Extending the Life of F-Class Gas Turbine Rotors for Improved Operational & Maintenance Costs

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THE FUTURE OF GAS TURBINE TECHNOLOGY
ETN Global

Agenda

Overview of Rotor Lifetime Evaluation Process

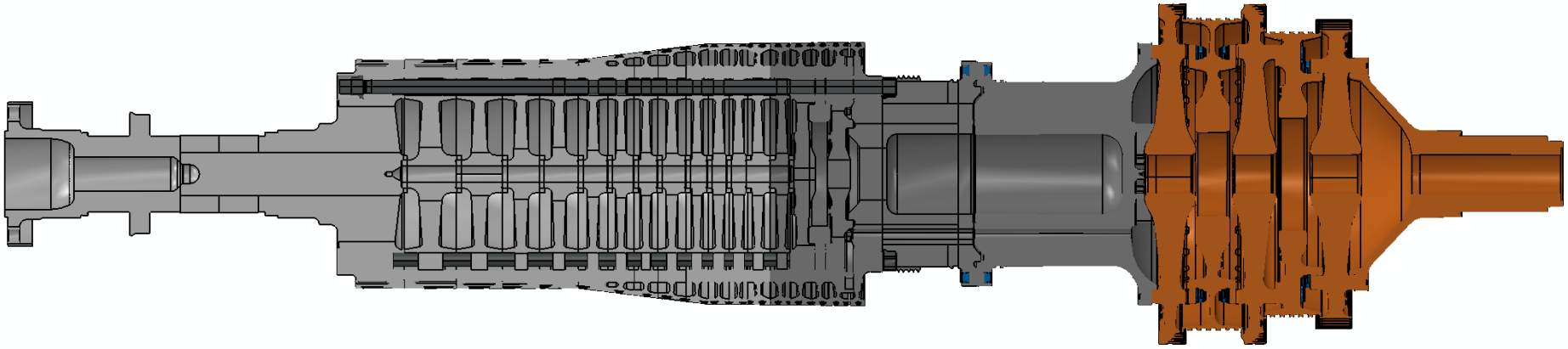
Inspection Findings and Evaluation

Return to Service

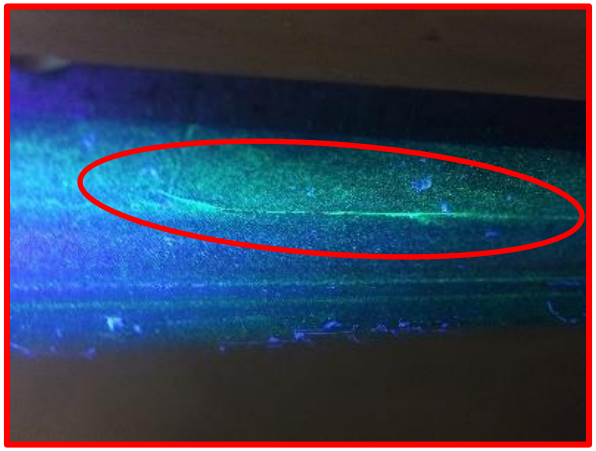
Conclusions

Gas Turbine Rotor Lifetime Evaluation

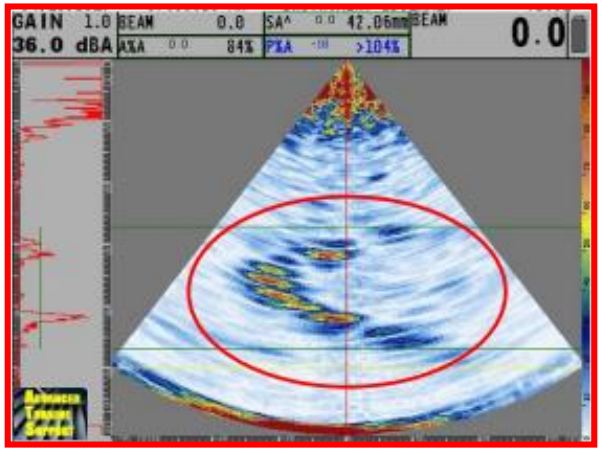
Overview



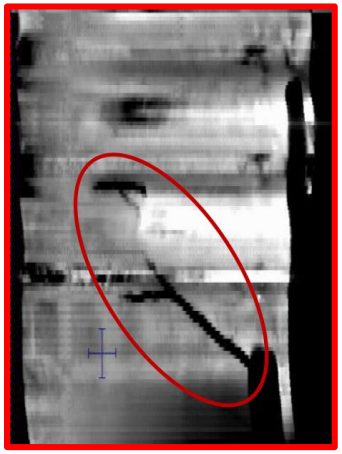
