Designation: E2534 – 20

Standard Practice for
Targeted Defect Detection Using Process Compensated Resonance Testing Via Swept Sine Input for Metallic and Non-Metallic Parts[1]

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 for metallic or non-metallic parts to compare resonance patterns from a sample under test to reference teaching sets of known acceptable and targeted defect samples. The resonance pattern differences can be used to distinguish acceptable parts with normal process variation from parts with targeted material states and defects 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

E3081 Practice for Outlier Screening 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:*

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 *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.

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[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**

3.2.6 *Process Compensated Resonance Testing (PCRT), n*—a nondestructive examination method that enhances swept sine input RUS with pattern recognition capability and statistical scoring.

3.2.6.1 *Discussion*—PCRT more effectively discriminates between resonance frequency shifts due to unacceptable conditions and resonance frequency shifts due to normal, acceptable manufacturing process variations. The process employs the measurement and analysis of acoustic or ultrasound resonance frequency patterns, or both. PCRT pattern recognition tools identify the combinations of resonance patterns that most effectively differentiate acceptable and unacceptable components. Statistical scoring of the resonance frequencies is used to compare components to known acceptable and unacceptable populations, quantify process variation, and characterize component populations.

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

3.2.8 *Resonant Ultrasound Spectroscopy (RUS)*—Basic RUS (**1**)[3] was originally applied in fundamental research applications in physics and materials science.

3.2.8.1 *Discussion*—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.

3.2.9 *sort, n*—a software program capable of classifying a component as acceptable or unacceptable.

3.2.10 *teaching set, n*—a population of components including examples of known acceptable and known unacceptable components representative of the range of acceptable variability and unacceptable variability; the teaching set may consist entirely of physical components, or a combination of physical components and modeled components whose resonance spectra are generated by physics-based simulations.

3.2.11 *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 variation from normal and acceptable process variations 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. The resonance spectrum is then compared to resonance spectra for known acceptable components and unacceptable components. The database of known acceptable and unacceptable components is established through the collection of a teaching set of components that represent the range of acceptable process variation and the unacceptable conditions of interest. 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. PCRT pattern recognition tools identify the combination of resonance frequencies that most effectively differentiate the acceptable and unacceptable components. Statistical tools score each component based on its similarity to the known acceptable and unacceptable populations and establish scoring PASS/FAIL limits for each criterion. A component with resonance frequencies sufficiently similar to the acceptable components and different from the unacceptable components will pass the PCRT inspection. A component that fails either criteria will be rejected. 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. If unacceptable samples are not available, an alternative PCRT approach called PCRT Outlier Screening may be applied. Practice E3081 describes the Outlier Screening approach.

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. The process for using frequency changes between different points in time to perform NDT and process monitoring and control is described

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

in more detail in Practice E3213. One example of a PCRT application is gas turbine engine blades. Application of PCRT to the blades in the production environment can detect targeted manufacturing and material defects such as casting shrinkage, cracks, voids, shifted cores, heat treatment irregularities, and other material variation. Since turbine blades are periodically inspected throughout their useful lives, PCRT can be applied during these in-service inspections to accept only parts that are free of service-induced defects such as gamma prime solutioning, rafting, creep, cracks, inter-granular attack, and excessive wear and fatigue.

4.1.5 This practice is intended to provide a practical guide to the application of PCRT-based nondestructive testing (NDT) to targeted defects in both 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 misclassification of a part. 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 (acoustic through ultrasonic, depending on the part characteristics) and measuring its mechanical response. Fig. 1 contains a schematic for one embodiment of a PCRT apparatus. The swept sine wave proceeds in small frequency steps over a previously determined broadband frequency range of interest. 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, density, and material 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) (Fig. 3) 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 both shifts to a lower value and then alters the mode shape. Other resonances representing different resonance mode shapes 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. 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

