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Standard Practice for In Situ Examination of Ferromagnetic Heat-Exchanger Tubes Using Remote Field Testing[1]

This standard is issued under the fixed designation E2096/E2096M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This practice describes procedures to be followed during remote field examination of installed ferromagnetic heat-exchanger tubing for baseline and service-induced discontinuities.

1.2 This practice is intended for use on ferromagnetic tubes with outside diameters from 0.500 to 2.000 in. [12.70 to 50.80 mm], with wall thicknesses in the range from 0.028 to 0.134 in. [0.71 to 3.40 mm].

1.3 This practice does not establish tube acceptance criteria; the tube acceptance criteria must be specified by the using parties.

1.4 *Units*—The values stated in either inch-pound units or SI units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this practice to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

2.2 *ASNT Documents:*[3]

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

ANSI/ASNT-CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

2.3 *Other Documents:*

Can CGSB-48.9712-95 Qualification of Nondestructive Testing Personnel, Natural Resources Canada[4]

ISO 9712 Nondestructive Testing—Qualification and Certification of Nondestructive Testing Personnel[5]

NAS-410 Certification and Qualification of Nondestructive Testing Personnel[6]

3. Terminology

3.1 *General*—Definitions of terms used in this practice can be found in Terminology E1316, Section A, "Common NDT Terms," and Section C, "Electromagnetic Testing."

3.2 *Definitions:*

3.2.1 *detector, n*—one or more coils or elements used to sense or measure magnetic field; also known as a receiver.

3.2.2 *exciter, n*—a device that generates a time-varying electromagnetic field, usually a coil energized with alternating current (ac); also known as a transmitter.

3.2.3 *nominal tube, n*—a tube or tube section meeting the tubing manufacturer's specifications, with relevant properties typical of a tube being examined, used for reference in interpretation and evaluation.

3.2.4 *remote field, n— as applied to nondestructive testing*, the electromagnetic field which has been transmitted through the test object and is observable beyond the direct coupling field of the exciter.

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.07 on Electromagnetic Method.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

[4] Available from CGSB Sales Centre; Place du Portage, Phase 3, 6B1; 11 Laurier Street, Hull QC, Canada K1A 1G6.

[5] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[6] Available from Aerospace Industries Association (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209, http://www.aia-aerospace.org.

