MAINTENANCE TECHNICAL SUPPORT CENTER / MAINTENANCE MANAGEMENT OFFICE
ENGINEERING & TECHNICAL SUPPORT DEPARTMENT / OPERATIONS GROUP

maintenance bulletin

SUBJECT: Eddy Current Testing of Central Chiller Evaporator and Condenser Tubes

DATE: April 18, 1986

NO.: MMO-19-86

TO: Maintenance Capable Offices

FILE CODE: M

This bulletin is issued to replace MMO-23-80 dated March 19, 1980. Since that bulletin was issued, eddy current testing of chiller tubes has proven successful where the specifications in the bulletin were used and enforced. However, there has been a number of cases where the contractor did not fully comply with the specifications, and the test results were not conclusive and of little value. There has also been a number of instances where the contractor has requested waiver of certain provisions in the specification such as recording the test on a magnetic tape. Such waivers are unacceptable. Strict compliance with the specifications, especially those items emphasized in this bulletin, is required.

All chillers must be tested in accordance with the following requirements.

1. For locations where there is only one central chiller, and failure with extended downtime would disrupt operation, eddy current testing of both condenser and evaporator tubes shall be conducted on the same five (5) year cycle as when the evaporator is opened for cleaning and inspection. (See preventive maintenance guide A-27 in MS-1, Section 13.) Both evaporator and condenser sections shall be tested.

2. All central chillers ten years of age and older should have eddy current tests conducted at the next scheduled cleaning (5 year) of evaporator sections. Both evaporator and condenser sections shall be tested. Thereafter, tests should be conducted on a ten-year cycle unless the tests indicate defects which require more frequent inspection.

3. Absorption-type air conditioning shall have eddy current tests conducted on all sections (evaporator, condenser, absorber, and concentrator) every five (5) years.

4. When tube failure occurs, rather than replace all tubes (which is often done), eddy current tests should be conducted and only the defective tubes replaced. Tubes with thirty (30) percent or more wall thinning are normally considered candidates for replacement or isolation. This thirty-percent criterion will vary with type, model, and manufacturer of equipment. If defective tubes are isolated by plugging, the number of plugged tubes shall be less than 12% of the total number of tubes in the section.

5. Special (more frequent) eddy current tests should be conducted under the following conditions:

   a. When there is suspected damage to the tubes caused by poor water treatment or other maintenance deficiencies.

   b. On any make or model of central chiller that is known to be prone to tube failure.

   c. When a previous eddy current test indicated tube wall thinning but not to the extent requiring replacement or isolation. Eddy current tests may be conducted at more frequent intervals to determine if the tubes are continuing to deteriorate.

6. The attached specification (Exhibit 1) shall be used to solicit bids for eddy current testing. Exhibit 2 is from Section V, Article 8 of the ASME Boiler and Pressure Vessel Code (1983), and is referenced in the specification and included with this bulletin for information. A qualified eddy current testing firm should have access to this specification. Please note that this ASME specification is copyrighted and is not to be reproduced for the contractor.

7. The eddy current testing must be conducted in strict accordance with this specification in order to be dependable. Some of the salient requirements of the specification are:

   a. The calibration standard must be made from a tube that is identical (material, dimension, heat treatment) to the tubes being tested. If the contractor does not have identical tubing (with machined defects), he cannot accurately determine the percentage of wall thinning.

   b. The technician shall be employed full time in eddy current testing and shall be certified to meet the American Society for Non-Destructive Testing, Level II or equivalent.

   c. Recording of the tests on both magnetic tape and strip charts is required.

   d. The job site report should identify defective tubes and percentage of wall thinning. This should be confirmed by the written formal report within ten (10) days. Pulling tubes to calibrate and evaluate test should not be required.

e. Opening unit and cleaning tubes is not included in this specification.

As a matter of convenience, the presently known firms engaging in eddy current testing are listed in Exhibit 3. It is suggested that invitations for bid to obtain this service be sent to each of these firms to obtain the best possible price regardless of geographic location.

Questions or comments should be directed to Maintenance Technical Support Center, Plant Equipment Branch, P.O. Box 1600, Norman, OK 73070-6704; Telephone (PEN) 747-8253.

For Robert W Ashburn

R. Wayne Younkins
Field Director
Maintenance Technical Support Center
Office of Maintenance Management

Attachments

EXHIBIT 1: Electro-Magnetic Eddy Current Testing Specification

EXHIBIT 2: Article 8-Appendix I; ASME Boiler & Pressure Vessel Code

EXHIBIT 3: Prospective Bidder List for Eddy Current Testing

Specification for Electro-Magnetic Eddy Current Testing of Central Chill Water Plant Heat Non-Ferromagnetic Exchange Tubes

1. Complete eddy current testing of all heat exchanger tubes, both evaporation and condenser (plus concentrator and absorber tube in absorption units) of equipment described in Paragraph 2 will be conducted and report provided as specified herein. Test will be conducted between _____ (Dates).

