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2012 PACESETTER PLANTS


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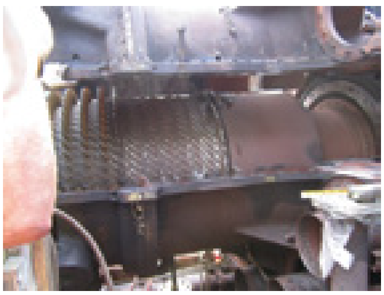
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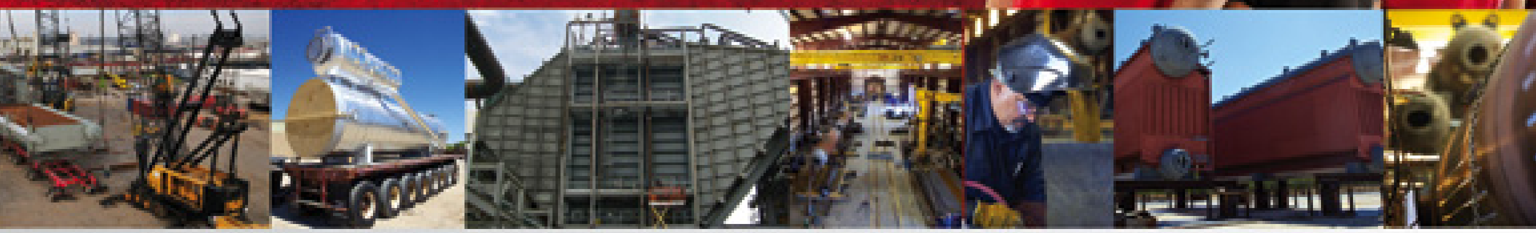

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FROM THE EDITOR

2013 User Group Meetings

February 6-7, D5-D5A Users, Mid-Year Meeting, Orlando, Fla. Details, including venue, as they become available at www.501d5-d5ausers.org. To register, email Gabe Fleck, chairman, gfleck@aeci.org.

March 10-13, Western Turbine Users Inc, San Diego, Calif, San Diego Convention Center. Chairman: Jon Kimble, jkimble@wellhead.com. Visit www.wtui.com for more information.

March 18-21, 501F Users Group, Annual Meeting, Charlotte, NC, Westin Charlotte. Chairman: Russ Snyder, russ.snyder@cleco.com. Contact: Caren Genovese, meeting coordinator, carengenovese@charter.net.

March 18-21, 501G Users Group, Annual Meeting, Charlotte, NC, Westin Charlotte. Meeting is co-located with 501F Users Group; some joint functions, including the vendor fair. Chairman: Steve Bates, steven.bates@suezenergyna.com. Contact: Caren Genovese, meeting coordinator, carengenovese@charter.net.

April 7-11, CTOTF—Combustion Turbine Operations Technical Forum, Spring Turbine Forum & Trade Show, Myrtle Beach, SC. Contact: Wickey Elmo, group and conference coordinator, info@ctotf.com.

April 29-May 1, HRSG User's Group, 21st Annual Conference & Exhibition, Tampa, Fla, Tampa Marriott Waterside Hotel & Marina. Contact: Robert Swanekamp, executive director, info@hrsgusers.org.

May 20-24, 7F Users Group, Conference & Vendor Fair, Greenville, SC, Greenville Hyatt Regency. Contact: Sheila Vashi, 7F operations manager, sheila.vashi@7Fusers.org.

June 4-6 (team-building event June 3), D5-D5A Users, Annual Conference & Vendor Fair. Details as they become available at www.501d5-d5ausers.org. Contact: Gabe Fleck, chairman, gfleck@aeci.org.

Week of June 24, V Users Group, Annual Conference, Williamsburg, Va. Venue not yet available. Contacts: Bob Pasley, chairman, bpasley@aeci.org; Dawn McCarter, conference coordinator, dawn.mccarter@siemens.com.

June TBA, Frame 6 Users Group, Annual Conference & Vendor Fair. Details as they become available at www.Frame6UsersGroup.org. Contact: Wickey Elmo, conference coordinator, wickelmo@carolina.rr.com.

July 15-18, Southwest Chemistry Workshop, Tempe, Ariz, Tempe Mission Palms Resort & Convention Center. Host utility: Salt River Project. Contact: David Bollinger, Chemist/Environmental Scientist, Desert Basin Generating Station, dave.bollinger@srpnet.com.

July 21-25, Ovation Users' Group, 26th Annual Conference, Pittsburgh, Westin Convention Center Hotel. Register for membership (end users of Ovation and WDPF systems only) at www.ovationusers.com and follow website for details as they become available.

September 8-12, CTOTF—Combustion Turbine Operations Technical Forum, Fall Turbine Forum & Trade Show, Coeur d'Alene, Idaho, The Coeur d'Alene Hotel, Contact: Wickey Elmo, group and conference coordinator, info@ctotf.com.

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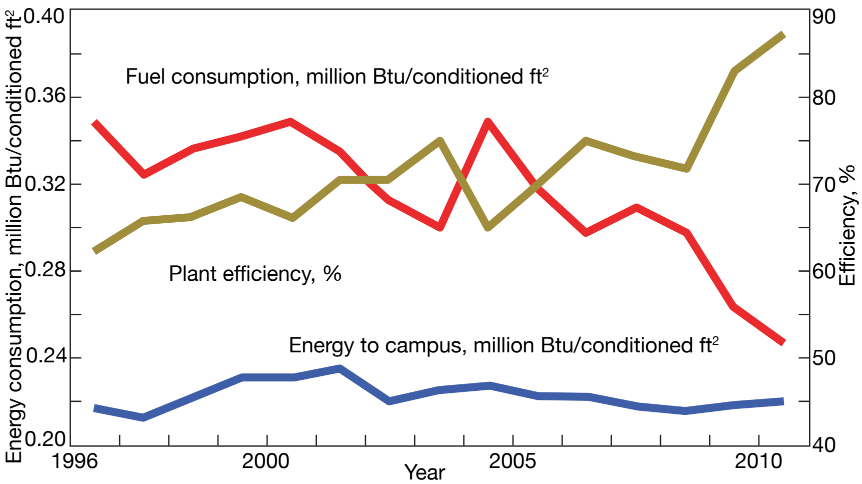
Optimization programs pay big dividends for campus utilities

By Jason Makansi, Pearl Street Inc

The University of Texas at Austin (UT) began a major expansion of campus utilities back in the mid-1990s. Today, the Utilities & Energy Management Dept (UEMD) provides all of the heating, cooling, and electric service for university's 18 million ft^2 of conditioned space. With 50,000 students and 20,000 staff, think of the challenge as supplying the comfort for a small city.

Particularly noteworthy is that laser-focused attention to energy management enabled the UEMD team to hold fuel consumption to that of 15 years ago, while the campus doubled in overall building space (Fig 1). The story on carbon emissions is even better (Fig 2). Carbon emissions today are equivalent to 1977 levels. Environmental performance is important, not only because UT is a world-renowned research institute, but also because the Carl J Eckhardt Heating & Power Complex (formerly the Hal C Weaver Power Plant) is in the middle of the campus. For its outstanding achievements in reducing fuel consumption and pollutant emissions, the Eckhardt facility has been selected to receive the CCJ's 2012 Pacesetter Plant Award (Sidebar 1).



