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Standard Practice for Resonance Testing Using the Impulse Excitation Method¹

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1. Scope

1.1 This practice covers a general procedure for using the Impulse Excitation Method (IEM) to facilitate natural frequency measurement and detection of defects and material variations in metallic and non-metallic parts. This test method is also known as Impulse Excitation Technique (IET), Acoustic Resonance Testing (ART), ping testing, tap testing, and other names. IEM is listed as a Resonance Ultrasound Spectroscopy (RUS) method. The method applies an impulse load to excite and then record resonance frequencies of a part. These recorded resonance frequencies are compared to a reference population or within subgroups/families of examples of the same part, or modeled frequencies, or both.

1.2 Absolute frequency shifting, resonance damping, and resonance pattern differences can be used to distinguish acceptable parts from parts with material differences and defects. These defects and material differences include, cracks, voids, porosity, material elastic property differences, and residual stress. IEM can be applied to parts made with manufacturing processes including, but not limited to, powdered metal sintering, casting, forging, machining, composite layup, and additive manufacturing (AM).

1.3 This practice is intended for use with instruments capable of exciting, measuring, recording, and analyzing multiple whole body, mechanical vibration resonance frequencies in acoustic or ultrasonic frequency ranges, or both. This practice does not provide inspection acceptance criteria for parts. However, it does discuss the processes for establishing acceptance criteria specific to impulse testing. These criteria include frequency acceptability windows for absolute frequency shifting, scoring criteria for statistical analysis methods (Z-score), Gage Repeatability & Reproducibility (R&R) for diagnostic resonance modes, and inspection criteria adjustment (compensation) for manufacturing process and environmental variations.

1.4 This practice uses inch pound units as primary units. SI units are included in parentheses for reference only and are mathematical conversions of the primary units.

¹ This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.06 on Ultrasonic Method.

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

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 ASTM Standards:²

E1316 Terminology for Nondestructive Examinations

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

2.2 ISO and Other International Standards:

EN 1330-2 Non-destructive testing — Terminology — Part 2: Terms common to the non-destructive testing methods³

ISO 12680-1:2007 Methods of test for refractory products — Part 1: Determination of dynamic Young's modulus (MOE) by impulse excitation of vibration⁴

ISO 22605:2020 Refractories — Determination of dynamic Young's modulus (MOE) at elevated temperatures by impulse excitation of vibration⁴

3. Terminology

3.1 Definitions:

3.1.1 The definitions of terms relating to conventional ultrasonic examination can be found in Terminology E1316.

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *bandwidth, n* —the range of frequencies excited and recorded in the inspection.

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 European Committee for Standardization (CEN), Avenue Marnix 17, B-1000, Brussels, Belgium, <http://www.cen.eu>.

⁴ Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, <http://www.iso.org>.

3.2.2 *broadband*, *n*—the bandwidth, excitation parameters, and data collection parameters developed specifically for a particular part type.

3.2.3 *classification*, *n*—the labeling of a training set of parts as acceptable or unacceptable or the labeling of different sets of parts according to their manufactured, maintenance, or repair process parameters.

3.2.4 *compensation*, *n*—the adjustment of inspection criteria to accommodate variation in part characteristics caused by manufacturing processes or environmental conditions. Compensation requires the correlation of characteristics to resonance responses. Examples of variations that can require compensation include part mass (caused by manufacturing process variation) and part temperature during the test caused by either process or environmental conditions, or both. Various statistical tools can identify combinations of resonance patterns that are influenced by process variations, and they can accommodate for these differences.

3.2.5 *false negative*, *n*—part failing the sort but deemed by other method of post-test/analysis to have acceptable or conforming specifications.

3.2.6 *false positive*, *n*—part passing the sort but exhibiting a flaw (either inside the teaching set of flaws or possibly outside the teaching set range of flaws) or nonconforming to specification.

3.2.7 *family*, *n*—part with supposed same geometry, size, mass, material.

3.2.8 *Fast Fourier Transform (FFT)*, *n*—an algorithm that calculates the discrete Fourier transform (DTF) of some sequence. The discrete Fourier transform is a tool to convert specific types of sequences of functions into other types of representations. Another way to explain discrete Fourier transform is that it transforms the structure of the cycle of a waveform into sine parts.⁵

3.2.9 *impulse excitation method*, *n*—a resonance inspection method that involves striking an object with a mechanical impact causing multiple resonances to be simultaneously excited.

3.2.10 *lot*, *n*—a quantity of parts consecutively made under the same manufacturing conditions using qualitatively homogeneous materials, usually identified on the parts with a unique number/letter or combination thereof. This number may be referred to as a lot code, batch code, or date code depending on the manufacturer's preference.

3.2.11 *resonance spectra*, *n*—the recorded collection of resonance frequency data, representing the vibrational modes, including frequency peak locations and the characteristics of the peaks, for a particular part.

3.2.12 *resonant inspection (RI)*, *n*—any induced resonant nondestructive examination method that excites mechanical resonances of a part for the purpose of identifying a part's conformity to an established acceptable pattern.

3.2.13 *resonant ultrasound spectroscopy (RUS)*, *n*—a non-destructive examination method, which employs resonant ultrasound methodology for the detection and assessment of variations and mechanical properties of a test object. In this procedure, whereby a rigid part is caused to resonate, the resonances are compared to a previously defined resonance pattern. Based on this comparison the part is judged to be either acceptable or unacceptable.

3.2.14 *sort*, *n*—a software program or data analysis method capable of classifying a part as uniquely different from other parts. A productionized sort could identify parts as acceptable or unacceptable.

3.2.15 *training set*, *n*—a group of like parts including examples of known acceptable and known unacceptable components representative of the range of acceptable variability and unacceptable variability.

3.2.16 *work instruction*, *n*—a document with stepwise instructions developed for each examination program detailing the order and application of operations for IEM examination of a part.

3.2.17 *Z-score*, *n*—a statistical analysis that describes the position of a part's distance from the calculated mean, when measured in standard deviation units.

4. Significance and Use

4.1 *IEM Applications and Capabilities*—IEM has been successfully applied to a wide range of NDT applications in the manufacture, maintenance, and repair of metallic and non-metallic parts. Examples of anomalies detected are discussed in 1.1 and 6.2. IEM has been proven to provide fast, cost-effective, and accurate NDT solutions in nearly all manufacturing, maintenance, or repair modalities. Examples of the successful application focuses include, but are not limited to: sintered powder metals, castings, forgings, stampings, ceramics, glass, wood, weldments, heat treatment, composites, additive manufacturing, machined products, and brazed products.

4.2 General Approach and Equipment Requirements for IEM:

4.2.1 IEM systems are comprised of hardware and software capable of inducing vibrations, recording the component response to the induced vibrations, and executing analysis of the data collected.

4.2.2 *Hardware Requirements*—Examples of a tabletop impact excitation system and a production-grade drop excitation system are shown in Fig. 1 and Fig. 2, respectively. IEM systems include: an excitation device (for example, modal hammer / impact device / dropping system) providing an impulse excitation to the object, a vibration detector (for example, microphone), a signal amplifier, an Analog-to-Digital Converter (ADC), an embedded logic, and a data User Interface (UI). Tested parts can typically be on any surface type, but they can also be supported (for example, foam support, held with an elastic) in consideration of possible damping influences. The following schematics show the basic parts for an impact excitation approach (Fig. 3) and a drop excitation approach (Fig. 4).

⁵ <https://www.techopedia.com/definition/7167/fast-fourier-transform-fft>.