2. Equipment Description:
   Manufacturer: _____
   Sizes (Tons): _____
   Manufacturers' Model No.: _____
   Manufacturers' Serial No.: _____
   Date Installed: _____
   Date of Last Retubing (condenser): _____
   Date of Last Retubing (evaporator): _____
   Date of Last Retubing (absorber): _____
   Date of Last Retubing (concentrator): _____
   Retubing Performed By: _____

3. Work Performed by USPS Personnel:
   USPS personnel will prepare equipment for testing by removing heat exchanger heads, piping, cleaning tubes, and erecting scaffolding.

4. Qualification of Contractor's Personnel:
   The contractor's personnel conducting the test and interpreting the results shall be employed full time in performing eddy current test and shall be certified to meet the American Society for Non-Destructive Testing, Level II or equivalent.

5. Reference Specification ANSI/ASME BPV-V:
   The test shall be performed in accordance with requirements and procedures in 1983 ASME Boiler and Pressure Vessel Code. Section V, Non-Destructive Examination, Article 8, Appendix I.

   a. The written procedure identified in I-23 of the above code is required.
   b. System calibration shall be confirmed each hour (see I-34 (b) of above referenced code section).
   c. The test shall be recorded as required in I-21 (d) and I-21 (e) of the above referenced code.

6. Record:
   The contractor shall provide strip chart recordings as follows:

   a. For each calibration standard and artificial discontinuity comparator used. These shall be annotated to identify each defect machined in the standard and the calibration of each division on the chart.
   b. For a typical good tube in each bundle.

c. For each defective tube. These shall be annotated to identify the tube and indicate the nature and extent of defect.
d. A copy of the magnetic tape record shall be maintained and furnished on request of the contracting officer.

7. Report:
A preliminary job site report shall be provided as soon as the test is completed. Within 10 working days following the completion of the test the contractor shall provide a complete test report using the following format.

a. Written test procedure (see I-23 of above referenced code).
b. Recommendations - list all tubes that are recommended for replacement or isolation and make complete description of defects, i.e., location, depth, inside or outside, etc.
c. Map of the location - shows tube layout with description locating tubes by row, number, and supports for evaporator and condenser of each machine.
d. The following is an example of a satisfactory method of showing row by row listing of tubes and findings.

ROW NO.	TUBE NO.	COMMENT
1	all	OK
2	6	OD wear .010 @ 15
2	8	OD wear .020 @ 15
2	balance	OK

e. Name(s) of technician performing tests and evaluating data.
f. Contractor's certification of technician's qualifications.

8. Schedule:
The contractor will schedule the test and provide at least two weeks (14 days) notice to the contracting officer so that the equipment can be prepared and arrangements made for USPS personnel to witness the test.

ARTICLE 8 — APPENDIX I

EDDY CURRENT EXAMINATION METHOD FOR INSTALLED NON-FERROMAGNETIC STEAM GENERATOR HEAT EXCHANGER TUBING

ARTICLE I-10
INTRODUCTION

I-11 SCOPE

This Appendix defines the Eddy Current (ET) examination method and equipment requirements applicable to installed non-ferromagnetic steam generator heat exchanger tubing. The method described here is intended to detect flaws, and quantify degradation of the tubing. The Appendix is intended to provide assurance that all steam generator tube examinations are conducted in such a manner that the indication from a flaw penetrating 20% or more of the tube wall is readily discernible from probe motion, flaw detection adjacent to supporting members is optimized, measurement error is minimized, and that the test results are consistent.

I-12 GENERAL REQUIREMENTS

(a) The requirements for test equipment, and examination procedures shall be in accordance with I-20.

(b) Calibrations shall be done in accordance with I-30.

ARTICLE I-20
EXAMINATION EQUIPMENT AND PROCEDURE

I-21 EQUIPMENT

(a) An Eddy Current Test (ET) instrument capable of operation at frequencies which meet the requirements of I-33 shall be used.

(b) The instrument shall provide phase and amplitude information. Its frequency response shall be flat, ± 15% of full scale from d-c to 100 Hz.

(c) The instrument shall display a two dimensional pattern by use of an X-Y storage display oscilloscope, whose frequency response shall be flat, ± 10% from d-c to 100 Hz.

(d) The magnetic tape recorder used during the examination shall have at least two channels and the capability for recording tube identification. The frequency response shall be flat, ± 15% from d-c to 100 Hz.

(e) The strip chart recorder used during the examination shall have at least two channels. The frequency response shall be flat over at least 20% of full scale from d-c to 100 Hz.