***A Summary of Changes section appears at the end of this standard**

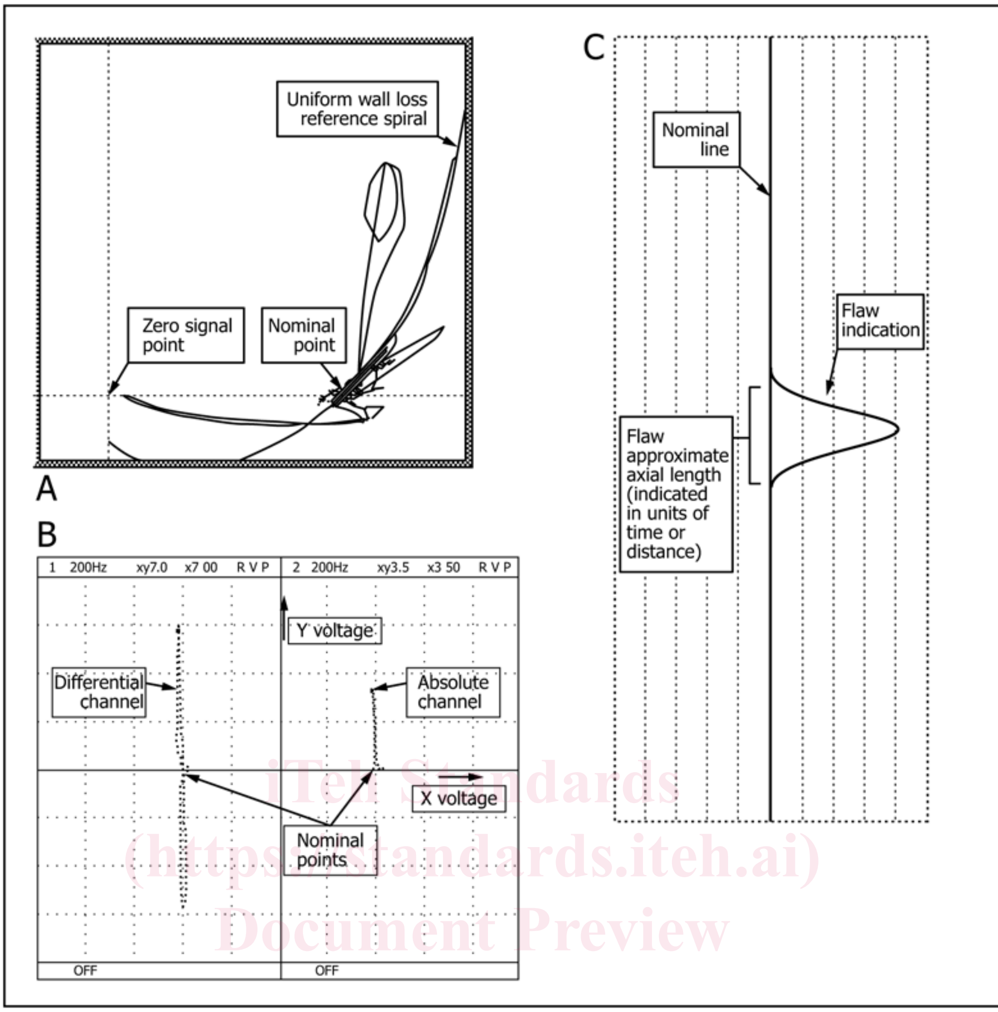


FIG. 1 A and B: Typical Phase-Amplitude Diagrams Used in RFT; C: Generic Strip Chart With Flaw

3.2.5 *remote field testing, n*—a nondestructive test method that measures changes in the remote field to detect and characterize discontinuities.

3.2.6 *using parties, n*—the supplier and purchaser.

3.2.6.1 *Discussion*—The party carrying out the examination is referred to as the "supplier," and the party requesting the examination is referred to as the "purchaser," as required in *Form and Style for ASTM Standards*, April 2004. In common usage outside this practice, these parties are often referred to as the "operator" and "customer," respectively.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *flaw characterization standard, n*—a standard used in addition to the RFT system reference standard, with artificial or service-induced flaws, used for flaw characterization.

3.3.2 *nominal point, n*—a point on the phase-amplitude diagram representing data from nominal tube.

3.3.3 *phase-amplitude diagram, n*—a two-dimensional representation of detector output voltage, with angle representing phase with respect to a reference signal, and radius representing amplitude (Fig. 1a and 1b).

3.3.3.1 *Discussion*—In this practice, care has been taken to use the term "phase angle" (and "phase") to refer to an angular equivalent of time displacement, as defined in Terminology E1316. When an angle is not necessarily representative of time, the general term "angle of an indication on the phase-amplitude diagram" is used.

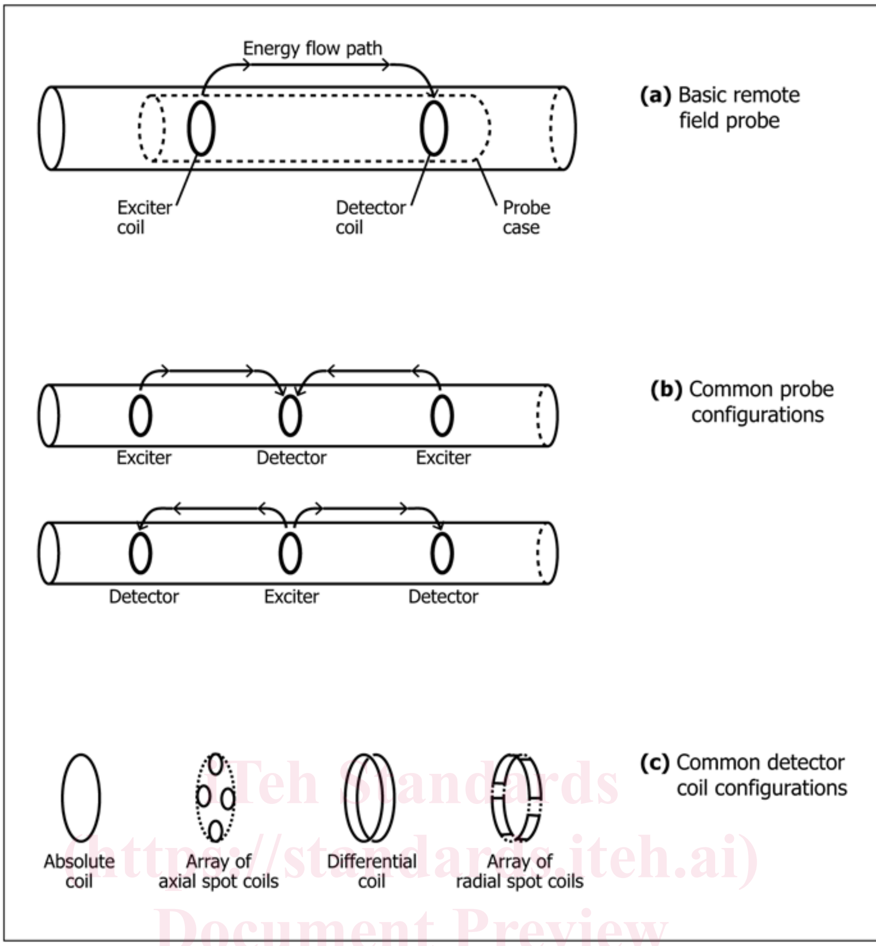
3.3.4 *RFT system, n*—the electronic instrumentation, probes, and all associated components and cables required for performing RFT.