Magnetic Particle



Phased Array UT



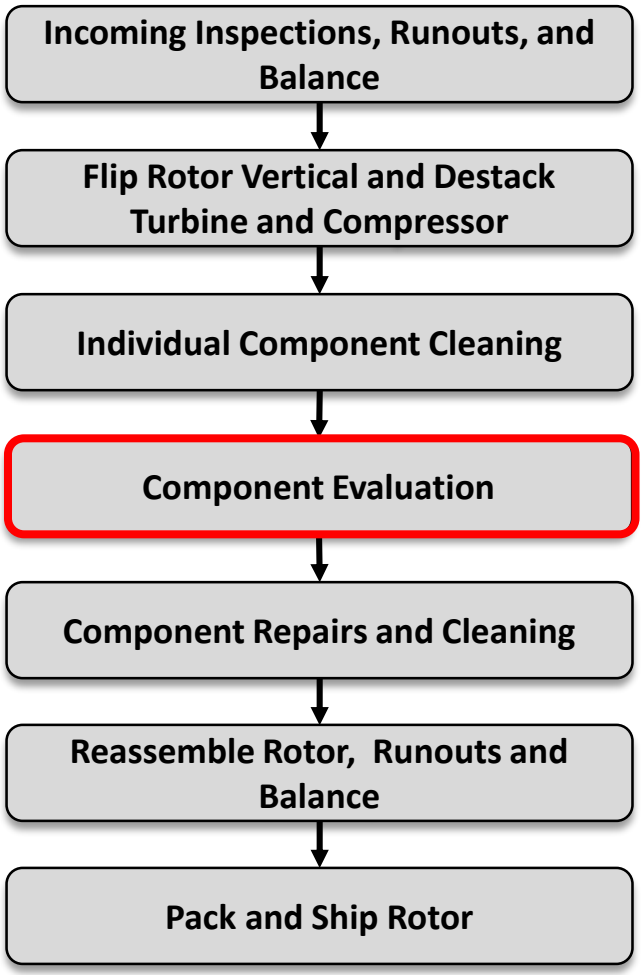
Eddy Current

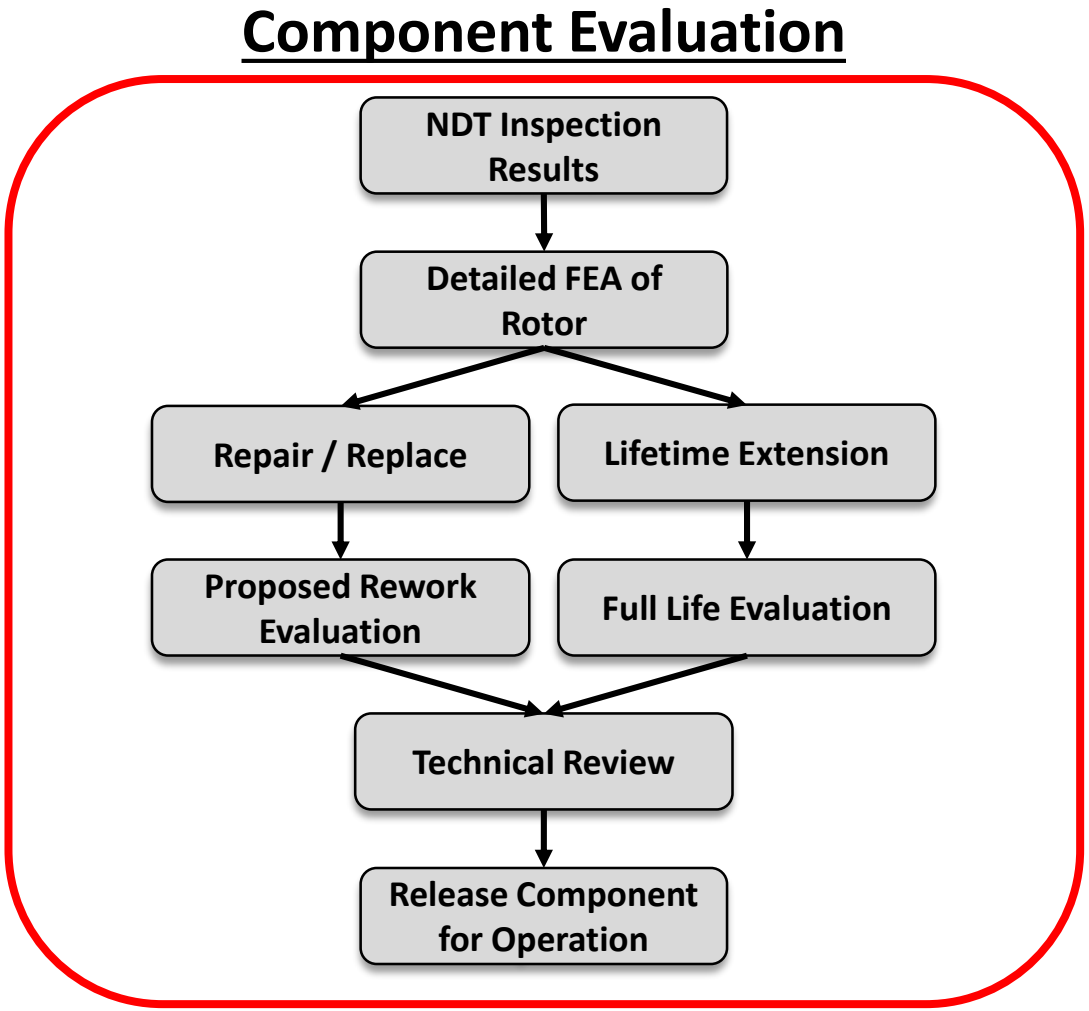


Issues Arising in Aging F-Class Rotors – O&M Budgets Require Unique Solutions

Gas Turbine Rotor Lifetime Evaluation

Rotor Overhaul Process

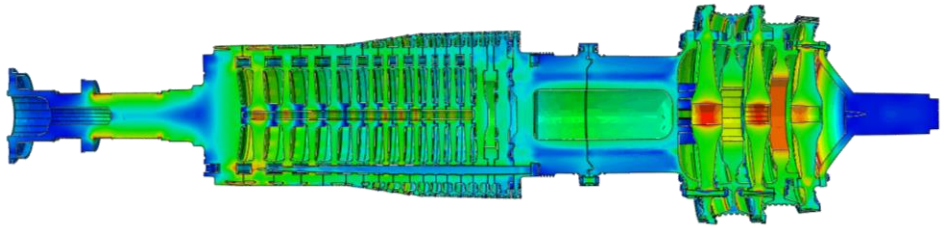


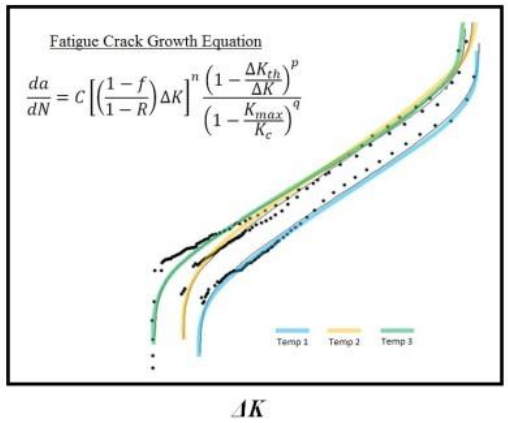


Comprehensive Component Lifetime Evaluation Requires Additional Efforts

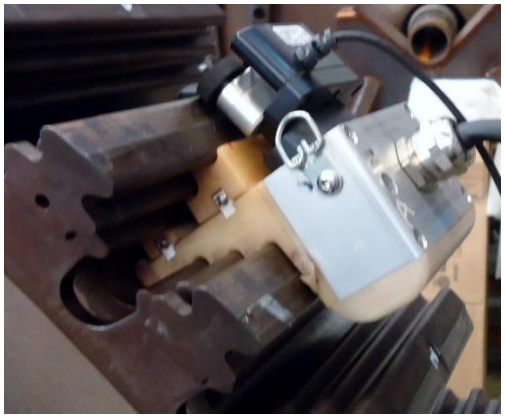
Gas Turbine Rotor Lifetime Evaluation

Foundation of Assessments





