Advanced Non-Destructive Testing (NDT)

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PROBLEM STATEMENT

Non-destructive testing (NDT) has long been a mainstay in aerospace manufacturing and maintenance operations. The ability to test parts without altering them structurally has been key to the reduction of in-service failures and increase in component life over the last 50 years. Advancements in materials and technologies, the shift towards condition based maintenance, and the cost savings of retirement for cause are all putting new requirements on NDT that traditional methods can not achieve. One specific instance of this is the need for an NDT method capable of rejecting hybrid bearing elements that contain surface or subsurface defects. Hybrid bearings are being used in several critical applications in the Joint Strike Fighter, and NDT of the bearings is a threat to the cost, schedule, and reliability of the platform. Current NDT methods applied to these ceramic components are expensive, can not find all the defect of interest, rely on operator interpretations of signals, and frequently use chemicals with deleterious effects on the environment. Under a NAVAIR Phase II SBIR, Process Compensated Resonance Testing (PCRT) is being successfully applied to NDT of hybrid bearing elements.

WHO CAN BENEFIT?

The PCRT technology being applied to hybrid bearing inspection also has wide applicability in Department of Defense (DoD) NDT. As demonstrated by the millions of automotive parts tested each year with PCRT and the growing acceptance of the technology by aerospace Primes, manufacturers and maintainers of all aerospace and power generation machinery can benefit from the reduced cost, improved performance, and component life extensions possible with PCRT.

CURRENT NDT TECHNOLOGIES

Legacy NDT methods include penetrant inspection, eddy current (ET) inspection, and X-ray inspection. Their effectiveness is limited because their results are unrelated to structural integrity, they fail to detect internal defects, they require subjective human interpretation, they introduce environmental risks, or they suffer from a combination of these shortcomings. PCRT offers a solution to each of these limitations and at a lower cost. Legacy NDT methods and their shortcomings are briefly described in the following.

Penetrant Inspection

Penetrant inspection techniques include Fluorescent Dye-Penetrant inspection (FPI) and Magnetic Particle inspection (MPI). FPI uses a liquid dye that is applied to the component. After dye application, the component is cleansed to remove background dye from the component surface. The remaining dye has penetrated surface cracks and will be visible under fluorescent light.

MPI involves magnetizing the part and spraying or immersing it in an ultraviolet (UV) luminous activated ferromagnetic particulate solution. Any ferromagnetic particles in the solution are trapped in magnetic discontinuities, such as cracks or scratches. The part is observed under UV light, which highlights the trapped particles.

Both penetrant approaches can highlight surface cracks that are too fine to detect with unaided visual inspection. However, neither can see substantively beneath the surface. PCRT, however, can detect sub-surface defects. Neither FPI nor MPI can differentiate between a non-serious scratch or surface craze and a structurally detrimental crack. PCRT results are directly related to structural integrity. Both techniques are environmentally and physically messy; they require dye, developer, or ferromagnetic chemicals, some of which require disposal as hazardous waste. PCRT is clean, requiring no chemical part preparation.

Eddy Current (ET) Inspection

Eddy currents are initiated in a conducting material by exposing them to a changing magnetic field. The eddy currents are measured for propagation through the material. Propagation is retarded by cracks or discontinuities in the material. This approach can detect sub-surface cracks. Unfortunately, ET is challenging to apply in the field. ET inspection results require interpretation by highly trained inspectors. It still can only detect surface crack indications. PCRT, however, gives a simple Pass/Fail result that requires no operator interpretation. Operator-to-operator variability is eliminated. PCRT can detect subsurface defects that ET cannot.

X-Ray Inspection

X-Ray inspection works like its well-known medical sibling. This approach identifies subsurface cracking, voids, and inclusions, as long as it is in the hands of highly trained inspectors and the cracks are parallel with the exposure direction. These requirements introduce more risk of human error and subjectivity. PCRT's simple Pass/Fail result removes human error and subjectivity from the equation. Field application of X-ray technology is problematic because of health and safety issues regarding X-ray emissions. PCRT uses no radiation and presents no health and safety risks.

TECHNOLOGY DESCRIPTION

Process Compensated Resonance Testing (PCRT)

PCRT is an evolution of Resonant Ultrasound Spectroscopy (RUS), the analysis of the resonant frequencies of a part to detect flaws. Developed by Los Alamos Nationals Lab and covered by ASTM Stand Guide E2001-08, RUS is based on the physics fundamental that rigid parts resonate at specific frequencies that are a function of mass, geometry, and material properties.