3.3.5 *RFT system reference standard, n*—a reference standard with specified artificial flaws, used to set up and standardize a remote field system and to indicate flaw detection sensitivity.

3.3.6 *sample rate*—the rate at which data is digitized for display and recording, in data points per second.

3.3.7 *strip chart, n*—a diagram that plots coordinates extracted from points on a phase-amplitude diagram versus time or axial position (Fig. 1c).

3.3.8 *zero point, n*—a point on the phase-amplitude diagram representing zero detector output voltage.



NOTE 1—Arrows indicate flow of electromagnetic energy from exciter to detector. Energy flow is perpendicular to lines of magnetic flux.

FIG. 2 RFT Probes

3.3.8.1 *Discussion*—Data on the phase-amplitude diagram are plotted with respect to the zero point. The zero point is separate from the nominal point unless the detector is configured for zero output in nominal tube. The angle of a flaw indication is measured about the nominal point.

3.4 *Acronyms:*

3.4.1 *RFT, n*—remote field testing

4. Summary of Practice

4.1 The RFT data is collected by passing a probe through each tube. The electromagnetic field transmitted from the exciter to the detector is affected by discontinuities; by the dimensions and electromagnetic properties of the tube; and by objects in and around the tube that are ferromagnetic or conductive. System sensitivity is verified using the RFT system reference standard. System sensitivity and settings are checked and recorded prior to and at regular intervals during the examination. Data and system settings are recorded in a manner that allows archiving and later recall of all data and system settings for each tube. Interpretation and evaluation are carried out using one or more flaw characterization standards. The supplier generates a final report detailing the results of the examination.

5. Significance and Use

5.1 The purpose of RFT is to evaluate the condition of the tubing. The evaluation results may be used to assess the likelihood of tube failure during service, a task which is not covered by this practice.

5.2 *Principle of Probe Operation*—In a basic RFT probe, the electromagnetic field emitted by an exciter travels outwards through the tube wall, axially along the outside of tube, and back through the tube wall to a detector[7] (Fig. 2a).

5.2.1 Flaw indications are created when (*1*) in thin-walled areas, the field arrives at the detector with less attenuation and less time delay, (*2*) discontinuities interrupt the lines of magnetic flux, which are aligned mainly axially, or (*3*) discontinuities interrupt the eddy currents, which flow mainly circumferentially. A discontinuity at any point on the through-transmission path can create a perturbation; thus RFT has approximately equal sensitivity to flaws on the inner and outer walls of the tube.[7]

5.3 *Warning Against Errors in Interpretation.* Characterizing flaws by RFT may involve measuring changes from

[7] Schmidt, T. R., "The Remote Field Eddy Current Inspection Technique," *Materials Evaluation*, Vol. 42, No. 2, Feb. 1984, pp. 225-230.

nominal (or baseline), especially for absolute coil data. The choice of a nominal value is important and often requires judgment. Practitioners should exercise care to use for nominal reference a section of tube that is free of damage (see definition of "nominal tube" in 3.2.3). In particular, bends used as nominal reference must be free of damage, and tube support plates used as nominal reference should be free of metal loss in the plate and in adjacent tube material. If necessary, a complementary technique (as described in 11.12) may be used to verify the condition of areas used as nominal reference.