Total Life Evaluation of Rotors



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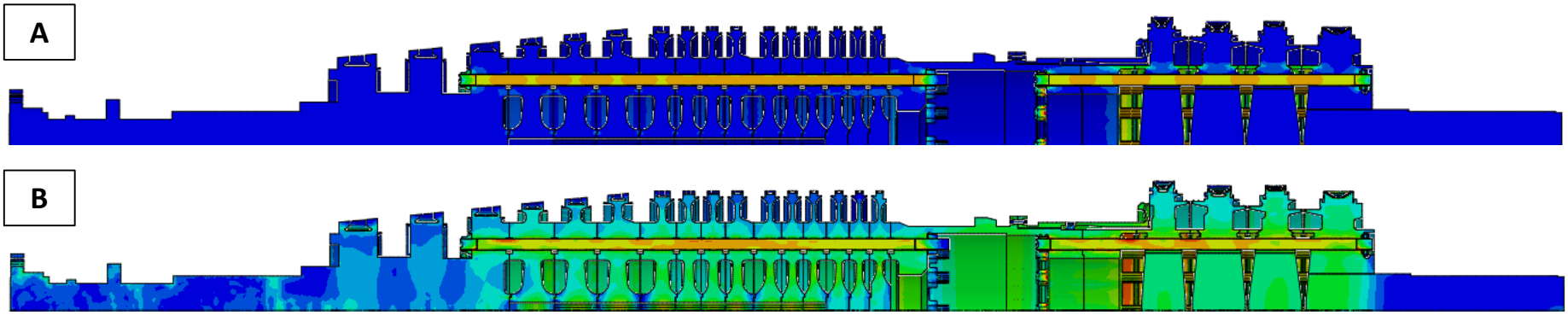
Lifetime Evaluation Requires All Components for a Meaningful Assessment

Gas Turbine Rotor Lifetime Evaluation

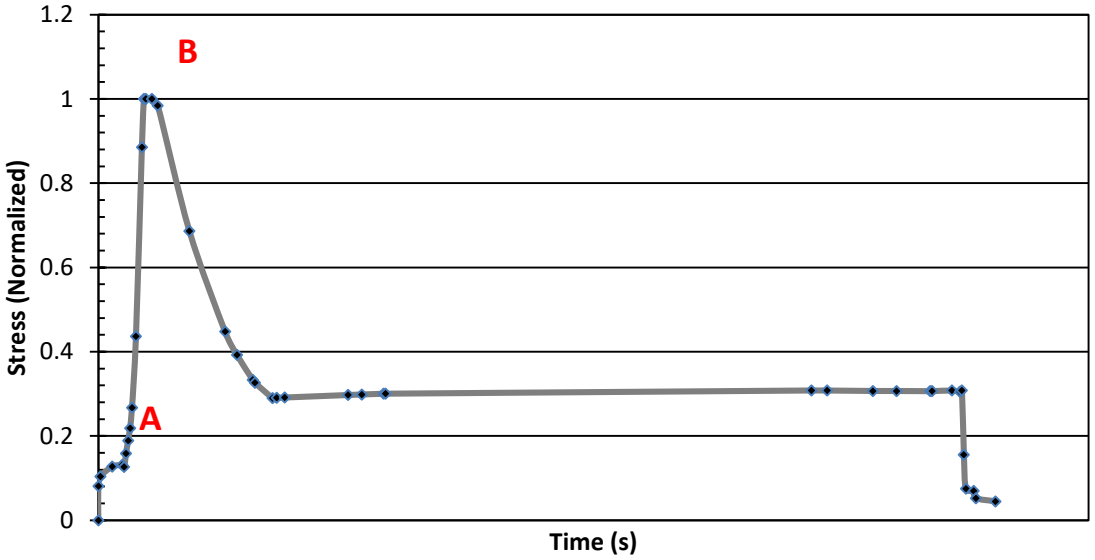
Transient Mechanical Analysis



Load Details

A – Assembly loading, including bolt tension, interference fits, and gravity loading

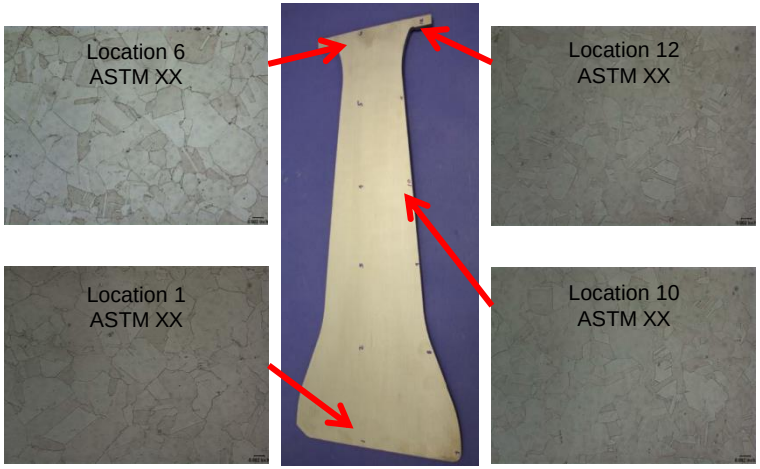
B – The stress response at a single time point during start up