1. Carl J Eckhardt Heating and Power Complex dramatically reduced fuel consumption and improved efficiency while maintaining energy flows to a growing campus between 1996 and today. CO_2 emissions avoided by burning less fuel totaled 88,000 tons

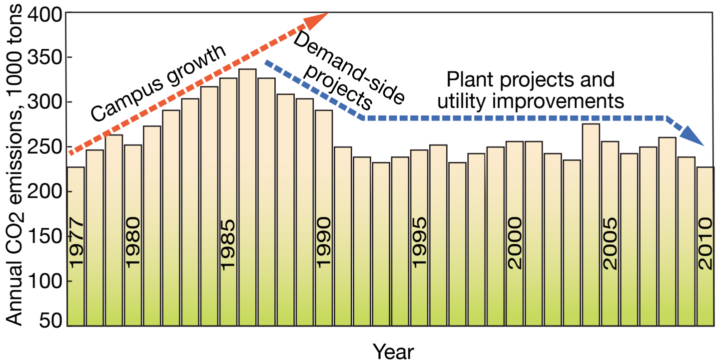
"Key to the efficiency improvement," says UEMD Executive Director Juan Ontiveros, "is an optimization program that we implemented to achieve the lowest electric consumption per ton of chilled water, coupled with a real-time hydraulic model of the chilled-water distribution system. The results from this effort identified a straightforward operational strategy," he says. "Run the gas turbine/generators flat out but match them to actual campus demand and pair the HRSG steam output with the steam turbines, swing the fired

1. Eckhardt embraced a standard of excellence still revered

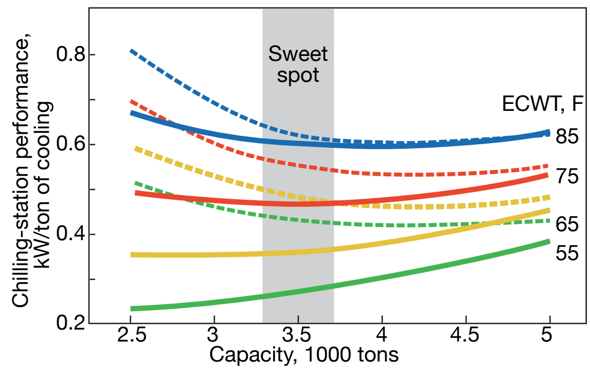
Carl J Eckhardt Jr, for whom the UT Austin Heating & Power Complex is named, would have been proud of the accomplishments of Utilities & Energy Management Dept Executive Director Juan Ontiveros and his staff, as described in the main article. Eckhardt is a UT icon. With two engineering degrees from the university and a faculty post, he accepted responsibility in 1931 for what was known then as the UT Physical Plant.

Born Oct 28, 1902 in Yorktown, Tex, Eckhardt earned a bachelor of science in mechanical engineering degree in 1925 and his master's in 1930. He taught mechanical engineering at the university from 1926 until his retirement in 1973. Eckhardt also is regarded an expert on UT history, having written six books on the subject. He remained an active supporter of the institution until his death Jun 29, 1995.

Among his many papers on file in Austin is a report, "Specifications for a complete steam generating system: Main Power Plant, University of Texas." Like Ontiveros and his team, Eckhardt was respected for his many achievements in the powerplant as well as for the reassembly of famed Santa Rita No. 1 oil rig on the Austin campus. The rig, the first to "blow in" on university-owned property in West Texas, ultimately produced more than $300 million in revenues for the Permanent University Fund.



2. Carbon emissions from the Eckhardt Complex were the same in 2010 as they were in 1977, while the number of conditioned ft^2 on campus went from nine to 17 million and electric production about doubled to 372 million kWh



3. Optimization routine applied to the chilled-water system identifies a "sweet spot" for part-load operation of the electric chillers. Curves illustrate compressor variable-speed performance at different temperatures of entering condenser water (ECWT). Note the increase in cooling-station efficiency with decreasing water temperature

boilers to meet load changes, and optimize the chilled-water system." Cooling consumes from 30% to 50% of the plant's total load energy requirement.

The plant enlisted Optimum Energy LLC, Seattle, to operate the chilling stations using OptimumLOOP™. This software platform enables real-time monitoring of chiller-plant equipment and calculates the most efficient sequencing of that equipment based on real-time building loads, without compromising on occupant comfort or process cooling requirements.

Important to the success of OptimumLOOP is feedback provided by Termis hydraulic modeling software supplied by 7-Technologies A/S, Birkerod, Denmark, now owned by Schneider Electric. "Termis gives us a visual look into what is happening to the real-time flows in the loops," says Ontiveros. The model takes as inputs weather conditions, real-time building energy flows, plant chilled-water flow, and differential-pressure (DP) readings from critical points in the system to predict and validate conditions throughout the network—including flow-constraint locations.

Fifteen new DP sensors were added to give the system a more complete data set. This is valuable information if you have multiple chiller plants that can be dispatched on a common loop. "Now we can strategically analyze process conditions when different equipment (for example, chillers) is dispatched," notes Ontiveros.

The basic goal of system optimization is to use the least amount of electricity to produce a ton of chilled water by doing the following:

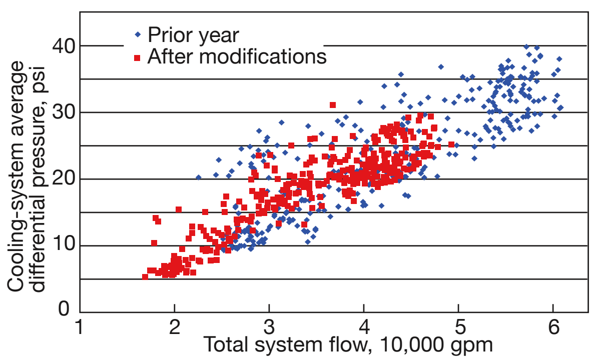
- Running at the lowest DP possible to minimize cooling-water pumping horsepower.
- Simultaneously resetting chilled-water supply temperature when conditions allow.
- Operating the pumps and chillers optimally by controlling the speeds of the motors to meet actual load needs. This goes hand in hand with optimally dispatching the other constant-speed equipment in the other stations to achieve the lowest number of kilowatts per ton of cooling.

A critical goal was to operate the system more efficiently at part load because the campus is at peak conditions only about 20% of the annual operating hours, which is typical of most cooling systems (Sidebar 2).

