The Impact of Increased Unit Cycling on Steam Turbine Failure Modes

February 20, 2019

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Preview of Industry Trends

• Steam Turbine
  – **More Cycling**
    • Two-shifting
  – Reduced minimum loads
  – Re-powering of vintage coal assets
  – Higher inlet temperatures
  – Combined cycle application

• Generator
  – Along for the ride!
## Flexible Operations Impact on Steam Turbine Failure Modes

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### Flex Ops

#### Impacted Components
- HP and IP Early Stage Rotating and Stationary Blading
- Valve components
- Inner casing
- Rotor blade attachments
- Rotor peripheral surfaces
- Blade Roots
- Blade Roots (1st stage HP or large IP Blades)
- Bearing, Pedestals, Foundations
- HP, IP, LP and Generator Rotors
- LP Rotor Blade Attachments
- LP Blading
- LP Seals/Grooves
- LP Rotor Disc Faces
- Turbine Rotor and Blades
- Full unit

#### Best Practices
- SPE coatings on early stages
- Operate in sliding pressure mode to reduce thermal differences
- Upgrade blade path components to reduce impingement angles
- Face valve components
- Minimize steam to metal mismatch to reduce thermal stresses
- Ensure detailed NDE plan to impact for cracking
- Optimize hold speeds and times based on rotor NDE findings and crack growth analysis
- Utilize steam seal prewarming on cold starts
- Audit Operational Data to Ensure:
  - Compliant with load and backpressure limits
  - Correct warmup hold speeds
  - Vacuum is broken at correct RPM during coast down
  - Set appropriate seal clearances for the mode of operation
  - Ensure complete casing insulation on cover and base
  - Factor in cold vs. hot alignment differences
  - High speed balance flexible rotors
- NDE Impact all wet rows for SCC in rotor blades attachments
- Uncertainty on stress:
  - Axial Entry: MT of End Face
  - Finger Root: Partial blade removal
- Frequency test tuned LP blading to trend the change in blade frequencies from mass loss due to erosion
- Calculate Eddy Current inspection of eroded areas
- Smoothing of erosion damage is not typically recommended as it will increase future erosion rates
- Frequency test tuned LP blading to trend the change in blade frequencies from mass loss due to erosion
- Complete Eddy Current inspection of eroded areas
- Audit different expansion instrumentation is calibrated

#### Significant Impact
- Significant Impact

#### Moderate Impact
- Moderate Impact

#### Minor or No Impact
- Minor or No Impact

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STEAM TURBINE FAILURE MECHANISMS
Steam Turbine Cycling Considerations

• Primary Failure Mechanisms
  – Low cycle fatigue cracking of rotor, blades, casing, generator
  – Solid particle erosion
  – Vibration and radial/axial rubbing
  – Distortion of casing

• Secondary Failure Mechanisms
  – High cycle fatigue cracking
  – Water droplet erosion

• Operational Concerns:
  – Vibration
  – Turbine water induction
  – Differential expansion
  – Boiler/HRSG issues
  – Overspeed
  – Loss of Lube Oil
LOW CYCLE FATIGUE (LCF)
Cracking – Cycling

- Primarily driven by LCF – areas with stress concentrations are of highest concern
  - Startup/shutdown cycles
    - Thermal stresses $\rightarrow \Delta T$;
      HP & IP vs LP
      » Creep interaction degrades material properties
    - Mechanical stresses $\rightarrow \sigma = m r \omega^2$
- Can be exacerbated by specific startup/shutdown practices
  - Improper or inadequate soak times
Cold Start Steam-to-Metal Temperature Mismatch
Common Inspection Findings
EROSION – SOLID PARTICLE AND WATER DROPLET EROSION
Solid Particle Erosion

- First few stages of IP and HP blading, and valves
- Damage caused by high velocity rust particles striking blading
- Surface roughness deteriorates fatigue strength
- Operator Awareness
  - Minimize startups/load swings - dislodge particles
  - Operate in sliding pressure mode - reduces throttle pressure which keeps velocities down
Tenon SPE
Nozzle Plate and Block SPE
LP Water Droplet Erosion

• Surface roughness caused by droplets reduces fatigue properties
• Reduces mass of tuned blades
• Repair Considerations
  – Blade frequency testing and trending
  – Stellite repair and/or stellite solid nose bar
  – Flag stellite
  – Blade replacement
• Operator Awareness
  – Keep reheat temperatures at design level
Erosion Rates are Non-Linear

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HIGH CYCLE FATIGUE (HCF)
Partial Arc Admission - HP inlet

- **Control Stage Blading Issue**
- **Shock Loading**
  - Increased steady loading
  - Impact entering the arc excites blade modes (usually first mode)
- **Nozzle Passing Frequency Concerns**
  - Impulse blading
  - High nozzle exit velocities
- **Operation and/or design changes may be required to correct this issue**
Stall Flutter – LP Blading

- Flow separation produces vibrations
- Occurs in last stage of LP under low load and high back-pressure conditions
- Conditions of concern:
  - Longer blade designs with lower first blade mode frequencies
  - High air in-leakage
  - Summer periods where backpressure control is challenged
  - Potential for increase in failure mode with shift towards load cycling
EVENT DRIVEN
Water Induction Common Causes

• Extraction Sources
  – Leaking Feedwater Heater Tubes
  – Level Control Failures
  – Poor design – heater drains
  – Obstructed extraction line drains

• Main Steam Sources
  – Inadequate drains or not at low point
  – Fast start after boiler trip
  – Attemperator spray malfunctions

• Steam Seal Systems
  – Auxiliary source issues
  – Clogged gland seal header or inadequate drains
  – Operational
Loss of Lube Oil

- Loss of primary and emergency lube oil pumps
- Rotor loses oil wedge and babbitt damage occurs. This leads to a significant radial drop of rotor
- Can result in major rub damage, with potential for high hardness and rotor bowing
Turbine Trip Protection

• Worst case is overspeed event with severe damage
• Potential problem indications:
  – Slow or sticky steam valve operation
  – Delays in rolling down to turning gear due to valve leakage
  – Delays in valve closure
• Mitigation?
  – Valve testing
  – Routine overspeed testing
  – Routine maintenance
  – Sampling and analysis of hydraulic oil
  – Thorough testing to any newly installed turbine trip system
  – Trip on Reverse Power
Thank you – Questions?