Standard Practice for
Acoustic Pulse Reflectometry Examination of Tube Bundles[1]

This standard is issued under the fixed designation E2906/E2906M; 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 use of Acoustic Pulse Reflectometry (APR) technology for examination of the internal surface of typical tube bundles found in heat exchangers, boilers, tubular air heaters and reactors, during shutdown periods.

1.2 The purpose of APR examination is to detect, locate and identify flaws such as through-wall holes, ID wall loss due to pitting and/or erosion as well as full or partial tube blockages. APR may not be effective in detecting cracks with tight boundaries.

1.3 APR technology utilizes generation of sound waves through the air in the examined tube, then detecting reflections created by discontinuities and/or blockages. Analysis of the initial phase (positive or negative) and the shape of the reflected acoustic wave are used to identify the type of flaw causing the reflection.

1.4 When proper methods of signal and data analysis are developed, APR technology can be applied for sizing of flaw/blockage indications.

1.5 The values stated in either SI units or inch-pound 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 non-conformance with the standards.

1.6 *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:*[2]

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

2.2 *Other Documents:*

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

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

NAS-410 Certification and Qualification of Nondestructive Test Personnel[4]

3. Terminology

3.1 *Definitions*—See Terminology E1316 for general terminology applicable to this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *acoustic pulse reflectometry*—a technology for detecting, locating and analyzing sound reflections caused by discontinuities and abrupt changes on the internal surface of tubes and pipes as a response to an induced acoustic signal within the examined structure.

3.2.2 *reference signal*—a measured signal from a typical tube in the examined bundle without flaws or blockages. Reflections in the reference signal indicate structural features of the tube, probe or adaptor.

3.2.3 *signal-to-noise ratio (SNR)*—the ratio of the signal's Root Mean Square (RMS) to RMS of the noise signal.

3.2.4 *output gain*—the gain of the sound-source amplifier.

[1] This test method is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.10 on Specialized NDT Methods.

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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 Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org.

4. Summary of Practice

4.1 This practice describes the use of APR technology to detect, locate and identify flaws and blockages in tube bundles.

4.2 The practice describes typical APR apparatus and provides guidelines for:

4.2.1 APR system setup and performance verification.

4.2.2 APR examination and evaluation of examination results including signal analysis, indication detection, location, identification and sizing.

4.2.3 Preparation of examination report.

5. Significance and Use

5.1 APR technology is used for detection, location and identification of internal diameter (ID) flaws-indications and blockages in tube bundles.

5.2 Reliable and accurate examination of tube bundles is of great importance in different industries. On-time detection of flaws reduces a risk of catastrophic failure and minimizes unplanned shutdowns of plant equipment. Fast examination capability is of great importance due to reduction of maintenance time.

5.3 APR examinations are performed for quality control of newly manufactured tube bundles as well as for in-service inspection.

5.4 Performing an APR examination requires access to an open end of each tube to be examined.

5.5 Flaws that can be readily detected and identified include but are not limited to through-wall holes, ID pitting, erosion, blockages, bulging due to creep and plastic deformation due to bending.

5.6 APR can be applied to tube bundles made of metal, graphite, plastic or other solid materials with straight and curved sections. The APR technology has been found effective on tubes with diameters between 12.7 mm [½ in.] to 101.6 mm [4 in.] and lengths up to 18 metres [60 feet].

5.7 Closed cracks on ID surface, without significant geometrical alternation on ID surface, may not be detected by APR.

5.8 APR technology can be used for flaw sizing when special signal and data analysis methods are developed and applied.

5.9 In addition to detection of flaws and blockages, APR technology can be applied for assessing tube ID surface cleanliness, providing valuable information for equipment maintenance and improving its performance.

5.10 Other nondestructive test methods may be used to verify and evaluate the significance of APR indications, their exact position, depth, dimension and orientation. These include remote visual inspection, eddy current and ultrasonic testing.

5.11 Procedures for using other NDT methods are beyond the scope of this practice.

5.12 Acceptable flaw size can be calculated using methods of fracture mechanics and/or numerical modeling using finite element analysis techniques. These calculations are beyond the scope of this document.

6. Basis of Application

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

6.2 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally and internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, NAS-410, 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 described in Specification E543. The applicable edition of Specification E543 shall be specified in the contractual agreement.

6.4 *Extent of Examination*—The extent of examination includes the entire tube bundle unless otherwise specified.