5.4 *Probe Configuration*—The detector is typically placed two to three tube diameters from the exciter, in a location where the remote field dominates the direct-coupling field.[7] Other probe configurations or designs may be used to optimize flaw detection, as described in 9.3.

5.5 *Comparison with Conventional Eddy-Current Testing*—Conventional eddy-current test coils are typically configured to sense the field from the tube wall in the immediate vicinity of the emitting element, whereas RFT probes are typically designed to detect changes in the remote field.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this standard.

6.2 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.3 *Qualification of Nondestructive Testing Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as specified in Practice E543, with reference to sections on electromagnetic testing. The applicable edition of Practice E543 shall be specified in the contractual agreement.

7. Job Scope and Requirements

7.1 The following items may require agreement between the using parties and should be specified in the purchase document or elsewhere:

7.1.1 Location and type of tube component to be examined, design specifications, degradation history, previous nondestructive examination results, maintenance history, process conditions, and specific types of flaws that are required to be detected, if known.

7.1.2 The maximum window of opportunity for work. (Detection of small flaws may require a slower probe pull speed, which will affect productivity.)

7.1.3 Size, material grade and type, and configuration of tubes to be examined.

7.1.4 A tube numbering or identification system.

7.1.5 Extent of examination, for example: complete or partial coverage, which tubes and to what length, whether straight sections only, and the minimum radius of bends that can be examined.

7.1.6 Means of access to tubes, and areas where access may be restricted.

7.1.7 Type of RFT instrument and probe; and description of reference standards used, including such details as dimensions and material.

7.1.8 Required operator qualifications and certification.

7.1.9 Required tube cleanliness.

7.1.10 Environmental conditions, equipment, and preparations that are the responsibility of the purchaser; common sources of noise that may interfere with the examination.

NOTE 1—Nearby welding activities may be a major source of interference.

7.1.11 Complementary methods or techniques (including possible tube removal) that may be used to obtain additional information.

7.1.12 Acceptance criteria to be used in evaluating flaw indications.

7.1.13 Disposition of examination records and reference standards.

7.1.14 Format and outline contents of the examination report.

8. Interferences

8.1 This section describes items and conditions which may compromise RFT.

8.2 *Material Properties:*

8.2.1 Variations in the material properties of ferromagnetic tubes are a potential source of inaccuracy. Impurities, segregation, manufacturing process, grain size, stress history, present stress patterns, temperature history, present temperature, magnetic history, and other factors will affect the electromagnetic response measured during RFT. The conductivity and permeability of tubes with the same grade of material are often measurably different. It is common to find that some of the tubes to be examined are newer tubes with different material properties.

8.2.2 Permeability variations may occur at locations where there was uneven temperature or stress during tube manufacture, near welds, at bends, where there were uneven heat transfer conditions during service, at areas where there is cold working (such as that created by an integral finning process), and in other locations. Indications from permeability variations may be mistaken for, or obscure flaw indications. Effects may be less severe in tubes that were stress-relieved during manufacture.

8.2.3 Residual stress, with accompanying permeability variations, may be present when discontinuities are machined into a reference standard, or during the integral finning process.

8.2.4 RFT is affected by residual magnetism in the tubing, including residual magnetism created during a previous examination using another magnetic method. Tubes with significant residual magnetism should be demagnetized prior to RFT.

8.3 *Ferromagnetic and Conductive Objects:*

8.3.1 Objects near the tube that are ferromagnetic or conductive may reduce the sensitivity and accuracy of flaw characterization in their immediate vicinity. Such objects may in some cases be mistaken for flaws. Knowledge of the mechanical layout of the component to be examined is recommended. Examples of ferromagnetic or conductive objects include: tube support plates, baffle plates, end plates, tube sheets, anti-vibration bars, neighboring tubes, impingement plates, loose parts, and attachments clamped or welded to a tube.

NOTE 2—Interference from ferromagnetic or conductive objects can be of practical use when RFT is used to confirm the position of an object installed on a tube or to detect where objects have become detached and have fallen against a tube.

8.3.2 *Neighboring Tubes:*

8.3.2.1 In areas where there is non-constant tube spacing (bowing) or where tubes cross close to each other, there are indications which may be mistaken for flaws.