(f) The ET system shall be capable of detecting and recording flaws originating on either tube wall surface and extending to a depth of 20% or more through the tube wall.

(g) Probes with absolute and/or differential coil arrangements may be used.

(h) Probe drive to meet the requirements of I-42.

(i) Probe positioning devices (optional).

I-23 PROCEDURE REQUIREMENTS

When the referencing Code Section requires it, Eddy Current (ET) examinations shall be performed in accordance with a written procedure. Each procedure shall include at least the following information:

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(a) tube material, diameter, and wall thickness;

(b) size and type of probes, including manufacturer's name, description or part number, and length of probe cable;

(c) examination frequency or frequencies;

(d) manufacturer and model of ET equipment;

(e) scanning speed during examination;

(f) inspection technique, i.e., hand probe, mechanized probe drive, remote control fixture, etc.;

(g) calibration procedure and calibration standards;

(h) data recording equipment and procedures;

(i) procedure for interpretation of results;

(j) additional information as necessary to describe the examination.

ARTICLE I-30
CALIBRATION

I-31 EQUIPMENT SPECIFICATIONS

(a) The oscillator output frequency to the drive coil shall be within its indicated frequency, ±5%.

(b) The vertical and horizontal linearity of the Cathode Ray Tube (CRT) display shall be within ±10% of the deflection input voltage.

(c) The CRT vertical and horizontal trace alignment shall be parallel to the graticule lines ±2 deg.

(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 the indicated value ±5%.

(f) The amplification in both channels of the ET instrument shall be equal to each other at all sensitivity settings within ±5%.

(g) The two output channels of the ET instrument shall be orthogonal ±3 deg. at the test frequency.

(h) The above parameter shall be certified annually.

I-32 CALIBRATION STANDARDS

The calibration standards shall be manufactured from a length of tubing of the same nominal size and material type (chemical composition and heat treatment) as that to be examined in the vessel. The standard shall contain calibration discontinuities as follows:

(a) 100% drill hole (0.052 in. diameter for ¾ in. O.D. tubing and smaller and 0.067 in. diameter for larger tubing).

(b) Four flat bottomed holes, 3/16 in. diameter, spaced 90 deg. apart in a single plane around the tube circumference, 20% through the tube wall from the O.D.

(c) A 1/16 in. wide 360 deg. circumferential groove, 20% through from the inner tube surface. (Required for absolute coil calibration only.)

(d) A 360 deg. circumferential groove ⅛ in. wide and 10% through from the outer tube surface. (Required for absolute coil calibration only.)

(e) All calibration discontinuities shall be spaced so that they can be identified from each other and from the end of the tube.

(f) Each standard shall be identified by a serial number.

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

(h) The actual dimensions of the calibration discontinuities and the ET system response to those applicable shall become part of the permanent record of the standard.

(i) Alternate calibration discontinuities may be used, if they are proven capable of meeting the requirements of I-33.

I-33 SYSTEM CALIBRATION

The examination system shall be calibrated utilizing the standard described in I-32.

(a) Differential Coil Calibration

(1) Set the ET instrument at a test frequency chosen so that the phase angle of a signal from the four 20% flat bottomed holes is between 50 deg. and 130 deg. rotated clockwise from the signal of the through the wall hole (Fig. I-33-1).

(2) The sensitivity shall be sufficient to produce a response from the through-the-wall hole with an amplitude minimum of 50% of the full CRT screen height. At this setting, the phase and amplitude of signals from each applicable calibration discontinuity shall be clearly distinguishable.

(3) Adjust the phase or rotation control of the ET instrument such that the signal response due to probe motion is horizontal on the CRT screen.

(4) Withdraw the test probe through the calibration standard, recording the responses of the applicable calibration discontinuities. Ascertain that they are clearly indicated by the instrument and distinguishable from each other as well as from probe motion signals.