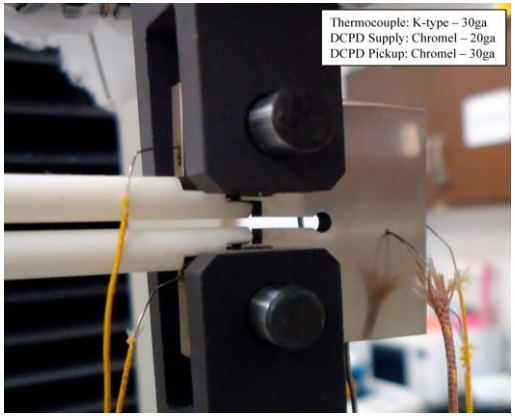


Structural Model Developed to Capture the Transient Stress Range

Gas Turbine Rotor Lifetime Evaluation

Material Testing



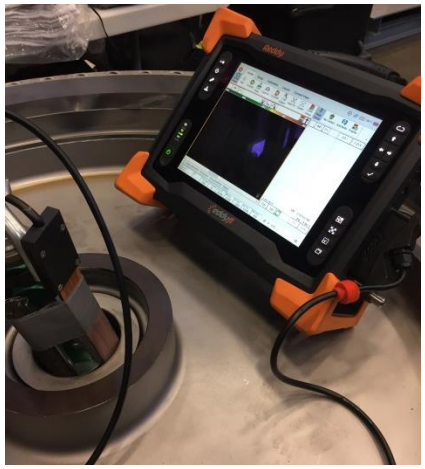


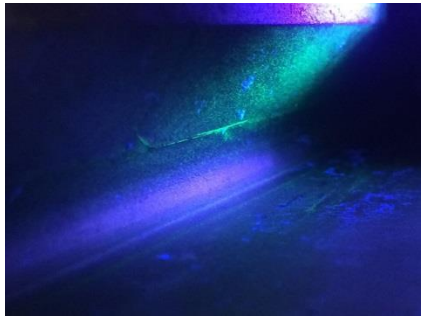
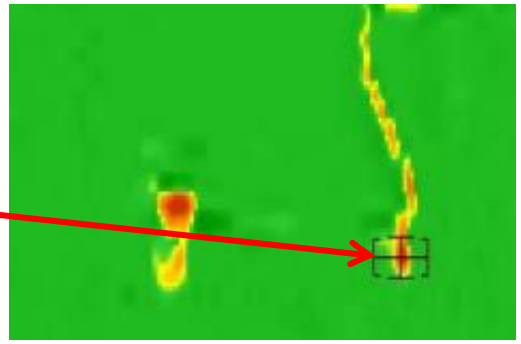
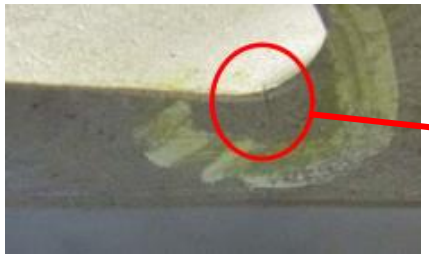
Extensive Material Test Programs with Virgin and Service Exposed Material

Gas Turbine Rotor Lifetime Evaluation

Advanced NDT Inspections

- Non-destructive (NDT) inspections include:
  - Metallurgical evaluation
  - MPI/FPI
  - Eddy current inspection
  - Ultrasonic inspection
- Inspections target key failure modes:
  - Surface defects
  - Forging/Volume defects
  - Frame-specific issues
    - Compressor disk slot cracking
    - Intermediate shaft cracking
    - Turbine disk cracking



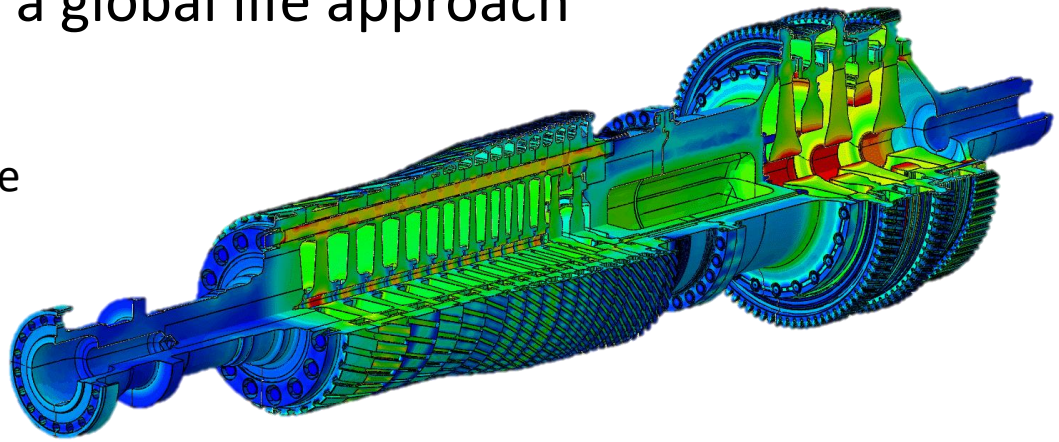





Comprehensive Set of Overlapping Inspections to Find ALL Defects

Gas Turbine Rotor Lifetime Evaluation

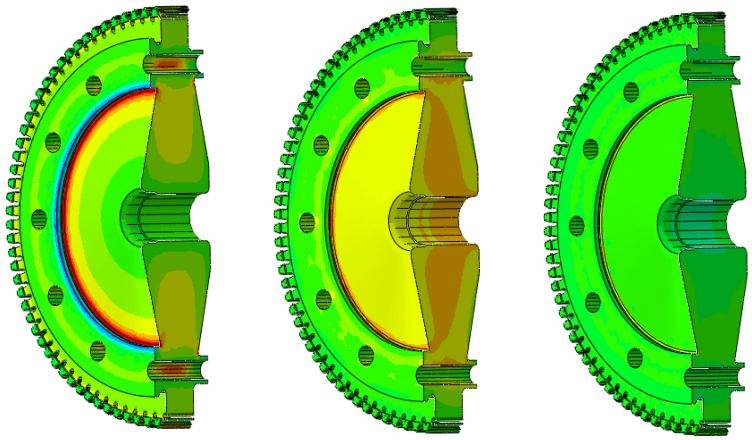
Total Life Evaluation

- Full engine model enables a global life approach
- Lifetime Analyses include:
  - Low-Cycle and High-Cycle Fatigue
  - Crack Growth
  - Creep