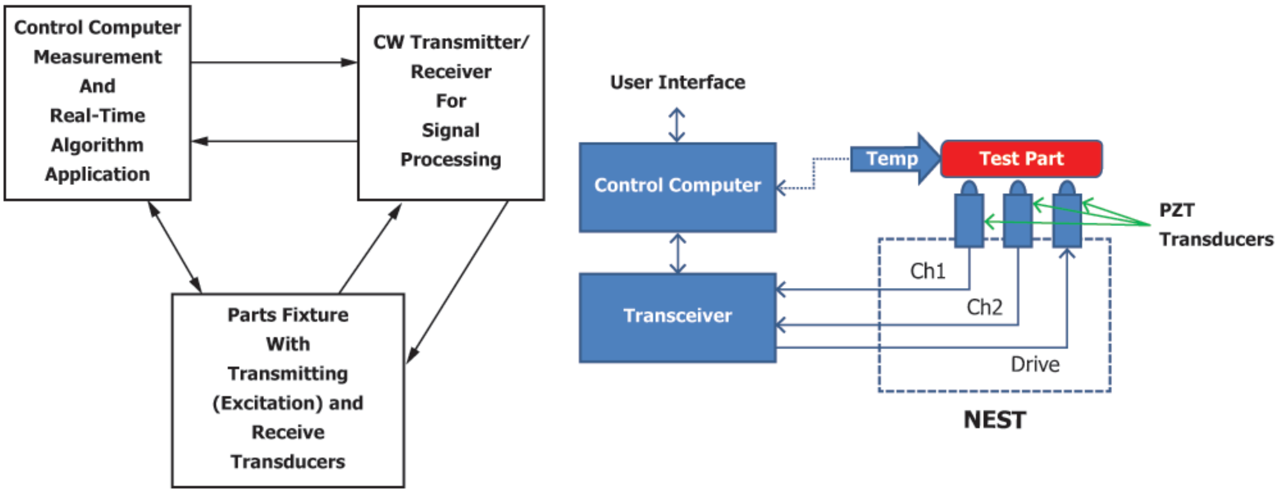

FIG. 1 PCRT System Schematics

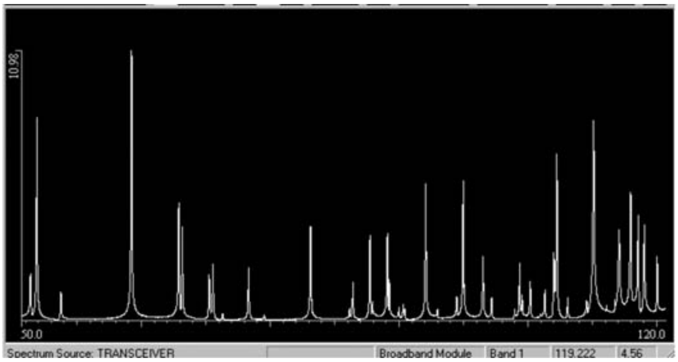

FIG. 2 Resonance Spectra (50 kHz – 120 kHz)

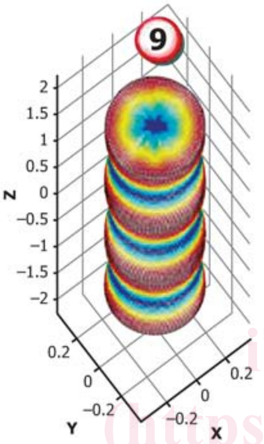

FIG. 3 Torsional Mode for Cylinder

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. 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) Steel, iron, and aluminum rocker and control arms

(3) Aircraft and industrial gas turbine engine components (blades, vanes, disks)

(4) Cast cylinder heads and cylinder blocks

(5) Sintered powder metal gears and clutch plates

(6) Machined forged steel steering and transmission components (gears, shafts, racks)

(7) Ceramic oxygen sensors

(8) Silicon wafers

(9) Gears, including those with induction hardened or carburized teeth

(10) Ceramic matrix composite (CMC) material samples and components

(11) Components with shot peened surfaces

(12) Machined or rolled-formed fasteners

(13) Components made with additive manufacturing

(14) Aircraft landing gear, wheel, and brake components

(15) Components made with metal injection molding

5.2 *General Approach and Equipment Requirements for PCRT via Swept Sine Input:*

5.2.1 PCRT systems comprise hardware and software capable of inducing vibrations, recording the component response to the induced vibrations, and executing analysis of the data collected. Inputting a swept sine wave into the part has proven to be an effective means of introducing mechanical vibration and can be achieved with a high quality signal generator coupled with an appropriate active transducer in physical contact with the part. Collection of the part's frequency response can be achieved by recording the signal generated by an appropriate passive vibration transducer. The software required to analyze the available data may include a variety of suitable statistical analysis and pattern recognition tools. Measurement accuracy and repeatability are extremely important to the application of PCRT.

