, corrosion, or other conditions, a minimum fill factor of 60% may be used provided all other requirements of this Article are met.

VIII-850 TECHNIQUE

VIII-851 PROBE DATA ACQUISITION SPEED

The probe data acquisition speed shall not exceed that which provides adequate frequency response and sensitivity to the applicable calibration discontinuities and be adjusted to provide a minimum digitization of 30 samples/in.

VIII-852 RECORDING

The eddy current signal data from all test frequencies shall be recorded on the recording media as the probe traverses the tube.

VIII-853 AUTOMATED DATA SCREENING SYSTEM

When automated eddy current data screening systems are used, each system shall be qualified in accordance with a written procedure.

VIII-860 CALIBRATION

VIII-861 EQUIPMENT CALIBRATION

VIII-861.1 Analog Equipment. The following shall be verified by annual calibration:

(a) the oscillator output frequency to the drive coil shall be within 5% of its indicated frequency

(b) the vertical and horizontal linearity of the cathode ray tube (CRT) display shall be within 10% of the deflection of the input voltage

(c) the ratio of the output voltage from the tape recorder shall be within 5% of the input voltage for each channel of the tape recorder

(d) the chart speed from the strip chart recorder shall be within 5% of the indicated value

(e) amplification for all channels of the eddy current instrument shall be within 5% of the mean value, at all sensitivity settings, at any single frequency

VIII-861.2 Digital Equipment. Digital equipment shall be calibrated after repairs which may change the instrument's accuracy are made.

VIII-862 CALIBRATION REFERENCE STANDARDS

VIII-862.1 Calibration Reference Standard Requirements. Calibration reference standards shall conform to the following:

(a) Calibration reference standards shall be manufactured from tube(s) of the same material specification and nominal size as that to be examined.

(b) A comparison of the system null points observed in the calibration reference standard and the tubing to be examined shall be performed to validate that the resistivity of the calibration reference standard and the tubing being examined is comparable as determined by Level III.

(c) Artificial discontinuities in calibration reference standards shall be spaced axially so they can be individually evaluated and their eddy current responses can be differentiated from each other and from the ends of the tube. The as-built dimensions of the discontinuities shall become part of the permanent record of the calibration referenced specimen.

(d) Each calibration reference standard shall be permanently identified with a serial number.

VIII-862.2 Calibration Reference Standards for Differential and Absolute Bobbin Coils. Calibration reference standards shall contain the following artificial discontinuities as a minimum:

(a) A single hole drilled 100% through the tube wall, $^{1}/_{32}$ in. (0.8 mm) in diameter for $^{3}/_{8}$ in. (10 mm) and smaller O.D. tubing, $^{3}/_{64}$ in. (1.2 mm) in diameter for greater than $^{3}/_{8}$ in. (10 mm) to $^{3}/_{4}$ in. (19 mm) O.D. tubing, and $^{1}/_{16}$ in. (1.5 mm) for tubing larger than $^{3}/_{4}$ in. (19 mm) O.D.

(b) Four flat-bottom drill holes, $^{3}/_{16}$ in. (5 mm) in diameter, spaced 90-deg apart in a single plane around the tube circumference, 20% through the tube wall from the outer tube surface.

(c) One 360 deg circumferential groove, $^{1}/_{8}$ in. (3 mm) wide, 10% through the tube wall from the outer tube surface.

(d) One 360 deg circumferential groove, $^{1}/_{16}$ in. (1.5 mm) wide, 10% through the tube wall from the inner tube surface. Optional on smaller diameter tubing that may not facilitate tooling.

(e) The depth of the calibration discontinuities, at their center, shall be accurate to within 20% of the specified depth or 0.003 in. (0.076 mm), whichever is smaller. All other dimensions of the calibration discontinuities shall be accurate to within 0.010 in. (0.25 mm).

(f) Additional calibration discontinuities that simulate the anticipated or known conditions in the tubing or as specifically defined by the owner may be included on the same calibration standard with the above required discontinuities or on a separate standard.

(g) The additional calibration discontinuities described in (f) do not need to meet the tolerances in (e) as long as they simulate the anticipated conditions of the tubing to be examined and their actual as-built dimensions are used for the evaluation of the data.

(h) The additional calibration discontinuities described in (f) should

(1) allow for three calibration curve set points (e.g., 60%, 40%, 20% through wall)

(2) have an adequate axial dimension to encompass the field of the probe coils [e.g., $^{5}/_{8}$ in. (15 mm)] for large volume wall loss discontinuities, such as steam erosion or tube-to-tube wear

VIII-863 BASE FREQUENCY

The base frequency shall be between f_{90} and 2.1 × f_{90} as defined by the following equations:

(a) Minimum Base Frequency:

$$f_{90} = 4.8\frac{\rho}{t^2\mu_r}$$

(b) Maximum Base Frequency:

$$2.1 \times f_{90} = 10\frac{\rho}{t^2\mu_r}$$

where

f_{90} = the frequency which generates a 90 deg phase separation between a shallow inside originated defect and a shallow outside originated defect
ρ = tube material resistivity (μΩ·cm)
t = tube wall thickness [in. or (mm/25)]
μ_r = relative magnetic permeability (μ_r = 1.0 for nonmagnetic materials)

VIII-864 SETUP AND ADJUSTMENT

VIII-864.1 Differential Bobbin Coil Technique.

