Designation: E 690 – 98

Standard Practice for In Situ Electromagnetic (Eddy-Current) Examination of Nonmagnetic Heat Exchanger Tubes[1]

This standard is issued under the fixed designation E 690; 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 eddy-current examination (using an internal, probe-type, coil assembly) of nonmagnetic tubing that has been installed in a heat exchanger. The procedure recognizes both the unique problems of implementing an eddy-current examination of installed tubing, and the indigenous forms of tube-wall deterioration which may occur during this type of service. The document primarily addresses scheduled maintenance inspection of heat exchangers, but can also be used by manufacturers of heat exchangers, either to examine the condition of the tubes after installation, or to establish baseline data for evaluating subsequent performance of the product after exposure to various environmental conditions. The ultimate purpose is the detection and evaluation of particular types of tube integrity degradation which could result in in-service tube failures.

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

1.3 *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 standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing[2]

E 1316 Terminology for Nondestructive Examinations[2]

2.2 *Other Documents:*

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing[3]

ANSI/ASNT-CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel[3]

MIL-STD-410E Nondestructive Testing Personnel Qualification and Certification[4]

NAS-410 NAS Certification and Qualification of Nondestructive Personnel (Quality Assurance Committee)[5]

3. Terminology

3.1 Standard terminology relating to electromagnetic examination may be found in Terminology E 1316, Section C, Electromagnetic Testing.

4. Summary of Practice

4.1 The examination is performed by passing an eddy-current probe through each tube. These probes are energized with alternating currents at one or more frequencies. The electrical impedance of the probe is modified by the proximity of the tube, the tube dimensions, electrical conductivity, magnetic permeability, and metallurgical or mechanical discontinuities in the tube. During passage through the tube, changes in electromagnetic response caused by these variables in the tube produce electrical signals which are processed so as to produce an appropriate combination of visual displays, alarms, or temporary or permanent records, or combination thereof, for subsequent analysis.

NOTE 1—The agency performing the testing or examination shall meet the requirements of Practice E 543.

5. Significance and Use

5.1 Eddy-current testing is a nondestructive method of locating discontinuities in tubing made of materials that conduct electricity. Signals can be produced by discontinuities located either on the inner or outer surfaces of the tube, or by discontinuities totally contained within the tube wall. When using an internal probe, the density of eddy currents in the tube wall decreases very rapidly as the distance from the internal surface increases; thus the amplitude of the response to outer surface discontinuities decreases correspondingly.

5.2 Some indications obtained by this method may not be relevant to product quality. For example, an irrelevant signal may be caused by metallurgical or mechanical variations that

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[1] This practice is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.07 on Electromagnetic Methods.

Current edition approved Dec. 10, 1998. Published February 1999. Originally published as E 690 – 79. Last previous edition E 690 – 91.

[2] *Annual Book of ASTM Standards*, Vol 03.03.

[3] Available from Smerican Society for Nondestructive Testing, 1711 Arlingate Plaza, P.O. Box 28518, Columbus, OH 43228–0518.

[4] Available from Standardization Documents Order Desk, Bldg. 4, Section D, 700 Robbins Ave. Philadelphia, PA 19111–5904, Attn: NPODS.

[5] Available from Aerospace Industries Association of America, Inc., 1250 Eye Street, N.W., Washington, DC 20005.

are generated during manufacture but that are not detrimental to the end use of the product. Irrelevant indications can mask unacceptable discontinuities occurring in the same area. Relevant indications are those that result from nonacceptable discontinuities. Any indication above the reject level, which is believed to be irrelevant, shall be regarded as unacceptable until it is proven to be irrelevant. For tubing installed in heat exchangers, predictable sources of irrelevant indications are lands (short unfinned sections in finned tubing), dents, scratches, tool chatter marks, or variations in cold work. Rolling tubes into the supports may also cause irrelevant indications, as may the tube supports themselves. Eddy-current testing systems are generally not able to separate the indication generated by the end of the tube from indications of discontinuities adjacent to the ends of the tube (end effect). Therefore, this examination may not be valid at the boundaries of the tube sheets.