PCRT combines RUS with proprietary pattern recognition algorithms, based on Mahalanobis-Taguchi System (MTS) statistical analysis, to identify the resonance spectra characteristics that represent acceptable parts and those caused by unacceptable defects. The operator is presented with a clear Pass/Fail result that requires no interpretation. This eliminates operator subjectivity and the need for expertise in analyzing the test results, enabling full automation. *PCRT is the only NDT technology that can effectively compare the results of successive inspections to detect the accumulation of fatigue and damage.*

Figure 1 shows examples of selected resonances for acceptable and unacceptable parts. The upper spectrum is a ceramic ball with no defects. The lower spectrum is for a ball with a C-spall crack as indicated by the resonant peak split. The structural defect in the part is directly reflected in the resonant spectra.

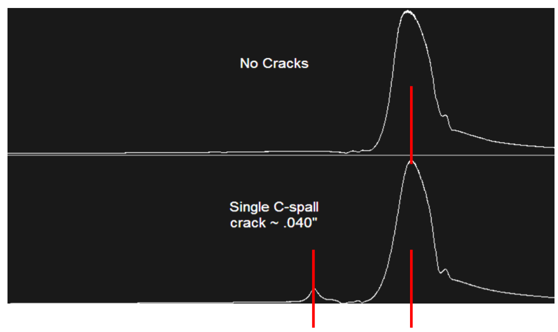

Figure 1 – Resonance Split at 2.1 MHz due to C-spall cracks on 9/8" Ceramic Ball

Figure 2 provides an overview of the basic process flow for establishing a PCRT System.

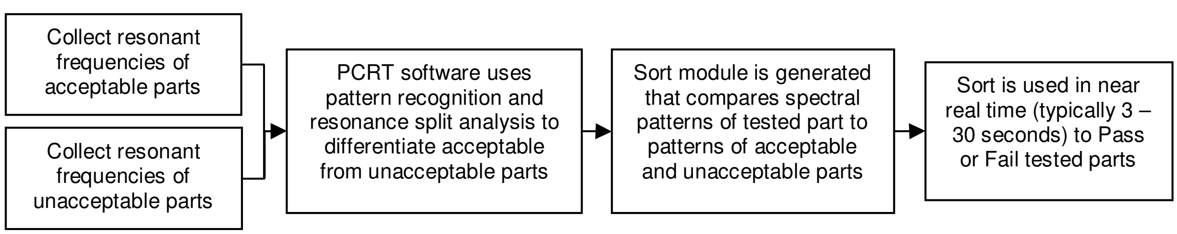

Figure 2 – PCRT Testing Process Flow

The PCRT System consists of a control computer, a transceiver, and a component nest. The computer, loaded with the PCRT software, provides the user interface and communicates with the transceiver. The transceiver is a precision signal generator and spectrum analyzer. The nest holds three lead-zirconate-titantate (PZT) contact transducers that interface with the part. One transducer excites the part while the other two measure the part's resonant response. A PCRT system diagram is shown in Figure 3, and sample hardware is shown in Figure 4. The nest shown is for a ceramic ball. Testing a part is simple. The part is placed on the nest, the part temperature is recorded (so the software can compensate for frequency variation vs. temperature), and the testing software is run. Tests require no part preparation and are typically completed in seconds, yielding superior throughput and cost-effectiveness.

