NOTE: MIL-STD-2032 has been redesignated as a Test Method Standard. The cover page has been changed for Administrative reasons. There are no other changes to this Document.

INCH-POUND

MIL-STD-2032(SH)
14 September 1990
SUPERSEDING
NAVSHIPS 0905-475-3010 REV A

DEPARTMENT OF DEFENSE
TEST METHOD STANDARD

EDDY CURRENT INSPECTION OF HEAT EXCHANGER TUBING ON SHIPS OF THE UNITED STATES NAVY

AMSC N/A AREA NDTI

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

FOREWORD

1. This Military Standard is approved for use by the Naval Sea Systems Command, Department of the Navy, and is available for use by all Departments and Agencies of the Department of Defense.

2. Beneficial comments (recommendations, additions, deletions) and any pertinent data which may be of use in improving this document should be addressed to: Commander, Naval Sea Systems Command, SEA 55Z3, Department of the Navy, Washington, DC 20362-5101 by using the self-addressed Standardization Document Improvement Proposal (DD Form 1426) appearing at the end of this document or by letter.

3. This standard contains nondestructive testing and reporting for eddy current inspections of heat exchanger tubing. These requirements are designed to ensure the integrity and reliability of inspections performed.

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APPENDIX

1. SCOPE

1.1 General. This standard provides the minimum requirements to conduct the eddy current inspection of nonferromagnetic tubing in heat exchangers on Navy ships. In this document, the term "heat exchanger" applies to condensers, reboilers, etc. Minimum requirements are specified for inspection personnel, equipment, procedures, evaluation, and reporting of results.

2. APPLICABLE DOCUMENTS

2.1 Government documents.

2.1.1 Specifications, standards, and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed in the issue of the Department of Defense Index of Specifications and Standards (DoDISS) and supplement thereto, cited in the solicitation (see 6.2).

STANDARD

MILITARY

MIL-STD-271 - Requirements for Nondestructive Testing Methods.

(Unless otherwise indicated, copies of federal and military specifications, standards, and handbooks are available from the Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.)

2.1.2 Other government documents, drawings, and publications. The following other government documents, drawings, and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues are those cited in the solicitation.

PUBLICATIONS

NAVAL SEA SYSTEMS COMMAND (NAVSEA)

901-LP-254-000 - Condensers, Heat Exchangers, and Air Ejectors.

NAVSEA INSTRUCTION 9254.1 - Inspection of Steam Condensers on Nuclear Surface Ships and Submarines.

(Copies of standards and publications required by contractors in connection with specific acquisition functions should be obtained from the contracting activity or as directed by the contracting officer.)

2.2 Non-Government publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of the documents which are DOD adopted are those listed in the issue of the DoDISS cited in the solicitation. Unless otherwise specified, the issues of documents not listed in the DoDISS are the issues of the documents cited in the solicitation (see 6.2).

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)
Boiler and Pressure Vessel Code, Section V, Article 8.

(Application for copies should be addressed to the American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017.)

AMERICAN SOCIETY FOR NONDESTRUCTIVE TESTING, INC. (ASNT)
SNT-TC-1A - Recommended Practice.

(Application for copies should be addressed to the American Society for Nondestructive Testing, Inc., 4153 Arlingate Plaza, Columbus, OH 43228-0513.)

2.3 Order of precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

3.1 Absolute mode. Mode of operating an eddy current probe where signal response is based on the total detected electromagnetic properties of one section of the tube (and adjacent structures and conductive deposits). The absolute mode is sensitive to shallow or gradual wall loss, support structures and conductive deposits.

3.2 Calibration. Calibration is the verification of proper equipment response against a known standard.

3.3 Calibration standard. Representative tube with prefabricated defects used to standardize instrument set-up.

3.4 Coil. Electric coil in an eddy current probe which induces electromagnetic current in the inspected part and detects the part's electromagnetic response.

3.5 Defect. Defect is a discontinuity (e.g., wall loss, pit, or crack) whose size, shape, orientation, location, or properties makes it detrimental to the useful service of the part in which it occurs or which exceeds the accept or reject criteria for a given design.

3.6 Differential mode. Mode of operating an eddy current probe in which adjacent coils are electrically connected in series opposition, so that electromagnetic conditions not common to both tube regions tested simultaneously by the opposed coils will imbalance the system and thereby yield an indication. The differential mode is sensitive to abrupt discontinuities and usually provides more reliable defect depth estimates.

3.7 Fill factor. Fill factor is a measure of the electromagnetic coupling between the coil and the test object. It is the square of the ratio of the coil diameter to the bore diameter for internal probes.

3.8 Gain. Gain is the amplification level setting for the receiving circuit in an instrument. Instrument gain is usually set to normalize response signal amplitude using a calibration standard.

3.9 General thinning. Uniform or gradual wall loss in a tube, generally occurring gradually over several inches or more axially.

3.10 Inspection activity. Inspection activity is the organization performing the inspection. Unless otherwise specified by the contract or order, the inspection activity shall be fully responsible for the quality of inspection results and the qualification or certification of individuals conducting inspections.

3.11 Localized thinning. Wall loss in a local area of the tube. Localized thinning is generally characterized by beginning and reaching maximum wall loss within about one inch of tube length.

3.12 Noise. Noise is any undesired signal that tends to interfere with the normal reception or processing of a desired signal. In flaw detection, noise is an undesired response to physical or electromagnetic variables. Nearby welding, arc cutting, and high speed electrical tools can cause unacceptable noise levels during eddy current testing.

3.13 Obstructed tube. Obstructed tube is a tube which contains a dent, debris, scale, or other condition which prevents the probe from being inserted the full length of the tube.

3.14 Permeability variation. Defect-like signal not caused by a defect, but by local variation in a part's electromagnetic material properties (non-geometric). These variations can normally be overcome using magnetic bias probes.

3.15 Phase analysis. Phase analysis is an instrumentation technique which discriminates between variables in the test part by the different phase angle changes which these conditions produce in the test signal. For differential mode inspections, phase analysis is used to estimate defect through-wall extent and distinguish defects from other signal sources (e.g., support structures and conductive deposits).

3.16 Phase angle. Phase angle is the angular equivalent of the time displacement between corresponding points on two sine waves of the same frequency. In eddy current testing, phase angle is the angle on the CRT (measured clockwise) from the left horizontal to the eddy current signal of interest.

3.17 Plugged tube. Plugged tubes shall be defined as follows:

(a) Temporarily plugged tube. A temporarily plugged tube is one which has a temporary plug (for example, wood or phenolic) inserted, but no metal plug or thimble.
(b) Permanently plugged. A permanently plugged tube is one in which the hole has been permanently plugged by a blind-ended plug rolled into the tube sheet.

3.18 Probe. Probe is an eddy current sensor for use in a tube.

3.19 Probe motion or probe wobble. Lateral probe motion in the tube. This produces noise or signal variations not necessarily related to any defect.

3.20 Signal mix. Signal mix is the elimination or suppression of undesirable signals; for example, those signals caused by conditions such as tube support plates, conductive deposits, and inside diameter (ID) variations (pilgering). Signal mixing allows mixing or subtraction of eddy current signals to enhance the signal-to-noise ratio.

3.21 Signal-to-noise ratio. Signal-to-noise ratio is the ratio of values of signal (response containing information) to that of noise (response containing no information).

3.22 Test and inspection. The terms "test" and "inspection" are used interchangeably and refer to performance of specific procedures and applications of acceptance criteria as required.

3.23 Vector analyzer. Vector analyzer is a device used to measure signal phase angle.

4. GENERAL REQUIREMENTS

4.1 Equipment. The equipment package shall provide the capability to perform eddy current inspections required by this standard. Specific inspection techniques may not require the use of all equipment specified in 4.1.1 through 4.1.7. Each activity shall be responsible for selecting and using test equipment to meet the requirements of the inspection to be performed. Signal display and recording equipment shall have a frequency response so that differences in peak signal amplitudes between static (probe stationary) and dynamic (probe in motion at inspection speed) are less than 10 percent. Eddy current instruments shall be calibrated in accordance with the manufacturer's specifications (oscillator accuracy, output voltages, and so forth) at intervals not to exceed 12 months and whenever the equipment has been repaired.