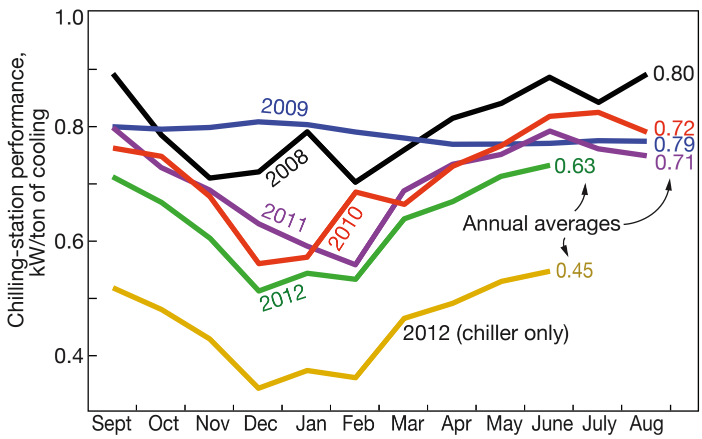
Intelligence + VFDs

The added intelligence offered by the optimization software would have had little benefit without critical hardware upgrades. The plant now has variable-frequency drives (VFD) on the chillers, condenser cooling-water pumps, cooling-tower fans, and chilled-water supply pumps in the newest chilling station. In a nutshell, the optimization routine identifies a "sweet spot" (Fig 3) for chillers to operate under part-load conditions and simultaneously does the same for the cooling-tower fans and pumps to optimize condenser water temperature. Plus, it regulates the chilled-water pumps to deliver the water with the least amount of horsepower, using loop pressure data (Fig 4).

Bottom line is that optimization has reduced energy consumption by 28% to 30%. One of the unanticipated benefits was that the chilled-water system now runs at a higher overall



4. System improvements dramatically reduced the pumping power required by the chilled-water system to deliver the same level of cooling achieved the year prior to when the modifications were made (above)



5. A culture of continuous improvement, equipment modifications, and the efficiency optimization program have contributed to a dramatic reduction in electric demand over the last five years (right)

2. How to reduce energy consumption in district cooling systems

A constant-speed chiller with control valves cannot offer the part-load efficiencies necessary for minimizing the electrical demand of district cooling systems. This is where variable-speed drives (VSDs) come into play. Their use on chiller compressors, cooling-tower fans, condenser cooling-water pumps, and chilled-water pumps eliminates throttling and other losses associated with constant-speed motors, with the benefit of reducing energy consumption by more than 25% in large cooling systems—such as the one serving the University of Texas at Austin.

Most readers of the CCJ design, build, operate, and/or maintain large electric generating plants typically equipped with single- or two-speed motor drives on pumps and fans. The bottom-line benefit of using variable-speed drives in large combined cycles, particularly in these days of inexpensive gas, is relatively insignificant and power engineers focus on other aspects of plant O&M to improve profitability.

If you have never been affiliated with a combined heat and power (CHP) plant, the refresher below might help you better understand the challenges facing colleagues responsible for the economical operation of district heating and cooling systems and why they embrace VSDs.

Power versus speed. Reducing the speed of a compressor, fan, and/or pump is a great way to save energy, provided the lower speed is consistent with the output required by the cooling system to deliver the level of comfort expected. You may recall the pertinent equation below:

$$Power2/Power1 = (Speed2/Speed1)^3.$$

This means that if a compressor with a full-load rating of 1600 hp at 4000 rpm can deliver the output required at 2000 rpm, the power used to run the compressor drops by a factor of eight to 200 hp. Throttling to reduce load obviously makes little sense if a significant amount of operating time is at part load.

The term "lift" used in connection with cooling systems is synonymous with the term "head" used in power-plants. Both are the pressure differential that a compressor, fan, or pump must develop to serve load. The greater the lift, the more power required to pump or compress a liquid or gas.

To understand what a high lift requirement means in common physical terms, think of a car having to travel up a hill. Its engine must operate at higher rpms than on level ground to maintain the same speed. Likewise, a compressor's impeller must rotate faster to deliver a given amount of refrigerant at higher lift (pressure). The penalty in each case is higher energy consumption—gasoline for the car, electricity for the compressor.

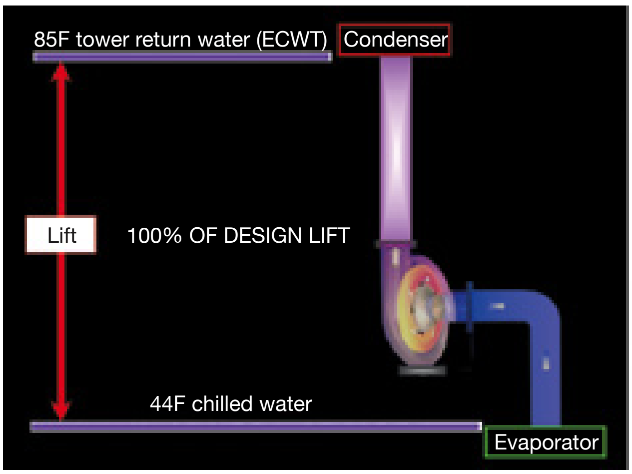
Lift varies as the square of the speed, as the following equation states:

$$DP2\ (\text{differential pressure})/DP1 = (Speed2/Speed1)^2.$$

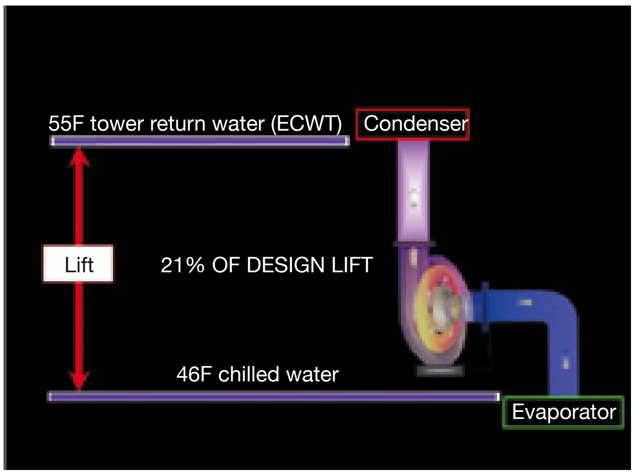
Thus, if the rated lift of a compressor is 80 psi at 4000 rpm, halving compressor speed will reduce lift by a factor of four to 20 psi. One of the challenges of operating a cooling system like UT's, which is six miles long, is to minimize electric consumption while assuring sufficient lift to satisfy cooling expectations at the far reaches of the network.

Impact of water temperatures. The refrigerant compressor, the largest power consumer in the chilled-water plant, offers significant financial inducement for properly managing lift. Important to note is that a compressor's lift requirement depends on the temperature differential between the water leaving the chiller and the tower return water—referred to as the entering condenser water temperature (ECWT) by CHP personnel.

Compressor lift can be managed by controlling either or both of these temperatures. The lift developed by the compressor at full design capability is illustrated in Fig A. Fig B depicts compressor operation at 46% of design speed, equivalent to a power draw of only 9.7% of the full-load value. Allowing the entering condenser water to fall to 55F and increasing the leaving chilled water by 2 deg F to 46F reduces lift to 21% of the design value.



A. Compressor operates at full capability



B. Compressor operates at 46% of capacity

delta T because buildings are no longer overcooled by over-pressurization of the distribution loop. This lowered peak chilled-water flow, and also reduced chemical treatment costs in the chilled-water supply system and cooling tower, because less heat must be rejected.