(b) Absolute Coil Calibration

(1) Set the ET instrument at a test frequency

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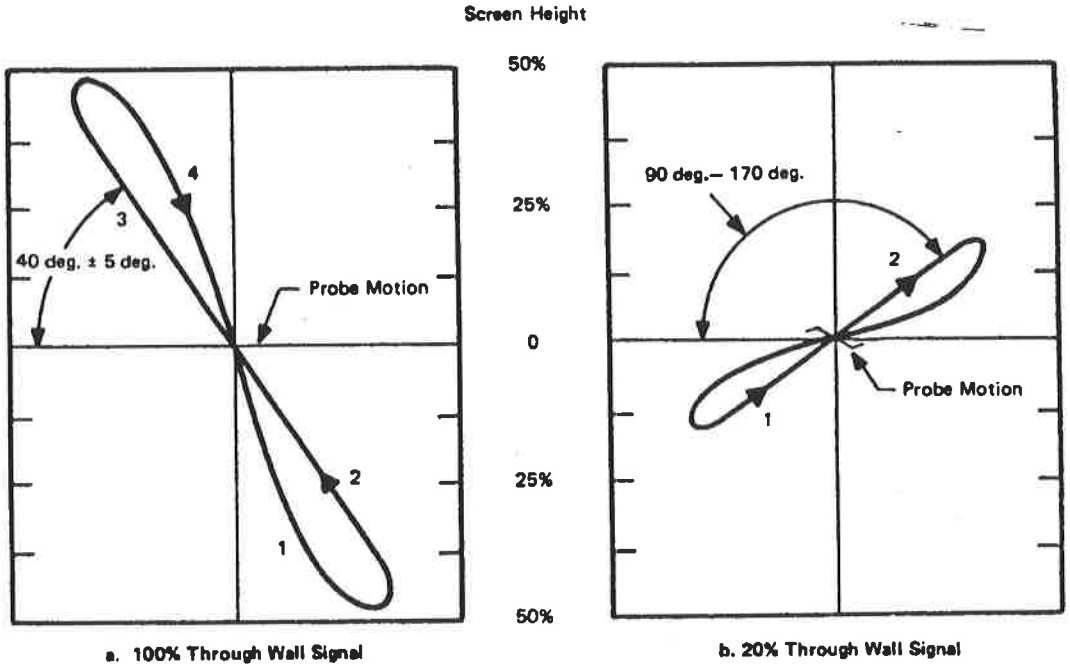

a. 100% Through Wall Signal

b. 20% Through Wall Signal

NOTES:
(1) Angles and signals are approximate.
(2) Arrows and numbers denote CRT trace motion as probe is withdrawn past calibration discontinuity.

FIG. I-33-1 EXAMPLES OF TYPICAL SIGNALS FROM A PROPERLY CALIBRATED DIFFERENTIAL COIL PROBE SYSTEM

chosen so the phase angle of a signal from the 10% O.D. groove is between 50 deg. and 130 deg. from the tangent drawn to the tip of the signal of the through the wall hole (Fig. I-33-2).

(2) Position the test probe inside the calibration standard with the coil in a section of the tube free of artificial flaws and balance the instrument to null the output.

(3) Adjust the phase or rotation control of the ET instrument such that the signal response from the O.D. groove is vertical on the CRT screen.

(4) Withdraw the test probe through the calibration standard, recording the responses of the applicable calibration discontinuities. Ascertain that they are clearly indicated by the instrument and distinguishable from each other as well as from probe motion signals.

I-34 CALIBRATION CONFIRMATION

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

(b) The system calibration shall be confirmed from time to time, as required by the referencing Code Section.

(c) Should the system be found to be out of calibration as defined in I-33, the equipment shall be recalibrated. The recalibration shall be noted on both the magnetic tape and the strip chart.

I-35 CALIBRATION TO CORRELATE SIGNALS TO DEPTH OF DISCONTINUITIES

The depth of discontinuities is primarily shown by the phase angle of the ET signal they produce. A relationship of artificial discontinuity depths versus signal phase angle shall be developed for the examination being performed (see Fig. I-35-1). For this purpose, the following artificial discontinuity comparators shall be used:

EXHIBIT 2

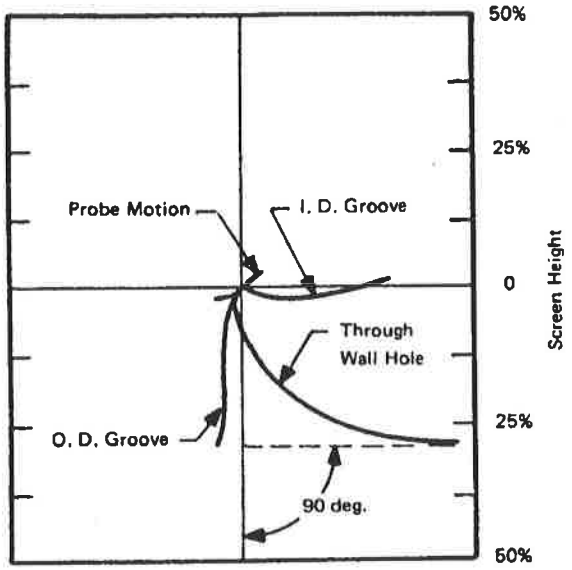

FIG. I-33-2 EXAMPLE OF TYPICAL SIGNALS FROM A PROPERLY CALIBRATED ABSOLUTE COIL PROBE SYSTEM

(a) The artificial discontinuity comparators shall be manufactured from a length of tubing of the same nominal size (diameter and wall thickness) and material as the tubes being examined.

(b) The artificial discontinuities shall be flat bottom holes drilled to varying depths.