5.2.2 *Hardware Requirements*—A swept sine wave signal generator and response measurement system operating over the desired frequency range of the test part are required with accuracy better than 0.002 %. The signal generator should be calibrated to applicable industry standards. Transducers must be operable over same frequency range. Three transducers are typically used; one *Drive* transducer and two *Receive* transducers. Transducers typically operate in a dry environment, providing direct contact coupling to the part under examination. However, non-contacting response methods can operate suitably when parts are wet or oil-coated. Other than fixturing and transducer contact, no other contact with the part is allowed as these mechanical forces dampen certain vibrations. For optimal examination, parts should be placed precisely on the transducers (generally, ±0.062 in. (1.6 mm) in each axis provides acceptable results). The examination nest and cabling shall isolate the *Drive* from *Receive* signals and ground returns, so as to not produce (mechanical or electrical) *cross talk* between channels. Excessive external vibration or audible noise, or both, will compromise the measurements.

5.3 *Constraints and Limitations:*

5.3.1 PCRT cannot separate parts based on visually detectable anomalies that do not affect the structural integrity of the part. It may be necessary to provide additional visual inspection of parts to identify these indications.

5.3.2 Excessive process variation of parts may limit the sensitivity of PCRT. For example, mass/dimensional variations exceeding 5 % may cause PCRT to be unusable.

5.3.3 Specific anomaly identification is highly unlikely. PCRT is a whole body measurement and differentiating between a crack and a void in the same location is generally not possible. It may be possible to differentiate some anomalies by using multiple patterns and training sets. The use of physics-based modeling and simulation to predict the resonance frequency spectrum of a component may also allow relationships between resonance frequencies and defect locations/characteristics to be established.

5.3.4 PCRT will only work with stiff objects that provide resonances whose frequency divided by their width at half of the maximum amplitude (Q) are greater than 400 to 500. Although steel parts may be very stiff and perfectly reasonable to use for PCRT, steel foil would generally not be.

5.3.5 While PCRT can be applied to painted and coated parts in many cases, the presence of some surface coatings such as vibration-absorbing materials and heavy oil layers may limit or preclude the application of PCRT.

5.3.6 While PCRT can be applied to parts over a wide range of temperatures, it should not be applied to parts that are rapidly changing temperature. The part temperature should be stabilized before collecting resonance data.

5.3.7 Misclassified parts in the teaching set, along with the presence of unknown anomalies in the teaching set, can significantly reduce the accuracy and sensitivity of PCRT.

6. Procedure

6.1 Successful PCRT application development and implementation follows a standard flow. The stepwise functions required in the flow are:

(1) Collection of a teaching set of components

(2) Design and fabrication of a test nest or appropriate fixturing

(3) Understanding the effects of temperature on the resonance spectra

(4) Specification of a resonance broadband data collection parameters

(5) Evaluate system measurement repeatability and reproducibility (similar to Gauge R and R) with respect to mounting parameters

(6) Collection of data from the teaching set of parts

(7) Analysis of collected data for pattern recognition

(8) Generation of a sort to classify examined parts

(9) Validation of the sort against the teaching set components and unknown components

(10) Issuance for the work instruction for the specific part

(11) Validation of work instructions and technician training against control set of components

(12) Execution of the work instruction for component examination

6.1.1 *Collection of Teaching Set Parts*—The collection of the initial teaching set of components is critical to the successful application of PCRT. The teaching set must represent the range of acceptable variation in the part appropriate to the intended state of the parts to be examined and must also represent the known range of anomalies of interest. While it is possible to add additional acceptable and unacceptable parts to the teaching set over time, it is most desirable to have full range of representation of both acceptable and unacceptable variability from the onset of the project. The total number of parts required for the teaching set varies as a function of the range of acceptable and unacceptable variations present. A guideline however is that roughly 100 parts with a ratio of two acceptable components to one unacceptable component works for most applications. Processes that produce tightly controlled parts with small acceptable variations may require a smaller teaching set, while a process with a wide range of acceptable variation and multiple sources of anomalies may require large teaching sets. It is critical that the classifications of the teaching set be accurate, and that they are made by personnel knowledgeable of the design, validation, examination, and minimum required functional requirements of the part. Improperly classified parts in the teaching set lead to reduced sensitivity to anomalies, increased false positive examination results, and increased potential for a false negative examination result.

