Generator

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Fleet Trends & Lifecycle Considerations
Generator Lifecycle – 6B NA Fleet

- Expect the worst... Fleet populations are aging towards increased risk of rotor & stator rewinds, Now is the time to start planning for rewinds
- Plan for the best... Trend past and current operational data, unit history and test & inspect data to manage operational risk level
- Take what comes... Site specific conditions will dictate proactive vs. reactive maintenance approach
GEK 103566 – Creating an Effective Generator Maintenance Program

Revision L Updates

Combining legacy GE with legacy Alstom

- Added Low Oxygen Stator Cooling Water System recommendations
- Combined Stator & Rotor Test and Inspections

Added Retaining Ring & “When to Remove Rotor” recommendations

Updated Rotor Life Management recommendations

Terminology changes:

- 1st Year Inspection (Major Scope) → First Inspection
- Minor Inspection/Inspection A → Borescope Inspection
- Major Inspection/Inspection B → Robotic Inspection
- MAGIC/DIRIS → Robotics

Borescope Inspection:

- Visual inspection through the end shields or cooler(s)
- Electrical tests per Tables 3 → 5

Robotic Inspection:

- Rotor In-Situ Inspection via Robotics
- Stator & Rotor Tests and Inspections per Tables 3 → 5
Creating an Effective Generator Maintenance Program

Revision L Updates – Inspection & Maintenance Intervals

### Rev K

<table>
<thead>
<tr>
<th>Model</th>
<th>1st Year Inspection (Major Scope)</th>
<th>Maintenance Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual</td>
<td>Minor</td>
</tr>
<tr>
<td>Type of Hours/Starts</td>
<td></td>
<td>Factored</td>
</tr>
<tr>
<td>H35 (71H2), H37 (71H2), H42, H43, H44, H45, H46, H47 (4A46), T43 (4A43), T45 (4A45)</td>
<td>8,000 Turbine Hours; 250 Starts</td>
<td>24,000 to 32,000 Turbine Hours; 900 to 1,250 Starts</td>
</tr>
<tr>
<td></td>
<td>Liquid Cooled</td>
<td>24,000 to 32,000 Turbine Hours; 900 to 1,250 Starts</td>
</tr>
<tr>
<td></td>
<td>All Other Models</td>
<td>26,000 to 36,000 Turbine Hours; 30,000 to 40,000 Turbine Hours</td>
</tr>
<tr>
<td></td>
<td>Asphalt Stator Bar Windings for Care Length over 150 Inches</td>
<td>12,000 to 15,000 Turbine Hours; 400 to 800 Starts; 13,000 to 15,000 Turning Gear Hours</td>
</tr>
</tbody>
</table>

### Rev L

**First Inspection**
- 8,000 Turbine Hours; 250 Starts; 4,000 Turning Gear Hours

**Inspection and Maintenance Intervals**
- 8,000 Turbine Hours; 250 Starts; 4,000 Turning Gear Hours
- 24,000 to 32,000 Turbine Hours; 900 to 1,250 Starts; 40,000 to 64,000 Turbine Hours; 1,800 to 2,400 Starts

*In the absence of operating experience and resulting condition assessments, Table 2 lists the recommended inspection intervals for turbo- generators. Generators can be inspected commensurate with the associated turbine inspection outage. These initial intervals should be reviewed and adjusted as operating and inspection experiences are accumulated.*

LC = Liquid Cooled

Alternate borescope and robotic inspections
Follow figures 1 and 2 as examples
### Events or Trends Predicating Rotor Removal

<table>
<thead>
<tr>
<th>Events or Trends Predicating Rotor Removal</th>
<th>Required Maintenance or Repair Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abnormal operating events as listed in Section 2: Maintenance Planning</td>
<td>Rotor tooth and wedge inspection and repair to remove hardened material</td>
</tr>
<tr>
<td>Rotor vibration trends coupled with flux probe shorted turns or blocked ventilation passages</td>
<td>Rings off cleaning up to field rewind</td>
</tr>
<tr>
<td>Stator wedge looseness trends</td>
<td>Partial or full stator re-wedge or retightening</td>
</tr>
<tr>
<td>Air gap foreign object damage</td>
<td>Core or wedge repair</td>
</tr>
<tr>
<td>Stator winding insulation degradation indicated through DC leakage or Partial Discharge trending</td>
<td>Partial or Full stator rewind</td>
</tr>
</tbody>
</table>