6.5 *Reexamination of Repaired/Re-cleaned Worked Tubes*—Reexamination of repaired/re-cleaned items is not addressed in this practice and if required shall be specified in the contractual agreement.

7. Apparatus

7.1 Acoustic Pulse Reflectometry equipment includes:

7.1.1 An APR probe with:

7.1.1.1 A wideband sound source, usually a loudspeaker, capable of producing frequencies typically in the range of 0 to 8 kHz. Pulse width should be short enough to distinguish between reflections generated by flaws located at a mutual distance defined by practical requirements of the test. The sound source level should be high enough to ensure that the weakest reflected signal of interest is above the background noise level.

7.1.1.2 A probe-to-tube adaptor for matching between the probe diameter and the ID of the tube under inspection.

7.1.1.3 A microphone for measuring reflected sound waves.

7.1.2 A main unit that:

7.1.2.1 Generates and amplifies electric signals, typically performed by a processor, Digital-to-Analog Converter (DAC) and amplifier.

7.1.2.2 Sends the generated electric signals to the probe's sound source.

7.1.2.3 Records signals produced by reflected waves and captured by the microphone in a format suitable for evaluation, typically performed by a preamplifier, Analog-to-Digital Converter (ADC) and a processor.

7.1.2.4 Stores and displays measured data.

7.1.2.5 Optionally analyzes and interprets the measured data.

8. Calibration

8.1 System calibration shall include the complete Acoustic Pulse Reflectometry examination system and performed annually or prior to the first use.

8.2 Any change of the probe, extension cables, acoustic pulse reflectometry instrument, computer, or other recording instruments shall require recalibration of the system, and recalibration shall be noted on the report.

8.3 Should the system be found to be out of calibration during the examination, it shall be recalibrated. The recalibration shall be noted on the report. All tubes examined since the last valid calibration shall be reexamined.

9. System Setup and Performance Verification

9.1 System setup and performance verification shall be performed prior to conducting APR examination.

9.1.1 After setup a hardware test shall be conducted to make sure that all components are working. A test measurement shall be performed on a sample tube, and basic properties of the signal verified, such as signal amplitude and shape, to be within the specifications of the manufacturer.

9.1.2 APR system setup performed by adjustment of output gain to achieve the best SNR for the particular tube geometry and noise level. This is done by increasing output gain in steps. The output gain level is considered optimal when the noise created by a nonlinear distortion becomes larger than the background noise.

9.1.3 Performance verification of the system shall be conducted to ensure detection and sizing of flaws or blockages of interest prior to every APR examination. Performance verification can be done by examination of reference tube bundles. A typical reference tube bundle will include both flawless tubes and tubes with flaws including blockages, pits, holes and end-of-tube erosions. Performance verification is done by examination of the tubes in the bundle and identification of all flaws. An example of a reference tube bundle is provided in the Non-Mandatory Appendix.

10. Procedure

10.1 *Preparation for Examination:*

10.1.1 Verify that tube surfaces are sufficiently clean for conducting APR examination so possible discontinuities are surface open.

10.1.2 Blow out residual water.

10.2 Perform measurements on each tube of the bundle by inserting the APR probe's adaptor into the tube end, triggering the sound source, measuring reflections and storing measured signals into memory. Good sealing between the adaptor and the tube end should be ensured.

10.3 *Signal Analysis:*

10.3.1 Perform high pass signal filtering in the case of low frequency drift in the signal caused by elevated low frequency noise.

10.3.2 Perform low pass signal filtering in the case of high frequency signal oscillations caused by elevated high frequency noise.

10.3.3 It is recommended to subtract the reference signal from all the measured signals to eliminate reflections caused by structural features, the probe or the adaptor, that are not flaw or blockage related.

10.3.4 *Indication Detection*—Detect indications of flaws or blockages by considering recorded signals in the time domain and selecting positive and negative deviations of the signal which are above the noise level.

10.3.5 *Indication Location*—Evaluate location of detected indications by considering time-of-flight of the wave, speed of sound, adjusted for temperature from the probe to the source of reflection and back. Data shall be recorded as each tube is measured.

10.4 *Indication Identification*—It is possible to identify the type of the detected indication (through-wall holes, partial wall loss, tube blockages) by considering the form of the reflected signal (see Appendix X1).

