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Standard Practice for Determination of Metal Purity Based on Elastic Constant Measurements Derived from Resonant Ultrasound Spectroscopy[1]

This standard is issued under the fixed designation E2985/E2985M; 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 is intended for use with resonant ultrasound spectrometers capable of exciting, measuring, recording and analyzing multiple whole body mechanical vibration resonant frequencies within parts exhibiting acoustical ringing in the acoustic or ultrasonic, or both, resonant frequency ranges.

1.2 This practice uses Resonant Ultrasound Spectroscopy (RUS) to distinguish conforming parts, as determined from qualified training sets, from those containing significant anomalies in their elastic properties.

1.3 The basic functions of a RUS monitoring system are to detect and classify resonance phenomena. Solid structure resonances are governed by the part's dimensions, density and elastic properties. When a material substitution occurs in a precious metal, the chosen metals have almost identical densities and unchanged dimensions, leaving only the elastic properties to affect the resonances.

1.4 This practice can be used to replace destructive methods, which damage the test object through drilling or melting, or both.

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 standard.

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

E2001 Guide for Resonant Ultrasound Spectroscopy for Defect Detection in Both Metallic and Non-metallic Parts

2.2 *Other Referenced Documents*

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

NAS-410 NDT Certification[4]

SNT-TC-1A Personnel Qualification and Certification in Nondestructive Testing[5]

3. Terminology

3.1 *Definitions*—The definitions of terms relating to conventional ultrasonic examination can be found in Terminology E1316.

3.2 *Resonant ultrasound spectroscopy (RUS)*—Basic RUS was originally applied in fundamental research applications in physics and materials science. A few other recognizable names include acoustic resonance spectroscopy, acoustic resonant inspection, and resonant inspection. Guide E2001 documents RUS extensively. A nondestructive examination method which employs the measurement and analysis of acoustic or ultrasound resonance patterns, or both, for the identification of acceptable variations in the physical characteristics of test parts in production environments. In this procedure an isolated, rigid part is caused to resonate. Certain resonances are measured and compared to a previously defined acceptable pattern combination of resonances. Based on this comparison the part is judged

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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 National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.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.

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

to be acceptable or, if it does not conform to the established pattern, to be unacceptable.

4. Summary of Practice

4.1 Reports indicating that gold bullion is being physically hollowed and replaced with similar density metals, such as tungsten, are surfacing. While not a huge concern for the original manufacturer, the secondary exchange market can experience disruption if the integrity of the asset comes into question. Verifying the sample purity is critical and must be performed quickly and nondestructively. Several potential test methods are applicable, but most are not good solutions for expense and technical reasons.

4.2 In physics, resonance is the tendency of a system to oscillate at a greater amplitude at some frequencies than at others. These are known as the system's resonance frequencies and are generally functions of the square root of the stiffness over the mass. Since each unique metal has a set of defined elastic constants, the stiffness of any two metals will always be different, meaning that the resonances produced from any driving forces will be different and easily measured. Resonances can be produced from any swept sine spectrometer (preferred) or with an impulse function (striking with a hammer). Independent of how the resonance spectrum is created, it can be measured and compared with known good samples to observe whether or not it has been altered as described in 4.4.

4.3 RUS, as defined in Guide E2001, describes a sample being excited by an exciting mechanical input (transducer) at a plurality of ultrasonic frequencies (the swept sine method), and sensing the resonant mechanical responses with the inverse process (one or two mechanical receiving transducers). A dynamic signal analyzer is connected to receive the response of the sample and to output the resonance spectrum. Either a computer, or visual observation, then determines the relevant resonances that adequately describe the conforming spectrum.

4.4 Training sets of acceptable bullion are readily available, and several mints have intentionally created doped samples to be used for comparison. This "training set" procedure has been used with multiple NDT methods to establish selection criteria. To manufacture training sets, metals of similar density are employed. For example, the density of gold is 19.30 g/cm^3 and tungsten is 19.25 g/cm^3, almost indistinguishable. Moreover, since bullion is cast into a form, the dimensions of a billet are not exact due to production variations. All of the world standard gold bars are defined as being 400 Troy ounces (12,441 g [27.43lb]). Any bar weighing from 380 to 420 Troy ounces (11,819 to 13,063 g) satisfy this requirement. Of course, the real value depends only on an accurate weight, which is stamped on the sample. RUS spectra are measured for many different samples to observe the differences from different mints and geometries. A RUS examination of doped samples is then used to illustrate spectral differences and establish detection limits.

5. Significance and Use

5.1 Since the beginning of human history, currency has existed in the form of metal coins and bullion. Thieves learned that shaving some precious metal provided a method to change its value. Substitution of common metals for precious metals of higher value was commonplace until weighing methods became so accurate, that it became easily detected. Alloys were also used as substitutes until inexpensive spectrometers became available which ended the counterfeiting practice. The rapid rise in the value of gold inspired the unscrupulous to find a new method. Tungsten was widely used for light bulb filaments until regulations changed that market. The great abundance of tungsten now available, coupled with the almost identical density of gold, presented a new opportunity.