4.1.1 Multi-frequency eddy current instrument. A multi-frequency eddy current instrument shall be used to detect impedance changes produced by tube discontinuities and to record the principal changes on a storage CRT, a strip chart, and a magnetic tape recorder. In addition, the instrument shall:

(a) Be capable of operating at the required test frequency(s).
(b) Operate in the differential and absolute modes, either sequentially or simultaneously. Instruments with the capability to perform the differential and absolute modes of inspection simultaneously at multiple frequencies may be used to preclude reinspection.
(c) Balance the impedance bridge automatically or manually.
(d) Enable 360-degree rotation of the phase.
(e) Adjust the gain to provide amplification of the eddy current signals.
(f) Suppress or eliminate undesirable signals by signal mix.

4.1.2 Strip chart. The inspection system shall incorporate instrumentation that produces a two-or-more channel strip chart display of the eddy current instrument output voltages. The strip chart display may be an integral part of the eddy current instrument.

4.1.3 Magnetic tape recorder. A four-or-more channel magnetic tape recorder shall be used to record the output voltages from the eddy current instrument. Alternative magnetic storage media may be used. The recorder may be an integral part of the eddy current instrument.

4.1.4 Probe puller. Where practicable, a probe puller or pusher that pulls at a constant speed shall be used. Manual probing may be performed with local eddy current examiner approval.

4.1.5 Probes. Inside diameter probes shall be used to provide inspection coverage of heat exchanger tubing. A fill factor of 0.80 or higher shall be used (see 3.7). Dependent upon inspection requirements, one or more of the following probes shall be used:

(a) A differential coil probe with two coils, each having a coil length of 1/16 to 1/8 inch. Coil separation shall not be less than one-half the coil length and not greater than on coil length.
(b) An absolute coil probe with a coil length of 1/16 to 1/8 inch shall be used to evaluate tube wall loss due to thinning. If the instrument can operate a differential coil in the absolute mode, a separate absolute coil is not necessary.
(c) Other probes may be used for special applications. For example, axial wound, rotating, pancake, magnetic bias, profilometry probes, etc.

4.1.6 Calibration standards. Calibration standards shall be manufactured from a length of tubing of the same nominal size, wall thickness, and material type (chemical composition and heat treatment) as that to be examined. The actual dimensions of the calibration discontinuities shall be measured and verified. Records of the verification shall be available for review. Depending on the inspection being performed, one or more of the calibration standards specified in 4.1.6.1 through 4.1.6.4 shall be required. The standards specified in 4.1.6.1 through 4.1.6.4 are also applicable for the inspection of finned tubing. The center of discontinuities machined into finned tubing shall be centered between the fins. Also, the depth of discontinuities in finned calibration standards shall be based on the root of the fins, not the outside diameter (OD) of the fins.

4.1.6.1 ASME type calibration standard. The ASME type calibration standard shall be used for the differential mode phase angle analysis evaluation of pitting as shown on figure 1.

4.1.6.2 Thinning standard. The 360-degree machined ring standard (see figure 2) shall be used to evaluate thinning such as that caused by acid attack or exfoliation corrosion which tends to have a large circumferential extent. The milled flat thinning standard (see figure 3) shall be used to evaluate thinning such as that caused by steam erosion, which generally occurs in only part of a tube's circumference.

4.1.6.3 Tapered area sensitivity standard. The tapered area sensitivity standard (see figure 4) shall be used to verify sensitivity in the tapered region of finned tubing such as that used in air conditioning condensers.

4.1.6.4 Slotted standard. The slotted standard (see figure 5) using a length of tube with an axial and circumferential slot machined into the OD shall be used to verify the capability of the equipment to detect axial and circumferential cracks.

4.1.7 Borescope. An optical borescope may be used for verification of eddy current indications on the tube inner diameter and accessible areas of the tube outer diameter, for example, near tube ends and in tapered regions of finned tubing.

4.2 Procedure. Each inspection activity shall prepare and maintain written eddy current test procedures which conform to this standard. The procedures shall be approved by the cognizant certified eddy current examiner and include the following information:

(a) Material type (chemical composition and heat treatment), outer diameter, and wall thickness of the tubing to be inspected.
(b) Probe sizes and types, including manufacturer and model number (or coil size, spacing, etc., if standard model not available).

to tubeless tube,

(c) Test frequency(s).
(d) Eddy current equipment manufacturer and model.
(e) Scanning method (for example, hand probe or mechanized probe drive). If a mechanized probe drive is used, identify manufacturer, model and pull speed.
(f) Calibration procedure and calibration standards.
(g) Data recording equipment and procedures.
(h) Data recording and format requirements.
(i) Procedure for interpreting results. This procedure shall also identify specific reporting thresholds of signals, if used.
(j) Tube numbering method.
(k) Any other variables or requirements that affect eddy current test results or are needed to describe the test.
(l) Signature of the certified eddy current examiner.

4.2.1 Procedure qualification. Procedures shall be qualified by performing an operational test. The qualification shall include testing the reference standards to prove known discontinuities can be readily detected and evaluated using the written procedure. The cognizant certified eddy current examiner shall witness the qualification.

4.3 Personnel. Personnel shall be certified in accordance with MIL-STD-271. In addition to the eddy current personnel requirements in MIL-STD-271, personnel interpreting eddy current data shall be certified as an inspector (level II) or examiner (level III) specifically for the evaluation of eddy current data from nonferromagnetic tubing. This special certification requires additional training, experience, and examination specifically in data analysis. The amount of additional training, experience, and testing shall, as a minimum, be equal to the eddy current inspector qualification requirements. The "25-percent rule" specified in ASNT SNT-TC-1A may be used to simultaneously obtain eddy current and eddy current interpretation work experience.

5. DETAILED REQUIREMENTS

5.1 Heat exchanger inspection preparation. Full access to all tubes at one end of the heat exchanger is required.

5.1.1 Heat exchanger design review. Prior to inspection, the heat exchanger technical manual and other documentation as required shall be used to determine the following:

(a) Tube material type, size, wall thickness, length, and layout.
(b) Total number of tubes and number of tubes per section, if applicable.
(c) Location and number of tube sheets and supports.
(d) Location of steam connections, baffles, and partitions.
(e) Location of visual inspection access points.

5.1.2 Tube cleaning. Tubes shall be free of obstructions and cleaned to allow passage of eddy current probes. Tube cleaning methods are provided in NAVSEA 901-LP-254-0000. The high pressure water jet (hydroblast) is the preferred cleaning method. Tubes shall be air dried after cleaning.

5.1.3 Tube identification. Each heat exchanger tube is identified by a unique letter or number grid system as specified in the component technical manual. If a tube identification system is not in the technical manual, the tube numbering system used in the prior eddy current inspection shall be used. If the numbering system used in the prior eddy current inspection is unknown or unavailable:

(a) Contact NAVSEA's Heat Exchanger Branch for nuclear ship steam condensers.
(b) For all other heat exchangers, number tubes using letter designations for tube rows and number designations for tube columns, starting with "A1" in the upper left corner of the tube sheet from which the inspection is being performed.

5.1.4 Extent of inspection. The extent of the inspection shall be as directed by the contract or design requirement. Minimum information provided to the inspection activity will include the type of discontinuities required to be detected, inspection extent, and acceptance criteria (see 5.3).

5.2 Eddy current inspection procedure. The minimum procedures for eddy current inspection of heat exchanger tubes shall be as specified in 5.2.1 through 5.2.4.

5.2.1 Equipment. Inspection equipment selected shall be based on the type of discontinuity to be detected and shall meet the appropriate requirements of 4.1. Magnetic media recordings shall be made of all inspections and channels. Strip charts (paper or electronically displayed) shall be used as needed for evaluation. Calibrations, recalibrations, and calibration verifications shall be recorded on the same magnetic media and strip charts as the inspection data.

5.2.2 Calibration techniques. The eddy current test system shall be calibrated utilizing the standards specified in 4.1.6 for the type of discontinuity to be detected. The calibration operation shall include the complete testing system. Calibration shall be performed before the start of each inspection utilizing one or more of the techniques specified in 5.2.2.1 through 5.2.2.3. Recalibration shall be as specified in 5.2.3.