(a) The sensitivity shall be adjusted to produce a minimum Lissajous response of 50% screen height from the four 20% flat-bottom holes or as determined by the cognizant Level III or data analyst.

(b) The phase rotation shall be adjusted so the signal response due to the 10% inside originated groove is within 5 deg of the horizontal axis (max rate). The response due to the through-wall hole forms either up and to the left or down and to the right first as the probe is withdrawn from the calibration reference standard.

(c) Withdraw the probe through the calibration reference standard at the qualified examination speed. Record the responses of the applicable calibration reference standard discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

(d) The f_{90} frequency should be verified by a 90 deg phase separation between the inside and outside originated 10% deep grooves. See example in Figure VIII-864.1.

VIII-864.2 Absolute Bobbin Coil Technique.

(a) The sensitivity shall be adjusted to produce a minimum Lissajous response of 25% screen height from the four 20% flat-bottom holes or as determined by the cognizant Level III or data analyst.

(b) The phase rotation control shall be adjusted so the signal response due to the 10% inside originated groove is within 5 deg (peak-to-peak) of the horizontal axis. The signal response due to the through-wall hole can be formed up and to the left or down and to the right as the probe is withdrawn from the calibration reference standard.

(c) Withdraw the probe through the calibration reference standard at the qualified examination speed. Record the responses of the applicable calibration reference standard discontinuities. The responses shall be clearly indicated by the instrument and shall be distinguishable from each other as well as from probe motion signals.

(d) The f_{90} frequency should be verified by a 90 deg phase separation between the inside and outside originated 10% deep grooves. See example in Figure VIII-864.2.

VIII-864.3 Digital System Off-Line Calibration. The eddy current examination data is digitized and recorded during scanning for off-line analysis and interpretation. The system setup of phase and amplitude settings shall be performed off-line by the data analyst. Phase and amplitude settings shall be such that the personnel acquiring the data can clearly discern that the eddy current instrument is working properly.

VIII-864.4 System Calibration Verification.

(a) Calibration shall include the complete eddy current examination system. Changes of any probe, extension cables, eddy current instrument, recording instruments,

Figure VIII-864.1
Differential Technique Response From Calibration Reference

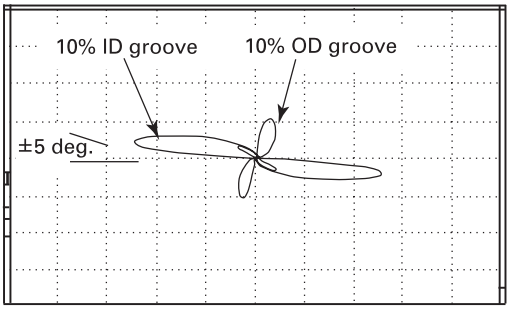
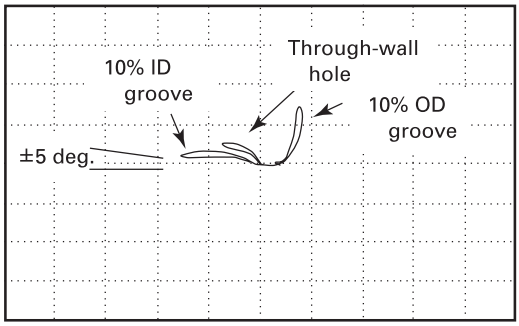


Figure VIII-864.2
Absolute Technique From Calibration Reference Standard



or any other parts (essential variables) of the eddy current examination system hardware shall require recalibration.

(b) System calibration verification shall be performed and recorded at the beginning and end of each unit of data storage of the recording media and every 4 hr.

(c) Should the system be found to be out of calibration (as defined in VIII-864.1 and VIII-864.2), the equipment shall be recalibrated. The recalibration shall be noted on the recording media. The cognizant Level III or data analyst shall determine which tubes, if any, shall be reexamined.

VIII-870 EXAMINATION

The maximum probe travel speed used for examination shall not exceed that used for calibration. Data shall be recorded as the probe traverses the tube.

VIII-880 EVALUATION

VIII-881 DATA EVALUATION

Data shall be evaluated in accordance with the requirements of this Appendix.

VIII-882 MEANS OF DETERMINING INDICATION DEPTH

For indication types that must be reported in terms of depth, a means of correlating the indication depth with the signal amplitude or phase shall be established. The means of correlating the signal amplitude or phase with the indication depth shall be based on the basic calibration standard or other representative standards that have been qualified. This shall be accomplished by using curves, tables, or equations and aided by software.

VIII-883 FREQUENCIES USED FOR DATA EVALUATION

All indications shall be evaluated. Indication types, which must be reported, shall be characterized using the frequencies or frequency mixes that were qualified.

VIII-890 DOCUMENTATION

VIII-891 REPORTING

VIII-891.1 Criteria. Indications reported in accordance with the requirements of this Appendix shall be described in terms of the following information, as a minimum:

(a) location along the length of the tube and with respect to the support members, when the indication identification is relevant to a specific location (i.e., fretting @ baffle 2)

(b) depth of the indication through the tube wall

(c) frequency or frequency mix from which the indication was evaluated

VIII-891.2 Depth. The maximum evaluated depth of flaws shall be reported in terms of percentage of tube wall loss. When the loss of tube wall is determined by the analyst to be less than 20%, the exact percentage of tube wall loss need not be recorded, i.e., the indication may be reported as being less than 20%.