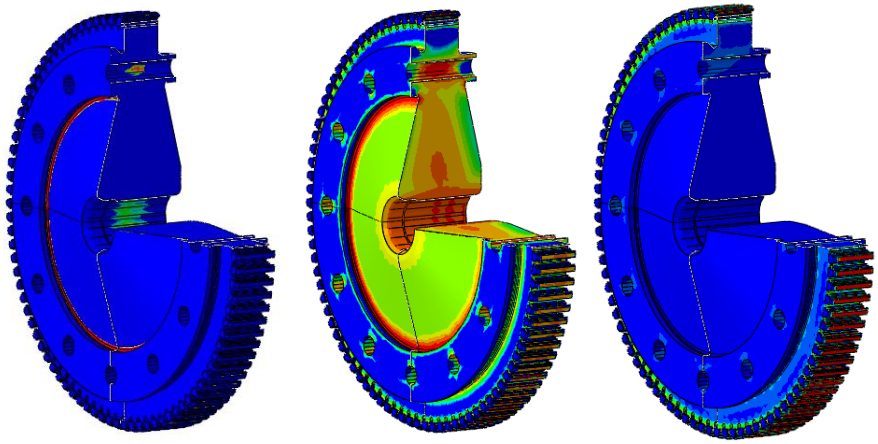


Stress Decomposition

σ_r σ_ϑ σ_z



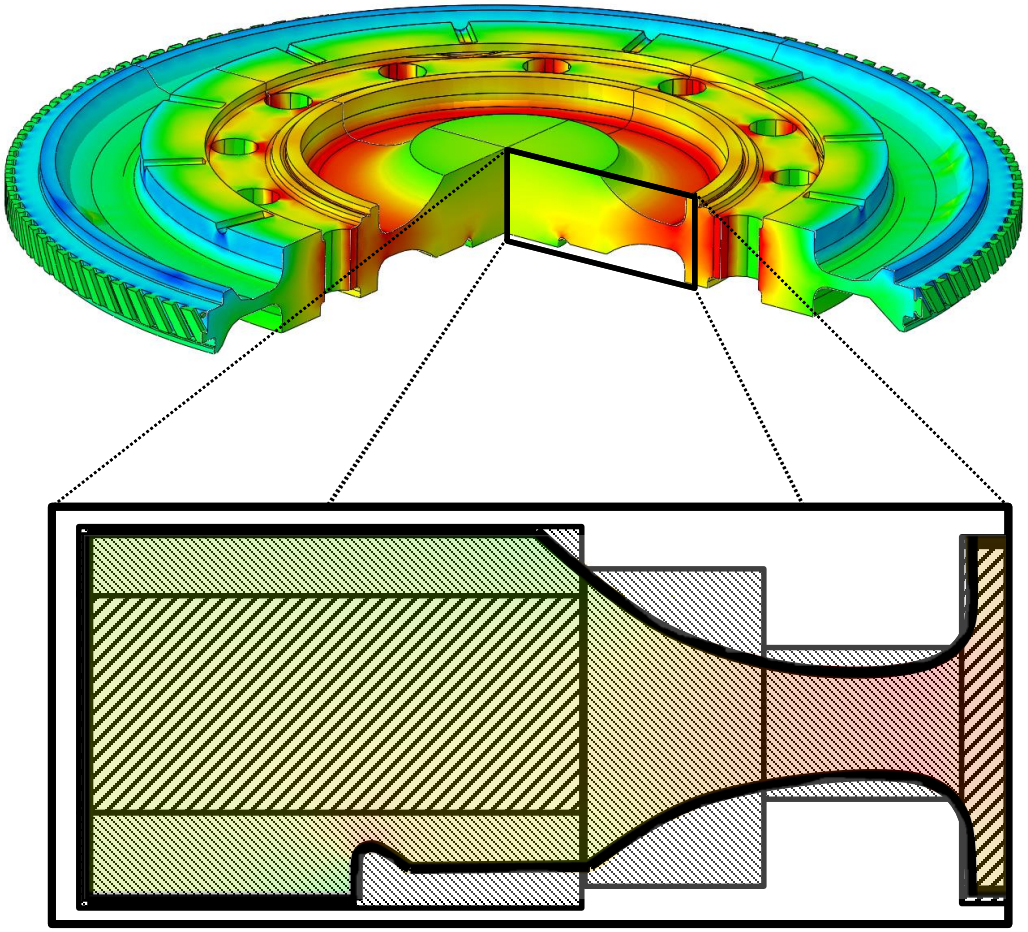
LCF/HCF Crack Growth Creep



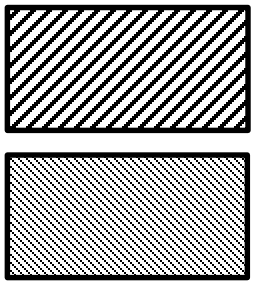
Rotor Failure Mechanisms Captured via Proprietary Lifing Methodologies

Gas Turbine Rotor Lifetime Evaluation

Development of Inspection Requirements



Zone Reporting



1 Interval – ERS > X.X mm
2 Intervals – ERS > X.X mm

1 Interval – ERS > X.X mm
2 Intervals – ERS > X.X mm

*ERS (Equivalent Reflector Size) values are for demonstration only.

Inspection Requirements Defined via FE and Lifetime Analyses

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Return to Service

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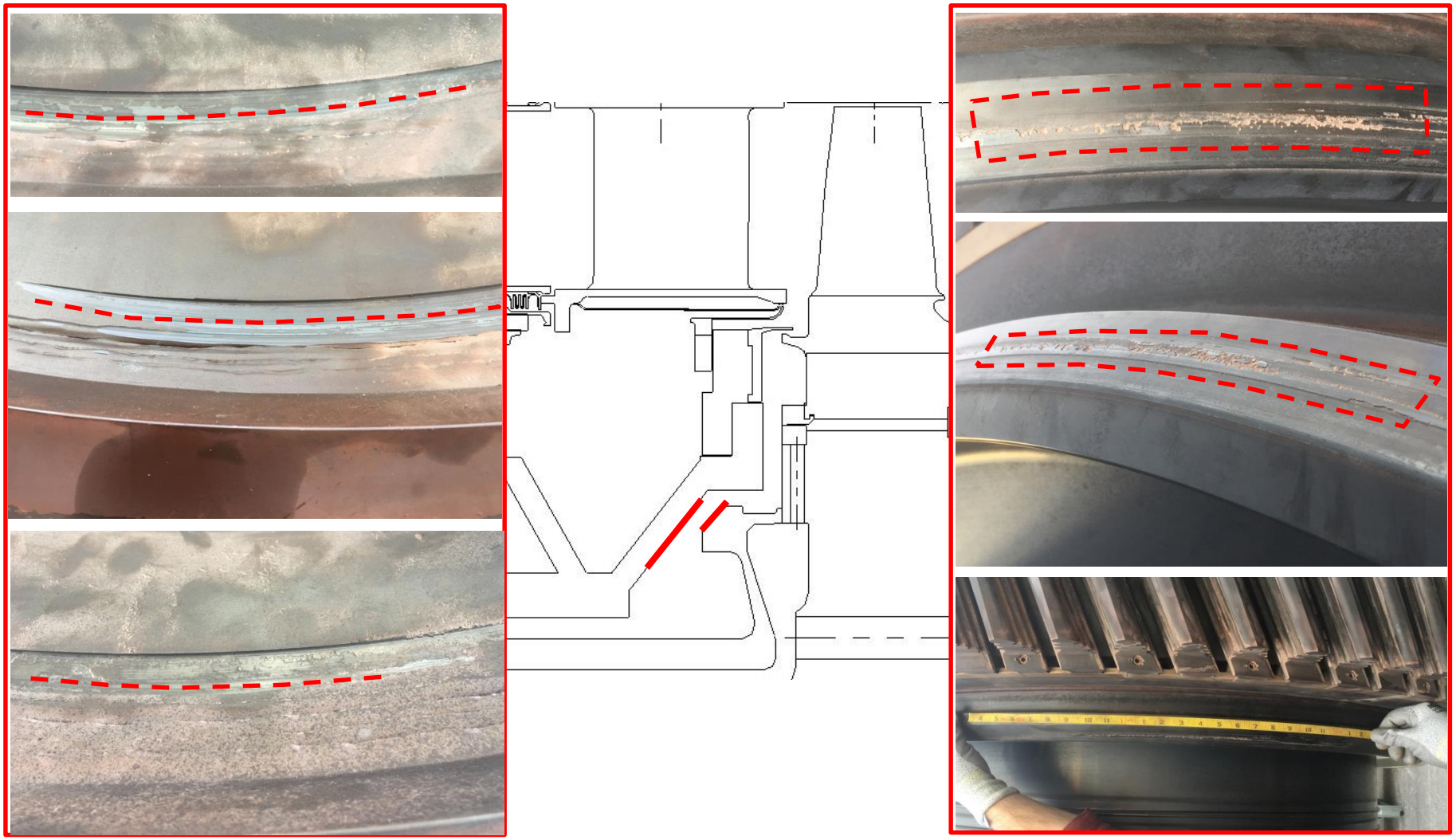
Inspection Findings and Evaluation