(c) Where the depth of the hole is the same as the one used for Equipment Calibration (see I-32) the same Standard may be used.

(d) The tolerances for the dimensions of the holes shall be the same as those specified for the Calibration Standards (see I-32).

(e) Except for the holes specified in (f)(1) below, all holes shall be far enough apart to avoid interference between signals.

(f) Depth of artificial discontinuities:

(1) four flat bottom drill holes, $\frac{3}{16}$ in. diameter, 20% through the wall [same as the Calibration Standard (b) in I-32];

(2) one flat bottom drill hole, $\frac{3}{16}$ in. in diameter × 40% through the wall from the outside surface;

(3) one flat bottom drill hole, $\frac{7}{64}$ in. in diameter × 60% through the wall from the outside surface;

(4) one flat bottom drill hole, $\frac{5}{64}$ in. in diameter × 80% through the wall from the outside surface;

(5) one through the wall drill hole [same as the Calibration Standard (a) in I-32].

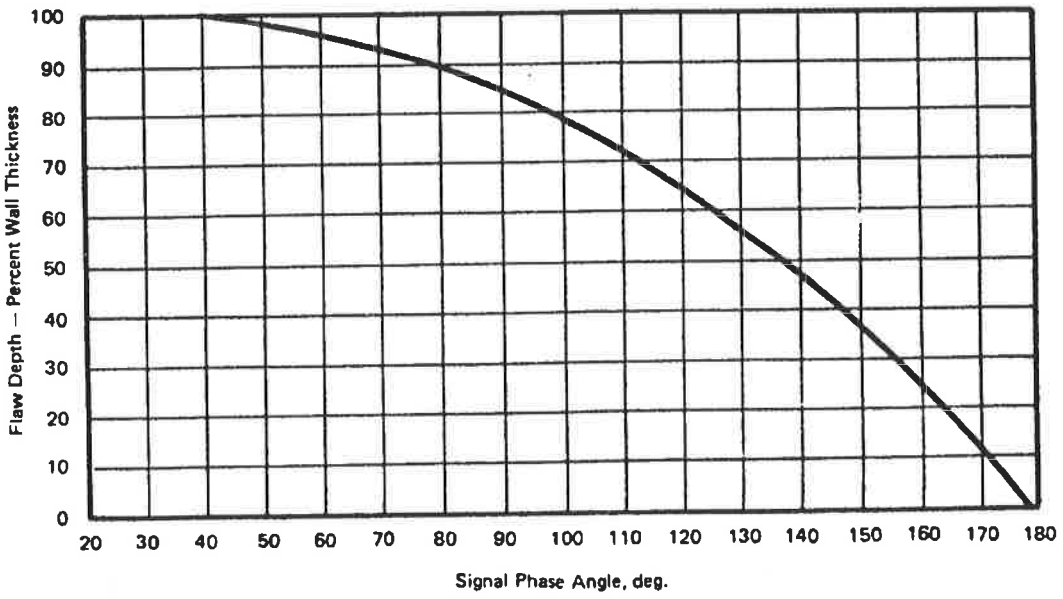

FIG. I-35-1 PHASE ANGLE VS. FLAW DEPTH INCONEL TUBE 400 KHz (TYPICAL)

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(g) Other artificial discontinuity comparators may be used, if they can be demonstrated to be at least equal.

ARTICLE I-40
EXAMINATION

I-41 GENERAL

When recording is desired, all data shall be recorded on both the magnetic tape and the strip charts, as the test probe traverses the tube.

I-42 TRAVERSE SPEED

The maximum traversing speed is determined by the frequency response of the electronic system employed. For equipment with the specifications cited in I-21, the traverse speed during examination shall not exceed 14 in./sec. Higher traverse speeds may be used if adequate frequency response and sensitivity to the applicable calibration discontinuities, can be demonstrated.

ARTICLE I-50
EVALUATION

I-51 GENERAL

It is usually necessary to evaluate the data obtained. Such evaluation shall be made in accordance with requirements of the referencing Code Section.

EXHIBIT 2

STANDARD DEFINITIONS OF TERMS RELATING TO ELECTROMAGNETIC TESTING

SE-268

(Identical with ASTM E 268-80)

absolute coil—a coil (or coils) that respond(s) to the total detected electric or magnetic properties, or both, of one section of a part undergoing electromagnetic test without comparison to another section of the part, or to another part.

absolute measurements—*in electromagnetic testing*, measurements made without a direct reference using an absolute coil in contrast to differential and comparative measurements. (See also **absolute coil**.)

absolute readout—*in electromagnetic testing*, the signal output of an absolute coil. (See also **absolute coil**.)

absolute system—an electromagnetic testing system that uses a coil assembly and associated electronics to measure the total electromagnetic properties of a test part without direct comparison to another section of the part or to another part. (See also **absolute coil**.)