VIII-891.3 Nonquantifiable Indications. A nonquantifiable indication is a reportable indication that cannot be characterized. The indication shall be considered a flaw until otherwise resolved.

VIII-892 SUPPORT MEMBERS

VIII-892.1 Location of Support. The location of support members used as reference points for the eddy current examination shall be verified by fabrication drawings or the use of a measurement technique.

VIII-893 RECORDS

VIII-893.1 Record Identification. The recording media shall contain the following information within each unit of data storage:

(a) procedure identification and revision
(b) plant site, unit, and Owner
(c) heat exchanger identification
(d) data storage unit number
(e) date of examination
(f) serial number of the calibration standard
(g) operator's identification and certification level
(h) examination frequency or frequencies
(i) mode of operation including instrument sample rate, drive voltage, and gain settings
(j) lengths of probe and probe extension cables
(k) size and type of probes
(l) probe manufacturer's name and manufacturer's part number or probe description and serial number
(m) eddy current instrument model and serial number
(n) probe scanning mode and direction during data acquisition
(o) application side — inlet or outlet
(p) slip ring serial number, as applicable
(q) tube material, size, and wall thickness

VIII-893.2 Tube Identification.

(a) Each tube examined shall be identified on the applicable unit of data storage and should be consistent with the manufacturer's as-built drawings, Owner's numbering scheme, and/or previous inspection.

(b) The method of recording the tube identification shall correlate tube identification with corresponding recorded tube data.

VIII-893.3 Reporting.

(a) The Owner or his agent shall prepare a report of the examinations performed. The report shall be prepared, filed, and maintained in accordance with the referencing

Code Section. The procedures and equipment used shall be sufficiently identified to permit the comparison of existing results to those of previous and subsequent examinations. This shall include initial calibration data for each eddy current examination system or part thereof.

(b) The report shall include a record indicating the tubes examined (this may be marked on a tubesheet sketch or drawing), any scanning limitations, the location and depth of each reported flaw, and the identification and certification level of the operators and data evaluators that conducted each examination or part thereof.

(c) Tubes that are to be repaired or removed from service, based on eddy current examination data, shall be identified.

VIII-893.4 Record Retention. Records shall be maintained in accordance with requirements of the referencing Code Section.

Material de Estudo
Não Divulgar

MANDATORY APPENDIX IX
EDDY CURRENT ARRAY EXAMINATION OF FERROMAGNETIC AND NONFERROMAGNETIC MATERIALS FOR THE DETECTION OF SURFACE-BREAKING FLAWS

IX-810 SCOPE

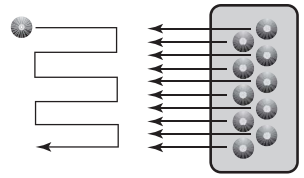
This Appendix provides the requirements for the detection and length sizing of surface-breaking flaws on ferromagnetic and nonferromagnetic materials using the eddy current array (ECA) technique.

IX-820 GENERAL REQUIREMENTS

IX-821 ECA TECHNIQUE

The ECA technique may be applied to detect linear and nonlinear surface-breaking flaws. Length sizing of flaws may also be accomplished when an encoder is used. ECA may be used on ferromagnetic and nonferromagnetic materials. ECA provides the ability to electronically monitor the output of multiple eddy-current sensing coils placed side by side or in other orientations within the same probe assembly. The ECA technique effectively replaces raster scanning with a single-pass scan, provided the probe size is adequate to cover the area of interest (see Figure IX-821-1). When a surface flaw is encountered by the magnetic field of an individual coil, eddy currents generated in the material change their flow and provide a secondary magnetic field in opposition to the coil's primary magnetic field. Modifications to the coil's primary magnetic field are processed and presented on the equipment's strip chart, phase-amplitude diagram, and two-dimensional and/or three-dimensional C-scan displays.

Figure IX-821-1
ECA Technique Compared to Raster Scan



IX-822 WRITTEN PROCEDURE REQUIREMENTS

The ECA examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table IX-822-1. The written procedure shall establish a single value, or a range of values, for each requirement.

IX-823 PROCEDURE QUALIFICATION

When a written procedure qualification is specified by the referencing Code Section, a change of a requirement in Table IX-822-1 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

IX-824 PERSONNEL QUALIFICATION

The user shall be responsible for assigning qualified personnel to perform the ECA examinations in accordance with the requirements of this Appendix, the referencing Code Section, and their employer's written practice. The minimum qualification level of personnel performing ECA examinations shall be Eddy Current (ET) Level II with a minimum of 20 hr supplemental ECA training. Supplemental training on the use of the ECA method shall cover, at a minimum, the following topics:

(a) training on the specific ECA hardware and software used
(b) ECA advantages and limitations
(c) ECA probe types, construction, and operation
(d) channel standardization
(e) C-scan interpretation
(f) phase-amplitude data analysis interpretation
(g) encoded scans

Table IX-822-1
Written Procedure Requirements for an ECA Examination

Requirement	Essential Variable	Nonessential Variable
Instrument (manufacturer, model)	X	...
Probe (manufacturer, model)	X	...
ECA probe topology	X	...
Examination frequencies, drive voltage, and gain settings	X	...
Scanning mode (e.g., manual, mechanized, or remote-controlled)	X	...
Scan plan, coverage, overlap, and scanning direction	X	...
Identity of calibration reference standard(s)	X	...
Minimum sample density along scanning axis [samples/inch (samples/millimeter)]	X	...
Surface condition	X	...
Maximum scanning speed during data acquisition	X	...
Personnel qualification	X	...
Data recording	...	X
Data analysis parameters	...	X
Examination specimen numbering	...	X

IX-825 PROCEDURE DEMONSTRATION

The examination procedure shall be demonstrated to the satisfaction of the Inspector and responsible Level III in accordance with requirements of the referencing Code Section.