A reduction in building steam use was another bonus of the program because the correct amount of chilled water was delivered to buildings, thereby preventing overcooling. It's clear that optimization has provided dramatic value system-wide (Fig 5).

Referring to the illustration, each point on the curves is the monthly average power consumption to produce a ton of cooling, which is the best measure of chilling-station efficiency. The top five curves give the total power requirement—chiller compressors, cooling-tower and chilled-water pumps, and fans; the lowest curve gives chiller-only performance for 2012.

The 2010 and 2011 numbers reflect first use and the positive impact of the OptimumLOOP performance enhance-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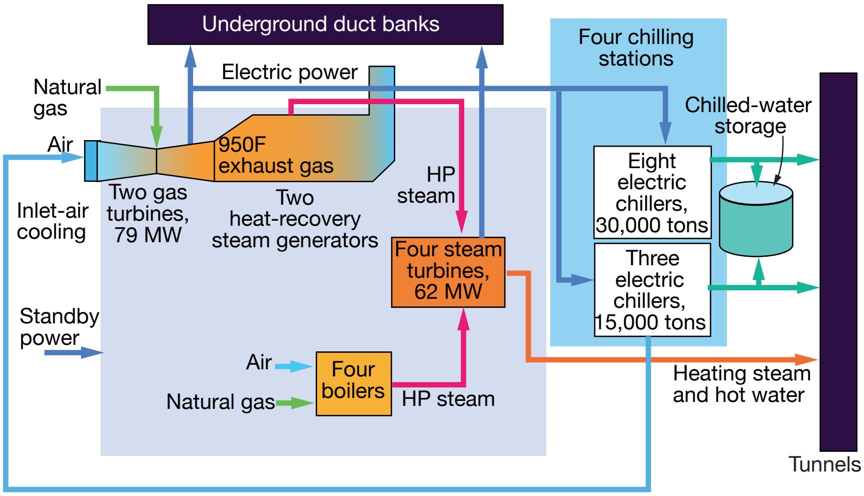

6. Gas turbine/generators are run flat out while the fired boilers handle load swings. The facility has multiple levels of redundancy because there is no external backup for steam, hot water, and chilled water. Redundancy, plus meticulous attention to maintenance and training, and a sophisticated control and monitoring system, have led to an exceptional level of reliability

ment software. The 2012 numbers reflect the performance gain from lowering the chilled-water distribution pressure, which reduced pumping power requirements. Plant personnel took this step after data analysis revealed instances where more kilowatts per ton were being consumed by the cooling towers and pumps than by the chillers. The benefit was larger than expected.

Capital investment in the program included $200,000 to implement the optimization software and $400,000 for each of the chiller VFDs, plus the pumps and tower fans. Two side notes regarding the VFDs: They must be housed in cool ventilated areas, which slightly penalizes parasitic load; also, you must pay close attention to avoiding harmonics—such as from the cooling-tower fans. Ontiveros describes the new 15,000-ton chilling station, using Johnson Controls Inc's York OM chillers paired with Toshiba VFDs, as "the most efficient in the US."

"We paid for the Termis software during the calibration process," claims Ontiveros, "when three inadvertently closed chilled-water loop isolation valves impairing system efficiency were identified using the model. In addition, we have already paid for all of the chilling station VFDs using OptimumLOOP." He went on: "Last summer was the hottest on record, and we still saved around $900,000 in energy cost."

From fired boilers to GT

Utilities service started at UT in 1929 with a pair of 1.5-MW turbine/generators fed steam from lignite-fired boilers. Today, the system (Fig 6) includes the following:

- A 1980s-vintage 45-MW gas turbine/generator and a 32.5-MW GT installed in 2009, each with chilled-water inlet air cooling and coupled to its own supplementary-fired heat-recovery steam generator (HRSG).
- Four gas-fired boilers commissioned between 1945 and 1968 with a total capability of 800,000 lb/hr. The HRSGs and conventional fired boilers supply steam to a 420-psig header.
- Four steam turbine/generators, totaling 62 MW, that operate on steam from the 420-psig header. All steamers have a condenser; three also have a 165-psig extraction system. When a turbine is in service, a small amount of steam must flow to the condenser.
- Three new chillers totaling 15,000 tons of capacity and eight older electric chillers totaling 30,000 tons, divided among four chilling stations. The chillers are supported by 39,000 ton-hours of chilled-water storage at 12-deg-F delta T, with a peak capability of 6500 tons. The 4-million-gal tank was installed two years ago.

Thermal energy (chilled water and steam) is distributed to the campus via a six-mile tunnel system, electricity via underground duct banks. The plant contracts with Austin Energy, the local utility, for 25 MW of standby power, but the campus is on its own when it comes to steam and chilled water. Even so, reliability is calculated at 99.9998% over the last 40 years.

The exceptional reliability results from various factors: Multiple options for prime equipment and related support equipment, a thoughtful and methodical approach to maintenance using both preventive and predictive methods, a campus-specific test-based training and certification program for personnel, and a carefully conceived digital control system that monitors, operates, and dispatches the entire energy system.

The control system is comprised of multiple proprietary systems: Siemens AG (PCS 7) and Emerson Process Management Power & Water Solutions (Ovation) for balancing thermal energy production and electric generation, and GE Proficy supervisory control and data acquisition (SCADA) system for power distribution (see second section below for details). All are tied together using Allen Bradley programmable logic controls (PLC) displayed through RSView®32™ (human machine interface) and linked to a GE Proficy historian. Simply put, a holistic solution.

The control and monitoring system seamlessly handles electrical generator upsets using the 100-MVA substation connected to the Austin Energy system though a ring of four 50-MVA transformers to import back-up power as needed. Steam for campus heating and hot-water production normally is provided by the extraction turbines. Alternatively, two redundant pressure-reducing stations operating on HP steam from the HRSGs and/or gas-fired boilers can satisfy thermal requirements.

Key to managing energy-system performance is LightRidge Resources LLC's (Houston) PE-Advisor™, a real time thermal model of the entire system that allows for continuous monitoring of predicted conditions against actual conditions. This system helps identify equipment and instrumentation problems when operating data stray from the predicted data. In essence, PE-Advisor allows the campus energy system to be managed in real time.

System control and monitoring evolved from a totally manual, pneumatically operated plant in 1996 to the highly integrated digitally controlled system employed today. Ontiveros said, "There was no way to manage the growth, efficiency, and reliability expected of us without being brave and transforming the system while serving loads without interrupting campus utilities."

UEMD staff stretched campus generating capability from 85 MW to the current 137 MW by doing the following:

- Uprating the 1988 W251–B10 gas turbine from 36 to 45 MW. Cost: $10,000. Lesson learned: Question everything and focus continually on making improvements. Turns out


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that years back in this GT/HRSG unit's history someone solved an HRSG economizer flashing problem by dialing back the GT to 36 MW—less heat, no flashing. A relatively simple fix to HRSG circuitry enabled operation of the GT at rated load without flashing.

