Termoflores
Reference D5/D5A
Gas Turbine Upgrades

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Gas Turbine Modernizations

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Project Overview

Customer
- Zona Franca Celsia

Location
- Barranquilla, Columbia

Gas Turbine Frame
- W501D5

Outages
- November 2017 Major
- April 2018 Major

Modernizations Applied
- Si3D Turbine Modernization
- Bolted Compressor Rotor
- IIEP 2.0 Combustor Hardware

Customer’s Objectives
- Increased Power
- Decreased Heat Rate (increased efficiency)
- Frame Lifetime Extension
- Interval Extension
- Increased Reliability
- Repair Cost Savings
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Si3D™ Turbine Upgrade

Package Features
• Aerodynamic redesign of stage 1 blade / vane & row 2 vane
• Cooling air savings – component cooling reduction & sealing improvements
• Leverage advanced frame technology

Expected Program Benefits
• Improved efficiency / increased power with Si3D re-aero
• Higher firing temp’s with IIEP 2.0 Combustors
• D5-D5A interchangeability (D5 requires D5A blade ring)

Expected GT Performance*
• D5: Up to ~5 MW; 300 BTU/kWhr
• D5 with FTI Up to ~10.5 MW; 333 BTU/kWhr

Heat rate and power improvement

* Performance increases depend on site specific configuration
Si3D™ Turbine Redesign (Stages 1-2)

- Si3DTM row 1 & 2 vanes with riffle seals
- Si3DTM row 1 blades with new sealing hardware
- TBC coated ring segments rows 1 & 2
- Upgraded thrust bearing pads
- Redesigned stage 2 thermocouples
- Row 2 interstage seal housing baffle plate modification
- Features already included in standard D5As:
- Cooling flow modulation rows 2 & 3
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W501D5/D5A Bolted Compressor

Enhanced Design Features:

- Visible blade locking keys (no change in blade attachment)
- Retrofit to Turbine spindle (marriage coupling joint)
- Reparability-Individual disc replacement
- Shear pins to transfer torque
- Multiple Spindle bolt design
- Vibratory Response
- Enhanced Air-separator
- Improved Materials result in increased life
- Spigot fits from disc to disc support 10 minute fast start

Features adapted from 501F style compressor rotor
Bolted Compressor Enhancements

Shear pins throughout compressor

Collared nuts both ends

10 spindle bolts w/ rolled threads

Both EOST & mechanical overspeed & key phaser designs supported

All compressor discs / CTT use advanced materials
Bolted Rotor Configuration

Intended Benefits:
- Bolted configuration produces straighter rotor
- Improved materials results in increased life
- Bolted / spigot configuration supports 10 minute fast start

Standard D5/D5A blade locking

2-piece air separator to reduce potential imbalance, and less thermally sensitive

No change to static hardware
Rotor Dynamic Enhancements

New stage 7 field balance plane (casing modification required)

Additional shop balance plane at stage 12

Bolted configuration intended to produce straighter / improved run-outs

2-piece air separator intended to reduce potential imbalance
Design Features
Two Piece Air-Separator

• Bolted on disc reduces radial motion of the torque tube mating flange by bolting mass to TD1
• Proven design. Multiple units with 150K+hrs with lead unit ~200K hours

New air separator designed to reduce potential for shifting / source of vibration
• Reduced mass of forward section
• Aft section bolted to rotor
Two Piece Air Separator Details

New Sealing Surface with reduced free-rotating mass is much stiffer

Blade 1 cooling supply holes

Bolted Disc

Slots to clear TD1 cooling holes

Torque Tube

Bolted Disc

Assembly View

Previous Sealing surface

New Sealing Surface

Torque Tube

TD1
W501D5/D5A Bolted Compressor Rotor Design – Fast Start Implementation

Current D5 Startup schedule: TG > FSNL = 20 min; Synch = 0.5 min; Load = 8.5 min
Total = ~29 min

- Rotor design is intended to allow “fast start” = 10 min to full load
- Improved GT acceleration rate
- Improved GT loading rate = 24 MW/min
- Controls modifications - “fast start button” added and firing curves modified
- Fast start factors (Equivalent starts) - 10x per fast start

Fast Start D5 Startup schedule: TG > FSNL = 8 min; Synch = 0.5 min; Load = 5.5 min
Total = ~14 min
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D5/D5A Redesigned Combustion System
IIEP 2.0 Combustor Hardware

- Redesigned Transition Cylinder
- Redesigned Water Injection Nozzle
- Redesigned Basket
- Redesigned Cross Flame Tube
- Outer Transition seal eliminated!