IX-830 EQUIPMENT

IX-831 DIGITAL DATA ACQUISITION EQUIPMENT

ECA equipment shall manage the ECA probe signals based on a channel multiplexing or a parallel channel system. ECA instrumentation with a minimum frequency range of 1 kHz to 4 MHz and associated software shall be used. The ECA instrument and software shall

(a) allow standardizing the ECA probe signal response by conducting individual adjustments (e.g., scaling) to the data response of each coil channel in order to provide a uniform response and sensitivity among the array channels (i.e., channel standardization).

(b) display data as a two-dimensional C-scan allowing for image-based analysis. Data shall also be displayed in the traditional phase-amplitude diagram and strip chart views.

(c) allow adjustment of encoder settings and display resolution (inch/sample [millimeter/sample]).

(d) allow recording of the ECA data in a format for evaluation and archival storage.

IX-832 PROBES

ECA probes shall

(a) provide coverage that extends 0.125 in. (3.2 mm) beyond the area of interest unless multiple overlapping scans are used.

(b) exhibit a uniform sensitivity across the array sensor. Overlapping individual sensing elements may be required to achieve a level of uniform sensitivity (e.g., multiple staggered rows of single sensing elements is typical). For the purpose of detection only, multiple scans of the same reference standard flaw shall maintain an amplitude response of at least 60% of the maximum amplitude detected. See Figure IX-832-1.

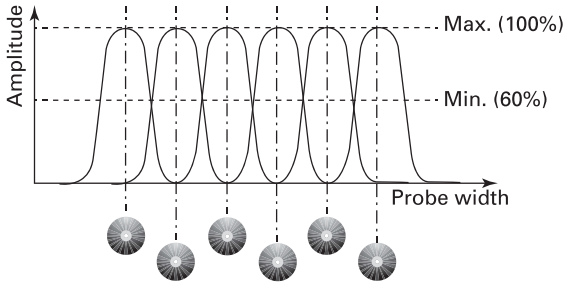
(c) allow detection of volumetric and linear surface-breaking flaws in all orientations.

(d) match the geometry of the area of interest to minimize the distance between the surface examined and the individual sensing elements (i.e., lift-off).

IX-833 REFERENCE STANDARD (SEE FIGURE IX-833-1)

A reference standard shall be constructed of the same material grade as to be examined. The surface roughness of the reference standard shall be representative of the surface roughness of the component surface to be examined. The reference standard shall have 1.5 in. (38 mm) of a flaw-free region at the beginning and end of the longitudinal scanning direction. Ferromagnetic and

Figure IX-832-1
Array Coil Sensitivity Variance



GENERAL NOTE: Multiple scans of the same flaw shall consistently provide at least 60% of the maximum detected amplitude.

nonferromagnetic reference standards shall have a minimum of one flat-bottom hole and three surface notches. The surface notches shall include oblique (i.e., 45 deg), transverse, and longitudinal orientations. The distance between flaws in the same longitudinal direction shall be a minimum of 0.5 in. (13 mm). The flat-bottom hole shall have a maximum diameter and depth of 0.062 in. (1.57 mm) and 0.040 in. (1.0 mm), respectively. Each notch length, width, and depth shall be a maximum of 0.062 in. (1.57 mm), 0.010 in. (0.25 mm), and 0.040 in. (1.0 mm), respectively. In addition, reference standards for ferromagnetic and nonferromagnetic materials shall have a long transverse notch of constant depth for use with channel standardization. The length of the long transverse notch shall be at least 1.0 in. (25 mm) longer than the coverage of the ECA probe coils. The width and depth of the long notch shall be a maximum of 0.010 in. (0.25 mm) and 0.040 in. (1.0 mm), respectively. When the examination region of interest is a curved surface requiring a rigid probe with a matching contoured surface, a reference specimen representing that particular geometry with the above referenced flaws shall be used. Machining during the manufacture of the reference standard shall avoid excessive cold-working, overheating, and stress to prevent magnetic permeability variations.

IX-840 APPLICATION REQUIREMENTS

IX-841 SCANNING SPEED

The scanning speed shall not exceed that which provides detection of the reference standard flaws. A data-amplitude-based signal-to-noise ratio (SNR) for all flaws shall be maintained at a value greater than 3. The minimum sample density along the scanning axis shall be 50.0 samples/in. (2.0 samples/mm).

IX-842 COATED SURFACES

(a) When examining a coated material, the coating thickness on the reference standard shall be the maximum allowed on the examination surface by the coating specification. Plastic shim stock may be used to simulate nonconductive coatings for procedure qualification.

