



Designation: E2534 – 10

Standard Practice for Process Compensated Resonance Testing Via Swept Sine Input for Metallic and Non-Metallic Parts¹

This standard is issued under the fixed designation E2534; 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 identify metallic and non-metallic parts' resonant pattern differences that can be used to identify parts with anomalies causing deficiencies in the expected performance of the part in service. This practice is intended for use with instruments capable of exciting, measuring, recording, and analyzing multiple whole body mechanical vibration resonant frequencies within parts exhibiting acoustical ringing in the audio, or ultrasonic, resonant frequency ranges, or both. PCRT is used in the presence of manufacturing process variance to distinguish acceptable parts from those containing significant anomalies in physical characteristics expected to significantly alter the performance. Such physical characteristics 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 properties differences, residual stress, and dimensional variations.

1.2 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.

1.3 *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:²

E1316 Terminology for Nondestructive Examinations

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.

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

3. Terminology

3.1 Definitions:

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 *resonant ultrasound spectroscopy (RUS)*—Basic RUS **(1)**³ 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 that 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 to be acceptable or, if it does not conform to the established pattern, unacceptable.

3.2.2 *process compensated resonant testing (PCRT)*—a non-destructive examination method which is an enhancement to RUS providing greater ability to identify resonant frequency shifts due to flaws and unacceptable variations in components in the presence of acceptable resonant frequency shifts accountable to normal manufacturing process variations. The process employs the measurement and analysis of acoustic or ultrasound, or both resonance patterns for the identification of unacceptable variations in the physical properties of examined parts in production environments. In classic RUS, this procedure in an isolated, rigid part is caused to resonate. resonances are measured and compared to a previously defined acceptable pattern of resonances. Based on this comparison the part is judged to be acceptable or, if it does not conform to the established pattern, to be, by default, unacceptable.

³ The boldface numbers in parentheses refer to a list of references at the end of this practice.

3.2.3 *teaching set*—a group of like components including examples of known acceptable and known unacceptable components representative of the range of acceptable variability and unacceptable variability.

3.2.4 *sort*—a software program capable of classifying a component as acceptable or unacceptable.

3.2.5 *classification*—the labeling of a teaching set of parts as acceptable or unacceptable.

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

3.2.7 *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.

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

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

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

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

4. Summary of Practice

4.1 Introduction:

4.1.1 Many variations on resonant testing have been used as an applied nondestructive examination tool in simple applications discriminating structural anomalies that significantly alter performance and are much greater than those seen in normal production parts as they vary in the population. The details of this basic form of resonant testing are outlined in Guide E2001.

4.1.2 Process compensated resonant 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 anomalies in a part from resonance variations resulting from normal and acceptable process variations such as mass, density and dimension variations within the acceptable tolerance for that part.(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 frequencies determined by the part's mass, geometry, and material properties, then recording the part's resonant responses to the

swept sine input signal. By comparing the resonance patterns of known acceptable components and unacceptable components, PCRT applications are *taught* to be sensitive to resonance variations associated with unacceptable components and also *taught* to be insensitive to variations associated with acceptable components. This initial teaching phase produces a part specific examination application, applying known statistical tools to the entirety of the collected spectra of the available acceptable and unacceptable parts while determining a set of relationships of resonant frequencies representing patterns found in the acceptable parts, and selecting those relationships specifically excluding patterns found in the spectra of unacceptable parts. This procedure yields a sort for examination that compares portions of the spectra of the part being examined to a set of relationships determined in the teaching phase. If the spectra of the examined component fall within an acceptance range of the acceptable pattern, then the part will be classified as acceptable. In one examination cycle, PCRT-based techniques can test for a single anomaly, or for combinations of anomalies, as listed in 1.1. The PCRT measurement yields a whole body response, finding structurally-significant anomalies anywhere within the part, but it is generally not capable of determining the type or location of the anomaly. A teaching set of parts must contain both acceptable and unacceptable samples as determined by someone knowledgeable of the design, validation testing, and minimum functional requirements of the part.

4.1.4 PCRT can be applied to new parts in the production environment, to parts currently in service, or in a combined program in which parts are initially classified as free of substantial anomalies in production, and then periodically re-examined with PCRT in order to monitor for the accumulation of fatigue and damage resulting from use. An example of the application of PCRT is given here with respect to gas turbine blades. Application of PCRT to the blades in the production environment can be used to accept only parts free of manufacturing and material defects such as cracks, voids, shifted cores, heat treatment irregularities, and the like. Since turbine blades are periodically inspected throughout their useful lives, PCRT can be applied during these inspections to accept only parts that are free of service induced defects such as gamma prime solutioning, rafting, cracks, inter-granular attack, or excessive wear.

4.1.5 This practice is intended to provide a practical guide to the application of PCRT based nondestructive examination (NDT) to metallic and non-metallic parts. It highlights the steps necessary to produce robust and accurate test applications and outlines potential weaknesses, limitations and factors that could lead to a part's misclassification. Some basic explanations of resonances, and the effects of anomalies on them, are found in 4.2. Some successful applications and general description of the equipment necessary to successfully apply PCRT for classification of production parts are outlined in 5.1 and 5.2, respectively. Additionally, some constraints and limitations are discussed in 5.3. The general procedure for developing a part-specific PCRT application is laid out in 6.1.