acceptance level—a test level above or below which test specimens are acceptable in contrast to rejection level.

acceptance limits—test levels used in electromagnetic inspection that establish the group into which a material under test belongs.

acceptance standard—*in tubing inspection*, a tube used to establish the acceptance level with artificial discontinuities as specified in the applicable product standard.

amplitude distortion—same as **harmonic distortion**.

amplitude response—that property of a test system whereby the amplitude of the detected signal is measured without regard to phase. (See also **harmonic analysis** and **phase analysis**.)

annular coils—See **encircling coils**.

annular coil clearance—the mean radial distance between adjacent coil assembly and test part surface in electromagnetic encircling coil examination.

artificial discontinuity—reference discontinuities, such as holes, grooves, or notches that are introduced into a reference standard to provide accurately reproducible sensitivity levels for electromagnetic test equipment.

band pass filter—a wave filter having a single transmission band; neither of the cut-off frequencies being zero or infinity.

bobbin coil—See **ID coil**.

bucking coils—same as **differential coils**.

circumferential coils—See **encircling coils**.

coil size—the dimension of a coil, for example, length or diameter.

coil spacing—*in electromagnetic testing*, the axial distance between two encircling coils of a differential system.

comparator coils—*in electromagnetic testing*, two or more coils electrically connected in series opposition but arranged so that there is no mutual induction (coupling) between them such that any electric or magnetic condition, or both, that is not common to the test specimen and the standard, will produce an unbalance in the system and thereby yield an indication.

comparative measurements—*in electromagnetic testing*, measurements made in which the unbalance in the system is measured using comparator coils in contrast to differential and absolute measurements. (See also **comparator coils**.)

comparative readout—*in electromagnetic testing*, the signal output of comparator coils. (See also **comparator coils**.)

comparative system—an electromagnetic test system that uses coil assemblies and associated electronics to detect any electric or magnetic condition, or both, that is not common to the test specimen and the standard. (See also **comparator coils**.)

coupling—two electric circuits are said to be coupled to each other when they have an impedance in common so that a current in one causes a voltage in the other.

cut-off level—same as **rejection level**.

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defect resolution—a property of a test system that enables the separation of indications due to defects in a test specimen that are located in close proximity to each other.

depth of penetration—*in electromagnetic testing*, the depth at which the magnetic field strength or intensity of induced eddy currents has decreased to 37 % of its surface value. The depth of penetration is an exponential function of the frequency of the signal and the conductivity and permeability of the material. Synonymous terms are standard depth of penetration and skin depth. (See also **skin effect**.)

diamagnetic material—a material whose relative permeability is less than unity.

NOTE—the intrinsic induction, B_i, is oppositely directed to the applied magnetizing force H.

differential coils—two or more coils electrically connected in series opposition such that any electric or magnetic condition, or both, that is not common to the areas of a specimen being electromagnetically tested will produce an unbalance in the system and thereby yield an indication.

differential measurements—*in electromagnetic testing*, measurements made in which the imbalance in the system is measured using differential coils in contrast to absolute and comparative measurements. (See also **differential coils**.)

differential readout—*in electromagnetic testing*, the signal output of differential coils. (See also **differential coils**.)

differential system—an electromagnetic testing system that uses coil assemblies and associated electronics to detect an electric or magnetic condition, or both, that is not common to the areas of the specimen being tested. (See also **differential coils**.)

differentiated signal—*in electromagnetic testing*, an output signal that is proportional to the rate of change of the input signal.

eddy current—an electrical current caused to flow in a conductor by the time or space variation, or both, of an applied magnetic field.

eddy current testing—a nondestructive testing method in which eddy current flow is induced in the test object. Changes in the flow caused by variations in the specimen are reflected into a nearby coil, coils, or Hall effect device for subsequent analysis by suitable instrumentation and techniques.

edge effect—*in electromagnetic testing*, the disturbance of the magnetic field and eddy currents due to the proximity of an abrupt change in specimen geometry (edge). This effect generally results in the masking of discontinuities within the affected region. (This effect is also termed the end effect.)

effective depth of penetration—*in electromagnetic testing*, the minimum depth beyond which a test system can no longer practicably detect a further increase in specimen thickness. (If the minimum thickness for the frequency used is not exceeded, or the specimen thickness is not rigidly controlled, the test may be influenced by the specimen thickness.)

effective permeability—a hypothetical quantity that describes the magnetic permeability that is experienced under a given set of physical conditions such as a cylindrical test specimen in an encircling coil at a specific test frequency. This quantity may be different from the permeability of the particular metal being tested in that it takes into account such things as the geometry of the part, the relative position of the encircling coil, and characteristics of the magnetic field.

