A Resonance-Based Approach for Life Monitoring of Fan Blades

-Leanne Jauriqui, Lem Hunter, Greg Weaver, Thomas Köhler
What does Vibrant do?

Vibrant Corporation uses its proven PCRT services to:

- Help reduce field failures by screening population outliers
- Support Big Data Analytics
  - Quantitatively monitor part streams, via 100% NDE, to evaluate correlation to manufacturing and operational variables, aid in process control, and provide quantitative life-monitoring feedback.

CERTIFIED:
AS9100 Rev D and ISO 9001:2015

Resonant Ultrasound Spectroscopy (RUS) and PCRT application are described by ASTM Standard Guide E2001-13 and ASTM Standard Practice E2534-10.

PCRT is FAA-approved for gas turbine engine blade inspection.
PWC presents PCRT Success
Sep 18

A4A 2016 - Better Way Award
Sep 18

https://www.ntsb.gov/investigations/Pages/DCA18MA142.aspx
Delta TechOps updates PCRT Success

PWC presents PCRT Success

A4A 2016 - Better Way Award

https://www.ntsb.gov/investigations/Pages/DCA18MA142.aspx
CFM56-7 Fan Blade Failure
Aug 27

Delta TechOps updates PCRT Success
Sep 18

PWC presents PCRT Success
Sep 18

A4A 2016 - Better Way Award
Sep 18

Oct 1

2nd CFM56-7 Fan Blade Failure - Passenger Killed
Apr 17

Apr 20

OEM recommends inspection of ALL fan blades
Jun 13

FAA issues emergency AD requiring inspection of fan blades older than 30,000 cycles
Apr 20

Pending AD

OEM develops inspection in response to failure, incorporates into Repair
Jan 15

OEM issues SB requiring inspection of fan blades older than 20,000 cycles, every 3000 cycles
Jun 13

https://www.ntsb.gov/investigations/Pages/DCA18MA142.aspx
Meeting AD Requirements…

Is a SCRAMBLE!

- Purchase new equipment
- Train/Hire new NDT personnel
- Modify maintenance schedules
- Manage replacement part inventory
- Update Programs/Documentation
- Manage PR
- Get ready to do it again real soon…
How does this happen?

Best Industry Practice Design
Risk-Based Inspection
FAA Oversight

That shouldn’t have happened ...
It must have been ...
It could be ...

Uncertainty
Uncertainty in Life … and Work

DID I LEAVE
THE STOVE ON?

Did I Leave the Garage Door Open?

“IT COULD BE A SHOOTING STAR, IT COULD BE A HUKE FROM NORTH KOREA!!”

“I CAN’T REMEMBER IF I TOOK MY PPIS TODAY—DO I LOOK DEPRESSED?”

Am I Doing a Good Enough Job?

Vibrant
What did all of these have in common?
What did all of these have in common?

They all received industry-standard inspections prior to failure.

Are we doing everything we could?
Sources of Uncertainty

In Part Models, which are used to predict risk:

- Material Properties
- Post-Processing Effectiveness – HT, SP, HIP
- “Normal” Service Conditions
- Best Manufacturing Control Scenarios
- Extreme Service Conditions
- Repair Processes
Mitigating Uncertainty

Inspections to reduce risk:

- Gross non-fill, bar end, green damage
- Machining damage or missed operation
- Surface-Breaking inclusion, shrink / crack, porosity
- Internal inclusion, shrink, porosity
- Internal inclusion, shrink, porosity
- Creep
- Accumulation of Fatigue
- Microstructural Change
- Wrong Material, Wrong Stress State, Off-Grain
- Out of Spec Dimensions
- FOD
Mitigating Uncertainty

Inspections to reduce risk:

- 100-300% Visual Inspection
  - Gage, Visual
- 100% Xray
- 100% EC

Accumulation of Fatigue

- 100% FPI, UT

Gage, Visual

Microstructural Change

Wrong Material, Wrong Stress State, Off-Grain

Wrong Material, Wrong Stress State, Off-Grain

100% Xray

Surface-Breaking inclusion, shrink / crack, porosity

Internal inclusion, shrink, porosity

100% EC

Wrong Material, Wrong Stress State, Off-Grain

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Wrong Material, Wrong Stress State, Off-Grain

Internal inclusion, shrink, porosity
Mitigating Uncertainty

Inspections to reduce risk:

- Gross non-fill, bar end, green damage
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- Creep
- Microstructural Change
- Wrong Material, Wrong Stress State, Off-Grain
- PCRT is sensitive to changes in the material

Out of Spec Dimensions

Sample Wrong Material, Wrong Stress State, Off-Grain
For the Fan Blades

• Was the Design model wrong? Was the Operational model wrong? Are the stresses different? Do cracks form sooner? Propagate faster?
  • Should we inspect more frequently? Start earlier?
  • Which parts are at the most risk?
  • How should we change the model? Are other parts at risk as well?