- Installing a new 25-MW steam turbine/generator from Siemens Demag Delaval Turbomachinery Inc.
- Replacing a 1965-vintage W191 gas turbine and companion HRSG with a GE LM2500+G4 DLE engine and new HRSG. Details in second section of this article.
- Installing inlet-air chiller coils on both GTs and replacing a critical cooling tower.

Ontiveros said, "This project gave me a lot of grey hair: I had to be a salesman, integrator, and crystal- ball reader to predict future loads so that new equipment could be right-sized. If that wasn't enough, my staff and I had to commission everything to perform as expected."

Nimble FD fans

Additional flexibility and efficiency were built into the old gas-fired boilers as well. Nos. 3 and 7, the most frequently used units, were retrofitted with Benz Air Engineering's proprietary Compu-NOx® system that uses VFDs on the forced-draft fan motors. A new flue-gas recirculation fan with VFD was added as well. In effect, this allows the fans to be controlled as one unit so combustion-air and flue-gas flows are precisely maintained against fuel flow, NO_x emissions, and excess O_2.

As a result of the VFD additions, the two boilers can safely operate between nearly zero steam production and full capability, which helps immensely with a "swing" unit. Combustion-system enhancements also improved boiler efficiency by 5% to 10%, reduced NO_x emissions by 91% when firing natural gas (42% when burning liquid fuel), and enable the boilers to run on 100% liquid fuel if necessary. The VFDs also allow the plant to eliminate the use of dampers for air flow control, improve FGR operation, and reduce noise levels in and around the plant.

New cogen unit greatly improves heat rate

The university's new cogen unit, installed in late 2009 and consisting of an LM2500+G4 DLE gas turbine from GE Energy coupled to an HRSG designed and built by Express Integrated Technologies LLC, Tulsa, dramatically improved the heat rate of the Eckhardt Power Complex. The W191 engine, which was demolished along with the HRSG serving it to make room for the new equipment, had a heat rate in the neighborhood of 17,000 Btu/kWh; heat rate of the G4 is about half that. The owner's engineer on the project was Jacobs Energy & Power Solutions.

The new gas turbine is the fourth generation of the LM2500 family and 17% more powerful than the third generation LM2500+. Power was increased by boosting air flow by 6%, raising the exhaust-gas temperature, and increasing the pressure ratio to 24.2:1 from 23.6. Design changes made to the LM2500+ to achieve the G4 performance were relatively minor.

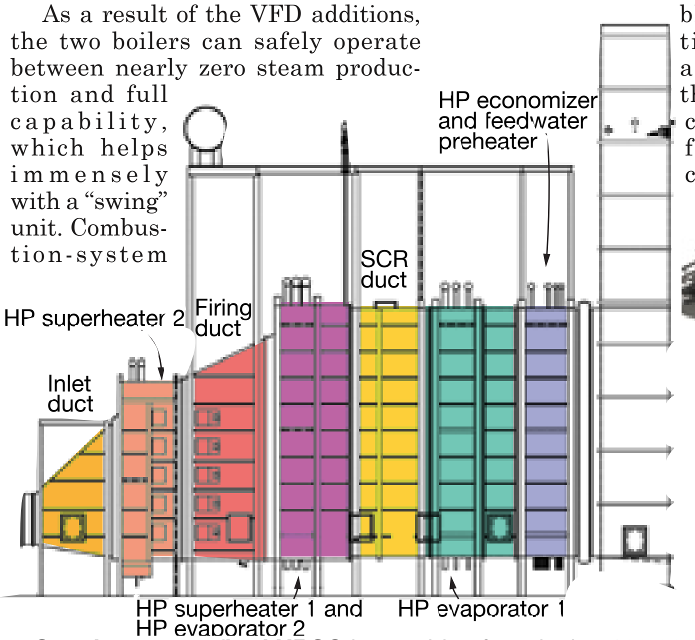
Examples: Small adjustments to blade and stationary vanes accommodated the increase in compressor mass flow, minor changes to airfoils improved blade cooling in the HP turbine, and implementation of material upgrades based on the latest aircraft experience protected hot-gas-path components, etc. Structurally, all frames—front, compressor rear, turbine mid, and turbine rear—remain unchanged, as do compressor front and aft cases, sump hardware, and the number of main bearings. A design upgrade associated with heat shields for the DLE combustor enable field replacement and a reduction in the maintenance-cycle time.

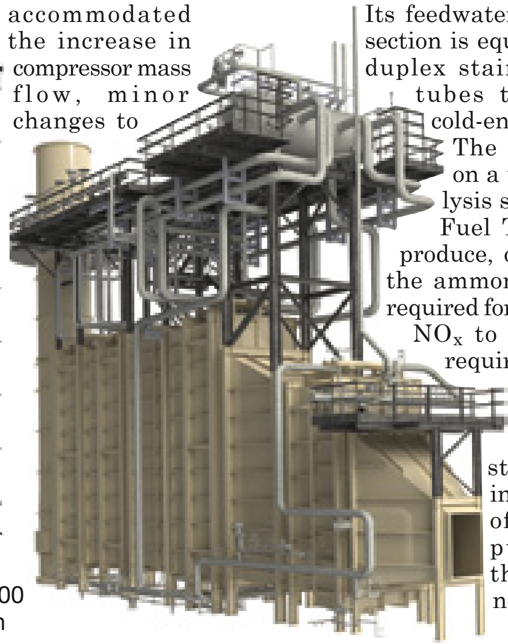
The G4, which operates about seven months annually at UT Austin, is "right-sized" for the campus at 32.5 MW. During the four coldest months, the new machine saves the university about $1 million per month. UT's relatively low wintertime electric requirement is not a good "fit" for the generating facility's 45-MW W251. Jacobs developed and ran models and optimization programs to assure that the new turbine and its HRSG would satisfy campus electrical and thermal requirements as intended.

The engine has performed well, Ontiveros told the editors, especially considering it was the world's first G4 for 60-Hz electric service. The hiccups experienced in the early going primarily were associated with malfunctioning control relays—$25 items loosely speaking—that caused turbine trips. Plant staff worked closely with the OEM, Ontiveros said, to quickly resolve issues.

HRSG installation challenge

The single-pressure HRSG, duct-burner equipped, produces up to 192,000 lb/hr of 450-psig/655F steam (Fig 7). Its feedwater preheater section is equipped with duplex stainless steel tubes to prevent cold-end corrosion. The SCR relies on a urea hydrolysis system from Fuel Tech Inc to produce, on demand, the ammonia reagent required for controlling NO_x to the 5 ppm required. Ontiveros did not want an ammonia storage tank in the middle of the campus. Recall that urea is non-toxic. Ontiveros





7. Supplementary-fired HRSG is capable of producing 192,000 lb/hr of 450-psig/655F steam. Unit is of single-pressure design

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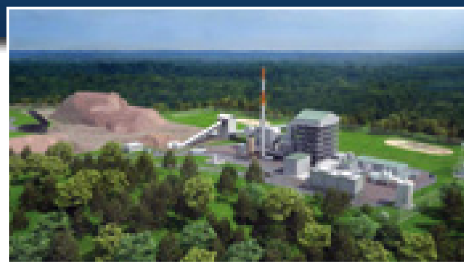