Driving towards online trending, in-situ testing and inspection

Rotor removal for repair purposes
Robotic Inspections
Types of robotic inspections:
- In situ air gap inspections
- In situ retaining ring inspections
- Wedge tapping

<table>
<thead>
<tr>
<th>Generator Model</th>
<th>Junior</th>
<th>Magi</th>
<th>Small</th>
<th>Retaining Ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>6A2</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6A3</td>
<td>✓*</td>
<td>✓*</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>6A6</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>T214-234</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

* Depends on entrance gap
In-Situ Retaining Ring Inspection

GE utilizes an inspection robot to detect indications of impeding cracks with the rotor in or out.

GEK 103566 inspection recommendations:

18-5 Retaining Rings:
• Visual at the borescope inspection
• NDT at the robotic inspection

18-18 Retaining Rings:
• ID inspected each time they are removed
• NDT
  • Prior to 30 years of service or 10K start\ stops
  • Then every 10 years after or 2K start\ stops

Customer benefits

| Shorter down time periods due to reduced dismantling (rotor in situ; end bells in place) without sacrificing safety and quality |
| Increased generator availability with faster returns to service |
| More accurate and reproducible assessments |
| Supports condition-based maintenance program development |
Inspection Data

512 robotic inspections carried out between 2011-2016 were examined:
• 20 rotors pulled
• 3 forced outages – 2 rotor ground. 1 Neg Sequence with arc strikes
• 2 Partial rewedge, 1 full rewedge
• 10 cases use visual, 2 field ground, 4 wedge test, 1 knife test, 3 electrical, 1 NDT, 1 vibration (>20)
• Electrical tests usually confirm other tests or conditions such as shorted turn and vibration

21 future recommendations
3 rewedge, 1 bump test, 17 visual findings

Visual Inspection is the key inspection – Data shows robots find the same visual defects as rotor out
Wedge Testing is second key inspection – Data shows WITS for TRS units is equivalent to rotor out
Generator Monitoring
Generator Health Monitor - Modules

Moving to condition-based maintenance

* Stand alone, check for applicability
## Generator Health Monitoring

### L1 Sensors
- Permanently installed, including cabling & connection boxes (GE or most third party)

### L2 GOLD\* Service
- Portable DAU
- Site visit twice a year
- Report on collected data

### L3 Service
- Permanently installed DAU
- Half yearly full report

### L4 Remote Service
- Permanently installed DAU
- Permanent data link & storage
- Weekly checks
- Quarterly full report

### Periodical Monitoring

- **L2 GOLD\* Service**
- **L3 Service**
- **L4 Remote Service**

### Continuous Monitoring

- **L2 GOLD\* Service**
- **L3 Service**
- **L4 Remote Service**

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GHM - partial discharge

**Sensors**
- Capacitive bus couplers
- Low frequency 9 nF sensors
- 1 Per phase + 1 at neutral point

**Monitoring**
- Slot PD
- Void/delamination PD
- Surface PD
- Phase to phase PD
- Vibration sparking
- Partial discharge location

**Identification of**
- Stator bar insulation condition
  - Aging of insulation
  - Semi-conductive coating deterioration
- Loose stator bars
- Generator contamination

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GHM - rotor flux

**Sensors**
- Rod-type probe
- Wedge mounted flip-up probe
- Wedge mounted pop-up probe

**Monitoring**
- Rotor inter-turn short circuits
- Accurately identification of effected slot
- Magnitude of fault
- Trend deterioration

**Identification of**
- Electrical breakdown of inter-turn insulation
- Mechanical breakdown of inter-turn insulation
- Carbon and oil contamination of windings
- Copper dusting due to excessive barring
- Turn to turn contact due to coil shorting, distortion or elongation
Rotor Flux case study

• Unit experienced a field ground trip due to a problem with the main terminal stud
• Rotor Flux Monitor had indicated 3 shorted turns in coil #8
• Unit was shutdown and the rotor removed
• Coil #8 was removed for repair. This was a high impedance fault.
GHM - rotor shaft voltage