Onsite Inspection

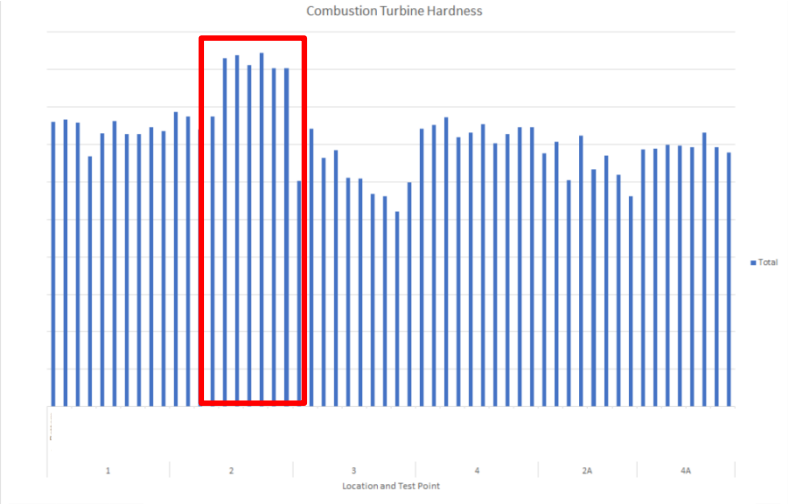


Inspect Rotating Components for Interaction with Static Structure

Inspection Findings and Evaluation

Onsite Inspection

- Onsite replication and hardness measurements to understand material condition
  - Measured circumference of Hammer Head
  - Control measurements made near cooling holes
- Elevated hardness measured in locations of heavy rub
  - Signs of significant overheating
  - Potential for material embrittlement
- Proposed onsite machining

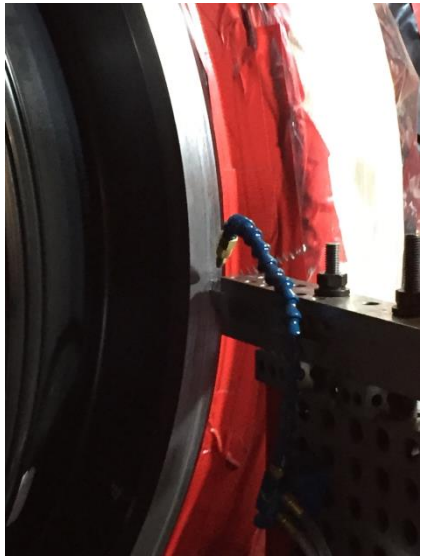


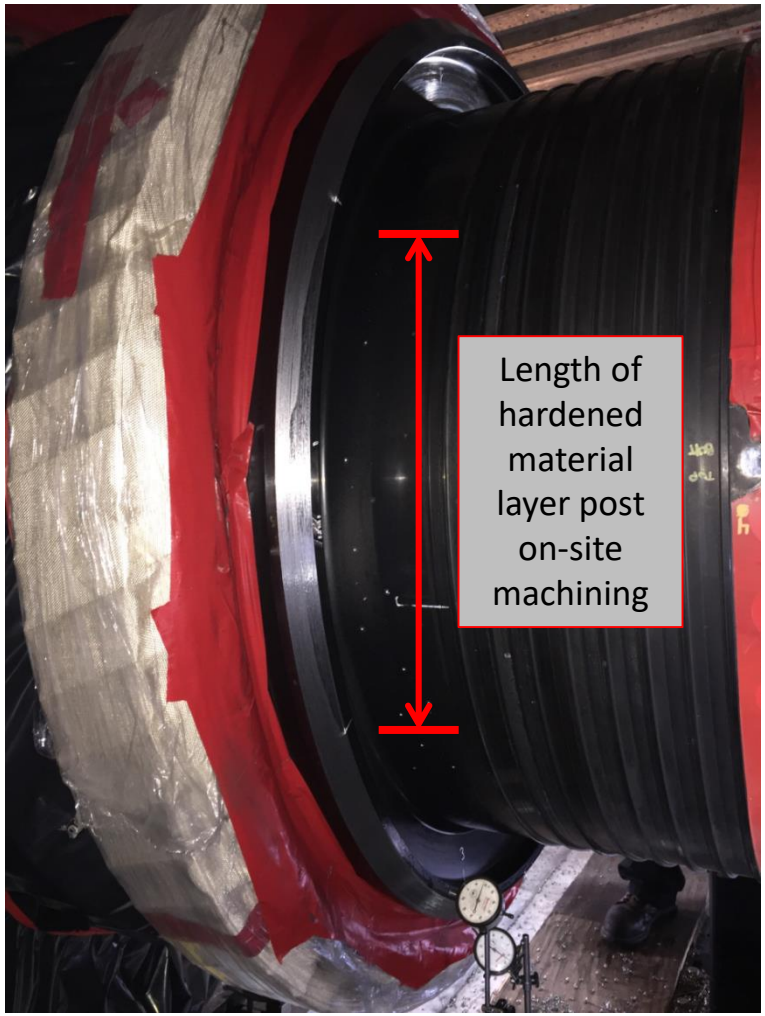
Must Remove Hardened Material to Restore to Baseline Material Properties

Inspection Findings and Evaluation

Onsite Inspection

- Field lathe used to grind/machine hardened material
  - Maximum depth defined via FE analyses
  - Hardness remained elevated at maximum depth
  - High risk – customer opted to replace



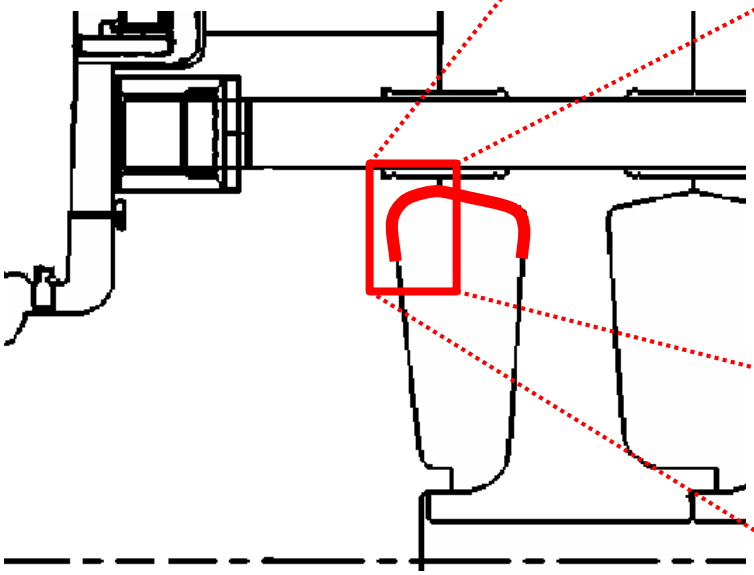


Unsuccessful Onsite Material Removal Resulted in Rotor Shop Visit for LTE

Inspection Findings and Evaluation

Shop Repairs – Surface Defects

- Disk web pitting
  - Pitting observed in the inner cavity of two disks near contact surface
  - “Wormholing” apparent in several pits, with some near the contact faces