(b) Using the maximum scanning speed specified by the procedure, the procedure shall be demonstrated to consistently detect the reference standard flaws through the maximum coating thickness regardless of flaw orientation. A data-amplitude-based SNR for all flaws shall be maintained at a value greater than 3.

IX-843 MAGNETIC PERMEABILITY VARIANCE

In the event that the magnetic permeability along the scanning axis changes to the extent that the ECA data signals on the phase-amplitude diagram become saturated, the NDE technician shall perform a system calibration verification using the reference standard, rebalance the instrument with the probe positioned in the affected area, and rescan the region.

IX-844 AUTOMATED DATA SCREENING SYSTEM

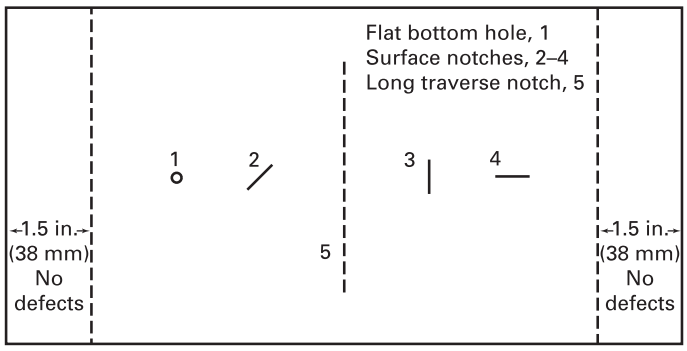
When automated eddy current data screening systems (e.g., alarm boxes) are used, each system shall be qualified in accordance with a written procedure.

IX-850 TECHNIQUE

IX-851 FREQUENCY, PROBE DRIVE, AND GAIN SELECTION

A single-frequency or multifrequency technique may be used. The frequency shall be selected to maximize the phase spread between the lift-off signal and reference flaws. Probe drive and gain shall be adjusted until the response of the reference flaws has a data-amplitude-based SNR greater than 3.

Figure IX-833-1
Example Reference Standard



IX-852 CHANNEL STANDARDIZATION

If the topology selected for an examination features different channel types (e.g., longitudinal and transverse sensitivity), channel standardization shall be performed for each channel type. The flaw response from each array channel shall be reviewed via the traditional phase-amplitude diagram to ensure that the channel standardization was completed successfully. The channel standardization process shall be performed on a reference standard with a machined notch of known length, width, and depth. Other reference points such as known lift-off or a metal-to-air transition may be used if equivalent performance to a machined notch can be demonstrated.

IX-853 COLOR PALETTE ADJUSTMENT

The color palette scale shall be adjusted until the reference flaws can be clearly distinguished when compared to lift-off, geometry change, and non-flaw-related signals.

IX-860 CALIBRATION

IX-861 EQUIPMENT CALIBRATION

ECA instrumentation shall be calibrated annually, when the equipment is subjected to damage, and/or after any major repair. A label showing the latest date of calibration and calibration due date shall be attached to the ECA instrument.

IX-862 SYSTEM CALIBRATION AND VERIFICATION

(a) System calibration of the examination equipment shall be performed with the use of a reference standard as specified in the written procedure. This calibration shall include the complete eddy current examination system and shall be performed prior to the start of the examination. A verification shall be performed at the conclusion of the examination or series of examinations.

(b) Calibration verification using the reference standard shall be performed when either of the following occurs:

(1) a change in material properties that causes signal saturation

(2) examination of a new component

IX-870 EXAMINATION

IX-871 SURFACE CONDITION

Cleaning of the material surface shall be conducted to remove loose ferromagnetic, conductive, and nonconductive debris.

IX-872 SCANNING METHOD (SEE FIGURE IX-872-1)

Pressure applied to the ECA probe shall be sufficient to maintain contact with the part under examination. When using a conformable array probe, consistent pressure shall be applied across all coils. The area of interest shall be examined with overlapping scans. Overlap along the scanning axis (i.e., scanning direction) shall include the end of the previous scan by at least one probe width. Overlap along the index axis shall include 0.250 in. (6.4 mm) of the previous scan. Note that the probe length overlap value [0.250 in. (6.4 mm)] is based on the coil sensitivity length within the probe body.

IX-873 SECONDARY SCANNING

When an encoder is not used, flaw locations may be confirmed by a supplemental manual single-channel eddy current (EC) technique, provided it has been qualified by a performance demonstration.

IX-880 EVALUATION

IX-881 RELEVANT VS. NONRELEVANT INDICATIONS

Nonrelevant indications may be produced by inconsistent probe contact with the surface, probe motion caused by geometric features, or changes in the material properties of the surface being examined. Indications that exhibit a phase response equivalent to a flaw response as demonstrated on the reference standard and that cannot be differentiated as a nonrelevant indication shall be evaluated and reported as a flaw.

IX-882 LENGTH SIZING

An encoder shall be used to accurately measure flaw length. The encoder resolution value shall be set to a maximum of 0.015 in./sample (0.38 mm/sample).