6.1.1.1 *Classification of Teaching Set Parts by NDT*—Other NDT techniques such as magnetic particle, dye penetrant, X-ray, eddy current, ultrasound, computed tomography, SONIC IR, Flash Thermography, and visual inspection can be useful in determining the correct classification of parts in the teaching set. However, it must be understood that indications from other NDT methods must be confirmed to be actual anomalies of interest by personnel knowledgeable of the design, validation, examination, and minimum required functional specifications of the part. An example that highlights this requirement is that a scratch in the surface of a part may result in a dye penetrant indication, yet the scratch is unlikely to have an effect on the resonance of the part, nor is it likely to adversely affect the structural integrity and/or performance of the part. By classifying this part as unacceptable in the teaching set due to the dye penetrant indication, an acceptable resonance pattern will be included in the population of unacceptable patterns, confound the pattern recognition algorithm and degrade the performance of the examination.

6.1.1.2 *Classification of Teaching Set Parts by Destructive Examination*—Destructive methods, including, but not limited to, static and dynamic functional examination, sectioning, and metallographic analysis, have proven to be the best classifiers for teaching set parts. Because the resonance spectra of a part can be stored permanently, classifications can be assigned to the spectra after destructive examination. When there is any doubt about the proper classification of a teaching set part, destructive testing is the recommended method for resolution. Functional performance examination of a statistically significant set of parts and assigning classifications based on performance (acceptable classification for parts meeting or exceeding design goals, unacceptable for all others) results in PCRT sorting that correlates well with part performance. Fig. 4 shows the results of such a program for clutch plates. All parts passing the sorting algorithm based on destructive examination meet or exceed design goal of 75k cycles.

6.1.1.3 *Creation of Teaching Set Parts with Physics-Based Simulation*—In the absence of statistically significant populations of teaching set parts, or in the absence of components with the defects of interest, physics-based simulations of components can be used to generate teaching set resonance spectra. Those simulated spectra can be input into the PCRT software and analyzed with the same tools as spectra collected from physical components. Simulations of the acceptable population must include the normal variation in geometric and material properties observed in the physical population. The unacceptable population must include accurate simulations of the defects or unacceptable material states of interest, or both.