6. Basis of Application

6.1 The following criteria may be specified in the purchase specification, contractual agreement, or elsewhere, and may require agreement between the purchaser and the supplier.

6.1.1 Type of eddy-current system, and probe (coil assembly) configuration,

6.1.2 Location of heat exchanger, if applicable,

6.1.3 Size, material, and configuration of tubes to be examined,

6.1.4 Extent of examination, that is, length, tube sheet areas, straight length only, minimum radius of bends, etc.,

6.1.5 Time of examination, that is, the date and location of the intended examination, and the expected environmental conditions,

6.1.6 The source and type of material to be used for fabricating the calibration standard,

6.1.7 The type(s), method of manufacture, location, dimensions, and number of artificial discontinuities to be placed on the calibration standard,

6.1.8 Allowable tolerances for artificial discontinuities, and methods for verifying compliance,

6.1.9 Methods for determining the extent of end effect,

6.1.10 Maximum time interval between equipment calibration checks,

6.1.11 Criteria to be used in interpreting and classifying observed indications,

6.1.12 Disposition of examination records and calibration standard,

6.1.13 Contents of examination report, and

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

NOTE 2—MIL-STD-410 is canceled and has been replaced with NAS-410, however, it may be used with agreement between contracting parties.

6.1.15 If specified in the contractual agreement, NDT agencies shall be qualified and evaluated in accordance with Practice E 543. The applicable edition of Practice E 543 shall be specified in the contractual agreement.

7. Apparatus

7.1 *Electronic Apparatus*:

7.1.1 The electronic apparatus shall be capable of energizing the probe coils with alternating currents of suitable frequencies, and shall be capable of sensing changes in the electromagnetic response of the probes. It is important to note that a differential coil probe system tends to maximize the response from abrupt changes along the tube length, while a single coil probe system usually responds to all changes.

7.1.2 Since many gradual changes are irrelevant, a differential coil system may permit higher gain than an absolute coil system, which enhances the response to small, short defects. Electrical signals produced in this manner may be processed so as to actuate an audio or visual readout, or both. When necessary, these signals may also be further processed to produce a permanent record. The apparatus should have some means of providing relative quantitative information based upon the amplitude or phase of the electrical signal, or both. This may take many forms, including calibrated sensitivity or attenuation controls, multiple alarm thresholds, or analog or digital readouts, or combination thereof.

7.2 *Readout Devices*, which require operator monitoring, such as an oscilloscope or oscillograph presentation, may be used when necessary to augment the alarm circuits. This may be necessary, for example, to find small holes, indications of which tend to be nearly in phase with the response from lands in skip-fin tubing. Since the lands cause very large signals to occur, phase discrimination may not prevent irrelevant alarms from tube support, if the alarm is set to reject the hole. By observing an oscilloscope or oscillograph, however, the ability to detect this type of defect may be improved, especially in areas between the tube supports.

7.3 *Test Coils*—Test coils shall be capable of inducing current in the tube and sensing changes in the electrical characteristics of the tube. The test coil diameter shall be selected to yield the largest practical fill-factor. The configuration of the test coils may permit sensing both small, localized conditions, which change rapidly along the tube length, such as pitting or stress corrosion cracks, and those which may change slowly along the tube length or from tube to tube, such as steam cutting, mechanical erosion, or metallurgical changes. The choice of coil diameter should be based upon requirements judged to be necessary for the particular test situation.

7.4 *Single-Coil or Differential-Coil Probe Systems*:

7.4.1 *Single-Coil Probe Systems*—In a single-coil probe system, the signal obtained from the interaction between the test coil, and the portion of the test specimen within its influence is often balanced against an off-line reference coil in a similar specimen, often with the aid of electrical compensation. In some systems, electrical balancing of the test coil is accomplished entirely by the use of an electrical balance reference.