5.2.2.1 Differential mode probe calibration. The following requirements apply for calibrating a differential mode eddy current system:

(a) Required test frequencies are shown in table I. Other frequencies are permitted, with eddy current examiner approval, if table I frequencies will not meet calibration requirements.

(b) Frequency selection will permit the ASME calibration standard (see figure 1) 20 percent flat bottom hole signal phase angle to be between 90 and 120 degrees clockwise from the through-wall hole signal.

(c) The eddy current system will produce a response from the ASME standard 20 percent flat bottom hole with a signal-to-noise ratio of 3-to-1 minimum. The signal shall span 3.5 to 5 major screen divisions or 4 to 6 volts, as applicable. Signal phase and amplitude must be distinguishable, without saturation, for each applicable calibration discontinuity.

(d) Signal response to probe motion shall be horizontal and the through-wall hole signal shall travel first down and to the right on the viewing screen. Calibration discontinuity responses shall be distinguishable from probe motion signals.

(e) Signal mixing to suppress tube support signals is required. Verify adequate signal mixing by showing the ASME 20 percent flat bottom hole can be clearly discerned and sized with the tube support ring centered over the hole.

(f) Record the calibration data as specified in 5.2.1. Establish a flaw depth evaluation curve from the data. Percent defect depth and phase angle constitute the vertical and horizontal axes of the curve, respectively (see figure 6). Instruments equipped with a vector analyzer and built-in calibration curve may be used in lieu of this plotted curve for estimating defect depth, provided the built-in calibration curve agrees with the calibration discontinuity signals within $\pm$ 2 degrees of phase angle.

TABLE I. Required primary test frequencies for differential mode phase angle analysis. 1/2/

Material type	Wall thickness (inch)	Frequency (± 5kHz) (kHz)
70-30 CuNi	0.049	150
70-30 CuNi	0.065	85
80-20 CuNi	0.065	45
90-10 CuNi	0.049	75
Titanium	0.049	180

1/For tubes not listed, required test frequencies shall be determined by using the following formula:

$$F = \frac{10\rho}{T^2}$$

F = test frequency
ρ = resistivity of tubing in micro-ohm-centimeter
T = wall thickness of tubing in inches

2/Signal mixing to suppress outer diameter tube support signals is required. Signal mixing shall be accomplished using a secondary subtractor frequency. The secondary frequency shall be one half the primary frequency when the primary frequency is below 300 kHz; the secondary frequency should be one fourth the primary frequency when the primary frequency is 300 kHz or above. If signal mixing is needed for unwanted inner diameter signals such as dents, pilgering or bulges, a secondary frequency twice the primary frequency shall be used. If these secondary frequencies do not provide an adequate mix, the secondary frequency can be modified, subject to certified eddy current examiner approval.

5.2.2.2 Absolute mode probe calibration. The following requirements apply for calibrating an absolute mode eddy current system.

(a) Probe frequency shall be approximately that specified for differential mode secondary frequency in 5.2.2.1. Other frequencies are permitted, with certified eddy current examiner approval.
(b) Signal mixing to suppress tube support signals is required. The mix frequency should be approximately half the primary absolute channel frequency. Other frequencies are permitted, with certified eddy current examiner approval.
(c) The eddy current system will produce a response from the 20 percent through-wall discontinuity in the applicable calibration standard with a signal-to-noise ratio of 3-to-1 minimum. The signal shall span 1 to 2 major screen divisions. Signals must be distinguishable, without saturation, for each calibration discontinuity.
(d) Signal response to probe motion shall be horizontal on the viewing screen, and calibration discontinuity responses shall be oriented upward and be distinguishable from probe motion signal.
(e) Verify the smallest calibration discontinuity can be clearly detected and evaluated while the tube support slip ring is positioned at the defect. When using the milled flat thinning standard (see figure 3), center the slip ring over the smallest discontinuity. When using the 360-degree machined ring standard, this ring (see figure 2) still overlaps the edge on the smallest discontinuity.
(f) Establish a calibration curve from the calibration data. The known depths of machined discontinuities and their corresponding signal deflections constitute the vertical and horizontal axes of the curve, respectively (see figure 7).

5.2.2.3 Special probe calibration for crack detection. The following requirements apply for calibrating an eddy current system to detect cracks.

(a) The probe design and test frequencies used will permit clearly discerning each slot in the slotted calibration standard, excluding the 20 percent slot (see figure 5).
(b) The eddy current instrument will produce a clear but unsaturated response to each slot in the standard, excluding the 20 percent slot, with a signal-to-noise ratio of 3-to-1 minimum.
(c) Signal response to probe motion shall be horizontal on the viewing screen, and calibration slot responses shall be distinguishable from probe motion signals.
(d) Verify, for each slot orientation, that the 40 percent slot can be clearly detected and evaluated while the tube support slip ring is centered over the slot.

5.2.3 Recalibration. Any change of test probe, extension cables, eddy current instrument, recording instruments, or power interruption shall require system recalibration. Calibration shall be verified (1) every 4 hours; (2) if the equipment has been left unattended; (3) when calibration is suspected of being in error; (4) at the beginning and end of each magnetic tape and strip chart; and (5) at the completion of the inspection. Should the system be found to be out-of-calibration, the equipment shall be recalibrated and all tubes inspected since the last valid calibration shall be reinspected. Out-of-calibration includes changes more than plus or minus 5 degrees phase angle from the calibration curve for the differential mode of calibration, or plus or minus 10 percent for the mid-range discontinuity of the standard for the absolute mode.

5.2.4 Noise interference. If noise occurs during inspection that interferes with signal interpretation, the inspection shall be discontinued until the noise is resolved.

5.3 Inspection techniques. Inspection techniques shall be as specified in 5.3.1 through 5.3.6.

5.3.1 Detection of local volumetric defects. The following techniques shall be used to detect and estimate defect depths for inner and outer diameter volumetric defects. These techniques are usable for localized defects including pitting, wear, intergranular attack, localized thinning, etc. Using the differential inspection mode, calibrate the system using the ASME calibration standard (see 4.1.6.1) and the procedure specified in 5.2.2.1. Signal mixing is required to suppress external tube support signals and may be needed to suppress other interferences such as dents and conductive deposits. Defect depths shall be estimated using the flaw depth evaluation curve discussed in 5.2.2.1 or a similar curve based on the mix. Inspection results shall be reported as specified in 5.4.

5.3.2 Detection of thinning. The following describes techniques that shall be used for detection and depth measurement of general tube thinning. The inspection shall be conducted using the absolute mode of inspection. Localized wall thinning shall also be evaluated using differential mode phase angle analysis. The system shall be calibrated using the appropriate calibration standard (see figures 2 and 3) and the procedure specified in 5.2.2.2. The flaw evaluation curve shall be used to determine depth of thinning during production inspections. Results shall be recorded and reported as specified in 5.4.

5.3.3 Detection of cracks. The following describes techniques that shall be used for eddy current inspection of heat exchanger tubes for omnidirectional cracks in localized areas. The system shall be calibrated using the calibration standard specified in 4.1.6.4 and the procedure specified in 5.2.2.3. The simulated tube support ring shall be used to assure that the slots in the calibration standard can be reliably detected adjacent to and under the tube support ring. During inspection, any crack-like signal shall be reported. Results shall be recorded and reported as specified in 5.4.

5.3.4 Detection of denting. Denting may be evaluated using the techniques discussed in 5.3.1 and 5.3.2. Additional techniques are not required. Dent signals with peak-to-peak signal amplitudes greater than twice the amplitude of the smallest applicable calibration discontinuity shall be reported under 5.4 requirements.

5.3.5 Evaluation of permeability variations. Magnetic bias probes shall be used in conjunction with the probes discussed above to evaluate suspected permeability variation signals. Using the magnetic bias probe, calibrate the inspection system using the ASME calibration standard (see 4.1.6.1) and the procedures specified in 5.2.2.1.

5.3.6 Obstructed tubes. Obstructed tubes shall be identified. The location and nature of the obstruction and the extent of the tube inspected shall also be reported. If practicable, smaller probes or supplemental cleaning methods shall be used to facilitate complete tube inspection.

5.4 Reporting and record requirements.

5.4.1 Reporting. Inspection activities shall prepare inspection reports and include the following:

5.4.1.1 Inspection summary cover letter. Inspection reports shall have a summary cover letter that shall include the following information (when applicable). For nuclear ship steam condensers, this letter shall conform to the requirements of NAVSEA Instruction 9254.1.

(a) Ship hull number.
(b) Units inspected and date.
(c) Extent of inspection for each unit (number of tubes in the unit and the number inspected by each inspection technique).
(d) Maximum indicated wall loss in each major heat exchanger section (e.g., air cooling sections in condensers).
(e) Number of tubes with 20 percent wall loss or greater.
(f) Number of tubes that were plugged or replaced, including the reason for plugging or replacement. Identify percentage of tubes with plugs.
(g) Number of previously plugged tubes.
(h) Number of tubes with crack indications.
(i) Any unusual defects or characteristics observed in performing the inspection or in analyzing the test results. Unusual characteristics include uninterpretable defect signals, and the presence of conductive deposits, distorted support plate signals or denting (see 5.3.4).

5.4.1.2 Detailed test parameters. The following inspection data shall be included in the inspection report:

(a) Ship hull number and condenser.
(b) The inspection procedure used.
(c) Identification of instrumentation and probes, including serial numbers.
(d) Inspector names.
(e) Date.
(f) Instrument settings that affect calibration (settings for frequency, mode, phase, gain and so forth).
(g) Calibration standard description and serial numbers.
(h) A list of inspection results for each tube inspected, (report as specified in the appendix).
(i) Characterization of denting extent, including approximate percentage of tubes with reportable denting in each major heat exchanger section and support location and approximate maximum and average dent signal amplitudes for reportable signals.
(j) A list of tubes with 20 percent wall loss or greater (report as specified in the appendix).
(k) A list of tubes that were plugged or replaced, including the reason for plugging or replacement (report as specified in the appendix.)
(l) A list of all previously plugged tubes (report as specified in the appendix).
(m) A list of all tubes with crack indications (report as specified in the appendix).

5.4.1.3 Detailed inspection results. Report all indications of 20 percent wall loss or greater, and any indications of cracking.

5.4.1.4 Tube sheet diagrams. The appropriate standard tube sheet diagrams shall be included in the report. Tube identification shall be in accordance with the standard tube sheet diagram used. The diagrams shall be marked to identify the location of tubes with 20 percent wall loss or greater and to identify blocked, cracked, or plugged tubes.

5.4.1.5 Metallographic or metallurgical reports. Include results of any analysis performed on the condenser tubes inspected. Supporting information and reports shall be referenced.

5.4.2 Classification of reports. Inspection reports of steam condensers and reboilers on nuclear surface ships and submarines shall be classified "CONFIDENTIAL." This requirement does not apply to fresh water or condensate cooled air ejector condensers or to distilling plant or refrigeration or air conditioning plant condensers.

5.5 Maintenance of inspection records. Unless otherwise specified in the contract or order, information necessary to verify and support the inspection results, for example, strip chart recording, calibration curves, calibration work sheets, magnetic tapes, and procedure, personnel, and equipment qualification records, shall be maintained by the inspection activity for 12 years after completing the inspection. Supporting information shall be auditable and stored in such a manner as to be protected from damage and deterioration. NAVSEA shall be notified prior to disposal of ET inspection records.

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Intended use. This standard is intended to be used to establish nondestructive testing requirements for eddy current inspections of heat exchanger tubing.

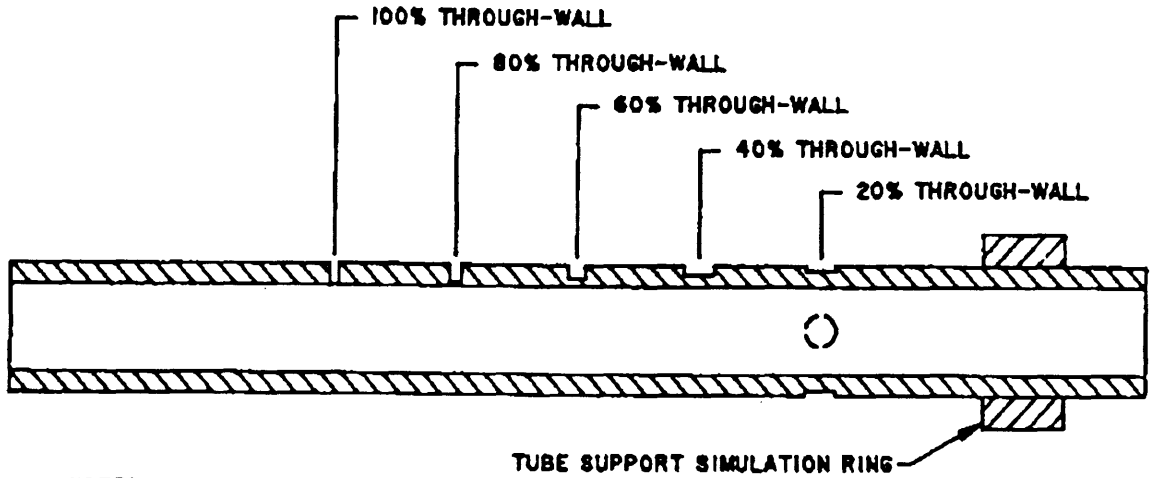
6.2 Issue of DODISS. (When this standard is used in acquisition, the applicable issue of the DODISS must be cited in the soliciation (see 2.1.1 and 2.2).

6.3 Subject term (key word) listing.

Absolute mode
Calibration
Condenser
Differential mode
Gain
Probe
Sensitivity
Signal-to-noise ratio

Preparing activity:
Navy - SH
(Project NDTI-N059)

A.026.F.001A



NOTES:

1. THE THROUGH-WALL HOLE SHALL BE 0.052 INCH IN DIAMETER FOR 3/4-INCH OD TUBING AND SMALLER, AND 0.067 INCH FOR LARGER ODS.
2. 80 PERCENT THROUGH-WALL HOLE SHALL BE 5/64 INCH DIAMETER.
3. 60 PERCENT THROUGH-WALL HOLE SHALL BE 7/64 INCH DIAMETER.
4. 40 PERCENT THROUGH-WALL HOLE SHALL BE 3/16 INCH DIAMETER.
5. FOUR 20 PERCENT THROUGH-WALL HOLES 3/16 INCH DIAMETER SHALL 90 DEGREES APART AROUND THE TUBE CIRCUMFERENCE.
6. DEPTH AND DIAMETER TOLERANDCE SHALL BE PLUS OR MINUS 0.003 INCH.
7. MINIMUM DISCONTINUITY SPACING SHALL BE 1 INCH. MINIMUM DISTANCE FROM DISCONTINUITIES TO END OF TUBE SHALL BE 2 INCHES.
8. TUBE SUPPORT SIMULATION RING MATERIAL TYPE AND THICKNESS SHALL BE THE SAME AS FOUND IN THE COMPONENT BEING INSPECTED. THE RING SHALL BE A SLIP-FIT AND THE RADIAL DIMENSION SHALL BE 3/8 INCH MINIMUM. RING TO TUBE DIAMETRAL CLEARANCE SHALL BE 0.016 INCH MAXIMUM.
9. HOLES SHALL BE FLAT-BOTTOM.

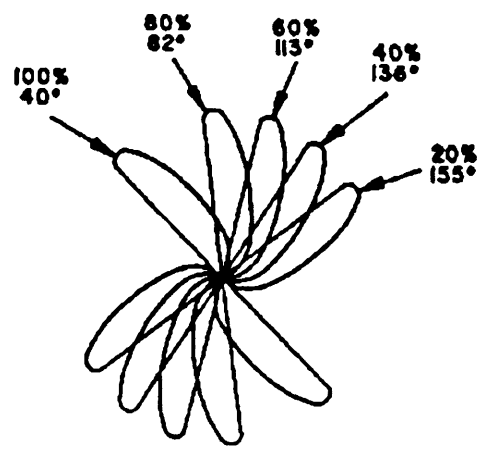
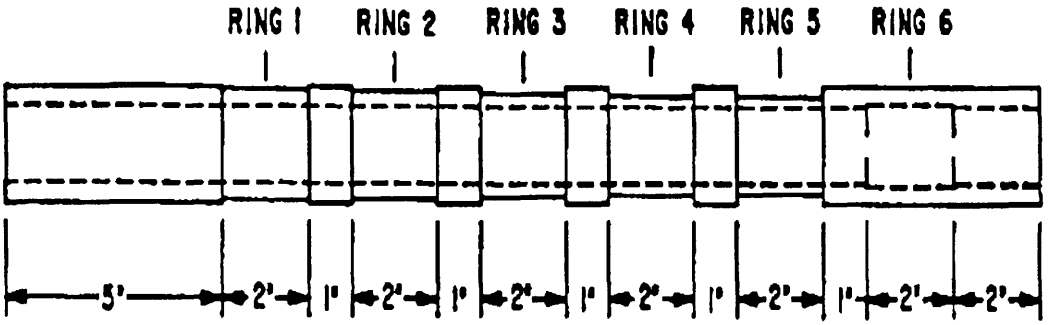


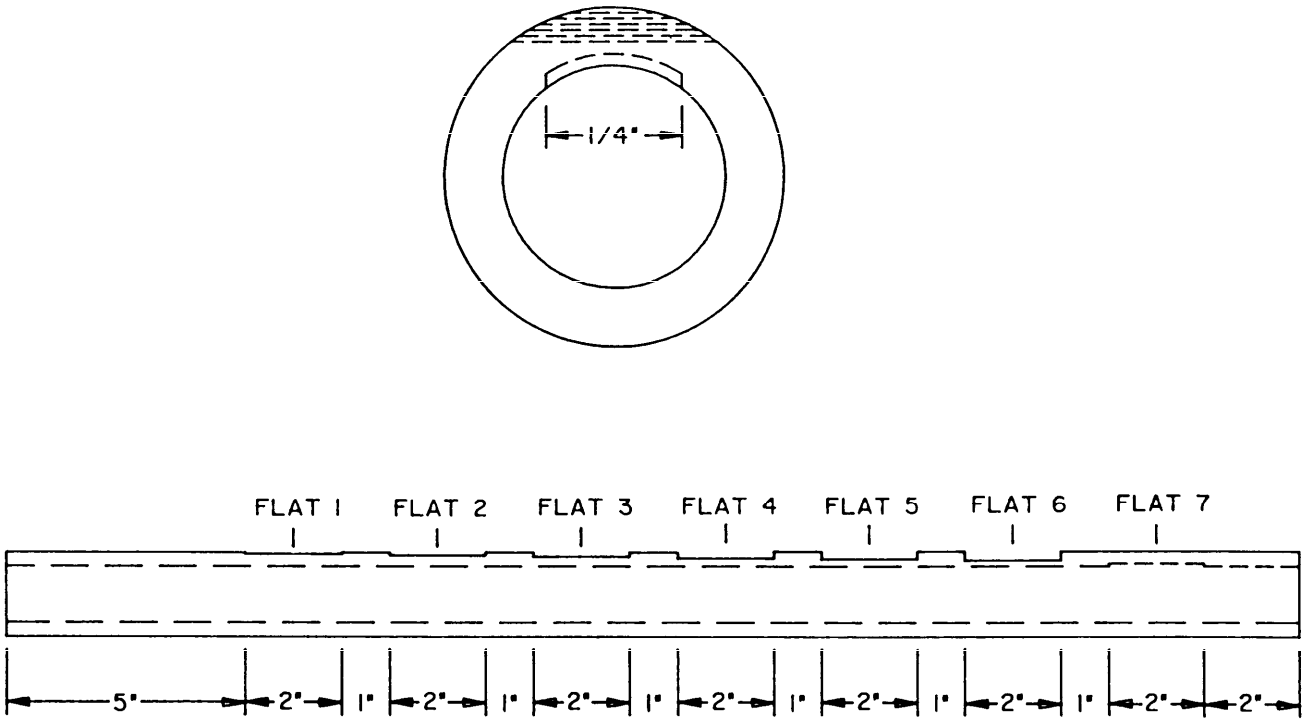
FIGURE 1. ASME type calibration standard with typical signal presentation.



NOTES:

1. DEPTH OF CALIBRATION DISCONTINUITIES SHALL BE AS FOLLOWS:
   RING 1 - 10 PERCENT THROUGH-WALL
   RING 2 - 20 PERCENT THROUGH-WALL
   RING 3 - 30 PERCENT THROUGH-WALL
   RING 4 - 40 PERCENT THROUGH-WALL
   RING 5 - 50 PERCENT THROUGH-WALL
   RING 6 - 10 PERCENT THROUGH-WALL (ID)
2. DEPTH TOLERANCE SHALL BE PLUS OR MINUS 0.003 INCH. TOLERANCE FOR OTHER DIMENSIONS SHALL BE PLUS OR MINUS 1/16 INCH. MAXIMUM CORNER BREAK RADIUS OF 0.020 INCH.
3. MACHINED SURFACE FINISH SHALL BE 63 ROUGHNESS HEIGHT RATING (RHR) MAXIMUM.
4. TUBE SUPPORT SIMULATION RING MATERIAL AND THICKNESS SHALL BE THE SAME AS FOUND IN THE COMPONENT BEING INSPECTED. THE RING SHALL BE SLIP-FIT AND RADIAL DIMENSION SHALL BE 0.375 INCH MINIMUM. RING TO TUBE DIAMETRAL CLEARANCE SHALL BE 0.016 INCH MAXIMUM.

FIGURE 2. 360-degree machined ring standard.

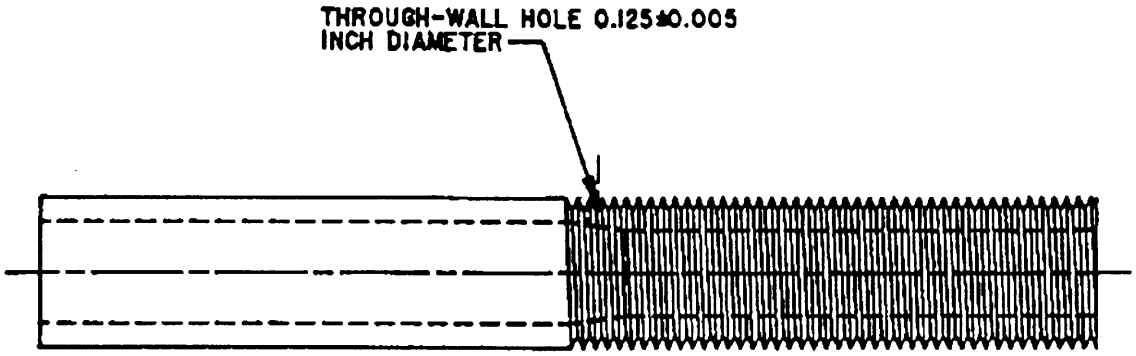


NOTES:

1. DEPTH OF CALIBRATION DISCONTINUITIES SHALL BE AS FOLLOWS:
   - FLAT 1 - 10 PERCENT THROUGH-WALL
   - FLAT 2 - 20 PERCENT THROUGH-WALL
   - FLAT 3 - 30 PERCENT THROUGH-WALL
   - FLAT 4 - 40 PERCENT THROUGH-WALL
   - FLAT 5 - 50 PERCENT THROUGH-WALL
   - FLAT 6 - 60 PERCENT THROUGH-WALL
   - FLAT 7 - 20 PERCENT THROUGH-WALL (ID)
2. DEPTH TOLERANCE SHALL BE PLUS OR MINUS 0.003 INCH. TOLERANCE FOR OTHER DIMENSIONS SHALL BE PLUS OR MINUS 1/16 INCH. MAXIMUM CORNER BREAK RADIUS OF 0.020 INCH.
3. MACHINED SURFACE FINISH SHALL BE 63 ROUGHNESS HEIGHT RATING (RHR) MAXIMUM.
4. TUBE SUPPORT SIMULATION RING MATERIAL AND THICKNESS SHALL BE THE SAME AS FOUND IN THE COMPONENT BEING INSPECTED. THE RING SHALL BE SLIP-FIT AND RADIAL DIMENSION SHALL BE 0.375 INCH MINIMUM. RING TO TUBE DIAMETRAL CLEARANCE SHALL BE 0.016 INCH MAXIMUM.