Improved LCC / designed to address identified distress modes, improve water spray and maintain current emissions and dynamics levels / 16k EBH / 1,600 ES inspection interval
Is 1600 ES equal to 16kEBH?
Jose Rafael Serje Polo, 10/1/2018
IIEP 2.0 Combustor Nozzle Details

- Improved Materials
- Heat shield added
- Improved water spray
- Improved oil spray

Water/Oil Interaction

Baseline through oil tip

New Water Spray

Improved Welds

Material Upgrades

Bellows

HA320 Heat Shield

Cooled Base Plate

Duplex Atomizer

Thread

Locking tab

Cap

Primary circuit

Secondary circuit

Conical metal seal

Seal
IIEP 2.0 Combustor Basket Detail

- IGCC Design Download – more efficient cooling (platefin)
- Extra cooling at key locations
- Cross Flame tube locations moved upstream
- Latest materials from Advanced frame turbines
IIEP 2.0 Combustor Transitions

- Enhanced design
- Smoother shape to reduce stagnation areas
- Flow turned sooner to spread flow
- Thicker panels to resist deformation
- Advanced cooling concept throughout panels
- Effusion cooling where needed
- Integrated Exit Piece (IEP), eliminates outer seal
- Latest materials from advanced frames
IIEP 2.0 Bolted Combustor Coupling (BCC)

**Bolted Combustor Coupling (BCC)**
- Bolted flange design
- Reduced distortion
- Retrofittable to existing transitions
- No relative motion between mating parts expected
- Scallops between bolts for life extension
- Cooling holes at transition junction
- Hard face mating surface with basket

**Design Experience:**
- Installed in Siemens W701DA units since 2000
- Based on validation data – reparable is a goal
- No reported operational issues
IIEP 2.0 Combustor System Installed
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<tr>
<th>Item</th>
<th>Improvement</th>
<th>Commercial Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity of 1X1 CC Plant</td>
<td>6 MW Increase</td>
<td>• More MWh available for sale annually</td>
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<tr>
<td></td>
<td></td>
<td>• Displaces duct firing</td>
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<tr>
<td>Heat Rate of 2X1 CC Plant</td>
<td>~376 BTU/kWh decrease</td>
<td>• Reduction in fuel gas costs due to increased GT efficiency</td>
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<tr>
<td>Recommended Inspection Interval</td>
<td>2 x current recommended inspection Interval</td>
<td>• Increased plant availability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Reduction in O&amp;M costs</td>
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New slide inserted for Flores 1 (CC 1x1)
Jose Rafael Serje Polo, 10/1/2018

It should be same as before
Jose Rafael Serje Polo, 10/1/2018
## Termoflores Reference D5A
### Project Results – Flores IV

<table>
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<tr>
<th>Item</th>
<th>Improvement</th>
<th>Commercial Benefit</th>
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<tbody>
<tr>
<td>Capacity of 2X1 CC Plant</td>
<td>~10 MW Increase</td>
<td>• More MWh available for sale annually</td>
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<td>• Displaces duct firing</td>
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<tr>
<td>Heat Rate of 2X1 CC Plant</td>
<td>~287 BTU/kWh decrease</td>
<td>• Reduction in fuel gas costs due to increased GT efficiency</td>
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<td>Recommended Inspection Interval</td>
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</table>
JRSP4  10 MW in the CC (8.5 Mw from the CT2)
Jose Rafael Serje Polo, 10/1/2018

JRSP5  -286.93 BTU/kWh with the CT2 upgrade
Jose Rafael Serje Polo, 10/1/2018

JRSP6  We pass from 10,600 to 16,000 EBH (combustor inspection interval).
Jose Rafael Serje Polo, 10/1/2018
Key Takeaways
(from all M&U Product Presentations)

- Advanced ULN combustion system can help achieve < 9 ppm NOx, while supporting advanced thermal performance upgrade products

- Wide array of performance upgrade products; e.g., FD2, per GT, up to 36 MW / - 620 BTU HR

- FD6 rotor technology (pre-swirler) can eliminate air separator and can significantly help improve performance

- Advanced Exhaust Solutions (SPEX and ATP) continue to perform very well

- Products for operating flexibility (LLTD, ALLTD, OTC+, GT-ACO, Inlet Heating) to support changing market demands

- Environmental Permitting and BoP equipment require necessary due diligence for proper implementation of M&U products
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Thank You!!

Question and Answer