8.3.2.2 Neighboring or adjacent tubes, in accordance with their number and position, create an offset in the phase. This phenomenon is known as the bundle effect and is a minor source of inaccuracy when absolute readings in nominal tube are required.

8.3.2.3 In cases where multiple RFT probes are used simultaneously in the same heat exchanger, care should be taken to ensure adequate spacing between different probes.

8.3.3 Conductive or magnetic debris in or on a tube that may create false indications or obscure flaw indications should be removed.

8.4 *Tube Geometry Effects:*

8.4.1 Due to geometrical effects (as well as to the effects of permeability variations described in 8.2.2), localized changes in tube diameter such as dents, bulges, expansions, and bends create indications which may obscure or distort flaw indications.

8.4.2 Reductions in the internal diameter may require a smaller diameter probe that is able to pass through the restriction. In the unrestricted sections, flaw sensitivity is likely to be limited by the smaller probe fill factor.

8.4.3 *RFT End Effect*—The field from the exciter is able to propagate around the end of a tube when there is no shielding from a tube sheet or vessel shell. A flaw indication may be obscured or distorted if the flaw or any active probe element is within approximately three tube diameters of the tube end.

8.5 *Instrumentation:*

8.5.1 The operator should be aware of indicators of noise, saturation, or signal distortion particular to the instrument being used. Special consideration should be given to the following concerns:

8.5.1.1 In a given tube, an RFT system has a frequency where the flaw sensitivity is as high as practical without undue influence from noise.

8.5.1.2 Saturation of electronic components is a potential problem in RFT because signal amplitude increases rapidly with decreasing tube wall thickness. Data acquired under saturation conditions is not acceptable.

8.5.2 *Instrument-induced Phase Offset*—During the amplification and filtering processes, instruments may introduce a frequency-dependent time delay which appears as a constant phase offset. The instrument phase offset may be a source of error when phase values measured at different frequencies are compared.

9. RFT System

9.1 *Instrumentation*—The electronic instrumentation shall be capable of creating exciter signals of one or more frequencies appropriate to the tube material. The apparatus shall be capable of phase and amplitude analysis of detector outputs at each frequency, independent of other frequencies in use simultaneously. The instrument shall display data in real time. The instrument shall be capable of recording data and system settings in a manner that allows archiving and later recall of all data and system settings for each tube.

9.2 *Driving Mechanism*—A mechanical means of traversing the probe through the tube at approximately constant speed may be used.

9.3 *Probes*—The probes should be of the largest diameter practical for the tubes being examined, leaving clearance for debris, dents, changes in tube diameter, and other obstructions. The probes should be of an appropriate configuration and size for the tube being examined and for the flaw type or types to be detected. Probe centering is recommended.

9.3.1 *Absolute Detectors*—Absolute detectors (Fig. 2c) are commonly used to characterize and locate large-volume and gradual metal loss.

9.3.2 *Differential Detectors*—Differential detectors (Fig. 2c) tend to maximize the response from small volume flaws and abrupt changes along the tube length, and are also commonly used to locate and characterize large-volume and gradual metal loss.

9.3.3 *Array Detector*—Array detectors use a configuration of multiple sensing elements (Fig. 2c). Each element is sensitive to a discrete section of the tube circumference. The elements may be oriented with their axes aligned axially or radially with respect to the tube.