FIGURE 3. Milled flat thinning standard.

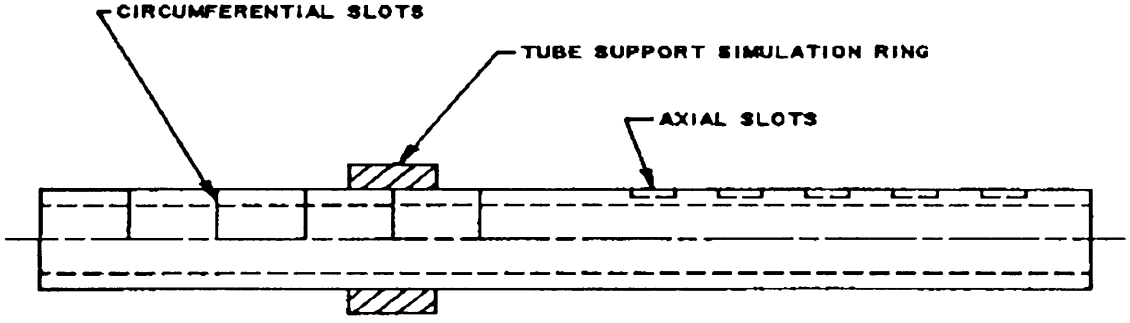
A.028.F.003A



NOTES:

1. LENGTH OF THE STANDARD SHALL BE APPROXIMATELY 12 INCHES WITH ONE-HALF OF THE LENGTH FINNED.

FIGURE 4. Tapered area sensitivity standard.



NOTES:

1. CIRCUMFERENTIAL SLOT DIMENSIONS SHALL BE 20, 40, 60, 80 AND 100 PERCENT THROUGH-WALL PLUS OR MINIUS 0.003 INCH, 0.006 ± 0.003 INCH WIDE, AND SHALL EXTEND 90 DEGREES AROUND THE TUBE CIRCUMFERENCE. SLOT SEPARATION SHALL BE 1 INCH.
2. AXIAL SLOT DIMENSIONS SHALL BE: 0.250±0.003 INCH LONG, 20, 40, 60, 80 AND 100 PERCENT THROUGH-WALL ±0.003 INCH DEEP, AND 0.012 ± 0.003 INCH WIDE. SLOT SEPARATION SHALL BE 1 INCH.
3. SLOT LOCATIONS ARE APPROXIMATELY AS SHOWN.
4. TUBE SUPPORT SIMULATION RING MATERIAL AND THICKNESS SHALL BE THE SAME AS FOUND IN THE COMPONENT BEING INSPECTED. THE RING SHALL BE SLIP-FIT AND THE RADIAL DIMENSION SHALL BE 0.375 INCH MINIMUM. RING TO TUBE DIAMETRAL CLEARANCE SHALL BE 0.016 INCH MAXIMUM.

FIGURE 5. Slotted standard.

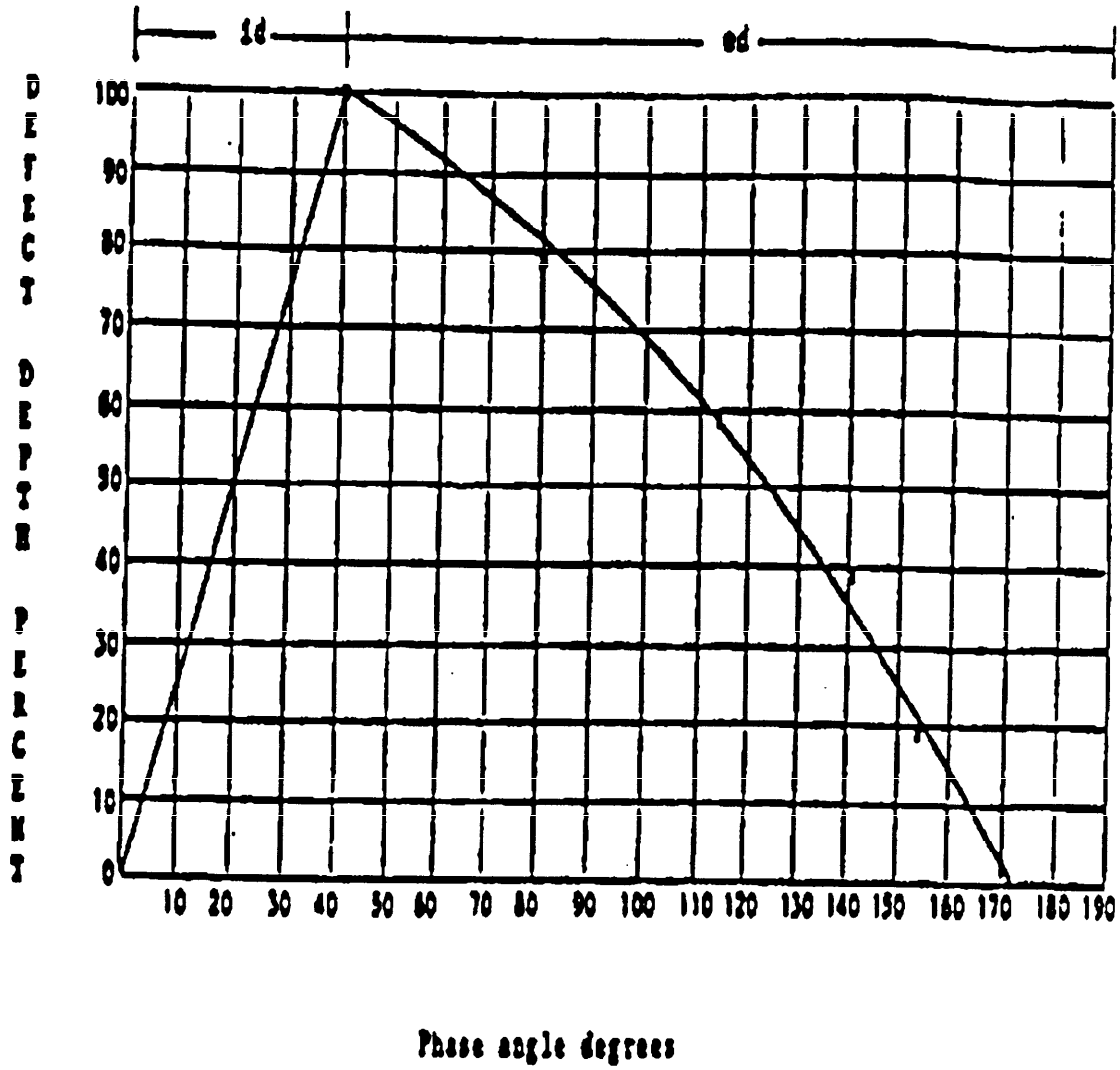


FIGURE 6. Typical defect evaluation curve for phase angle analysis.