5.2 RUS provides a method to create an unique electronic signature for each piece tested which is operator independent.

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*

6.2.1 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 similar 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 Practice E543. The applicable edition of Practice E543 shall be specified in the contractual agreement.

6.4 *Timing of Examination*—The timing of the examination shall be in accordance with a contractual agreement or with an established internal procedure.

6.5 *Extent of Examination*—This application requires sensor(s) placement such that the location where pipe movement occurs can be reliably detected.

6.6 *Reporting Criteria/Acceptance*—Reporting criteria for the examination results shall be in accordance with Sections 11 – 13.

6.7 *Reexamination of Repaired or Reworked Items*—Reexamination of repaired or reworked items is not addressed in this standard and if required shall be specified in a contractual agreement.

7. Examination Preparation

7.1 Before the examination begins, make the following preparations for RUS monitoring:

7.1.1 Determine the type, number, and placement of sensors. Two or three sensors are adequate for RUS testing with only a single part under examination;

7.1.2 The test stand shall be flexible to provide three point support, as this will ensure equal weight loading on each contact surface;

7.1.3 Appropriate resonant piezoelectric sensors with frequency range from 1 to 50 kHz shall be employed to provide the requisite excitation and receiving vibrations;

7.1.4 Establish communications between the control point for the application of the stimulus and responses to the examination control center;

7.1.5 Provide a means for continuously recording a measure of the resonances; and

7.1.6 A training set of parts should be assembled and examined by this method, from known "good" and "defective" pieces as previously determined by controlled castings. These data establish a baseline for future comparisons to define acceptable/reject parts, as this method is applicable to the repetitive examination of large sets of parts on a periodic basis, and not for one time testing of unique structures.

8. Safety Precautions

8.1 No specific safety hazards have been identified for this method, except for the physical handling of heavy parts (400 Troy ounce [27.43 lb billets]), which should be approached with caution

9. Calibration and Standardization

9.1 Annual calibration and verification of RUS sensors, preamplifiers (if applicable), signal processor (particularly the signal processor time reference), and RUS swept sine generator should be performed. Equipment should be adjusted so that it conforms to equipment manufacturer's specifications. A standard rectangular parallelepiped measuring 12.7 cm x 6.35 cm x 3.175 cm [5 in. x 2.5 in. x 1.25 in.] made from A36 low carbon steel plate shall accompany each system, and a baseline spectra shall be taken and stored for comparison. These dimensions were selected because they produce spectra in the same ranges of interest as the standard gold and silver billets.

9.2 A system performance verification must be conducted once per week whereby selected resonances shall be measured and compared with the baseline to ensure proper operation. Performance verifications can also be conducted during the examination if there is any suspicion that the system performance may have changed. Routine electronic evaluations (verification) must be performed any time there is a concern about signal generation or receiving performance. Each signal processor channel must respond within $\pm 3\ \Sigma$ when compared with the baseline sample.

10. Examination Procedure

10.1 RUS data shall be accumulated during the excitation of the structure, as specified in the written procedure.

10.1.1 The part to be examined shall be placed on a three point fixture such that the weight is equally distributed.

10.1.2 The part shall be examined according to the frequency range(s) established from an appropriate training set where the acceptable parts reliably indicate differences from known doped parts.

10.1.3 This procedure is followed for multiple parts and all data shall be archived to create a permanent record.

10.1.4 Following the examination of all parts within a series, repeat the performance verification in accordance with 9.2.

11. Examination Records

11.1 All system performance verification data and instrument adjustments, including equipment description and performance data, shall be included in the records of the examination with all pertinent qualification/certification records and be signed by the responsible RUS examiner. The information recorded should be sufficient to permit complete reanalysis of the results. This information should include, but not be limited to:

11.1.1 Serial number, dimensions of structure, purity of sample and, if possible, origin data,

11.1.2 Sensor specifications, frequency response and configuration of mounting stage,

11.1.3 Sensor locations,

11.1.4 Frequency ranges evaluated, and

11.1.5 Permanent data record of the measured RUS spectra in analog or digital form.

12. Interpretation of Results

12.1 All results shall be summarized on an appropriate display, or tabulated, or both, for ready reference and interpretation. This display or tabulation shall indicate the interpretation with respect to conforming, or nonconforming with pertinent comments.

13. Report

13.1 A report should contain at least the examination record, the interpretation of results and a diagram of the setup showing the sensor location(s). The report shall catalog all parts examined by type, serial number, weight and disposition (conforming/nonconforming)..

14. Keywords

14.1 elastic properties; nondestructive examination; nondestructive inspection; production variation; quality control; resonance inspection; resonances and vibration characteristics; resonant frequency; resonant mode; resonant ultrasound spectroscopy