**Sensors**
- Shaft grounding with copper braids
- Good contact even at high surface velocity
- High performance in contaminated conditions (oil and dirt)

**Monitoring**
- Electric discharge
- Shaft magnetization
- Shaft rubbing
- Grounding problems
- Brush sparking
- Rotor interturn faults

**Identification of**
- Bearing damage
  - Electro pitting
  - Voltage tracking
  - Electric erosion
  - Frosting
- Insulation breakdown
Questions?
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Revision L Updates – Inspection & Maintenance Intervals Examples

For this specific example, it is assumed that the turbine generator inspection and maintenance interval is determined by factored hours or actual hours, typical of a unit that is operating over 6000 hours per year.

Consult the appropriate maintenance and inspection manual for interval guidance. This example is meant to demonstrate how generator inspection and maintenance intervals would be synchronized for a gas turbine with the referenced intervals.
GHM – collector health monitor

Sensors
• Radio frequency current transformers

Monitoring
• Milliamp variation in excitation current
• Disruption of current flowing from the collector brushes to the collector rings
• Trend the variation

Identification of
• Sparking which is correlated to collector ring flashover
Collector health monitor case study

5% Spark Rate over a 3-hour period on month 1

Deep dive of data found a spike 10X of the threshold on month 2

• Site had an outage in month 3 and was instructed to closely inspect the collector / brush assembly

• A brush was found that was heavily worn and the brush holder appeared to, at some point, have carried current

• The collector surface was found to have salt deposits and corrosion
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Revision L Updates – Rotor & Retaining Ring Life Management

**Rotor Life Management**

<table>
<thead>
<tr>
<th>GENERATOR FIELD CHARACTERISTICS</th>
<th>INSPECTIONS REQUIRED</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-service and has a main body bore</td>
<td>Full suite of NDT inspections based on re-inspect recommendations</td>
</tr>
<tr>
<td>In-service with no main body bore</td>
<td>Full suite of NDT inspections except bore inspections</td>
</tr>
</tbody>
</table>

**Retaining Ring Inspection - New guidance is given in this revision**

**18Mn-5Cr RR - older configuration**
- Should be replaced due to history of stress corrosion cracking
- If not at a minimum inspected at each outage interval
  - Borescope Inspections - Visual inspections should be completed
  - Robotic Inspection - NDT should be completed

**18Mn-18Cr RR - current configuration**
- The ID inspected at each time they are removed using fluorescent penetrant
- NDT of the retaining ring
  - prior to 30 years of service or 10,000 start/stops
  - then every 10 years or 2000 start/stops

**Recommendations going forward....**

- First in-service inspection required at 20 years or 2000 starts/stops from COD.
- Re-inspect based on number of starts only; however, GE would reserve right to add year based recommendations dependent on age of the unit and/or operation profile.
- 2000 starts/stops will be the maximum recommendation.
In-Situ (Air Gap) Inspection

GE offers fast and reliable inspection of the turbo generator without the need to pull the rotor out. (OEM & OOEM)

1. Robotic Visual Inspection (via air gap)
2. Robotic Low Flux / EL-CID
3. Robotic Slot Wedging Tightness Test
4. HV tests
5. Brush gear inspection
6. Partial Visual Inspection (End winding)
7. Insulation Resistance Measurement
8. Rotor Inter Turn Short Circuit Detection (optional on Legacy GE)
9. Instrumentation check
10. Bump test (optional)

Customer benefits

- Up to 40% time saving compared to conventional inspection with rotor out
- Reduced costs by keeping rotor in, simplify crane support and lay down space
- Reduced risk during overhauls due to reduced dismantling
- Accurate and reproducible assessments
- Faster Return to Grid without sacrificing safety and quality
- Supports condition-based maintenance program development

Several robots to fit a broad range of generator types
Wedge tapping

- Applicable to units with a conformal wedging system
- Methods including acoustic tapping and hardness measurement rely on very low force applied to the wedge surface
- The resulting response is different for a tight wedge vs. a loose wedge.
- These methods are very sensitive but prone to variation due to wedge surface condition, oil, grease, and paint.