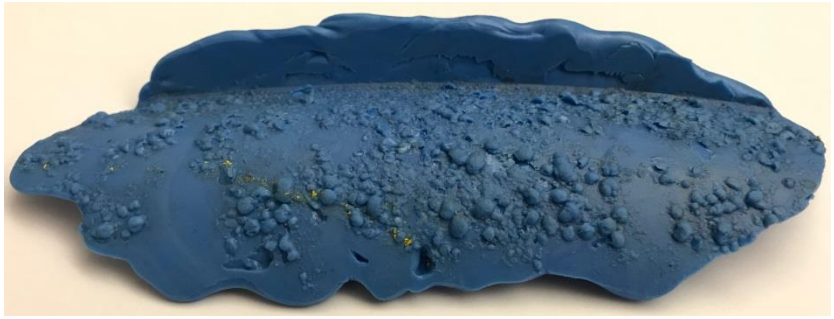


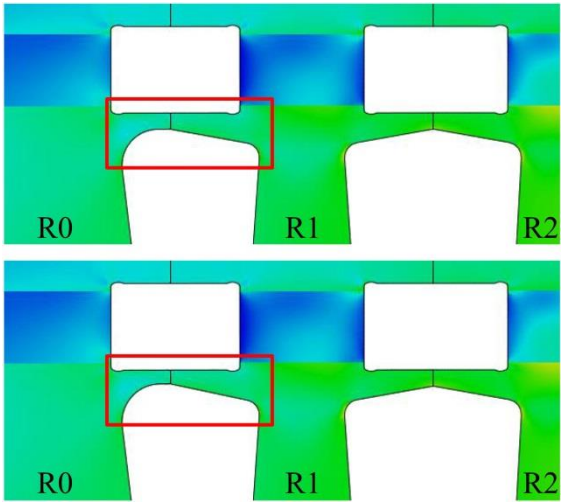
Extensive Wormholing Observed in a Moderately Stress Location

Inspection Findings and Evaluation

Shop Repairs – Surface Defects

- Repaired developed to remove pitting from internal surfaces
  - Depth understood via replications
  - Transient FE analyses completed to define envelope of allowable material removal
  - Final machining based on maximum depth and re-worked to disk webbing



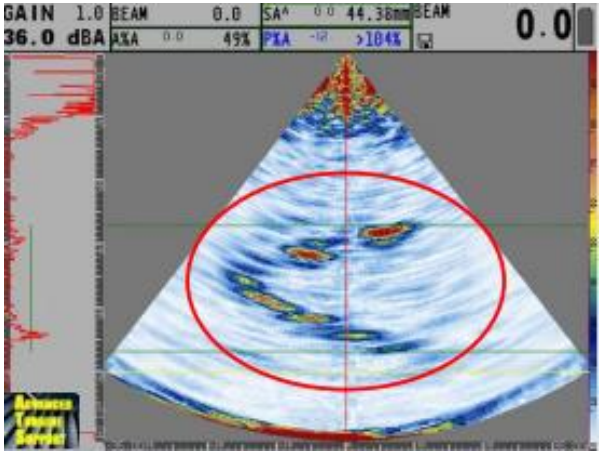


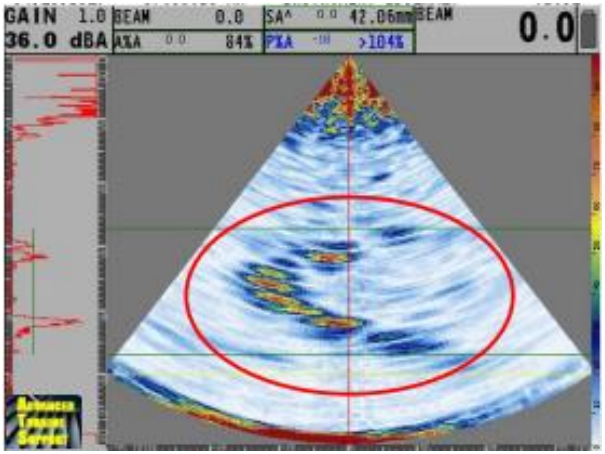
Transient Rotor Analyses Utilized to Provide Envelope for Pitting Removal

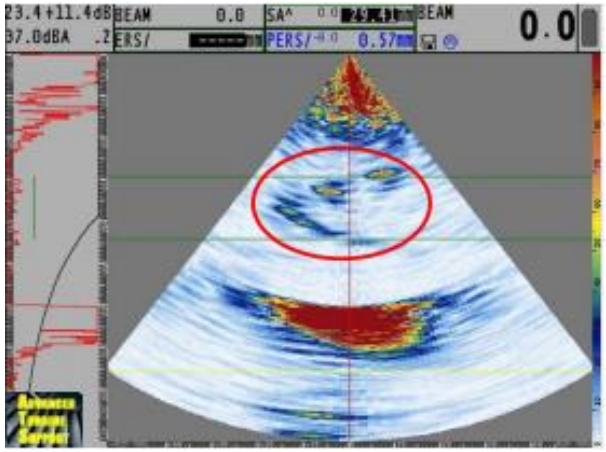
Inspection Findings and Evaluation

Shop Repairs – Internal Defects

- Forgings defects discovered throughout disk
  - Over 60 indications recorded
- Linking up of multiple indications
- Total length – > 19mm





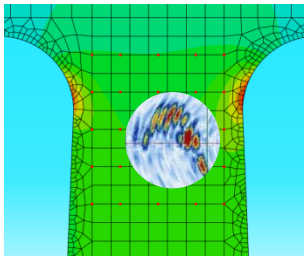


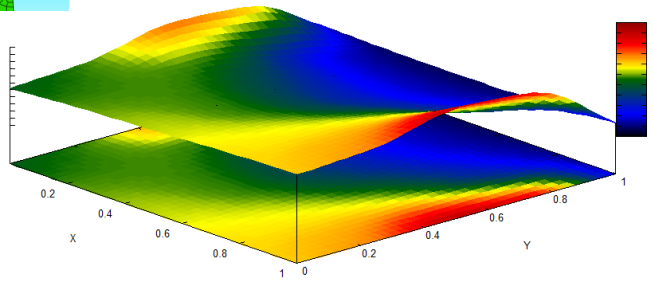
Significant Flaws Discovered in Cold End – No Visual Indications

