SOLUTION FOR GAS TURBINE ROTOR END OF LIFE

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Presentation Agenda

• Frame 7 Introduction
• Rotor End of Life
• Reverse Engineering Process
• Rotor Component Design and Analysis
• Production of Rotor Components
• Rotor Overhaul Example
• oOEM Experience List
• Summary
• Q&A
Frame 7EA Introduction

- GE® Frame heavy duty 7EA gas turbines, installed 1970 through to-date.
- Approximately 1100 units in operation.
- Note that recent model designation changed by OEM (7E.03)
Rotor Construction

- 7EA gas turbines have 17-stage compressor.

- Compressor rotor is assembled from individual stage bladed-wheel assemblies held by through-bolts.

- Compressor blades are installed on broached slots and held in axial position by staking.
Rotor End of Life

- For 7EA, rotor inspection at 200,000 Factored Fired Hour (FFH) or 5,000 Factored Fired Start (FFS).
- FFH and FFS calculated per OEM GER-3620.
- Rotor end of life defined by GETIL 1576/GER3620
- Failure to perform these inspections leaves the gas turbine at greater risk for failure.
Rotor Failure Mechanism

- Rotor carries highest energy. High stress & high temperature
- Environment (like salt corrosion, erosion) may contribute to premature failure of parts.
- Time, start-shutdown cycle, temperature, stresses impact low cycle fatigue (LCF) & creep.
- Rotor parts have finite design life. Planned inspection & life management critical
Rotor Failure Consequence

- Operational restrictions (e.g. power augmentation)
- Forced outage (e.g. trips, vibration)...Unit restarted immediately after remedy
- Contained failure (e.g. R0 blade or bucket liberation)...Unit restored after major repair
- Uncontained failure (e.g. wheel burst)...Serious damage to personnel/property

Frame 7EA – Nameplate 87 MW
Rotor Energy ~75 tons of TNT
Reverse/Re Engineering

Data Gather → Characterize → Model → Analyze → Refine & improve → Release to Manufacture

- Unit Field Inspection & Data Acquisition
- Unit Performance/Secondary Flow/Meanline Analysis
- Component/Assembly Characterization
- Component/Assembly 3D Modeling
- Metallurgical Evaluation, Analysis & Testing
- Laboratory Aerothermal & Structural Testing
- Legal Review
- IP

Computational Fluid Dynamics Analysis → Component Thermal Analysis → Component Structural Analysis → Component Vibration Analysis

Component Thermal & Structural Life Prediction → Component Sub-Modeling & Refined Life Prediction

Component Reverse-Engineering

Match Field Operating Experience

Component Product Definition

Manufacturing & Quality Procedure

Design Verification

Manufacturing
Reverse Engineering - Tools

- ATOS II triple scan blue light 3-D analyzer showing scanning of nozzle
- FARO Laser Scan of bucket
Reverse Engineering - Outage

• Typical Reverse Engineering data includes sub assemblies measurement, operational data, outage data, unit configuration, part numbers.

• Data collected before and after rotor is removed from unit. Casings and other sub-assemblies scanned.
Reverse Engineering - Overhaul

• Typically at onsite, EthosEnergy location.
• Individual parts and sub-assembly characterization
• Rotor is typically disassembled for scanning of parts.
Rotor Materials - oOEM

- Chemistry determination using X-ray diffraction technique
- Macro/ micro grain etching
- Hardness measurement
- Mechanical testing, (e.g. LCF, tensile).
Rotor Materials – OEM

- OEM Material data base used for rotors (such as NiCrMoV materials) and other parts.
- Design Basis & Standards
- OEM design practices and modeling tools
- EthosEnergy Standards & Processes
- OEM inspection and NDE standards

Typical W501D rotor
Engineering Analysis

- Access to tools & design methods
- Intellectual property
- Finite element modeling
- Transient analysis (cold start, start, warm start) Simulation
- Thermal analysis
- Structural analysis
- Lifing analysis
- Correlate observed failure modes
- Design improvements
Summary Results