electrical center—the center established by the electromagnetic field distribution within a test coil. A constant intensity signal, irrespective of the circumferential position of a discontinuity, is indicative of electrical centering. The electrical center may be different from the physical center of the test coil.

electromagnetic testing—a nondestructive test method for materials, including magnetic materials, that uses electromagnetic energy having frequencies less than those of visible light to yield information regarding the quality of testing material.

encircling coils—*in electromagnetic testing*, coil(s) or coil assembly that surround(s) the part to be tested. Coils of this type are also referred to as annular, circumferential, or feed-through coils.

end effect—See **edge effect**.

feed-through coils—See **encircling coils**.

ferromagnetic material—a material that, in general, exhibits the phenomena of magnetic hysteresis and saturation, and whose permeability is dependent on the magnetizing force.

fill factor—*for encircling coil electromagnetic testing*, the ratio of the cross-sectional area of the test specimen to the effective cross-sectional core area of the primary encircling coil (outside diameter of coil form, not inside diameter which is adjacent to specimen.)

fill factor—*for internal probe electromagnetic testing*, the ratio of the effective cross-sectional area of the primary internal probe coil to the cross-sectional area of the tube interior.

filter—a network that passes electromagnetic wave energy over a described range of frequencies and attenuates energy at all other frequencies.

gate—same as **rejection level**.

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harmonic analysis—an analytical technique whereby the amplitude or phase, or both, of the frequency components of a complex periodic signal is determined.

harmonic distortion—nonlinear distortion characterized by the appearance in the output of harmonics other than the fundamental component when the input wave is sinusoidal.

IACS—the International Annealed Copper Standard; an international standard of electrical conductivity.

ID coil—a coil or coil assembly used for electromagnetic testing by insertion into the test piece as in the case of an inside probe for tubing. Coils of this type are also referred to as inside coils, inserted coils, or bobbin coils.

impedance—the total opposition that a circuit presents to the flow of an alternating current, specifically the complex quotient of voltage divided by current.

impedance analysis—*in electromagnetic testing*, an analytical method that consists of correlating changes in the amplitude, phase, or quadrature components, or all of these, of a complex test signal voltage to the electromagnetic conditions within the test specimen.

impedance plane diagram—a graphical representation of the locus of points, indicating the variations in the impedance of a test coil as a function of basic test parameters.

incremental permeability—the ratio of the change in magnetic induction to the corresponding change in magnetizing force when the mean induction differs from zero.

initial permeability—the slope of the induction curve at zero magnetizing force as the test specimen is being removed from a demagnetizing condition (slope at origin of BH curve before hysteresis is observed).

inserted coil—See **ID coil**.

inside coil—See **ID coil**.

lift-off effect—the effect observed in an electromagnetic test system output due to a change in magnetic coupling between a test specimen and a probe coil whenever the distance between them is varied.

magnetic history—magnetic condition of a ferromagnetic part based on previous exposures to magnetic fields.

magnetic leakage flux—the excursion of magnetic lines of force from the surface of a test specimen.

magnetic saturation—that degree of magnetization where a further increase in magnetizing force produces no signficant increase in magnetic flux density (permeability) in a specimen.

modulation analysis—an analytical method used in electromagnetic testing that separates responses due to various factors influencing the total magnetic field by separating and interpreting, individually, frequencies or frequency bands in the modulation envelope of the (carrier frequency) signal.

noise—*in electromagnetic inspection*, any nonrelevant signal that tends to interfere with the normal reception or processing of a desired flaw signal. It should be noted that such noise signals may be generated by inhomogeneities in the inspected part that are not detrimental to the end use of the part.

nonferromagnetic material—a material that is not magnetizable and hence, essentially not affected by magnetic fields. This would include paramagnetic materials and diamagnetic materials.

normal permeability—the ratio of the induction (when cyclically made to change symmetrically about zero) to the corresponding change in magnetizing force.

optimum frequency—*in electromagnetic testing*, that frequency which provides the largest signal-to-noise ratio obtainable for the detection of an individual material property. Each property of a given material may have its own optimum frequency.

paramagnetic material—a material that has a relative permeability slightly greater than unity and that is practically independent of the magnetizing force.

phase analysis—an analytical technique that discriminates between varibles in a part undergoing electromagnetic testing by the different phase angle changes that these conditions produce in the test signal. See also **phase detection**.

phase angle—the angular equivalent of the time displacement between corresponding points on two sine waves of the same frequency.

phase detection—the derivation of a signal whose amplitude is a function of the phase angle between two alternating currents, one of which is used as a reference.

phase-sensitive system—a system whose output signal is dependent on the phase relationship between the voltage returned from a pickup or sensing coil and a reference voltage.

phase shift—a change in the phase relationship between two alternating quantitites of the same frequency.

probe coil—*in electromagnetic testing*, a small coil or coil assembly that is placed on or near the surface of test objects.

probe coil clearance—the perpendicular distance between adjacent surfaces of the probe and test part; also lift-off.

recovery time—the time required for a test system to return to its original state after it has received a signal.