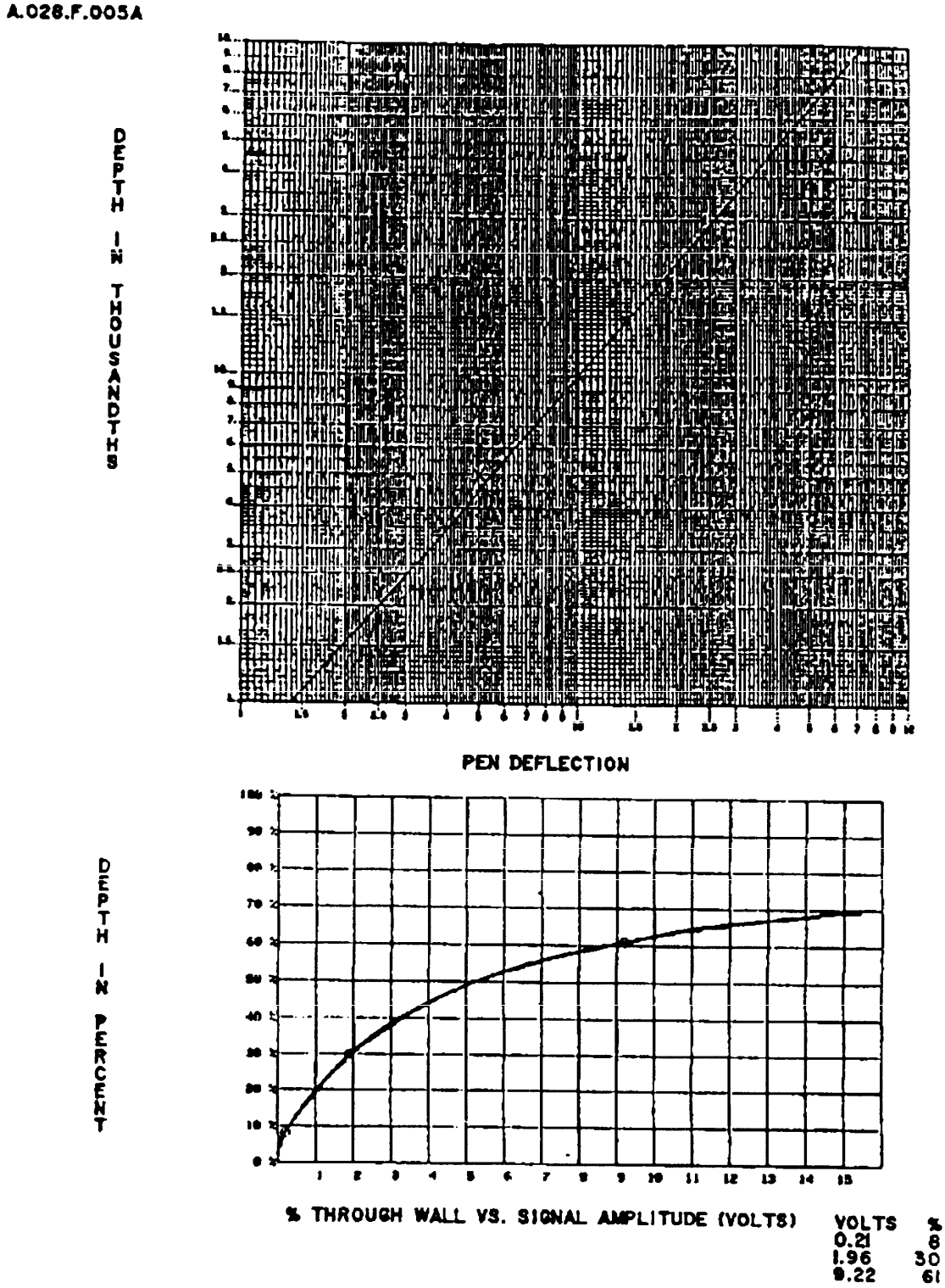


FIGURE 7. Typical absolute mode calibration curve for wall thinning.

APPENDIX

FORMAT FOR REPORTING EDDY CURRENT INSPECTION DATA

10. SCOPE

10.1 Scope. This appendix provides the requirements for reporting eddy current inspection data. These requirements are applicable to eddy current signals generated using various inspection probes such as the standard dual bobbin, magnetic bias bobbin, shielded bobbin, beaded joint flex, crosswound, and single and multiple coil pancake probes.

20. APPLICABLE DOCUMENTS

This section is not applicable to this appendix.

30. REQUIREMENTS

30.1 Requirements for reporting evaluated eddy current inspection data. The format for reporting evaluated eddy current inspection data is contained in Table II. Table III provides asummary of the permissible entries in the various fields defined in Table II. Table IV provides general comments to accompany the format defined in Table II.

TABLE II. Format for reporting eddy current inspection data.

Field #1, Column #2 - General Information/Probing Extent Indicator

'nx'xxx'xxx'xx.xx'xxx'xxx'xxx'xxxxxxxx±xx.x'xxxx'xxxx''xxxxxxxx'

Integer	Definition
1	Straight length of tube only
2	Straight length of tube plus U-bend region
3	Full length (i.e., tubesheet-to-tubesheet)
4	U-bend region only (as in using the tight U-bend (BJF) probe)
6	Plugged tube indicator (i.e., tube permanently plugged, flow-blocked, or temporarily plugged; see Field #12 for additional definition of the plugging disposition)

Field #2, Column #3 - Probing Side Indicator

'xn'xxx'xxx'xx.xx'xxx'xxx'xxx'xxxxxxxx±xx.x'xxxx'xxxx''xxxxxxxx'

Integer	Definition
1	Probing from inlet side or inlet/outlet end
2	Probing from outlet side or return end

Field #3, Columns #5:7 - Tube Row Indicator

'xx'nnn'xxx'xx.xx.'xxx'xxx'xxx'xxxxxxxx±xx.x'xxxx'xxxx''xxxxxxxx'

Integer	Definition
001:999	Tube row number
or	
00A:ZZZ	

Field #4, Column #9

'xx'xxx'nxx'xx.xx'xxx'xxx'xxx'xxxxxxxx±xx.x'xxxx'xxxx''xxxxxxxx

Integer	Definition
-	*

Field #5, Columns #10:11 - Tube Column Indicator

'xx'xxx'xnn'xx.xx'xxx'xxx'xxx'xxxxxxxx±xx.x'xxxx'xxxx''xxxxxxxx'

Integer	Definition
01:99	Tube column number
or	
0A:ZZ	

* Note: Dash (-) in alphanumeric designation means blank.

TABLE II. Format for reporting eddy current inspection data. - Continued

Field #6, Columns #13:17 - Signal Amplitude (Volts)

'xx'xxx'xxx'nn.nn'xxx'xxx'xxx'xxxxxxxx±xx.x'xxxx'xxxx''xxxxxxxx'

Decimal	Definition
nnn.nn	Peak-to-peak amplitude of the eddy current signal in volts. If the signal is saturated, the maximum estimated amplitude should be entered (e.g., 20.00) and the type of indication modifier SAT should be entered in Field #13. If only the amplitude for one-half of the signal can be measured, twice the measured amplitude for one-half of the signal should be entered and the indication modifier 1/2 should be entered in Field #13.

Field #7, Columns #19:21 - Signal Angle (Degrees)

'xx'xxx'xxx'xx.xx'nnn'xxx'xxx'xxxxxxxx±xx.x'xxxx'xxxx''xxxxxxxx'

Integer	Definition
000:360	Angle of the eddy current signal in degrees.

Field #8, Columns #23:25 - Defect Depth (Percent)

'xx'xxx'xxx'xx.xx'xxx'nnn'xxx'xxxxxxxx±xx.x'xxxx'xxxx''xxxxxxxx'

Integer	Definition
000:100	Depth of penetration of inside surface or outside surface defect in percent of wall thickness.

Field #9, Columns #27:29 - Channel Number/Coil Number

'xx'xxx'xxx'xx.xx'xxx'xxx'nnn'xxxxxxxx±xx.x'xxxx'xxxx''xxxxxxxx'

Channel Number (Dual Coil Bobbin Probe Data)

Integer	Definition
010	Primary frequency channel (differential)
020	Primary frequency channel (absolute)
030	Secondary frequency channel (differential, approximately 1/4 to 1/2 of primary frequency)
040	Secondary frequency channel (absolute)
050	Usually high frequency channel (differential, approximately twice the primary frequency)
060	Usually high frequency channel (absolute)
070	Usually low frequency channel (differential)
080	Usually low frequency channel (absolute)

TABLE II. Format for reporting eddy current inspection data. - Continued

Field #9, Columns #27:29 (continued)

Alphanumeric	Definition
*M-1	Mix 1 channel
M-2	Mix 2 channel
"	"
"	"
"	"
M-N	Mix N channel

Coil Number (Multiple Coil or Single Coil Pancake Probe Data)

Integer	Definition
010 020 030 040 050 060	Coil number for which pancake probe data is being reported. The data in Fields #1 through #5 and #10 through #13 may repeat for each coil seeing the same defect. However, the data in Fields #6 through #8 may differ for each coil seeing the same defect. The specific coil numbers which were excited should be identified in Field #14 in the first entry for a given defect indication. In some special cases, only the data for the coil with the largest amplitude need be reported rather than the data for each individual coil. However, unless otherwise noted, the data for each coil which was excited should be reported for a given defect.