- Stresses & temperature profile
- Critical locations
- LCF life calculations
- Blade frequency analysis
- Tolerance & stacking
- Assembly methods
- Parts & assembly drawings
- First article & process qualifications
- Process capability studies
Stress Prediction

- A - Blade Attachment (stress and temperature)
- B - Wheel Neck (stress and temperature)
- C - Bore/bolt holes (contact stresses)
- D - Female bore (operating stresses)
Critical Locations

• Internal and outer edge surfaces of all bolt holes inspected for flaws.
• High contact stresses due to bolt loading.
• Small edge radius on holes.
• Contact marks from bolt contact.
• Surfaces are uncoated.
Design Improvements

- LCF analysis of wheels
- Stress prediction in compressor wheels
- Proven OEM rotor disc materials.
Optimized Root Profile

- Round bottom compressor blade root profile geometry for stages 12-17 compressor wheels.
- EthosEnergy optimized round bottom blade root profile.
- Thicker web design for EthosEnergy wheels.
Wheel - Forging

- Forging pancake and machining drawings
- First article qualification
- Tooling development
- Final, finished machining.
- Final wheel Assembly & balance

Typical Production Sequence

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Wheel - Production

• Finish machining operation on individual wheels at EthosEnergy facility
• Manufacturing processes quality control & Service Excellence
• Final acceptance & sign-off of wheels
• Individual stage wheels shipped to Houston TX facility
Blade - Production

- Use the same material as OEM (ss403Cb, GTD450, etc.) for blades
- Can produce round slot bottom blades.
- Can produce in-kind blades to replace damaged blades
- Blades manufactured – Chicopee, MA facility
- EthosEnergy has blade inventory
Blades – New Design

• Patent pending round bottom design blade dovetail. Blade airfoil shape interchangeable with OEM-design
• Extended blade dovetail attachments eliminates need for spacers. [No spacer migration issue]
Rotor – Overhaul

Customer’s rotor arrives at rotor facility, Houston, Texas

Customer rotor transferred to rotor bay

Inspection – Bolt holes

Inspection – Journal

Inspection – Bolt

Inspection – S17 blade slot
Rotor – Disassembly
Advanced – NDE

• Mag particle and UT Inspection
• Advanced NDE (UT, Phase Array, etc.)
• Based on OEM and oOEM experience
• Engineering analysis of inspection findings
• Customized probes designed for location and flaw types
NDE – Probe Development

- Phase Array UT probes specific to geometry
- Sized for critical locations
- Blade attachment slots
- Undercut radius
- Wheel Neck
- OEM NDE Collaboration
Rotor – Stacking

Stage 17 wheel

Compressor bolting
Rotor – Final Balance

Mary rotors

Install buckets

Final Balance
Rotor – Pack/Ship

Completed rotor leaves EthosEnergy Facility
Rotor Solution(s)

• Solution A – NDE inspections during typical outage duration. Unit-specific rotor life assessment can be performed either at site or at EthosEnergy facility. No parts replaced.

• Solution B – Replace individual wheels. Rotor re-built during extended MI. Parts to be ordered in advance.

• Solution C – Replace life limiting rotor parts & Rotor Life Management. Rotor re-built during extended MI outage. Parts will be ordered in advance. Reverse engineering data on unit rotor for customized solution.

• Solution D – Exchange rotor option (low operation, overhauled rotor, ready to drop in the unit)
Summary

- **Fully integrated supplier** - EthosEnergy operates a fully equipped rotor service facility in Houston to service gas turbine rotors.

- **Enhanced operating capability** - Upgraded compressor disc material based on Siemens alloys.

- **Detailed Engineering Analysis** - A detailed characterization and design analysis of the entire rotor performed on the entire rotor system.

- Providing compressor rotor solutions to other customers and is in discussions with EPRI on an evaluation of its technology.
Experience

• EthosEnergy implements its Frame 7 rotor solution for a major US utility customer – unit successfully operating since 2015 and has accumulated over 150 starts.
• Frame 7 rotor solution sold to a major utility customer. EthosEnergy rotor solution to be implemented in 2017-18.
• EthosEnergy rotor solution independent verification – EPRI.
### Rotor – Experience List

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Q&A