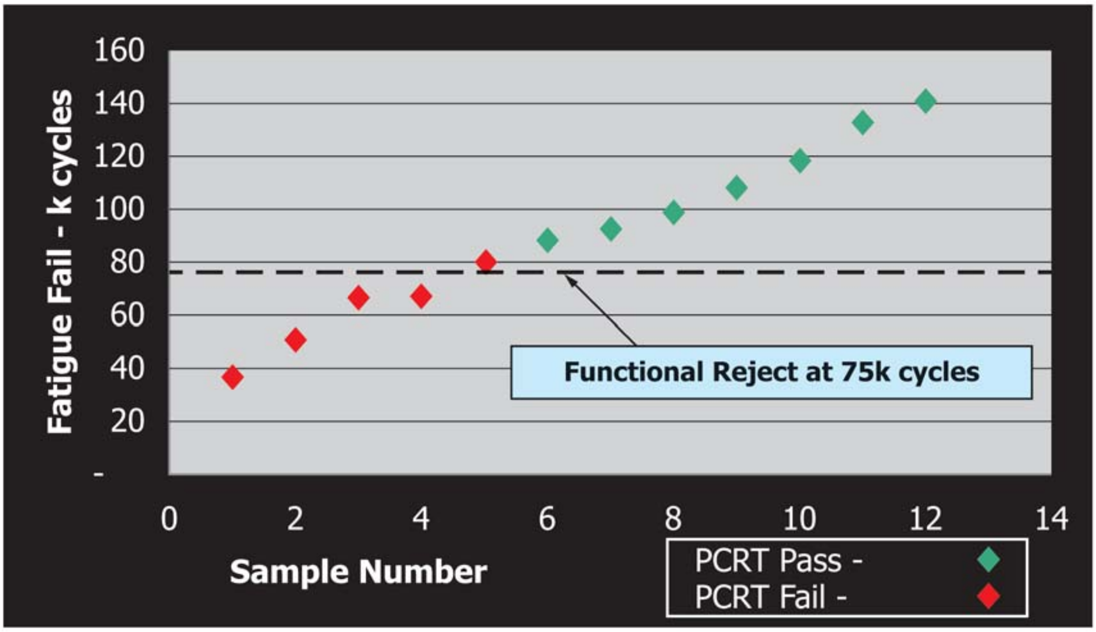

FIG. 4 PCRT Sort Based on Fatigue Failure Classifications

A teaching set using simulated resonance spectra must still include enough measured spectra from physical components to verify and validate the models. The methods for simulating the defects of interest should be verified and validated with examples of physical components with those defects. If end-use components with defects of interest are not available, coupon specimens with naturally occurring or induced examples of the defects may be compared with simulated examples.

6.1.2 *Design and Fabrication of Test Nest*—Because the nest on which testing is performed and data is collected defines the boundary conditions for the resonating part, care must be taken in its design to ensure accurate and repeatable location of the part relative to the transducers and support. While optimal nest design is often experimentally determined, the following objectives give direction to the experimentation:

(1) Position the driven transducer in an area of the part with significant mass to ensure adequate coupling of the transducer to the part.

(2) If multiple receive transducers are used, place them at different distances from the drive transducer, and attempt to have each carry a similar portion of the part's weight.

(3) The fixture should be isolated from vibrations induced by the operating environment.

(4) Ease of part placement and protection of transducers in operation should be considered in the design.

(5) If multiple nests are to be used to examine a single part type, the nests must be confirmed to produce comparable results for a given input.

(6) For parts up to about 45 lb (20.41 kg), the common practice is to support the part on the drive transducer and receiving transducers (see Fig. 5 and Fig. 6).

(7) For heavier objects, it is often more practical to support the part on some isolating material and to contact the part with the drive and receiving transducers, often lowered into contact from the top.

6.1.3 *Understanding Effects of Temperature on Resonance Spectra*—While PCRT can perform over the wide range in temperatures encountered in the manufacturing and operating environments, care must be taken to ensure that data quality is not adversely affected by temperature effects. Because the resonances of materials vary with changes in temperature, it is important that the effect of temperature on a particular part's spectra is well understood, and also important to ensure that the part is at a stable temperature during data collection and examination. At least one method of compensating for the effects of temperature on the resonance spectra of parts is covered under U.S. patents.

6.1.4 *Specification of Resonance Broadband and Data Collection Parameters*—Each part type will have a range of frequencies relevant to PCRT based on the part's mass, geometry, and material properties. An aluminum or steel part of 1 lb (0.45 kg) may have a useful frequency range of up to 200 kHz or greater, where as a steel part of 25 lb (11.34 kg) may have a frequency range of up to 50 kHz. Special applications such as ceramic roller elements may require frequencies above the 500 kHz – 10 MHz range. With the range of frequencies determined, the excitation and data collection parameters must be optimized throughout that range to ensure accurate and repeatable data is collected.

6.1.5 *Evaluation of the System Measurement Repeatability with Respect to Nest and Part*—Prior to collection of the training set data it is important to develop a complete understanding of the measurement repeatability and reproducibility for the system including the nest and part. First, a single acceptable part is designated as the *margin part*, and at least 30 full spectra for that part are collected, with the part being removed and replaced each time. It is advisable to collect the margin part spectra at a range of temperatures, and with a plurality of operators, that represents the anticipated operating environment of the PCRT system. The purpose of this data collection is to support statistical evaluation of the combined