10.5 *Indication Size Characterization*—When special methods of signal analysis are developed, it is possible to evaluate size of the detected indication by considering amplitude of the positive and negative deviations of the signal and time duration of the signal deviation. Particularly, in the case of blockage, APR can provide information about cross-section reduction. In the case of through-wall hole, it is possible to determine hole diameter and in the case of wall thickness reduction as a result of pitting or erosion, it is possible to evaluate overall, integral wall loss in the tube cross-section.

11. Report

11.1 A report of the examination shall be generated. The report shall include, at a minimum, the following information:

11.1.1 Owner, location, type, serial number, and identification of component examined,

11.1.2 Size, wall thickness, material type, and configuration of installed tubes,

11.1.3 Tube numbering system,

11.1.4 Extent of examination or tubes examined and length of tubes scanned,

11.1.5 Personnel performing the examination, and

11.1.6 Date of examination.

11.1.7 *Models, types, and serial numbers of components of the acoustic pulse reflectometry system:*

11.1.7.1 Probe-to-tube adapter model/type and extension length,

11.1.7.2 All instrument settings,

11.1.7.3 Signal-to-noise ratio,

11.1.7.4 Output gain,

11.1.7.5 Serial number(s) of reference tube(s),

11.1.7.6 Procedure used—identification and revision, and

11.1.8 Acceptance criteria used.

11.1.9 Identify tubes or specific regions where there was a limited sensitivity and other areas of reduced sensitivity or other problems caused reduced reliability of the APR examination.

11.1.10 Results of the examination and related sketches or maps of the examined area.

11.1.11 Other NDT examinations performed for further investigation or confirmation of test results.

11.1.12 Description of reference bundle tube(s) used for performance verification.

12. Keywords

12.1 acoustic pulse reflectometry; blockage; heat exchangers; through holes; tubes

APPENDIXES

(Nonmandatory Information)

X1. INDICATION TYPIFICATION

X1.1 It is possible to identify the type of the detected indication (through-wall holes, partial wall loss, tube blockages) by considering the form of the reflected signal.[5] Fig. X1.1 shows a schematic depiction of reflections from typical flaws. Assuming the impinging signal is a positive pulse, as in this figure, then a local decrease in cross section, caused for instance by a blockage, will have the form of a positive pulse followed by a negative one. An increase in cross section, caused by various forms of wall loss, will have the form of a negative pulse followed by a positive one. A through hole will appear as a sharp negative deviation followed by a slower return to zero. When special methods of signal analysis are developed, it is possible to use variations in reflection widths and heights for measuring abruptness or gradualness of these blockages and flaws, and their size.

[5] Amir, N., O. Barzelay, A. Yefet, T. Pechter, "Condenser Tube Examination Using Acoustic Pulse Reflectometry," *Journal of Engineering for Gas Turbines and Power*, January 2010, Vol. 132 / 014501-1.

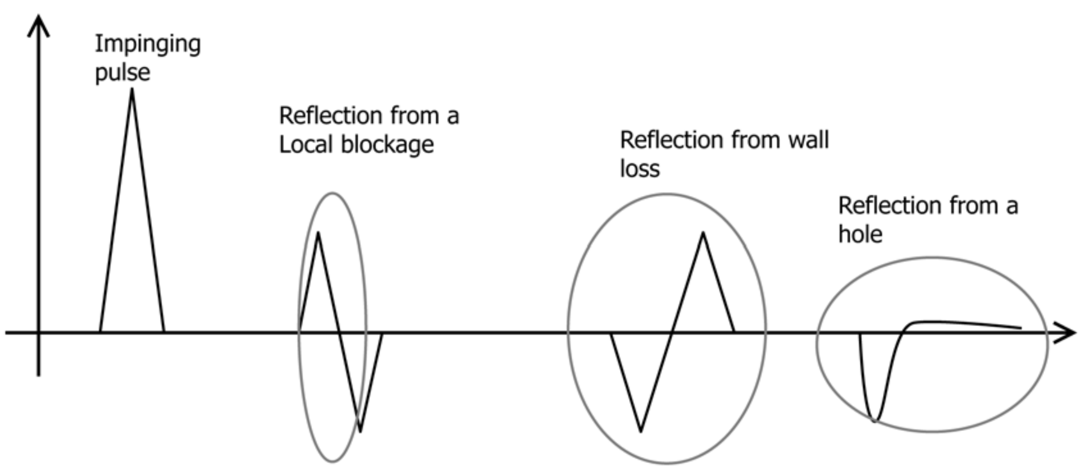

FIG. X1.1 Voltage vs. Time Plot—Signal Analysis from Various Types of Discontinuities

X2. PERFORMANCE VERIFICATION USING REFERENCE TUBE BUNDLE

X2.1 The recommended reference tube bundle should include at least one flawless blank tube, and three flawed tubes as specified in Fig. X2.1. The recommended dimensions of the reference tubes are:

- Length 1 metre [40 inch]
- Outer diameter 25 mm [1 in.]
- Wall thickness 2 mm [0.080 in.]