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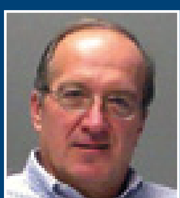
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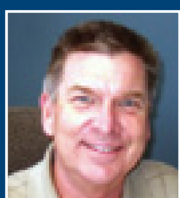
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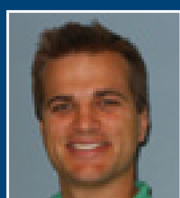
VP Engineering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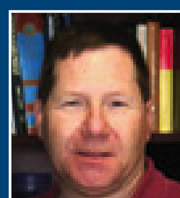
Doug Franks
Mgr. Electrical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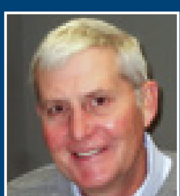
Mechanical


Chris Bramhall
Mgr. Bus. Develop.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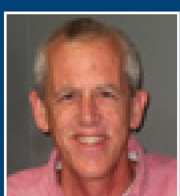
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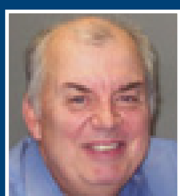
Dean Andrisevic
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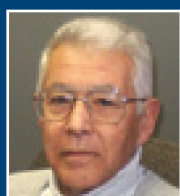
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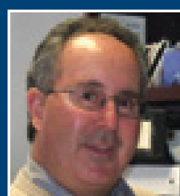
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8A-G. Unloading of HRSG modules and duct sections and their placement in the building required several separate handling steps and close coordination among all parties involved

said the basis for HRSG selection was life-cycle cost. The university wanted a well-made boiler that provided "value." The only issue with the boiler to date concerned ammonium sulfate fouling and corrosion of the condensate heater tube fins and has nothing to do with the unit's design. The chemicals were carried along with cooling-tower drift into the compressor. An effective solution involved operating the tower differently and reducing its duty.

The big challenge with respect to the HRSG was shoehorning it and the G4 into the building that was once home to the W191-powered cogen unit, and meeting a tight installation schedule. The new boiler was designed to install it in the available space with virtually no changes to the building structure. UT Austin, the editors were told, views the preservation of its buildings and the large oak trees that line the street in front of the Eckhardt Complex very seriously.

The schedule required that all of the major duct and heat-transfer modules be installed in one week over the 2009 spring break. A complication arose when design engineers realized that the door to the building could not accommodate the boiler modules—nominally 42 ft tall × 13 ft wide and the largest more than 11 ft in the direction of gas flow—without removing their legs and that the steam drum and mezzanine platform would have to be located above the roof line. Weight was another consideration: The heaviest module was 75 tons.

During the design phase, Express personnel worked closely with the owner, Jacobs Energy & Power, and the installation contractor to develop a method for moving the modules into the building using a system of three gantry-type hydraulic lifting devices (Fig 8A). The first set lifted the modules off the truck (B) and set them on four skates (C) so a forklift could move them into position for lifting by the crane (D).

The crane lifted each module in turn upright and swung it into position at the entrance to the building (E), where a set of lifting frames was attached, enabling the second gantry system to lift the module and bring it into the building (F). Once inside, the module was transferred to a third gantry system which moved at a right angle to the second. The third gantry moved the module into position with the modules already installed. Legs were then attached and the module snugged up to the HRSG train (G).

While all of this was going on inside

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Heating & Power Complex
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the building, logistics personnel were working with the trucking company and the university to choreograph the next load into place.

Powerplant controls

A major control system upgrade, implemented for the campus energy-supply systems in spring 2008, assures a high degree of operational reliability in the production and distribution of electrical and thermal energy. The state-of-the-art energy control and energy management system (ECEMS) accomplishes the following:

- Monitoring of power flows via the electrical tie to Austin Energy.
- Demand control.
- High-speed contingency analysis and load shedding.
- Control of reactive power.

The four tie lines connecting the university to Austin Energy are rated 69-kV. Voltage is transformed to 12 kV for campus use. Both gas turbines and two of the steam turbines produce power at 12 kV; the other two steamers generate at 4.16 kV and are dedicated to serving several old buildings.

Load on the distribution system varies during the day, as you would expect. It is maximum in the late afternoon/early evening, minimum at night. The ECEMS monitors and manages voltage, protecting the system during transients that conceivably could be problematic—such as an overvoltage condition at minimum load.

Distribution-system control is accomplished via a SCADA system running on redundant servers that communicates with external instrumentation and control devices. Communication is via two fiber rings, Ethernet, and OPC (open process control) links (OLE, object linking and embedding, is used for process control).

The SCADA program has a database that tells the software about the connected instrumentation and which parameters within the instruments to access. The database also may retain information on how often the parameters are accessed and if a given parameter is read-only or read/write, allowing the operator to change a value.

Demand control is the ECEMS function of greatest interest to most readers. In the Eckhardt Power Complex it controls the loads on the available gas and steam turbine/generators such that the amount of power purchased from the utility is equal to the desired amount of purchased power entered by the operator. The logic technically enables the operations team to buy power when it is less costly than producing it onsite and to sell electricity to Austin Energy when that works for both parties. However, the system always has operated in self-generation mode because dispatching to or taking from the Ercot grid is considered higher risk than self-generation.

The following steps outline the sequence in which loads are controlled on the steam and gas turbine/generators with all prime movers in service:

- Allow the GTs to reach their maximum load while operating the STs based on current process steam demand and minimum condenser flow.
- When the GTs are at maximum load, increase outputs from the STs until nameplate ratings are reached or the available amount of 420-psig header steam is exhausted.
- If the plant's internal generation is at max, and power demand continues to rise, satisfy the additional demand with steam produced by the fired boilers.
- If university power demand rises above that capable of being served by both internal and external sources, automatic load shedding can reduce load. Alternatively, the operator can decide on which loads to shed. CCJ

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Teamwork brings major HRSG repair project in on schedule, at budget

During the "bubble years" 2000 through 2004, about 250 combined cycles were commissioned in the US. The only way to have manufactured and installed this much equipment in five years, given the country's resource pool (people and materiel), was to standardize designs. One of the general assumptions made was that efficient F-class combined cycles would operate baseload. Minimizing the number of start/stop cycles (on paper at least), and assuming conservative ramp rates, simplifies the engineering effort.

But the market did not need so much base-load combined-cycle capacity, until perhaps now, and most of these plants were required to cycle—some daily and off on weekends—to pay the mortgage. Thermal cycles, pressure cycles, water and steam chemistry in and out of recommended limits, etc, took their toll and equipment aged much faster than expected. At least a few experts estimate that half the design lifetimes of some critical equipment have been consumed in 10 years or less.

Heat-recovery steam generators (HRSGs), indestructible as they might look, may have suffered most. These hunks of iron between two money machines often get no respect. You find lots of "turbine people" in combined-cycle facilities, but relatively few "boiler people."

Visual inspections identify fouled finned tubes, liner damage, cracking at drum nozzle penetrations, etc, but "what lies beneath"—such as flow-accelerated corrosion (FAC), corrosion fatigue, thermal fatigue, under-deposit corrosion, incompatible metallurgy—only can be detected by a rigorous program of tube sampling and/or nondestructive examination considered unnecessary by some decision-makers.