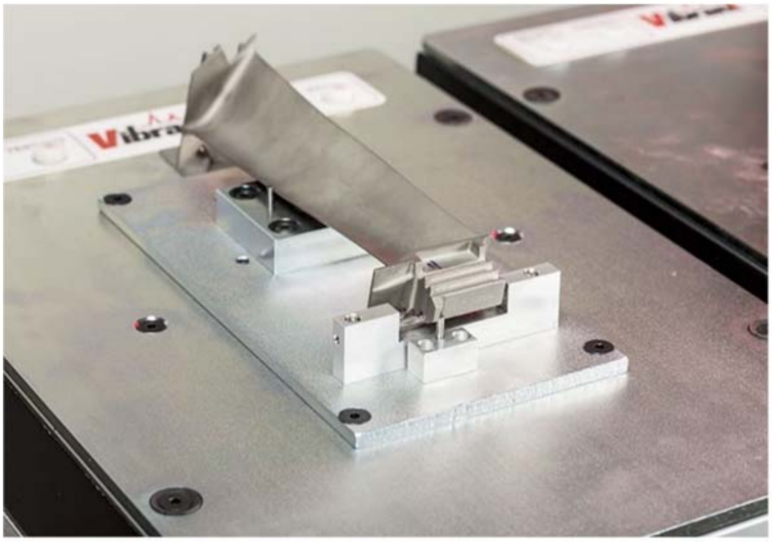

FIG. 5 Cast Turbine Blade Test Nest

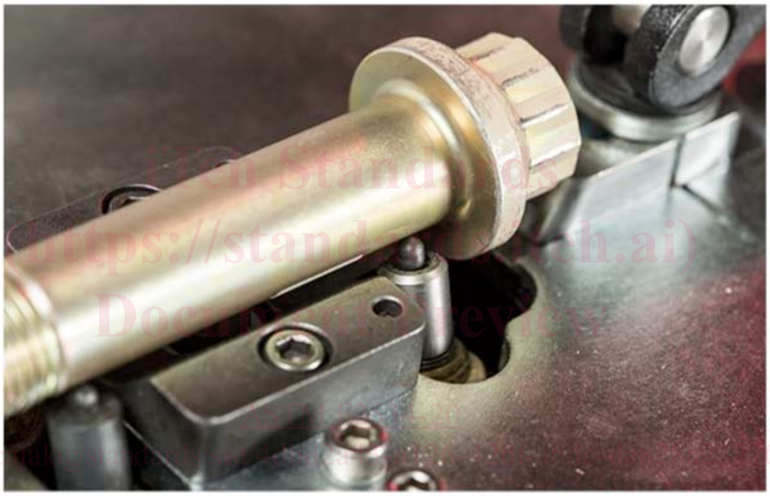

FIG. 6 Aerospace Fastener Test Nest

effect of placement accuracy and system measurement and operators' variability. If the results of this evolution show excessive variation and low repeatability, redesign of the nest may be required to improve part location and nest resonant effect. If multiple nests are to be used for a particular part type, all nests must be confirmed to have similar measurement repeatability. An example of a typical margin part statistical evaluation is shown in Fig. 7.

6.1.6 *Collection of Data from the Teaching Set Parts*—Once the nest has been developed, temperature effects are understood, and the broadband has been specified, full spectra data is collected from the parts in the teaching set.

6.1.7 *Analysis of Collected Data for Pattern Recognition*—With a complete set of spectra collected from the teaching set, and classifications of acceptable and unacceptable applied to

Margin Database Summary (FQ)	Page 1									
Column	1	2	3	4	5	6	7	8	9	10
Goods (30)										
Min (kHz)	3.955	7.246	13.487	13.951	18.084	19.459	20.074	23.435	24.405	24.872
Avg	4	7.248	13.499	13.961	18.093	19.471	20.088	23.444	24.413	24.878
Max	4.025	7.253	13.518	13.972	18.122	19.479	20.096	23.456	24.422	24.891
Range (kHz)	0.07	0.008	0.031	0.021	0.038	0.02	0.022	0.021	0.017	0.019
Range (%)	1.754	0.106	0.228	0.147	0.209	0.105	0.11	0.091	0.071	0.077
Std.Dev.	0.014	0.002	0.007	0.004	0.011	0.005	0.005	0.005	0.004	0.005
Std.Dev (%)	0.353	0.025	0.055	0.027	0.06	0.026	0.025	0.02	0.018	0.019

FIG. 7 Margin Part Statistical Evaluation