7.4.2 *Differential-Coil Probe Systems*—In a differential-coil probe system, the reference coil is identical to (again, often with the aid of electrical compensation), and on the same longitudinal axis as the test coil. In this type of configuration, both coils function simultaneously as test and reference coils, and the instrument responds only to unbalance voltages (that is, differential voltages) between the two coils.

7.4.3 In either the single or differential coil system, some form of original balance is attained and it is the disruption of this balance which provides the response signals that indicate deviations in the tube wall as compared to the original sample.

7.5 *Speed-Sensitive Equipment*—Eddy-current equipment that produces a variation in discontinuity signal response with variations in the test-scan speed. This is characteristic of equipment that employs filter networks to attenuate the detected signal at frequencies below or above, or both, an adjustable or fixed frequency. Speed insensitive d-c coupled equipment provides a constant discontinuity signal response with changing test speeds.

7.6 *Driving Mechanism*—A means of mechanically traversing the probe coil through the tube may be used. Whether the probe is traversed through the tube manually or mechanically, care should be taken to maintain as uniform a probe speed as possible to produce repeatable indications of discontinuities when using speed sensitive equipment.

7.7 *Phase-Selective System*—An instrumentation system that includes built-in circuitry to indicate phase differences in the response signal relative to the excitation signal. This ability aids in discriminating between abnormal conditions in the tube wall (cracks, pitting, wear from the tube supports) and normal change (lands in skip-fin tubing, the tube support itself, contaminants in or about the tube such as sludge, etc.). Phase may also provide information on defect position relative to the tube-wall surfaces, and this information may be used to estimate the relative severity of defects.

8. Reference Standards

8.1 The purpose of this type of examination is to provide information to aid in evaluating the condition of each heat exchanger tube, and in assessing the likelihood of failure during service. It is not possible to specify an all-inclusive reject level standard that would acknowledge all of the possible combinations of heat exchanger design (including tubing type and dimensions), environmental factors, type and amount of use, and acceptable level of operational shutdowns. The purpose of the standards is to standardize the instrument to find a number of common tube-wall changes of varying severity. The tube-wall deviations in a particular heat exchanger can be monitored over subsequent shutdowns, or be corrected, at the discretion of the user or through administration of a code specific to a class of users. Specific types and sizes of artificial discontinuities should be chosen to reflect both the purpose of the eddy-current examination in particular situations, and any knowledge of the type of defects, that can be expected to occur. A special consideration in this type of testing is the high probability of certain types of defects occurring in the area of the tube supports. It is recommended that a way of simulating the tube support (such as a simple outside diameter ring of a material similar to the tube support) be supplied, so that the influence of the tube support on the discontinuity signal may be observed.

8.2 The tube used when adjusting the sensitivity and phase settings of the apparatus shall be of the same material, dimensions, and configuration as the tubes installed in the heat exchanger.

8.3 It is important to note that artificial discontinuities may not be representative of natural discontinuities and may not provide a direct relationship between instrument response and discontinuity severity. They are intended only for establishing an approximation of sensitivity levels to various types of conditions. The relationship between instrument response and discontinuity size, shape, and location is important and should be established separately, particularly as a function of test frequency.

8.4 Since there may be a need to compare the results of this test procedure, as applied to a particular tube or heat exchanger, with the results of prior or subsequent examinations, it is important that a record be kept of each examination. The reference standard should be maintained to provide a basis for comparing results from successive examinations. In this situation it is recommended that the reference standards should provide at least three levels of readout, so that test data may be referred against a standardization curve. Tubes with indications in excess of a predetermined level should be recorded to identify the affected tube, its location, and, when necessary, to describe the level of response.