IX-890 DOCUMENTATION

IX-891 EXAMINATION REPORT

A report of the examination shall be generated. The report shall include, at a minimum, the following information:

(a) owner, location, type, serial number, and identification of test specimen examined

(b) material examined

(c) test specimen numbering system

(d) dimensions of surface area to be examined

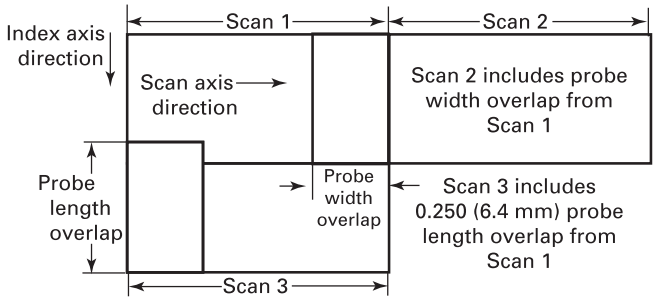
(e) personnel performing the examination

(f) date of examination

(g) ECA equipment manufacturer, model, and serial number

(h) ECA probe manufacturer, model, and serial number

Figure IX-872-1
Scanning Overlap



(i) instrument hardware settings (frequency, probe drive, gain, and sample rate)

(j) serial number(s), material, and drawing(s) of reference standard(s)

(k) procedure used, identification, and revision

(l) acceptance criteria used

(m) identification of regions of test specimens where limited sensitivity or other areas of reduced sensitivity occur

(n) results of the examination and related sketches or maps of the examined area

(o) complementary tests used to further investigate or confirm test results

(p) extension cable, manufacturer, type, and length

(q) qualification level of eddy current personnel

(r) coating-thickness gauge when required

IX-892 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.

MANDATORY APPENDIX X
EDDY CURRENT ARRAY EXAMINATION OF FERROMAGNETIC AND NONFERROMAGNETIC WELDS FOR THE DETECTION OF SURFACE-BREAKING FLAWS

X-810 SCOPE

This Appendix provides the requirements for the detection and length sizing of surface-breaking flaws on ferromagnetic and nonferromagnetic welds using the eddy current array (ECA) technique.

X-820 GENERAL REQUIREMENTS

X-821 ECA TECHNIQUE

The ECA technique may be applied to detect linear and nonlinear surface-breaking flaws. Length sizing of flaws may also be accomplished when an encoder is used. ECA may be used on ferromagnetic and nonferromagnetic welds. ECA provides the ability to electronically monitor the output of multiple eddy-current sensing coils placed side by side or in other orientations within the same probe assembly. The ECA technique effectively replaces raster scanning with a single-pass scan, provided the probe size is adequate to cover the area of interest (see Mandatory Appendix IX, Figure IX-821-1). When a surface flaw is encountered by the magnetic field of an individual coil, eddy currents generated in the material change their flow and provide a secondary magnetic field in opposition to the coil's primary magnetic field. Modifications to the coil's primary magnetic field are processed and presented on the equipment's strip chart, phase-amplitude diagram, and two-dimensional and/or three-dimensional C-scan displays.

X-822 WRITTEN PROCEDURE REQUIREMENTS

The ECA examination shall be performed in accordance with a written procedure that shall, as a minimum, contain the requirements listed in Table X-822-1. The written procedure shall establish a single value, or a range of values, for each requirement.

X-823 PROCEDURE QUALIFICATION

When a written procedure qualification is specified by the referencing Code Section, a change of a requirement in Table X-822-1 identified as an essential variable shall require requalification of the written procedure by demonstration. A change of a requirement identified as a nonessential variable does not require requalification of the written procedure. All changes of essential or nonessential variables from those specified within the written procedure shall require revision of, or an addendum to, the written procedure.

X-824 PERSONNEL QUALIFICATION

The user shall be responsible for assigning qualified personnel to perform the ECA examinations in accordance with the requirements of this Appendix, the referencing Code Section, and their employer's written practice. The minimum qualification level of personnel performing ECA examinations shall be Eddy Current (ET) Level II with a minimum of 20 hr supplemental ECA training. Supplemental training on the use of the ECA method shall, at a minimum, cover the following topics:

(a) training on the specific ECA hardware and software used
(b) ECA advantages and limitations
(c) ECA probe types, construction, and operation
(d) channel standardization
(e) C-scan interpretation
(f) phase-amplitude data analysis interpretation
(g) encoded scans

X-825 PROCEDURE DEMONSTRATION

The procedure shall be demonstrated to the satisfaction of the Inspector and responsible Level III in accordance with the requirements of the referencing Code Section.

X-830 EQUIPMENT

X-831 DIGITAL DATA ACQUISITION EQUIPMENT

ECA equipment shall manage the ECA probe signals based on a channel multiplexing or a parallel channel system. ECA instrumentation with a minimum frequency range of 1 kHz to 4 MHz and associated software shall be used. The ECA instrument and software shall

(a) allow standardizing the ECA probe signal response by conducting individual adjustments (e.g., scaling) to the data response of each coil channel in order to provide a uniform response and sensitivity among the array channels (i.e., channel standardization).

Table X-822-1
Written Procedure Requirements for an ECA Examination

Requirement	Essential Variable	Nonessential Variable
Instrument (manufacturer, model)	X	...
Probe (manufacturer, model)	X	...
ECA probe topology	X	...
Examination frequencies, drive voltage, and gain settings	X	...
Scanning mode (e.g., manual, mechanized, or remote controlled)	X	...
Scan plan, coverage, overlap, and scanning direction	X	...
Identity of calibration reference standard(s)	X	...
Minimum sample density along scanning axis [samples/inch (samples/millimeter)]	X	...
Surface condition	X	...
Maximum scanning speed during data acquisition	X	...
Personnel qualification	X	...
Data recording	...	X
Data analysis parameters	...	X
Examination specimen numbering	...	X

(b) display data as a two-dimensional C-scan allowing for image-based analysis. Data shall also be displayed in the traditional phase-amplitude diagram and strip chart views.