4.2 Resonances and the Effect of Anomalies:

4.2.1 The swept sine method of vibration analysis operates by driving a part at given frequencies (audio through ultrasound, depending on the part characteristics) and measuring its mechanical response. Fig. 1 contains a schematic for one embodiment of a PCRT apparatus. The process proceeds in small frequency steps over a previously determined and predicted range of interest. During such a sweep, the drive frequency brackets the expected location of a resonance. When the excitation frequency is not matched to one of the part's resonance frequencies, very little energy is coupled to the part; that is, there is essentially no vibration. At resonance, however, the energy delivered to the part is coupled, generating much larger vibrations. A part's resonance frequencies are determined by its geometry (to include the shape and dimensions) and by the density and the elastic constants (mechanically equivalent to mass, stiffness, and damping) of the material. An example of the resonance spectra for a part is shown in Fig. 2 for reference.

4.2.2 If a structural anomaly, such as a crack, is introduced into a region under strain, it will change the effective stiffness of a part (decrease stiffness for a crack). That is, the part's resistance to deformation will change and will shift some of the part's resonant frequencies (downward for decreasing stiffness). Voids in a region can reduce mass and increase certain resonant frequencies. In general, any change to a part that alters the structural integrity, changes a geometric feature or affects the material properties will alter its natural resonance frequencies. Graphic examples of the effects of various anomalies on resonances are presented in Guide E2001.

4.2.3 For example, the torsional (twisting) resonant modes represent a twisting of a part about its axis. In the simple example of a long cylinder, these resonances are easily identified because some of their frequencies remain constant for a fixed length, independent of diameter. A crack will reduce the ability of the part to resist twisting, thereby reducing the effective stiffness, and thus, the frequency of a torsional mode

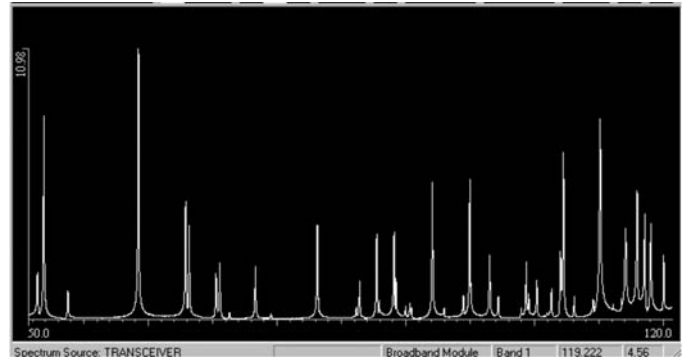


FIG. 2 Resonance Spectra (50 kHz – 120 kHz)

both shifts to a lower value and then alters the mode shape. Other resonances representing different resonant motions of the part will not be affected in the same manner. Also, a large structural anomaly can be detected readily by its effect on the first few resonant frequencies. However, smaller structural anomalies have much more subtle and localized effects on stiffness, and therefore, often require higher frequencies (high-order resonant modes and harmonics) to be detected. In general, it must be remembered that most parts will exhibit complex motions when resonating and analyzing the relationship between the resonant frequencies provides one way to generate the information necessary to interpret the data resulting from measuring the frequencies of the various resonant modes. These relationships form one basis for detecting the difference between normal, expected variations and variations indicating significant structural or geometric differences from one part to another. A broad body of research is available describing various other nonproprietary approaches to identifying significant features (flaws, damage, etc) from changes in their vibration characteristics in the presence of environment or process variation.(6)

5. Significance and Use

5.1 *PCRT Applications and Capabilities*—PCRT has been applied successfully to a wide range of NDT applications in the manufacture and maintenance of metallic and non-metallic parts. Examples of anomalies detected are discussed in 1.1.1. PCRT has been shown to provide cost effective and accurate NDT solutions in many industries including automotive, aerospace, and power generation. Examples of successful applications currently employed in commercial use include, but are not limited to:

- (1) Silicon nitride bearing elements
- (2) Investment cast steel rocker arms
- (3) Cast gas turbine blades
- (4) Stamped and brazed steel rocker arms
- (5) Cast aluminum knuckles and control arms
- (6) Cast ductile iron control arms
- (7) Cast cylinder heads and cylinder blocks
- (8) Sintered powder metal gears and clutch plates
- (9) Machined forged steel steering racks
- (10) Machined forged steel transmission gears and shafts
- (11) Ceramic oxygen sensors
- (12) Silicon wafers

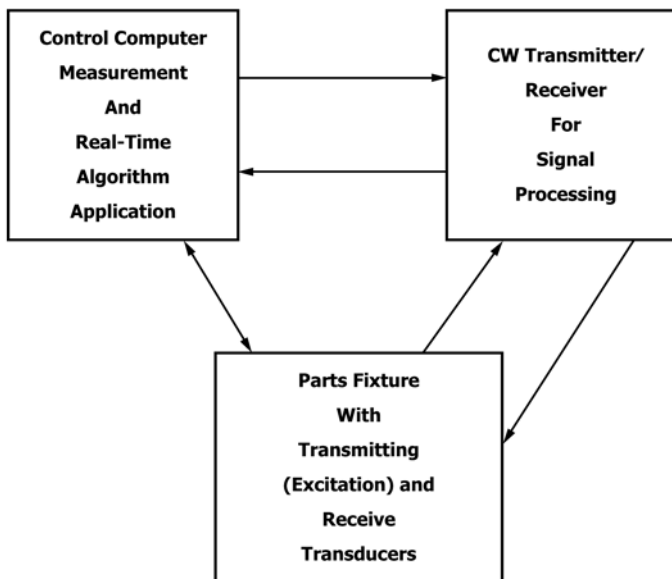


FIG. 1 PCRT System Schematic