Technical Considerations for Optimizing Steam Turbine Start Ups

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Agenda

• Why Optimize?
  • Vintage vs. Modern STG’s
  • Approach – Fracture Mechanics vs. Fatigue Principals

• Technical Considerations
  • Key Design Parameters
  • High Temperature Rotor Considerations
  • Operational Considerations

• Options for Optimization & Case Studies
  • Utilizing Existing Plant Systems
Why Optimize?

• Influx of renewables, low gas prices, and energy demand vs. supply has resulted in an oversaturated market

• Significant decrease in baseload assets
  • More start opportunities

• Many steam turbines are competing with combined cycle plants “designed” for cyclic duty
  • Requires competitive start times
  • Heat rate deficiencies may lead to cyclic duty cycle

• Reduced start times provide economic benefits
  • Reduced fuel and water costs
  • Potential for additional run opportunities
Vintage vs. Modern Steam Turbines

Vintage
On the “Back 9”
• HP/IP: Creep and embrittlement concerns, solid particle erosion, rotor bow, casing cracking
• LP: Stress corrosion cracking, water droplet erosion

Less Modern Designs
• Most have rotor bores
• Often, limited capital investment due to long term asset outlook
• Heat rate deficiencies

Modern or Retrofit
Early in Lifecycle
• Less accumulated fatigue damage
• Unlikely to have a rotor bore

“Not Out of the Trap”
• More aggressive duty cycle, i.e. cyclic duty
• 1050°F inlet steam conditions are common
• Designed for enhanced performance, can provide operability challenges
Approaches – Rotor Analysis

Fatigue: Stress - Life

- Large portion of fleet designed prior to adoption of fracture mechanics
- Number of cycles at a given stress level to initiate a crack
- Often provided multiple start up curves that have varying life consumptions

Fracture Mechanics (~1980’s)

- Current practice recognizes forgings are inherently flawed
- Therefore, we calculate the number of cycles to propagate a flaw from its current size to a critical size
- Function of stress, fracture toughness (temperature), and current flaw size and characteristics
Technical Considerations
Key Start Up Parameters

Pre-Roll:
- Steam superheat requirements
- Steam line warming
- Rotor eccentricity
- Condenser vacuum

Turbine Roll/Soak:
- OEM acceptable hold speeds
  - LP blading resonant frequencies
  - Rotor lateral critical speeds
- Steam to metal temperature mismatch
- Lube oil temperatures
- Shaft relative vibration levels
- Rotor heat soak times
- Differential expansion
- Steam chemistry
Why do Cold Starts Require Holds?

- HP & IP rotors are made from a different material than LP & Generator rotors
- HP & IP rotors require temperature to act ductile
- LP & generator rotors are ductile at room temperature
- Fracture toughness of HP & IP rotor increases during cold starts
  - Increased fracture toughness = improved safety margin
- When rotor temperature = Fracture Appearance Transition Temperature (FATT) rotor behaves 50% brittle, 50% ductile
- More ductile behavior -> greater fracture toughness -> larger critical flaw size
- Heat soaking improves rotor ductility, prior to introducing large stresses
How Do “Vintage” Rotors Age?

- Embrittlement occurs in areas where the rotor sees temperatures around 800°F
- Causes an increase in FATT -> takes more temperature to get ductile behavior

Influence of service temperature on rotor post service FATT (>100K hrs.)
Do Hold Speeds Matter?

Incorrect hold speeds can excite:

- Rotor lateral critical speeds – seen in bearing vibration measurement
- LP blading – not measured or seen in bearing vibration measurement
Steam to Metal Temperature Mismatch

- Minimize steam to metal mismatch to reduce thermal stresses

Steam to Metal Mismatch

> 500°F
Clearance Considerations for Cycling

- **Radial clearances**: critical speeds experienced during start up results in increase shaft deflection.

- **Axial clearances**: Common for units to experience differential expansion issues on start up - particularly reaction designs and retrofit designs.