• Was the inspection done? Was it done correctly?
  • Should we do it again?
  • Should someone else do it?
For the Fan Blades

• Why did “theirs” fail? Are “ours” different?
  • How critical are operating conditions?
  • How different are they?

• Should we replace them all?
  • With new parts of the same Design?
  • Or is a new design required?

• What if another one fails?
  • What if it fails differently?
Let’s Reduce Uncertainty

PCRT data can:

• Help validate models AND parts
  • Material properties are not invisible, and ARE reflected in resonance measurements.
  • Get smarter about material properties, material variation, and the effects of aging and damage.

Is our part what we modeled?
Validating Models

PCRT verifies whether material properties match the model.

<table>
<thead>
<tr>
<th>Part</th>
<th>Cast Bar Laue</th>
<th>Inversion</th>
<th>Re-Laue Side A</th>
<th>Re-Laue Side B</th>
</tr>
</thead>
<tbody>
<tr>
<td>WH9YC-2 (6)</td>
<td>37.9°</td>
<td>37.0°</td>
<td>37.0°</td>
<td>30.4°</td>
</tr>
<tr>
<td>WH9YG-1 (13)</td>
<td>8.7°</td>
<td>13.3°</td>
<td>13.3°</td>
<td>14.1°</td>
</tr>
<tr>
<td>YB2WN-1 (53)</td>
<td>6.6°</td>
<td>6.0°</td>
<td>7.7°</td>
<td>14.1°</td>
</tr>
<tr>
<td>YB2YF-2 (66)</td>
<td>0.9°</td>
<td>0.0°</td>
<td>0.5°</td>
<td>0.6°</td>
</tr>
</tbody>
</table>
Let’s Reduce Uncertainty

PCRT data can:
- Help validate models
- Evaluate the Part Stream over time
  - Assure supply is consistent with qualification parts
  - Identify/Correct process drift
  - Assure suppliers are making the same part
  - Combine part data with manufacturing data to improve process control

Are we (still) making the part we qualified?
Process Control for Part Supply

Monitor parts’ consistency with qualification parts. Detect Process Drift!
Let’s Reduce Uncertainty

PCRT data can:

• Help validate models
• Correlate to manufacturing control points
• Verify post-processing operations 100%
  • Consistent Heat Treat, regardless of furnace position
  • Quantify how much HIP changes part density

Are we getting the improvement that we want?
Verification of Critical Processing

Resonance Data is:

• Highly repeatable gage data
• Easily tracked like other SPC data sources
• Able to correlate with production settings to facilitate better control

- Training parts – no hardening
- Training parts – under-hardened
- Training parts – over-hardened
- Trial of new equipment
- Process Change Implemented
Let’s Reduce Uncertainty

PCRT data can:

• Help validate models
• Correlate to manufacturing control points
• Verify post-processing operations
• Monitor changes in parts, by serial number, over time
  • Measure HOW parts change
  • Detect changes in stress due to material change or crack propagation
  • Detect changes in parts that other NDT methods don’t see
• Combine part data with operational data and other NDT data to better understand aging and damage mechanisms

Are parts changing the way we expected?
Monitoring Parts over their Life

Batch 3115

112614

Batch 12115
Monitoring Parts over their Life

Batch 3115

Batch 529
Let’s Reduce Uncertainty

PCRT data can:

• Help validate models
• Correlate to manufacturing control points
• Verify post-processing operations
• Monitor changes in parts, by serial number, over time
• Combine with other data sources and inspection results for better risk management

Where can we take this next?
Combine Forces

Combine PCRT part data with:

- Design intent and model inputs
- Manufacturing data to improve process control
- Operational data and other NDE data to better understand aging and damage mechanisms
- Other NDE results to identify when one result can help better interpret the other
Where do we start?

**Fan Blades are a great opportunity.**

- Identify and Quarantine outlying components → Reduce risk!
- Collect data at lube visit, every 1600 cycles.
- Evaluate changes in parts over time, identify parts that are changing more (or less?), evaluate further.
  - Many wheels/LG have friendlier inspection intervals as well.
THANK YOU.