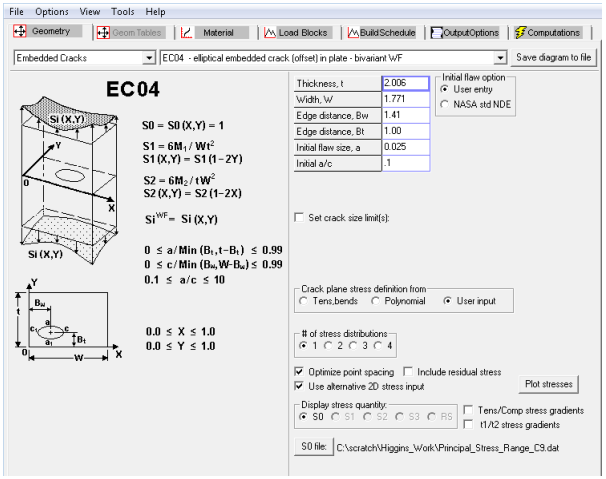
Inspection Findings and Evaluation

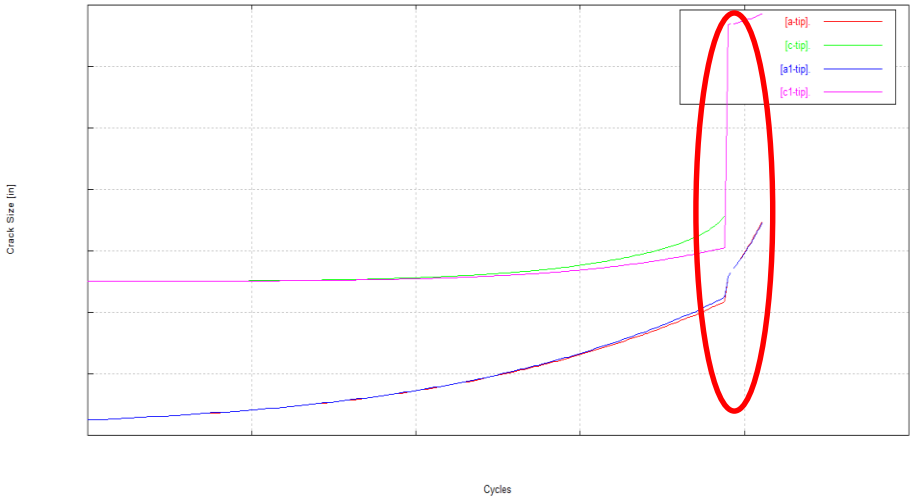
Shop Repairs – Internal Defects

- Detailed flaw analysis
  - Stresses pulled from transient rotor model
  - Fracture analysis of embedded flaws via NASGRO
  - Rotor life limited due to size of flaws
    - Original OEM lifetime acceptable, but…









Component Would Not Make Requested Interval – Replacement Necessary

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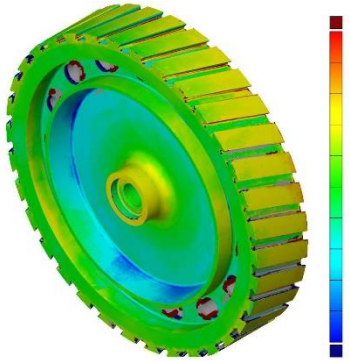
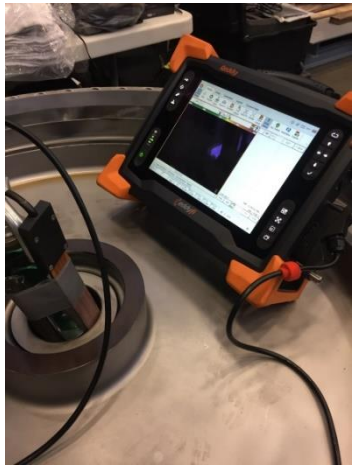
Return to Service

Market Sourcing Components

- Source used components from own inventory or third party
  - Dimensional Inspection
  - NDT Inspection
    - Chemistry / Metallurgical Evaluation
    - Full MT/ET/UT
  - Reassemble



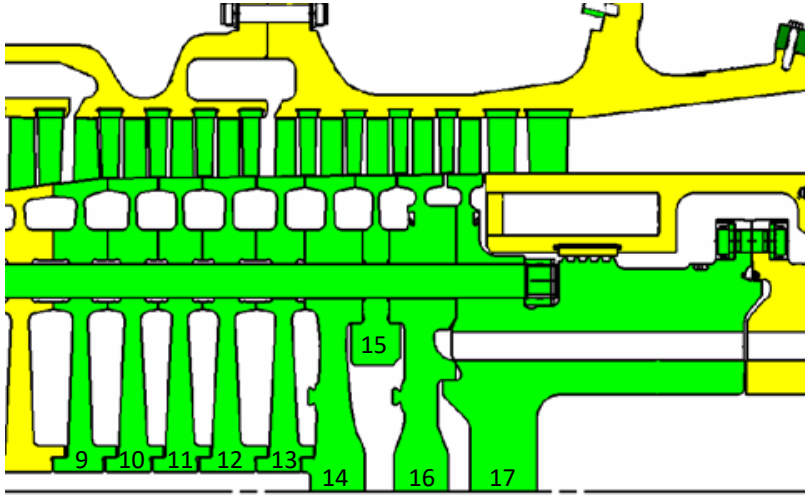


Fully-Vetted, Short Lead Time Options to Return Rotor to Service

Return to Service

New Make and Upgraded Solutions

- Replacement compressor disks
  - PSM Supply Chain; In-Kind Replacement
  - Includes several design improvements
    - Robust Back End with Round Bottom Slots
    - Optimized R14-R16 Clocking
    - Increased Bolt Length and Undercut



In-Kind Replacement or Upgraded Components to Extend Operation

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Summary

Extending F-Class Gas Turbine Rotors

- F-Class rotors are nearing their OEM recommended end of life
- Challenged O&M budgets require innovative rotor solutions
- To assess the true end of life, rotors must undergo an evaluation process
  - Complete disassembly of all components for detailed NDT interrogation – visual inspections will not suffice
  - Evaluation process must include detailed analytical modeling, representative material data, advanced NDT inspections, and comprehensive life prediction tools
- Components assessed individually – not as an assembly
  - True assessment based on as-found condition and operational profile
  - One scrap component does not scrap the entire rotor
  - Expect unforeseen findings
- Indications can become rotor life-limiting if not caught

Lifetime Assessments of F-Class Rotors Require Engineering-Backed Inspections

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