- Insufficient clearances can impact cycling capability
Start Up Modeling
Methodology

- Review latest boresonic and outage inspections
- FEA model of limiting rotor (Often IP rotor)
- Baseline analysis of cold start data
  - Review existing cold start
  - Evaluate stresses and temperatures in rotor from FEA model
  - Fracture mechanics analysis to establish limiting critical crack size during start up
- Compare limiting critical crack size to known flaws in the rotor to ensure substantial margin
- Modify start up process (pre-roll, roll, and loading) to reduce time while maintaining or improving safety margin

Goal is to improve start up safety margin while reducing overall time
FEA Model for Stress & Temp

Stress and temperature results reflect actual startup
Startup Objective: Maximize Rotor Critical Crack Size

- Rotor Fracture Toughness
- Crack Geometry
- Rotor Bore Stress
- Initial Flaw Size
- Boresonic Report

Rotor Metal Temperature and $\Delta T_{\text{Steam - Metal}}$ impacted by turbine start up procedure

Goal is improve rotor ductility (fracture toughness) through heating prior to introducing large rotor bore stresses (driven by $\Delta T$, RPM)
Cold Start Bore Temperature Results
Cold Start Bore Stress Results
Cold Start Calculated Bore Critical Crack Sizes with Steam Seal Pre-Heat

1. Opportunity
2.
3.
Options for Optimization
Start Up Modifications

- Steam conditions: temperatures and pressures
  - Reduction in thermal stresses, however steam must be hot enough to provide rotor heating
  - Earlier steam induction
  - Superheat requirements
- Preheat: steam seals
  - Steam seal preheat (~12 hrs) has significant benefit
  - Electric aux boiler can be an economical upgrade
- Soak speeds: optimized speeds and times
  - Low speed holds while rotor is brittle
  - Improved heat transfer at higher speeds
- Full speed holds: reduction of hold times
  - LP concerns at very low loads
  - Already reached peak rotational stresses
  - Limited heating benefit due to low flow
Steam Seal Preheat
Steam Seals In Practice – A Major Benefit

- Excellent correlation between Field thermocouples and TGA conduction model
- IP blade ring metal temperatures at roll were measured at ~150°F, HP first stage metal temperatures ~175°F
Modified Optimized Hold Speeds and Times
Ramp to High Speed with Cold Rotor

Model Bore Temperature Results

Temperature (°F) vs Time (hours)

- Stage 1
- Stage 2
- Stage 3
- Stage 4
- Stage 5
- Stage 6
- Stage 7
- Stage 8
- Stage 9
- HRH T
- Speed

Ramp to High Speed with Cold Rotor

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Ramp to High Speed with Cold Rotor

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Ramp to High Speed with Cold Rotor

Model Bore Temperature Results

Temperature (°F) vs Time (hours)

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- HRH T
- Speed

Ramp to High Speed with Cold Rotor
Ramp to High Speed with Warm Rotor
Ramp to High Speed with Cold Rotor
Ramp to High Speed with Warm Rotor

Calculated Critical Crack Sizes

- Stage 1
- Stage 2
- Stage 3
- Stage 4
- Stage 5
- Stage 6
- Stage 7
- Stage 8
- Stage 9
- Rotor Speed

Critical Crack Size (inches)

Time (hours)

Rotor Speed (RPM)
Reduction Full Speed
Low Load Hold
Reduction of Time at Full Speed Low Load

• Prolonged hold at full speed and no/low load
• Rotating stresses are already maximum and limited additional heating until unit is loaded
• Multiple benefits to reducing this hold time
  • Windage heating concerns
  • LP exhaust flow recirculation
  • Differential expansion and unit heating concerns
  • Potential for increased rotor vibrations
  • LP blading vibration concerns
Closing Comments

• Significant fuel savings and dispatch benefit for steam turbines that can start quicker
• Opportunities exist to safely reduce cold start times without capital upgrades
• Approach utilizes recent inspection results, finite element analysis, and modern fracture mechanics principals
• In TG Advisers’ experience, cold start times on older steam turbines commonly can be reduced by 25% to 50% while still adhering to critical OEM design parameters and requirements