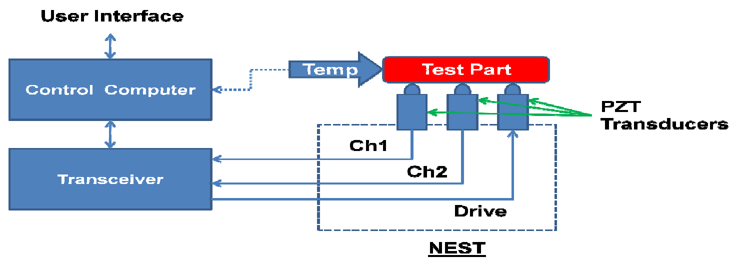

Figure 3 - Simple Diagram of a PCRT System

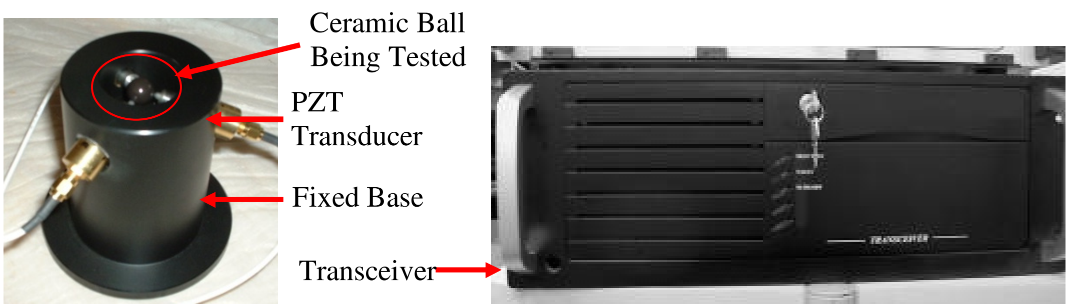

Figure 4 - PCRT Test Fixture and PCRT Transceiver

Table 1 - FAB Table

Feature	Advantage	Benefit
PCRT detects internal and surface defects.	PCRT detects defects other methods cannot	Better probability of detection
PCRT results correlate directly to structural integrity	Other methods rely on indications not related to structural integrity.	Fewer false positives, reduced scrap, lower costs
PCRT provides a simple PASS/FAIL result	Other methods require operator interpretation.	Allows automated testing, removes human error, lowers costs
PCRT evaluates entire part in seconds with a single test.	Other methods are slow and may not scan the whole part.	Fast testing means better throughput, lower costs
PCRT involves no chemicals, radiation, or other emissions.	Other methods are not environmentally-friendly.	Improved safety and regulatory compliance

CURRENT STATE OF DEVELOPMENT

PCRT is a mature NDT method with an extensive track record. The technology has been used in the automotive industry for 10 years. 150M automotive parts are tested with PCRT annually in the US, Europe, and Asia. Over the last 3 years Vibrant has tailored the technology for use in aerospace applications. Several production testing applications have been fielded including turbine blade inspections for the world's largest airline, and bearing component inspections for Department of Defense applications. PCRT's demonstrated use in these production environments indicates a state of development similar to a technology readiness level of 6.

REFERENCES

Name	Background
David Piotrowski **Delta Airlines** **(404) 714-3322**	Mr. Piotrowski is Vibrant's primary technical contact at Delta. He oversees the production testing of JT8D and CFM56-7 turbine blades and develops the Delta PCRT implementation plan.
David Heck **The Boeing Company** **(314) 234-8318**	Mr. Heck is with Boeing's metals group, and provided Vibrant with its first aerospace contracts. He has managed the evaluation of PCRT for various Boeing components, and directed application of PCRT for advanced manufacturing methods.
Dr. Surendra Singh **Honeywell Aerospace Manufacturing and Processes** **(602) 231-7028**	Dr. Singh has been working with PCRT for the last 8 years. He has led Honeywell's involvement in several PCRT based Phase I SBIR efforts as well as the current Phase II SBIR effort. Surendra performed his Six Sigma / Black Belt project on PCRT for hybrid bearing elements base on production testing performed by Vibrant on Honeywell DoD products.
Bob Moriarity **Rolls-Royce Corporation** **(317) 230-3598**	Mr. Moriarity has shepherded the introduction of PCRT to Rolls-Royce, and has been involved in developing the relationship which led to RR participation in the current Phase II SBIR effort.
David Durgin **The Verge Fund** **(505) 720-8808**	Mr. Durgin is a founding partner of a venture capital firm called The Verge Fund, and has invested in several PCRT companies. Initially co-founding the company Quasar (now owned by ITW Magnaflux) that developed PCRT, and most recently investing in Vibrant to pursue the aerospace market.
James Hopkins **NAVAIR** **(301) 342-0873**	Mr. Hopkins is Vibrant's primary contact at NAVAIR. He oversaw Vibrant's Phase I SBIR project for ceramic balls and currently oversees the Phase II project.

ABOUT THE COMPANY

Vibrant Corporation is an ISO and AS9100B certified PCRT services firm with significant ongoing contracts with commercial aerospace customers spanning manufacturing and MRO. Founded in 2006 and initially funded with $2.5M in Venture Capital and Equity Financing, Vibrant has built successful relationships with several major aerospace industry players including Boeing, Honeywell, Rolls-Royce Corporation, and Delta TechOps. In addition to these deeper relationships, Vibrant has carried out exploratory projects with Messier-Dowty, NASA, American Airlines, Williams International, McCauley, and Carpenter Technologies. Vibrant NDT Limited in the United Kingdom is a Tier II partner in the *Advanced Manufacturing Research Center with Boeing* (http://www.amrc.co.uk), where PCRT applications for advanced manufacturing are being developed with Boeing, Messier-Dowty, Rolls-Royce plc, BAE Systems, and other European aerospace companies. Through participation in the Navy Opportunity Forum, Vibrant aims to identify PCRT application opportunities, and develop partnerships that will accelerate the exploitation of those opportunities.