MANDATORY APPENDIX VIII
EDDY CURRENT EXAMINATION OF NONMAGNETIC HEAT EXCHANGER TUBING

VIII-810 SCOPE

This Appendix provides the requirements for bobbin coil, multifrequency, multiparameter, eddy current examination for installed nonmagnetic 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 methodology 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 contain, as a minimum, 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.

(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%.

Table VIII-821
Requirements for an Eddy Current Examination Procedure

Requirements (As Applicable)	Essential Variable	Nonessential Variable
Tube material, size (outside diameter), wall thickness and grade/temper	X	...
Mode of inspection — differential and/or absolute	X	...
Probe type	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

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) Coils shall be mounted as close to the outside of the probe as practical while providing sufficient protection against coil damage.

(d) The probe fill factor (probe diameter/tube inside diameter) shall be a minimum of 0.80.

VIII-850 TECHNIQUE

VIII-850.1 Probe Data Acquisition Speed. The traverse speed shall not exceed that which provides adequate frequency response and sensitivity to the applicable calibration discontinuities. Probe scanning speed is determined by test frequency and the length of the smallest defect to be detected and sized. The maximum probe data acquisition speed shall be 36 in./sec (90 cm/sec). For copper alloys (materials with a resistivity less than 50 μ ohm/cm), the maximum probe data acquisition speed shall be 18 in./sec (45 cm/sec).

VIII-850.2 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, temper, and nominal size as that to be examined in the vessel.

(b) The resistivity of the reference standard shall be within 2 μ ohm/cm of the resistivity of the tubing to be examined to ensure good results. When the resistivity of the reference standard differs from the tubes being tested, the resistivity of the reference standard shall be compared to that of the tubes being tested with a button probe at a frequency of at least 5 times greater than f_{90}.

(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 that are located on either the inner or outer surface of the tube specimen:

(a) One $^1/_{16}$ in. (1.6 mm) wide, 360 deg circumferential groove 10% through from the tube inner surface.

(b) One $^1/_8$ in. (3.2 mm) wide, 360 deg groove 10% through from the tube outer surface.

(c) One hole drilled 100% through the tube wall $^1/_{16}$ in. (1.6 mm) diameter.

(d) A sufficient number of artificial defects, such as EDM manufactured inner surface originated cylindrical rounded bottom pits, 180 deg outer surface originated wear scars, and inner surface originated 360 deg grooves to aid in developing a calibration relationship for sizing tube degradation.

(1) There shall be a minimum of three sizing discontinuities of each type having depths equal to 20%, 40%, and 60% of the nominal tube wall. As-built depths within 5% are sufficient.

(2) The length of sizing defects shall be selected to simulate the expected degradation mechanism. When general inside or outside originated wall loss is possible, the minimum length shall be $^5/_8$ in. (16 mm).

(3) Simulated internal pitting defects shall have a diameter that simulates the size pitting which may be encountered. The $^1/_{16}$ in. (1.6 mm) diameter 100% through-wall hole specified in (c) is intended to identify the appropriate relationship between inside and outside originated wall loss and should not be used to generate linear calibration curves for pit sizing.

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 SET-UP AND ADJUSTMENT

VIII-864.1 Differential Bobbin Coil Technique

(a) The sensitivity shall be adjusted to produce Lissajous and/or strip chart signals which clearly display the smallest defect expected to be measured by the differential signal.

(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 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.

(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 Lissajous and strip chart signals that clearly display the smallest defect to be measured with the absolute signal.

(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 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.

(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 set-up 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, 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 2 hr.

(c) Should the system be found to be out of calibration (as defined in VIII-864.2), the equipment shall be recalibrated. The recalibration shall be noted on the recording. All tubes examined since the last valid calibration 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.

Figure VIII-864.1
Differential Technique Response From Calibration Reference

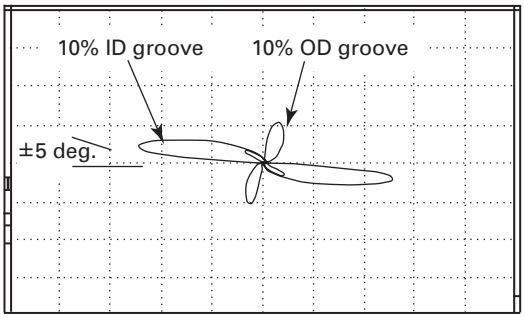
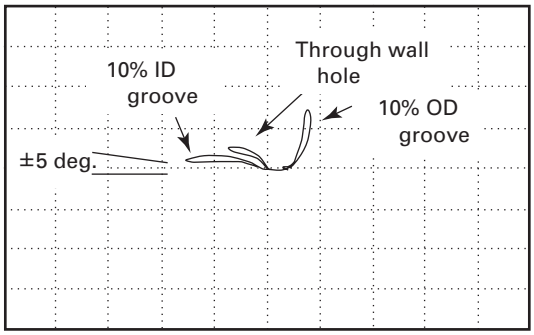


Figure VIII-864.2
Absolute Technique From Calibration Reference Standard



VIII-880 EVALUATION

VIII-880.1 Data Evaluation. Data shall be evaluated in accordance with the requirements of this Appendix.

VIII-880.2 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-880.2 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-890.1 REPORTING

VIII-890.1.1 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-890.1.2 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-890.1.3 Non-quantifiable Indications. A non-quantifiable indication is a reportable indication that cannot be characterized. The indication shall be considered a flaw until otherwise resolved.

VIII-890.2 SUPPORT MEMBERS

VIII-890.2.1 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-890.3 RECORDS

VIII-890.3.1 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 model and 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

VIII-890.3.2 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 and previous inspection.

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

VIII-890.3.3 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.

VIII-890.3.4 Record Retention. Records shall be maintained in accordance with requirements of the referencing Code Section.