The "real bad things" typically are identified only after an operator on rounds spots steam seeping from under insulation, makeup requirements skyrocket, or tubes are found separated from headers. But by then there are no easy fixes and corrective action is expensive.

Ontelaunee Energy Center (OEC) is a case in point. The nominal 550-MW, 2 × 1 combined cycle, powered by W501FD2 gas turbines, was designed by WorleyParsons Group Inc for base-load service. It began commercial operation late in 2002— the middle of the bubble. The Reading (Pa) plant was commissioned by Calpine Corp and cycled daily, or less frequently, until relatively recently. OEC was bought by LS Power Equity Partners in October 2005 when Calpine was forced into bankruptcy and resold a year later to Dynegy Inc. Today it is managed by Dynegy Power LLC.

Wear and tear on the plant's two HRSGs, including failures of pressure parts, hinted as far back as fall 2007 that design changes would likely be needed for the boilers to operate as required by the market. Field modifications last fall to implement the necessary design enhancements involved a 56-person onsite contractor staff and about 20,000 hours of craft labor within a six-week outage window. And this was only part of the work being conducted during the longest and most complex outage in OEC's history.

For challenging boiler work of this magnitude to meet both schedule and budget targets dead-center is a tribute to the technical competence, experience, and outstanding cooperation among the owner, HRSG manufacturer, and prime contractor. Joel Erwin managed the overall project for Dynegy Power from central engineering headquarters in O'Fallon, Ill; Plant Engineer Phyllis (Meals) Gassert directed much of the work on the deck plates; Dan Drury was the contact at Nooter/Eriksen (N/E) during the entire design process; and Bremco Inc's Don Revane managed the contractor's work from headquarters through Site Superintendent Bob Todt.

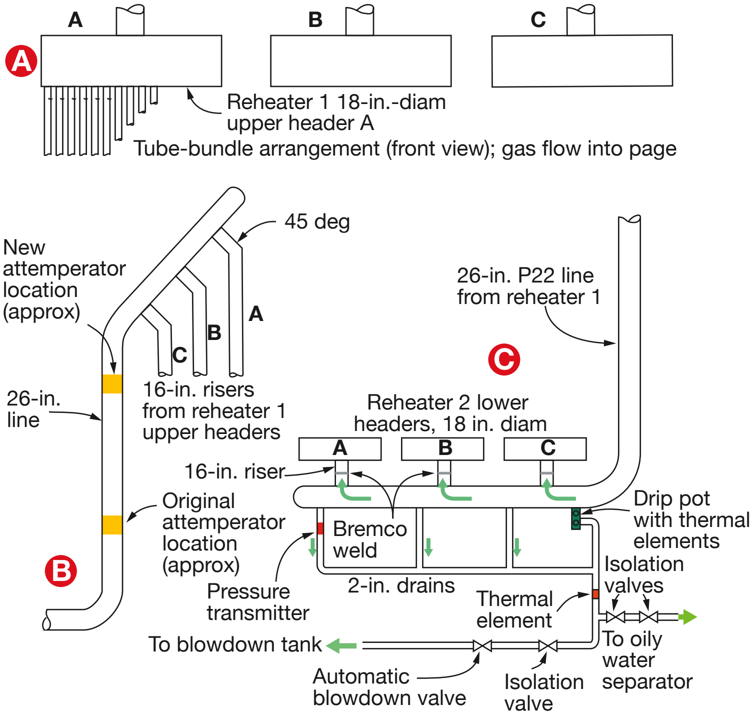
The success of the HRSG project establishes an industry benchmark for what's possible when a collaborative team-building environment is supported by all participants, earning Ontelaunee Energy Center the **CCJ's** 2012 Pacesetter Plant Award.

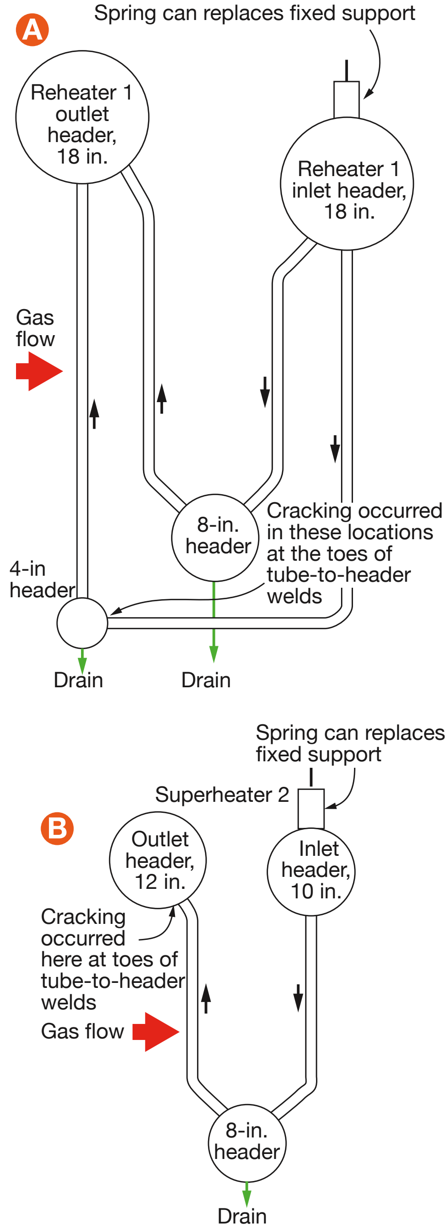
Problems surface early

Ontelaunee's HRSGs are triple-wide (three panels across as shown in Fig 1A), triple-pressure boilers. The horizontal centerlines of top and bottom headers are located just shy of 60 ft apart. Reheaters for these units are divided into two sections (Fig 2A)—Reheater 1 is the coolest, Reheater 2 the hottest (Fig 3). The two sections are connected by a 26-in.-diam heavily insulated P22 line located outside the boiler casing. The vertical section of this pipe includes an interstage desuperheater (Fig 1B).

As sketches 1B and 1C show, a 16-in. riser from each of Reheater 1's upper headers connects into a nominal 30-ft horizontal section of the 26-in. pipe. A 90-deg elbow directs the partially reheated steam downward through an attemperator and via a second 90-deg elbow to a horizontal section of pipe running under the lower headers for Reheater 2. This segment of pipe is equipped with three 16-in. riser nozzles which direct the Reheater 1 outlet steam to the upflow Reheater 2 tube panels.

First significant damage to Ontelaunee's HRSG pressure parts was found by an operator on rounds in fall 2007. The units were only five years old at the time. Wet insulation and a





1. Ontelaunee Energy Center's triple-wide heat-recovery steam generators have two reheater sections connected by a 26-in.-diam P22 pipe with an integral interstage desuperheater. Section A shows the general arrangement of upper headers for Reheater 1, which is located downstream from Reheater 2 in the hot gas path. B illustrates how steam from Reheater 1 flows to the 26-in. pipe, C how that steam enters Reheater 2 via the lower headers serving that section of the unit (above)

2. Fixed header supports for Reheater 1 and HP Superheater 2 contributed to cracking of bent tubes at the toes of the tube-to-header welds. Spring-can replacements appear to have virtually eliminated the problem (right)

whisper of steam from the lower horizontal pipe section on Unit 2 indicated the possibility of a through-wall crack in the 26-in. line just downstream of the elbow.