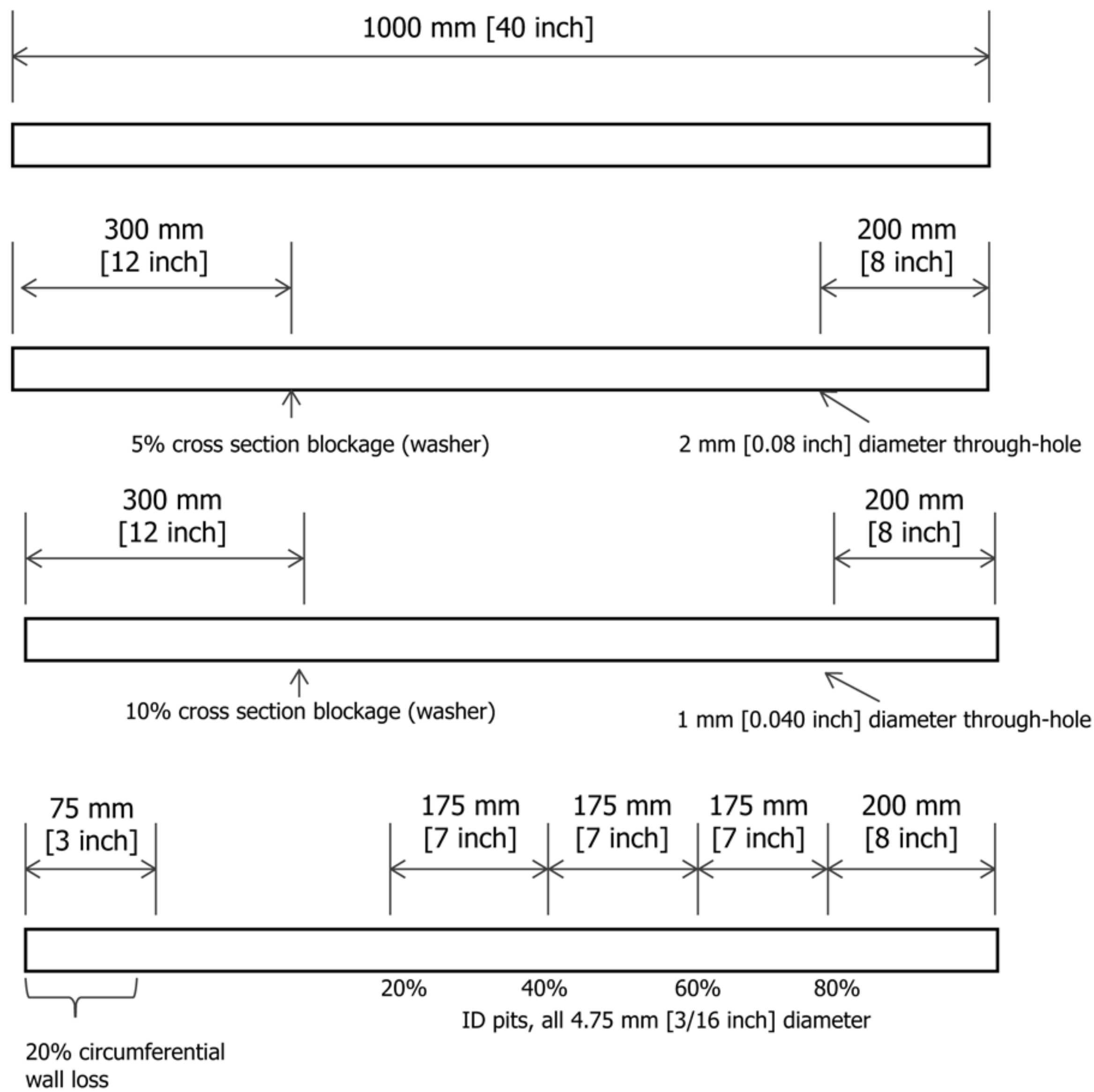

FIG. X2.1 Reference tube Specimens