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reference coil—*in electromagnetic testing*, the section of the coil assembly that excites or detects, or both, the electromagnetic field in the reference standard in a comparative system.

reference standard—a reference used as a basis for comparison or calibration. In tubing inspection, a tube with artificial discontinuities used for establishing the test sensitivity setting and for perodically checking and adjusting sensitivity setting as required. (See also **standard** (*1*).)

rejection level—the value established for a test signal above or below which test specimens are rejectable, or otherwise distinguished from the remaining specimens.

selectivity—the characteristic of a test system that is a measure of the extent to which an instrument is capable of differentiating between the desired signal and disturbances of other frequencies or phases.

signal gradient—same as **differential readout**.

signal-to-noise ratio—the ratio of values to signal (response containing relevant information) to that of noise (response containing nonrelevant information).

skin depth—see **depth of penetration**.

skin effect—the phenomena wherein the depth of penetration of electric currents into a conductor decreases as the frequency of the current is increased. At very high frequencies, the current flow is restricted to an extremely thin outer layer of the conductor. (See also **depth of penetration**.)

speed effect—the phenomenon in electromagnetic testing of which the evidence is a change in the signal voltage resulting from a change in the relative motion between the specimen and a test coil assembly.

standard—(*1*) a physical reference used as a basis for comparison or calibration; (*2*) a concept that has been established by authority, custom, or agreement to serve as a model or rule in the measurement of quality or the establishment of a practice or procedure.

standard depth of penetration—See **depth of penetration**.

test coil—the section of the coil assembly that excites or detects, or both, the magnetic field in the material under electromagnetic test.

test frequency—*in electromagnetic testing*, the number of complete cycles per unit time of the alternating current applied to the primary test coil.

test quality level—See **rejection level**.

three way sort—an electromagnetic sort based on a signal response from the material under test above or below two levels established by three or more calibration standards.

threshold level—the setting of an instrument that causes it to register only those changes in response greater or less than a specified magnitude.

two-way sort—an electromagnetic sort based on a signal response from the material under test above or below a level established by two or more calibration standards.

wobble—*in electromagnetic testing*, an effect that produces variations in an output signal of a test system and arises from variations in coil spacing (operational lift-off) due to lateral motion of the test specimen in passing through an encircling coil.

EXHIBIT 2

Prospective Bidders for Eddy Current Test, December 1979

Associated with Scott Company
Mechanical Contractors
1919 Market Street
Oakland, CA 94607-3399
Attn: Ed Fitzpatrick
(415) 834-2333

Carrier Service Operations
Machinery & Systems Division
1801 Gateway Boulevard
Richardson, TX 75080-3547
Attn: J. S. Wooddy

Conam Inspection
1245 West Norwood
Itasca, IL 60143-1186
Attn: Gary Conway
(312) 773-9400

Cramer & Lindell Engineering, Inc.
P.O. Box 788
Essex, CT 06426-0788
(203) 767-2111

Eastern Testing and Inspection, Inc.
9220 Collins Avenue
Pennsauken, NJ 08110-1039
(609) 662-0333

Hunter Blakely & Associates, Inc.
P.O. Box 25303
Charlotte, NC 28212-5303
(704) 535-4300

Law Engineering Testing Co.
P.O. Box 18288
Raleigh, NC 27619-8288

Natkin Service Company
P.O. Box 9425
Houston, TX 77261-9425
Attn: Jim Scanlon
(713) 923-2739

New Boston Service Company, Inc.
225 Grove Street
West Roxbury, MA 02132-4519
(617) 327-8317

Peabody Testing Service
140 12th Avenue North
Nashville, TN 37203-3694
(615) 259-3527

Renewal Parts Corporation
9501 Santa Fe Springs Road
Santa Fe Springs, CA 90670-2624
Attn: Larry Center, President
(213) 946-1365

Train/Service First
4500 Morris Field Drive
Charlotte, NC 28208-5837
Attn: Herman McNabb
(704) 398-4600

Tube Analysis, Inc.
P.O. Box 767
Marbleton, GA 30059-0767
(404) 944-1332

U.S. Testing Co.
1415 Park Avenue
Hoboken, NJ 07030-3415
(201) 792-2400

Zetec
P.O. Box 140
Issaquah, WA 98207-0001
Attn: Clyde Denton
(206) 392-5316

Also, contact local refrigeration service companies and non-destructive testing firms for possible aids. Please note that the addresses are national headquarters and many have branch offices through the nation. Therefore, invitation to bid should be sent to each regardless of geographic location.

EXHIBIT 3