Designation: E3081 – 21

Standard Practice for Outlier Screening Using Process Compensated Resonance Testing via Swept Sine Input for Metallic and Non-Metallic Parts[1]

This standard is issued under the fixed designation E3081; 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 a general procedure for using the process compensated resonance testing (PCRT) via swept sine input method to perform outlier screening on populations of newly manufactured and in-service parts. PCRT excites the resonance frequencies of metallic and non-metallic test components using a swept sine wave input over a set frequency range. PCRT detects and analyzes component resonance frequency patterns and uses the differences in resonance patterns between acceptable and unacceptable components to perform non-destructive testing. PCRT frequency analysis compares the resonance pattern of a component to the patterns of known reference populations of the same component and renders a pass or fail result based on the similarity of the tested component to those populations. For non-destructive testing applications with known defects or material states of interest, or both, Practice E2534 covers the development and application of PCRT sorting modules that compare test components to known acceptable and unacceptable component populations. However, some applications do not have physical examples of components with known defects or material states. Other applications experience isolated component failures with unknown causes or causes that propagate from defects that are beyond the sensitivity of the current required inspections, or both. In these cases, PCRT is applied in an outlier screening mode that develops a sorting module using only a population of presumed acceptable production components, and then compares test components for similarity to that presumed acceptable population. The resonance differences can be used to distinguish acceptable components with normal process variation from outlier components that may have material states or defects, or both, that will cause performance deficiencies. These material states and defects include, but are not limited to, cracks, voids, porosity, shrink, inclusions, discontinuities, grain and crystalline structure differences, density-related anomalies, heat treatment variations, material elastic property differences, residual stress, and dimensional variations. 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.

1.2 *Units*—The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

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

1.4 *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

E2534 Practice for Targeted Defect Detection Using Process Compensated Resonance Testing Via Swept Sine Input for Metallic and Non-Metallic Parts

E3213 Practice for Part-to-Itself Examination Using Process Compensated Resonance Testing Via Swept Sine Input for Metallic and Non-Metallic Parts

3. Terminology

3.1 *Definitions:*

[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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[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.

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

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

3.2 *Definitions:*

3.2.1 *broadband, n*—the range of frequencies, excitation parameters, and data collection parameters developed specifically for a particular part type.

3.2.2 *classification, n*—the labeling of a teaching set of parts as acceptable or unacceptable.

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

3.2.4 *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.

3.2.5 *margin part, n*—a single part representative of a part type that is used to determine measurement repeatability and for system verification.

3.2.6 *Process Compensated Resonance Testing (PCRT), n*—PCRT is a nondestructive examination method that enhances RUS with pattern recognition capability. PCRT more effectively discriminates resonance frequency shifts due to unacceptable conditions from resonance frequency shifts due to normal, acceptable manufacturing process variations. The process employs the swept sine measurement and analysis of acoustic or ultrasonic resonance frequency patterns, or both. PCRT pattern recognition tools identify the combinations of resonance patterns that most effectively differentiate acceptable and unacceptable components. In outlier screening applications, statistical scoring of the resonance frequencies is used to compare components of the presumed acceptable population, quantify process variation, and characterize component populations.

3.2.7 *quality factor (Q factor), n*—dimensionless property of resonance peak that describes the peak shape, that is, width relative to the peak center frequency; peaks with higher Q factor values are narrower and sharper.

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

3.2.9 *Resonant Ultrasound Spectroscopy (RUS), n*—basic RUS was originally applied in fundamental research applications in physics and materials science (**1**)[3]. Other recognizable names include acoustic resonance spectroscopy, acoustic resonant inspection, and resonant inspection. Guide E2001 documents RUS extensively. RUS is a nondestructive examination method that employs the measurement and analysis of acoustic or ultrasonic resonance frequencies, or both, for the identification of acceptable variations in the physical characteristics of test parts in production environments. In this procedure an isolated, rigid component is excited, producing oscillation at the natural frequencies of vibration of the component. Diagnostic resonance frequencies are measured and compared to resonance frequency patterns previously defined as acceptable. Based on this comparison, the part is judged to be acceptable or, if it does not conform to the established pattern, unacceptable.

3.2.10 *sort, n*—for outlier screening applications, a software program capable of classifying a component as acceptable or outlying.

3.2.11 *teaching set, n*—for outlier screening applications, a group of like components including examples of only presumed acceptable production components representative of the range of acceptable variability.

3.2.12 *work instruction, n*—stepwise instructions developed for each examination program detailing the order and application of operations for PCRT examination of a part.

4. Summary of Practice

4.1 *Introduction:*

4.1.1 Many variations on resonance testing have been applied as nondestructive examination tools to detect structural anomalies that significantly alter component performance. The details of this basic form of resonance testing are outlined in Guide E2001.

4.1.2 Process Compensated Resonance Testing (PCRT) is a progressive development of the fundamental principles of RUS, and can employ various methods for enhancing the discrimination capability of RUS. Throughout the 1990s, application of RUS for production NDT led to better understanding of the challenges associated with differentiating resonance variations caused by structural anomalies from resonance variations from normal and acceptable process variation in mass, material properties and dimensions (**2**), (**3**). PCRT first became commonly used in the production examination of metal and ceramic parts in the late 1990s (**4**). By the early 2000s, PCRT had essentially developed into the robust NDT capability it is today (**5**).

4.1.3 PCRT is a comparison technology using a swept sine wave to excite the components through a range of resonance frequencies determined by the part's mass, geometry, and material properties. In outlier screening applications, the resonance spectrum is then compared to resonance spectra for presumed acceptable components. The database of presumed acceptable components is established through the collection of a teaching set of components that represent the range of acceptable process variation. PCRT outlier screening applications are taught to be insensitive to variations associated with acceptable components and identify resonance variations that indicate outlier components. PCRT outlier screening can use Z-score statistical analysis of frequencies for a large number of resonance modes to determine frequency averages and frequency deviation and set limits for each value. A component that exceeds either the frequency average or frequency deviation limits is flagged as outlier. PCRT outlier screening can also use pattern recognition and statistical scoring using the Mahalanobis-Taguchi System (MTS) to evaluate a test component for similarity to the training population using a smaller number of resonance modes. A component that exceeds the MTS-based limits is flagged as an outlier. In one examination cycle, PCRT-based outlier screening can identify outlier parts

[3] The boldface numbers in parentheses refer to the list of references at the end of this standard.