8.5 Any combination of notch size and shape might be incorporated in a standard tube. This determination must be made by the party responsible for the examination, within the context of the overall considerations mentioned in 9.1, and the functions a standard notch tube can serve. In the simplest case, where it is desired to establish and periodically verify the response of the test system to identify tubes with indications greater than some predetermined level, a single reference notch that causes the system to give an indication at that level may be sufficient for standardization. Where it is anticipated that comparisons of indications obtained over a period of time will need to be analyzed for trend information, it is suggested that at least three similar notches of progressively greater size be used to establish a calibration curve.

8.6 Notched tubes may also be used as a guide in qualifying a particular test system, including the coil configuration, to detect tube wall changes that approximate the size, shape, and location of those types of natural defects which are of interest in a particular heat exchanger. This is not to be confused with a reference standard, because the intent of this type of experimentation is to simulate the natural discontinuities in the tube walls. The user of this standard is cautioned to consider the disparity that may exist between the eddy-current response from artificial notches, and the response from natural defects. It is especially important that in the case of materials where work hardening affects the permeability of the material, techniques such as electrical discharge or abrasive machining should be used to produce notches, rather than conventional machining operations.

8.7 A ring made of a material similar to that used for the tube supports of the heat exchangers being examined (usually plain carbon steel) may be used to simulate the signals obtained from the tube supports. The thickness of the ring (the dimension parallel to the longitudinal axis of the tube, when the ring is slipped over the tube) should be the normal thickness of the tube support in the vessel to be tested. The inside diameter of the ring should be equal to the nominal inside diameter of the holes in the tube support, and the minimum outside diameter of the ring should equal the inside diameter plus twice the thickness of the ring in the axial direction.

9. Adjustment and Standardization of Apparatus Sensitivity

9.1 Choose a test frequency appropriate for the alloy and dimensions of the tubes being examined. The optimum frequency for a particular type of instrument should be determined through experimentation with samples identical to the tubing in the heat exchanger to be examined. The test probe diameter should be as large as possible, consistent with the need to pass through each tube freely.

9.2 Adjustment and standardization of the test equipment should follow the manufacturer's recommendations, and an approved specific procedure related to the particular application.

10. Procedure

10.1 The tubes should be as clean as practical before eddy-current examination is attempted.

10.2 Standardize eddy-current system at the start of each examination, and routinely check at appropriate intervals or whenever improper functioning of the system is suspected. If improper functioning occurs, resulting in a loss of apparatus sensitivity, restandardize the system in accordance with Section 9, and reexamine all tubes examined since the last standardization.

10.3 Examine the appropriate tubes, and note those which produce signals that exceed a predetermined maximum in accordance with the specific procedure being used.

10.4 Since defects may be corrected or action deferred to the next examination, depending upon the economics of the situation as measured in terms of overall costs versus useful life, it is important to ensure that each examination is properly standardized and records are accurately kept in order to recognize trends for particular heat exchangers.

11. Report

11.1 A report documenting the circumstances and results of each examination should contain the following information:

11.1.1 *General*:

11.1.1.1 The dates the examination was conducted,

11.1.1.2 The owner of the heat exchanger and its exact location,

11.1.1.3 The manufacturer of the heat exchanger, its serial number, and the location of the tubes examined in the bundle, and

11.1.1.4 The name of the individual responsible for conducting the examination and the name of a representative of the heat exchanger owner responsible for approving the procedure.

11.1.2 *Instrument Standardization*:

11.1.2.1 The manufacturer of the instrument and its type,

11.1.2.2 The instrument standardization procedure,

11.1.2.3 The size of the probe and its type,

11.1.2.4 A description of the reference standard used,

11.1.2.5 A description of the response from notches in the reference standard, and

11.1.2.6 The instrument settings for frequency and signal conditioning.

11.1.3 *Results*:

11.1.3.1 The location in the tube bundle of significant discontinuities, noting the amplitude and other relevant characteristics of these indications, and

11.1.3.2 An interpretation of the results and a description of any special circumstances.

12. Keywords

12.1 curie temperature; eddy-current; electromagnetic; NDT; nondestructive testing