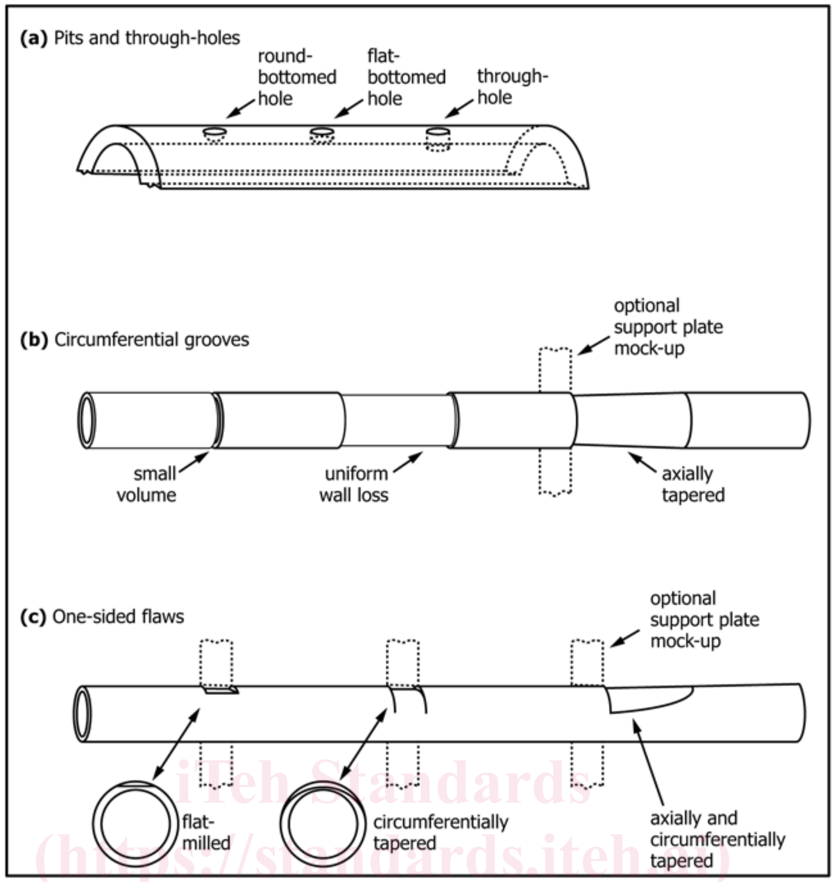
NOTE 3—The detector's response represents an average of responses to all flaws within its sensing area.

9.3.4 *Exciter and Detector Configurations*—Probes may have multiple exciters and detectors in a variety of configurations (see, for example, Fig. 2b). These configurations may reduce interference from support plates and other conductive objects.

9.4 *Data Displays:*

9.4.1 The data display should include a phase-amplitude diagram (Fig. 1a and 1b).

9.4.2 *Strip Charts*—Coordinates that may be displayed on strip charts include: horizontal position, vertical position, angular position, or radial position. Angular position may represent phase. Angular position and the logarithm of radial position for an absolute detector may be linearly related to overall wall thickness.



NOTE 1—Not to scale.

FIG. 3 Typical Artificial Discontinuities Used for Flaw Characterization Reference Standards

10. RFT Tube Standards

10.1 The RFT reference standards should be of the same nominal dimensions, material type, and grade as the tubes to be examined. In the case where a reference standard identical to the tubes to be examined is not available, a demonstration of examination equivalency is recommended. Subsection 11.6.2 specifies how to determine if a reference standard of different properties is appropriate for use.

10.2 The RFT system reference standard shall not be used for flaw characterization unless the artificial flaws can be demonstrated to be similar to the flaws detected.

10.3 *Typical Artificial Flaws in Flaw Characterization Standards:*

10.3.1 *Through, Round-Bottomed, and Flat-Bottomed Holes*—Holes of different depths are used for pit characterization, and may be machined individually or in groups. Drill and milling tools of different diameters can be used to produce different flaw volumes for a given depth of metal loss (Fig. 3a).

10.3.2 *Circumferential Grooves*—A circumferential groove is an area of metal loss whose depth at any axial location is uniform around the tube circumference. Short grooves, with a maximum axial length of less than one half a tube diameter, may be used to simulate small-volume metal loss. Grooves with an axial length of several tube diameters may be used to simulate uniform wall loss (Fig. 3b).

10.3.3 *One-Sided Flaws*—Metal loss is referred to as one-sided if it is predominantly on one side of a tube. Outside diameter long, flat flaws typically simulate tube-to-tube wear. Circumferentially tapered one-sided flaws typically simulate tube wear at support plates. Flaws tapered in both axial and circumferential directions typically simulate steam erosion adjacent to the tube support (Fig. 3c).

10.4 *RFT System Reference Standards*—Flaw depths are specified by giving the deepest point of the flaw as a percentage of the measured average wall thickness. Flaw depths shall be measured and accurate to within ±20 % of the depth specified or ±0.003 in. [±0.08 mm], whichever is smaller. All other flaw dimensions (such as length and diameter) shall be accurate to within ±0.010 in. [±0.25 mm] of the dimension specified. Angles shall be accurate to within ±5°.

10.5 *Artificial Flaws for RFT System Reference Standards:*

10.5.1 The RFT system reference standard has specific artificial flaws. It is used to set up and standardize a remote field system and to indicate flaw detection sensitivity. Unless otherwise specified by the purchaser, the artificial flaws for the RFT system reference standard are as follows: