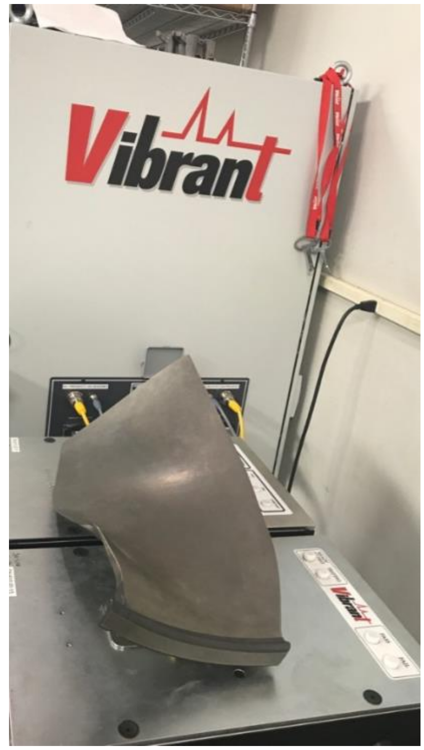
PCRT RESONANCE SOLUTIONS

FAN BLADE INSPECTION

This paper describes ways to apply Vibrant Process Compensated Resonance Testing (PCRT) to Fan Blades to improve Quality and to Reduce Risk

INTRODUCTION



PCRT RESONANCE SOLUTIONS FOR FAN BLADE INSPECTION

Over the last few years, there have been several high profile fan blade failures. These failures have been very public, quite dramatic, and have garnered a large media focus. The blade failures have pushed everything from the manufacturing, continued maintenance, and especially inspection, of these components into the spotlight.

Historic inspection methods are NOT providing the proper risk avoidance and safety factors. Newly implemented inspections are focused only on the latest area of interest and have an allowance for indications that are acceptable. A new approach to these component inspections is greatly needed that is quantitative and not just focused on singular areas of interest. We believe that solution is PCRT.

PCRT is a full body inspection that can detect part differences even when cracks are not present. PCRT can detect the fatigued area prior to crack initiation.

What is changing in the world of fan blade reliability? Is it a manufacturing issue? Maybe something related to the metallurgy? Could it be an operational issue? Or, is it some yet un-determined combination of all of these things? Whatever it is, it clearly needs to have the absolute attention of the engine manufacturers, the airline operators, the repair facilities, and the regulatory bodies.

The frequency with which these blade issues have occurred is very concerning. Historically, and over the last decade, fan blades have operated with quite high reliability and with only a few incidents. But, this reliability has decreased at a dramatic rate with 4 different fan blades failing within a 20 month period.

Vibrant's PCRT offers Resonance Solutions to support quality control and risk reduction with Fan Blade Inspection by:

- Assuring that parts with outlying resonance responses are not accepted, even if the OEM focused inspections have passing results.
- Supporting OEM inspections with a full body and metallurgically correlating result.
- Providing quantitative feedback compared to just a pass/fail result.
- Aiding in the understanding of how fatigue growth rates impact effective material properties.
- Providing automate-able, objective inspection metrics that can be tracked as a monitoring function, correlate to blade cycles and aging, and compared against previous operating / performance data to aid in risk assessment.

Since August of 2016, 4 fan blades have failed in flight. The incidents are as follows:

Date	Airline	Engine	Manufacturer
08-27-2016	Southwest Airlines	CFM56-7B	CFM/GE
06-25-2017	AirAsia X Trent	772B-60EP	Rolls Royce
02-03-2018	United Airlines	PW4077	Pratt & Whitney
04-17-2018	Southwest Airlines	CFM56-7B	CFM/GE

Notice that ALL of the major engine manufacturers have suffered a fan blade issue within the last year, as of the writing of this article. Failures span 3 different engine types and operations in different parts of the world.

Figure 1 – Image of Air Asia Trent 772 Failure (left) and United PW4077 failure (right).

Regulatory attention needs to be swift, enhanced, and much broader than it has been. With increased attention and focus these failures should be avoidable.

Historic and current inspection practices need to be reviewed, in light of recent results, and new inspections need to be considered to ensure that fan blades do not continue to fail. The new inspections need to be proactive, ensuring that a higher level of quality and risk avoidance is provided, not reactive to only the latest incident. PCRT is an excellent choice in this situation.

Experts are assuming that cracks were present and detectable for some time period prior to the failures, and that if the new ultrasonic testing (UT) or electromagnetic (ET) inspection methods had been in place that these risky blades would have been removed from service. However, these are the same experts that initially determined he original visual and liquid penetrant (PT) inspections would be sufficient protection against the risk of failure. It is also not clear WHY these specific blades cracked and failed when others have not. Did they have different material properties, different stress states, different (assumed non-critical) dimensions? Aerospace engine components are highly complex, made of advanced materials, and operate in a wide range of stress environments. It is difficult, even for experts, to model and predict behavior under every possible circumstance. PCRT can provide precise, quantitative measurements and big-data type inputs to improve understanding of the specific risks of individual components.

The newly mandated inspections for the CFM56 fan blade are bound to aid in reducing the risk of failure, but they will not completely eliminate the risk. These are limited to a very focused area of interest, but outside of that area, only the original, less sensitive inspections are required. The other recently failed engine models have not had new inspections suggested or required. These other failures also demonstrate that failures can occur in different locations, and with different mechanisms. It is likely not practical to implement focused inspections for every potential failure. Whole-body, material property driven inspections like PCRT provide reduced risk of multiple failure modes with a single test.

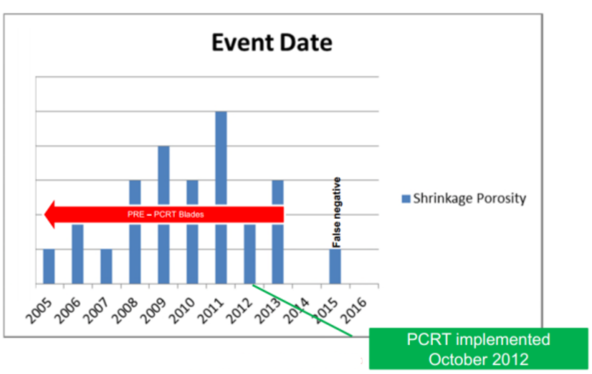
PCRT inspection can be used to segregate parts that fall outside of a qualified range, to help identify potential sources of failure that can be missed during the current required inspections.

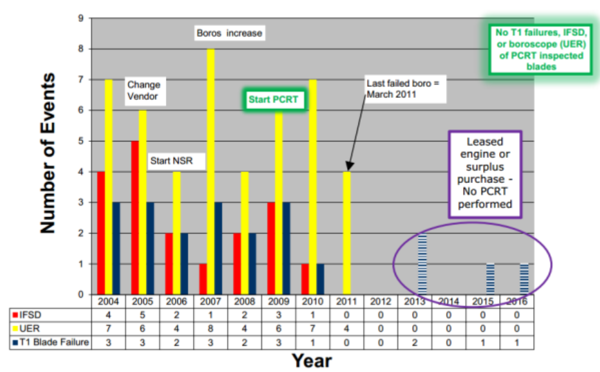
Figure 2 –Close up of Air Asia Trent 772 Failure

PROCESS COMPENSATED RESONANCE TESTING

PCRT is a whole-body resonance inspection method. Component resonances reflect the effective material properties of the whole part and allow very precise measurements. These resonance measurements can be used in many ways and specific to fan blades they can be implemented for structural issues that are blind to other NDT, issues like fatigue before cracking and for comparison of individual parts to themselves after service.

PCRT Outlier Screening, applied to fan blades, would assure that every individual blade has resonance responses similar to the rest of the blades in the engine set, or as compared to a serviceable population of a particular part number. Assuring that each blade has consistent resonances will ensure that there are no defective material issues present at the time of inspection. PCRT Outlier Screening inspections have dramatically reduced field failures for the JT8D engine for Delta, and the PW100 engine for P&WC. **Figure 3** shows what a typical PCRT Population Plot with Outlier Screening boundary looks like. Each point on the plot represents a single serialized component. The population distribution will be different from component type to component type, and so will the separation of Outliers from that population. The key is to set up inspection boundaries for both the x axis (average) and y axis (deviation). The average boundary will be driven by the population sigma and the deviation will be based on a population-based confidence interval. In the end, PCRT will provide a data driven inspection that ensures fan blade consistency and eliminates blades that respond abnormally.





	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
IFSD	4	5	2	1	2	3	1	0	0	0	0	0	0
UER	7	6	4	8	4	6	7	4	0	0	0	0	0
T1 Blade Failure	3	3	2	3	2	3	1	0	0	2	0	1	1

Engine Operators and OEMs who have implemented PCRT inspection have nearly eliminated all field issues (in-flight shut-down and un-planned engine removals) when traditional NDT could not. These PCRT customers have saved millions of dollars in part replacement, reduced inspection bottlenecks, and salvaged their safety and quality reputations.

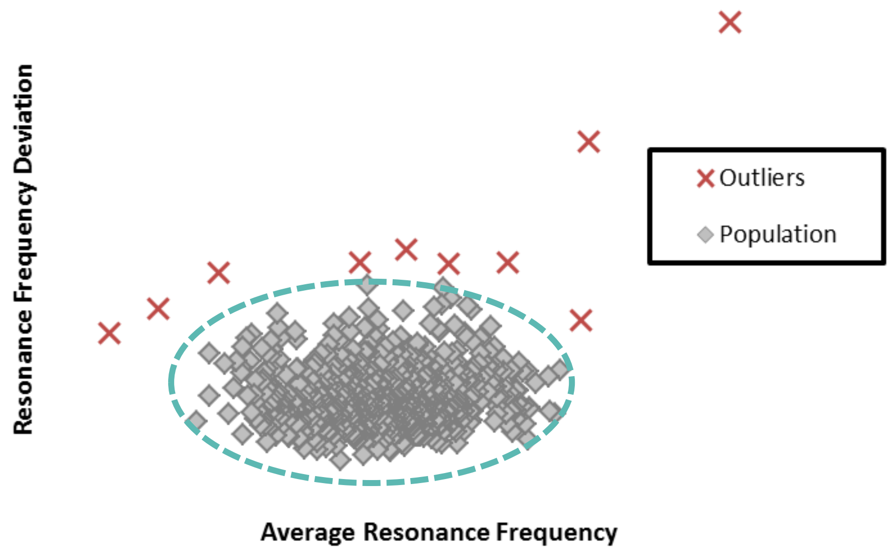


Figure 3 – Outlier Screening Plot

PCRT Part-to-Itself (PTI) approaches compare resonance data of blades to themselves as they age. Each blade's resonance response is saved by its unique serial number and at each inspection interval the new resonance response is analyzed and compared to the last measurement. The *change* in frequencies from blade measurement to blade measurement correlates directly to blade integrity over time, and provides new insight into repair and/or retirement ***for cause***. PCRT spectra are extremely sensitive to changes within the same component and this type of PTI inspection can detect the beginning of material changes that will lead to the onset of fatigue failure.

Figure 4 overlays the PTI trend of 'normal' parts on the PCRT Population Plot. Parts experiencing normal changes due to the service interval are highlighted by the red arrows, which reflect the overall change in the population. **Figure 5** highlights unusual changes experienced by a small portion of the population. These blades are segregated for further investigation.

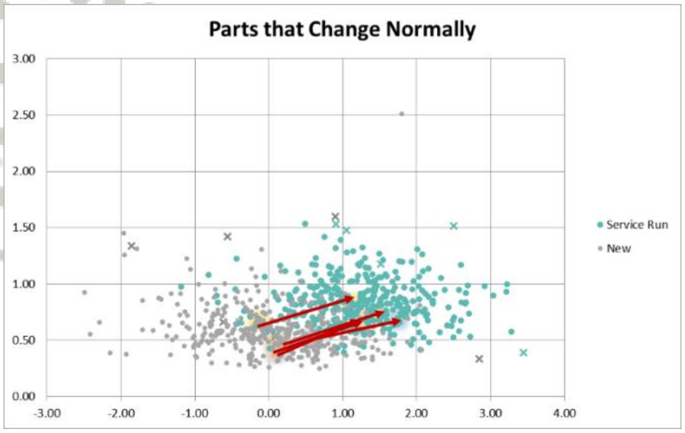


Figure 4 – NORMAL PTI and Population Changes from New state to Service Run.

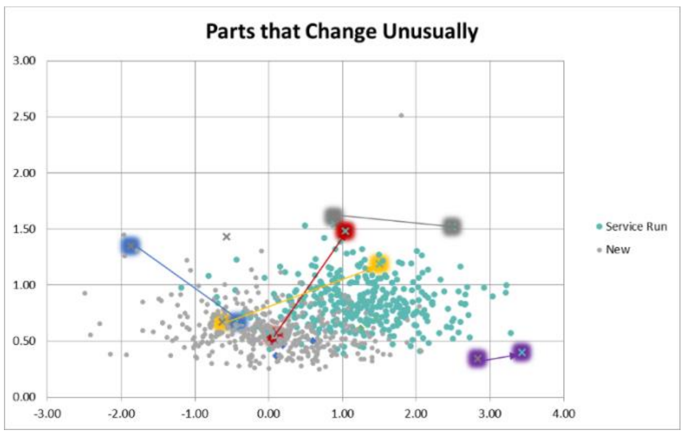


Figure 5 - UNUSUAL PTI and Population Changes from New state to Service Run.

PCRT inspections offer opportunities for risk mitigation, through removal of outlying components, and for life extension, by retiring components only when they are detected to have accumulated risky material changes. Both of these opportunities are unique to PCRT, and cannot be achieved by legacy inspection methods. Vibrant's solutions can also be used to support current fan blade inspections, to identify parts with higher risk of failure that are missed through the UT and ET inspections. PCRT's quantitative output can also be used to aid fatigue crack growth studies, and combine with other big data sources for expanded performance analytics.

PROPOSAL

Vibrant's PCRT Resonance Solutions have long-proven success for large-scale cast, forged and machined applications in the aerospace and automotive industries.

For the PW4077 and CFM56-7 engines, in addition to the inspections currently performed, Vibrant proposes:

- Collect resonance data for each fan blade, at each opportunity where the blade is removed.
    - Data collection will be performed using custom-fit tooling and hardware for each PN.. Data collection typically takes 2-4 minutes per part and can be performed by a Vibrant employee in a United facility, by a United employee (after some simple training), or at Vibrant's facility.
    - Vibrant recommends using initial measurements on at least 200 blades to develop a baseline population consisting of 'normal' variation. A Confidence Interval-based sorting boundary can be defined from this reference set.
- Perform PCRT Outlier Screening to remove blades which do not have material properties matching the, Vibrant/United determined, nominal/desired blade population.
- Compare PCRT results to results from other NDT inspections (those associated with repair or retirement, for example). Evaluate the opportunity to specifically target defect conditions known to be the highest risk to performance.
- Investigate Outlying blades using other non-destructive, or even destructive, means, to identify the source of the discrepancy for further corrective action.
- When (same serial number) blades are evaluated for a second time, perform PCRT PTI testing to compare the resonance spectra and ***quantify*** the degree of change. Segregate blades with change greater than expected (limits determined by Vibrant/United).
    - Again, Vibrant will use the 'resonance change' data from an initial group of blades to establish sorting boundaries which define 'expected change'. Targeted experiments, modeling, and operational data may also be used to assist in setting sorting criteria.

Contact Vibrant to discuss opportunities for PCRT in your business!

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Additional Reading & Resources

"America Makes: National AM Innovation Institute (NAMII) – Project 1: Non-destructive Evaluation (NDE) of Complex Metallic AM (AM) Structures," June 2014 Interim Report. AFRL-RX-WP-TR-2014-0162.

"Process Compensated Resonant Testing in Manufacturing Process Control," Material Evaluation, 63 736-739, (July 2005). Todorov, E., Spencer, R., Gleeson, S., Jamshidinia, M., Kelly, S., (June 2014). J. Schwarz, J. Saxton, and L. Jauriqui.

"Process Compensated Resonance Testing JT8D-219 1st Stage Blades," ATA NDT Forum 2008, (September 24, 2008). D. Piotrowski, L. Hunter, and T. Sloan.

"Delta TechOps Reduces Engine Inspection Costs by Nearly $2m Annually," Vibrant Corporation and Delta TechOps. (April 2014).

"Enhancing Reliability with Process Compensated Resonance Testing at Delta TechOps," ATA NDT Forum 2016, (September 28, 2016). D. Piotrowski, G. Weaver.

PCRT Standards & Approvals

ASTM E2001-13 Standard Guide for Resonant Ultrasound Spectroscopy - outlines capabilities and applications of several resonant inspection methods

ASTM Standard Practice E2534-15 – Describes auditable method for application of PCRT Targeted Defect Detection inspection

ASTM Standard Practice E3081-16 – Describes auditable method for application of PCRT Outlier Screening inspection

Federal Aviation Administration Approved – Since July of 2010 for the detection of micro-structural changes indicating over-temp of turbine blades (JT8D-219 HPT)

AS9100D & ISO9001:2015 – Certificate #10928 issued by PRI Registrar