(c) allow adjustment of encoder settings and display resolution [inch/sample (millimeter/sample)].

(d) allow recording of the ECA data in a format for evaluation and archival storage.

X-832 PROBES

ECA probes shall

(a) provide coverage that extends 0.125 in. (3.2 mm) beyond the area of interest inclusive of the heat-affected zone (HAZ), unless multiple overlapping scans are used.

(b) exhibit a uniform sensitivity across the array sensor. Overlapping individual sensing elements may be required to achieve a level of uniform sensitivity (e.g., multiple staggered rows of single sensing elements is typical). For the purpose of detection only, multiple scans of the same reference standard flaw shall maintain an amplitude response of at least 60% of the maximum amplitude detected. See Mandatory Appendix IX, Figure IX-832-1.

(c) allow detection of volumetric and linear surface-breaking flaws in all orientations.

(d) match the geometry of the area of interest to minimize the distance between the surface examined and the individual sensing elements (i.e., lift-off).

X-833 REFERENCE STANDARD (SEE FIGURE X-833-1)

X-833.1 General Requirements. A reference standard shall be constructed of the same material grade as to be examined. The surface roughness of the reference standard shall be representative of the surface roughness of the component surface to be examined. The reference standard shall have 1.5 in. (38 mm) of a flaw-free region at the beginning and end of the longitudinal scanning direction. Ferromagnetic and nonferromagnetic reference standards shall have a minimum of four flat-bottom holes and 12 surface notches. The surface notches shall have oblique (45 deg), transverse, and longitudinal orientations. The distance between flaws in the same longitudinal direction shall be a minimum of 0.5 in. (13 mm). Each flaw type shall be located in the HAZ, the crown of the weld, the fusion line of the weld, and the base material. In addition, reference standards for ferromagnetic and nonferromagnetic weld applications shall have a long transverse notch of constant depth for use with channel standardization. The length of the long transverse notch shall be at least 1.0 in. (25 mm) longer than the coverage of the ECA probe coils. The width and depth of the long notch shall be a maximum of 0.010 in. (0.25 mm) and 0.040 in. (1.0 mm), respectively. When the examination region of interest is a curved surface requiring a rigid probe with a matching contoured surface, a reference specimen representing that particular geometry with the above referenced flaws shall be used. Machining during the manufacture of the reference standard shall avoid excessive cold-working, overheating, and stress to prevent magnetic permeability variations.

X-833.2 Flush Welds. The flat-bottom holes and notches for flush weld reference standards shall have the following maximum dimensions:

(a) Flat-Bottom Holes

(1) diameter of 0.062 in. (1.57 mm)

(2) depth of 0.040 in. (1.0 mm)

(b) Notches

(1) length of 0.062 in. (1.57 mm)

(2) width of 0.010 in. (0.25 mm)

(3) depth of 0.040 in. (1.0 mm)

X-833.3 Nonflush Welds. The flat-bottom holes and notches for nonflush weld reference standards shall have the following maximum dimensions:

(a) Flat-Bottom Holes

(1) diameter of 0.125 in. (3.2 mm)

(2) depth of 0.040 in. (1.0 mm)

(b) Notches

(1) length of 0.188 in. (4.8 mm)

(2) width of 0.010 in. (0.25 mm)

(3) depth of 0.040 in. (1.0 mm)

X-840 APPLICATION REQUIREMENTS

X-841 SCANNING SPEED

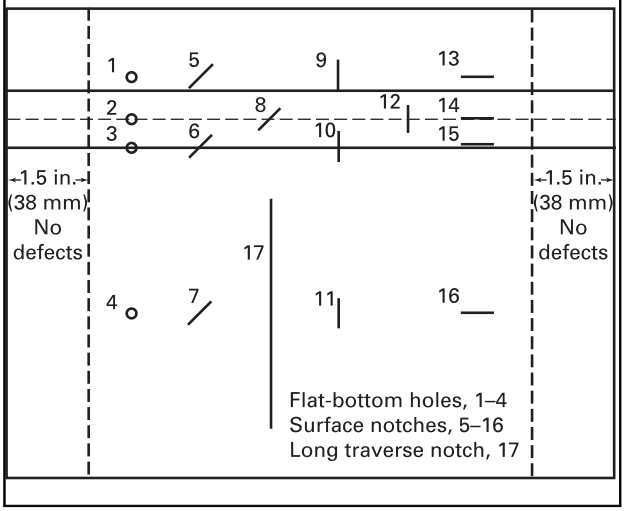
The scanning speed shall not exceed that which provides detection of the reference standard flaws. A data-amplitude-based signal-to-noise ratio (SNR) for all flaws shall be maintained at a value greater than 3. The minimum sample density along the scanning axis shall be 50.0 samples/in. (2.0 samples/mm).

X-842 COATED SURFACES

(a) When examining a coated material, the coating thickness on the reference standard shall be the maximum allowed on the examination surface by the coating specification. Plastic shim stock may be used to simulate nonconductive coatings for procedure qualification.