Field #10, Columns #31:38 - Reference Location

'xx'xxx'xxx'xx.xx'xxx'xxx'xxx'aaaaaaaa±xx.x'xxxx'xxxx''xxxxxxxx'

Alphanumeric	Definition
*EOT---IN	End of tube - inlet side or inlet/outlet end
EOT--OUT	End of tube - outlet side or return end

Field #11, Columns #39:43 - Distance Indicator From Reference Location (Inches)

'xx'xxx'xxx'xx.xx'xxx'xxx'xxx'xxxxxxxx±nn.n'xxxx'xxxx''xxxxxxxx'

Decimal	Definition
±nn.n	Distance of indication (defect, dent, etc.) in inches from reference location defined in Field #10.

* Note: Dash (-) in alphanumeric designation means blank.

TABLE II. Format for reporting eddy current inspection data. - Continued

Field #12, Columns #45:48 - Type of Indication/Tube Condition Indicator

'xx'xxx'xxx'xx.xx'xxx'xxx'xxx'xxxxxxxx±xx.x'aaaa'xxxx''xxxxxxxx'

Type of ET Indication

Alphanumeric	Definition
O.D.	Outside Diameter Defect
I.D.	Inside Diameter Defect
OTHER	Other Type of Indication or Tube Condition
*NDD-	No Detectable Defect
DENT	Dent Indication
P.V.	Permeability Variation Indication
DIST	Distorted ET Signal
DSP-	Distorted Support Plate Signal
DTS-	Distorted Tubesheet Signal
COND	Conductive Deposit Indication
RDEP	Residual Deposit Signal in Mix Channel
PID-	Positive Identification Probing
RBD-	Retest - Bad Data

Tube Condition Indicator

Alphanumeric	Definition
M.C.	Mandrel Chatter Indication
IDV-	Inside Diameter Variation
PTI-	Possible Tooling Indication
IRR-	Irregular Roll Indication
NRL-	Nonroll Condition (i.e., Tube is not Rolled into Tubesheet)
OBST	Obstructed Tube
PLG-	Plugged (Permanently)
TEMP	Temporary Plug

Field #13, Columns #50:53 - ET Indication Modifier.

'xx'xxx'xxx'xx.xx'xxx'xxx'xxx'xxxxxxxx±xx.x'xxxx'aaaa''xxxxxxxx'

* Note: Dash (-) in alphanumeric designation means blank.

TABLE II. Format for reporting eddy current inspection data. - Continued

Field #13, Columns #50:53 (continued)

ET Indication Modifier

Alphanumeric	Definition
*LKR-	Leaker
SHAL	Shallow Indication
MULT	Multiple Indications
THRU	Multiple Indications Throughout Tube Length
TANG	Indication at Tangent Point to the U-Bend
APEX	Indication at Apex of U-Bend
SAT-	Saturated Signal
1/2-	The Amplitude of Only One-Half of a Signal Could be Measured
DIST	Signal for Indication Identified in Field #12 is Distorted.
QUIK	Signal Developed Quickly with Regard to Axial Length
NORM	Signal Developed Normally with Regard to Axial Length
SLOW	Signal Developed Slowly with Regard to Axial Length
POSS	Possible Indication
FULL	Full Length Non-Roll Indication
STD-	Standard Run Indication
INC-	Incomplete Probing
VERF	Verified

Field #14, Columns #56:63 - Comments

'xx'xxx'xxx'xx.xx'xxx'xxx'xxx'xxxxxxxx±xx.x'xxxx'xxxx''aaaaaaaa'

Alphanumeric	Definition
AAAAAAAA	Additional Comments
AX-NN.N-	Axial Length of Indication
nnnnnn--	Specific Coils Excited in Multiple Coil Pancake Probing or Specific Orientations Excited in Single Coil Pancake Probing. This is the Only Entry Permissible in this Field for Multiple Coil and Single Coil Pancake Probing Data.

* Note: Dash (-) in alphanumeric designation means blank.

TABLE III. Permissible entries in the various fields defined in table I.

Field	12	3	4	5	6	7	8	9	10	11	12	13	14
Column	'xx'	xxx'	xxx'		xx.xx'	xxx'	xxx'	xxx'	xxxxxxxx	±xx.x'	xxxx'	xxxx''	'xxxxxxxx'
Values	11	000	00		00.00	000	000	1	EOT	IN-99.9	O.D.	LKR	AAAAAAAA
	22	:	:		:	:	:	:	EOT	OUT+99.9	I.D.	SHAL	AX NN.N
	3	999	99		99.99	360	100	8			OTHR	MULT	NNNNNN
	4	or	or					M 1			NDD	THRU	
	6	00A	0A					M N			DENT	TANG	
		:	:								P.V.	APEX	
		ZZZ	ZZ								DIST	SAT	
											DSP	1/2	
											DTS	DIST	
											COND	QUIK	
											RDEP	NORM	
											PID	SLOW	
											RBD	POSS	
											M.C.	FULL	
											IDV	STD	
											PTI	INC	
											IRR	VERF	
											NRL		
											OBST		
											PLG		
											TEMP		

TABLE IV. General comments to accompany the format defined in table I.

1. Comments (e.g., to identify the beginning or end of a reel of data, to identify a change of probes or a change in probe positioner, to elaborate on any tube, probe, defect condition, etc.) are permissible and are encouraged. However, Fields #1 and #2 should be blank for these comments (i.e., columns 2 and 3) because these fields are used to indicate that a tube has been inspected.

2. The disposition of every tube tested should be reported, regardless of whether it had any indication or not, so that a listing of tubes examined can be generated. The list of tubes reported should also include all obstructed tubes.

3. The entries identified for the various fields (summarized in Table II) should be used exclusively. If these entries are inadequate to describe a given condition, additional information should be incorporated by the use of comments (see item #1 above). The position of the entry in the field (i.e., left-adjusted, right-adjusted) as shown in Table II should be observed.

4. For multiple defect indications which are not explicitly listed because of the number of indications (identified by the type of indication modifier MULT in Field #13), the data for the defect with the largest depth and the data for the defect with the largest amplitude should be identified explicitly, as a minimum, if two such indications are actually observed (i.e., if they are not one and the same).

5. In general, the appropriate data for each coil (multiple coil pancake probing) should be reported for a given defect. However, in some special cases, the data entries can be collapsed into a single entry where the data for the coil with the largest amplitude should be reported. In either case, the specific coil numbers which were excited should be entered in the comment field (i.e., Field #14) in the first entry for a given defect indication.

6. If the type of indication DIST is used in Field #12, the depth of the indication in Field #8 should not be reported. If the type of indication OD is used in Field #12 with the modifier DIST in Field #13, the depth of the indication should be reported in Field #8.

STANDARDIZATION DOCUMENT IMPROVEMENT PROPOSAL

INSTRUCTIONS

1. The preparing activity must complete blocks 1, 2, 3, and 8. In block 1, both the document number and revision letter should be given.
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	MIL-STD-2032(SH)	14 September 1990

3. DOCUMENT TITLE
Eddy Current Inspection of Heat Exchanger Tubing on Ships of the United States Navy

4. NATURE OF CHANGE *(Identify paragraph number and include proposed rewrite, if possible. Attach extra sheets as needed.)*

5. REASON FOR RECOMMENDATION

6. SUBMITTER

a. NAME (Last, First, Middle Initial)	b. ORGANIZATION	
c. ADDRESS (Include Zip Code)	d. TELEPHONE (Include Area Code) (1) Commercial (2) AUTOVON (if applicable)	7. DATE SUBMITTED (YYMMDD)

8. PREPARING ACTIVITY

a. NAME	b. TELEPHONE (Include Area Code)	
Technical Point of Contact (TPOC): Mr. John Fallick (SEA 05M2) PLEASE ADDRESS ALL CORRESPONDENCE AS FOLLOWS:	(1) Commercial TPOC: 703-602-0143	(2) AUTOVON 8-332-0143
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