(b) Using the maximum scanning speed specified by the procedure, the procedure shall be demonstrated to consistently detect the reference standard flaws through the maximum coating thickness regardless of flaw orientation. A data-amplitude-based SNR for all flaws shall be maintained at a value greater than 3.

Figure X-833-1
Example Reference Standard



X-843 MAGNETIC PERMEABILITY VARIANCE

In the event that the magnetic permeability along the scanning axis changes to the extent that the ECA data signals on the phase-amplitude diagram become saturated, the NDE technician shall perform a system calibration verification using the reference standard, rebalance the instrument with the probe positioned in the affected area, and rescan the region.

X-844 AUTOMATED DATA SCREENING SYSTEM

When automated eddy current data screening systems (e.g., alarm boxes) are used, each system shall be qualified in accordance with a written procedure.

X-850 TECHNIQUE

X-851 FREQUENCY, PROBE DRIVE, AND GAIN SELECTION

A single-frequency or multifrequency technique may be used. The frequency shall be selected to maximize the phase spread between the lift-off signal and reference flaws. Probe drive and gain shall be adjusted until the response of the reference flaws has a data-amplitude-based SNR greater than 3.

X-852 CHANNEL STANDARDIZATION

If the topology selected for an examination features different channel types (e.g., longitudinal and transverse sensitivity), channel standardization shall be performed for each channel type. The flaw response from each array channel shall be reviewed via the traditional phase-amplitude diagram to ensure that the channel standardization was completed successfully. The channel standardization process shall be performed on a reference standard with a machined notch of known length, width, and depth. Other reference points such as known lift-off or a metal-to-air transition may be used if equivalent performance to a machined notch can be demonstrated.

X-853 COLOR PALETTE ADJUSTMENT

The color palette scale shall be adjusted until the reference flaws can be clearly distinguished when compared to lift-off, geometry change, and non-flaw-related signals.

X-860 CALIBRATION

X-861 EQUIPMENT CALIBRATION

ECA instrumentation shall be calibrated annually, when the equipment is subjected to damage, and/or after any major repair. A label showing the latest date of calibration and calibration due date shall be attached to the ECA instrument.

X-862 CALIBRATION AND VERIFICATION

(a) System calibration of the examination equipment shall be performed with the use of a reference standard as specified in the written procedure. This calibration shall include the complete eddy current examination system and shall be performed prior to the start of the examination. A verification shall be performed at the conclusion of the examination or series of examinations.

(b) Calibration verification using the reference standard shall be performed when either of the following occurs:

(1) a change in material properties that causes signal saturation

(2) examination of a new component

X-870 EXAMINATION

X-871 SURFACE CONDITION

Cleaning of the weld surface shall be conducted to remove loose ferromagnetic, conductive, and nonconductive debris.

X-872 SCANNING METHOD (SEE MANDATORY APPENDIX IX, FIGURE IX-872-1)

Pressure applied to the ECA probe shall be sufficient to maintain contact with the part under examination. When using a conformable array probe, consistent pressure shall be applied across all coils. The area of interest shall be examined with overlapping scans. Overlap along the scanning axis (i.e., scanning direction) shall include the end of the previous scan by at least one probe width. Overlap along the index axis shall include 0.250 in. (6.4 mm) of the previous scan. Note that the probe length overlap value [0.250 in. (6.4 mm)] is based on the coil sensitivity length within the probe body.

X-873 SECONDARY SCANNING

When an encoder is not used, flaw locations may be confirmed by a supplemental manual single-channel eddy current (EC) technique, provided it has been qualified by a performance demonstration.

X-880 EVALUATION

X-881 RELEVANT VS. NONRELEVANT INDICATIONS

Nonrelevant indications may be produced by inconsistent probe contact with the surface, probe motion caused by geometric features, or changes in the material properties of the surface being examined. Indications that exhibit a phase response equivalent to a flaw response as demonstrated on the reference standard and that cannot be differentiated as a nonrelevant indication shall be evaluated and reported as a flaw.

X-882 LENGTH SIZING

An encoder shall be used to accurately measure flaw length. The encoder resolution value shall be set to a maximum of 0.015 in./sample (0.38 mm/sample).

X-890 DOCUMENTATION

X-891 EXAMINATION REPORT

A report of the examination shall be generated. The report shall include, at a minimum, the following information:

(a) owner, location, type, serial number, and identification of test specimen examined

(b) material examined

(c) test specimen numbering system

(d) dimensions of surface area to be examined

(e) personnel performing the examination

(f) date of examination

(g) ECA equipment manufacturer, model, and serial number

(h) ECA probe manufacturer, model, and serial number

(i) instrument hardware settings (frequency, probe drive, gain, and sample rate)

(j) serial number(s), material, and drawing(s) of reference standard(s)

(k) procedure used, identification, and revision

(l) acceptance criteria used

(m) identification of regions of test specimens where limited sensitivity or other areas of reduced sensitivity occur

(n) results of the examination and related sketches or maps of the examined area

(o) complementary tests used to further investigate or confirm test results

(p) extension cable, manufacturer, type, and length

(q) qualification level of eddy current personnel

(r) coating thickness gauge when required

X-892 RECORD RETENTION

Records shall be maintained in accordance with requirements of the referencing Code Section.