Inspection following shutdown of the unit revealed a 10-in. transverse crack at the top of the pipe; about 20% of the crack had penetrated the 1.2-in. pipe wall. Because the unit was needed, a 4-ft section of the pipe was replaced before conducting a root-cause analysis. One thing engineers knew for sure: Heat from GT exhaust gas was not a contributing factor because the pipe was outside the casing.

As a precaution, Dynegy had the lower-elbow area of the Unit 1 HRSG x-rayed the following February (2008) and found no indication of damage. Two years later (April 2010), a circumferential crack was found at the base of the weld connecting the elbow to the horizontal run of pipe on Unit 2.

Then in May, a circumferential crack was found on Unit 1 at the base of the weld at the top of the elbow. This finding confirmed that an engineered solution was required to address the issue. Several months later, a base-metal crack was noted on the 26-in. line for Unit 1 above the same elbow. During demolition, a bulge in the pipe wall was in evidence about 2 ft above the elbow.

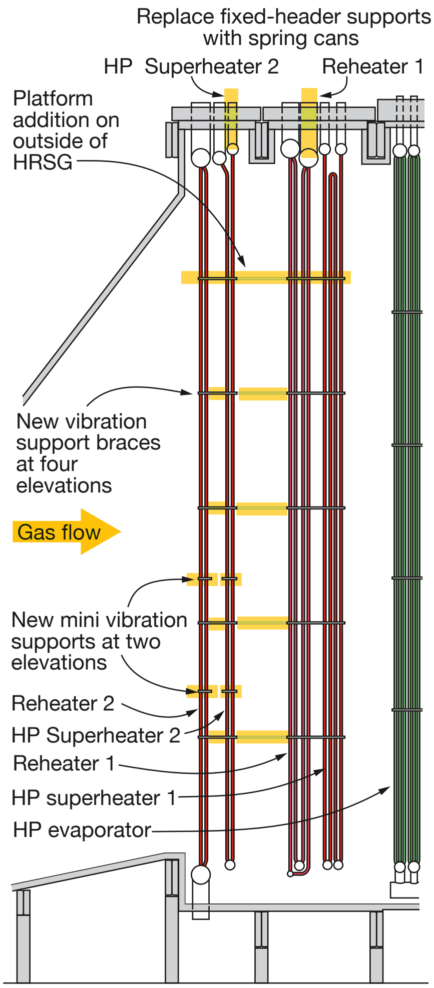
Cracking of the 26-in. pipe connecting Reheaters 1 and 2 was not the only indicator of HRSG problems. Cracks also were found in the heat-affected zones of about a half-dozen P91 tube-to-header welds at the top of Reheater 2, Row 2. The OEM repaired five in fall 2008 with 18-in. stubs; a couple of tubes had been repaired earlier. Structural Integrity Associates Inc analyzed several tubes and concluded that creep fatigue was the cause. Three more tubes failed by the following spring (2009).

The OEM's engineers believed water-quenching of the tubes was the root cause of the problem. Repair of the leakers in the middle tube bundle (Section B) during spring 2009 meant that the plant had taken two outages within a six-month period to correct the same problem. Clearly, this was unacceptable. But where was the water coming from? Sleuth work undertaken by plant personnel in 2010 would provide the answer.

The only logical source of water was the probe-type attemperator with fixed-orifice nozzles oriented in the direction of flow. The plant's O&M team, which works collaboratively to resolve issues, agreed with one of the mechanics in the group that the placement of magnetic thermocouples on the pipe surface above and below the elbow would provide at least some of the much needed data (Fig 4).

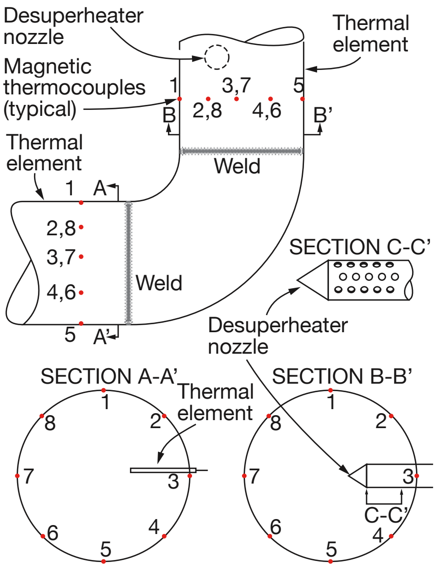
The idea certainly met expectations. Perhaps the most startling finding was that the external pipe surface on the left side (looking at Fig 4) could be as much as 400 to 600 deg F cooler than the right side, depending on plant output. Another important finding: When the plant operated above 68% of its full-load rating the temperature of the pipe was the same around the entire circumference—meaning all attemperator water evaporated.

Yet another important finding: Water that did not evaporate ran down



3. Partial side elevation shows arrangement of reheater and superheater sections and offers a snapshot of work done during the fall 2011 outage (left)

4. Original desuperheater did not perform as intended. Thermocouples were installed to gather data that revealed a dramatic difference in temperature from one side of the pipe to the other when unatomized water ran down the left side of the pipe at outputs below 68% of the unit's full-load rating (below)



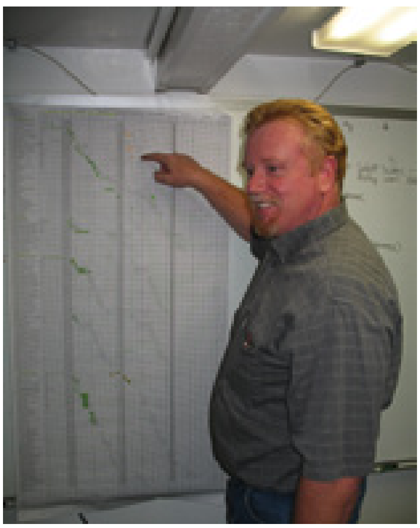
the left side of the pipe, curled around the elbow, and remained near the top of the 26-in. horizontal pipe. Most of the free water was sucked up into Bundles C and B, the first two in the flow path and the ones seeing most tube damage from quenching.

Note that the drain arrangement for the 26-in. horizontal section shown in Fig 1C was not installed when the problems were occurring. Back then there was only one drain at the end of the pipe where Bundle A is located.

Fall 2011 outage

Replacing the vertical and lower horizontal sections of the 26-in. interstage reheat piping for both Units 1 and 2, together with the lower elbows, was the most significant boiler project undertaken during the fall 2011 outage, which also involved an HP steam-turbine repair requiring the cover to come off. OEC hired Bremco to complete other HRSG work, including the following:

- Replacement of the reheat drain systems.
- Change-out of the fixed upper-header supports on Reheater 1 and Superheater 2 with a spring coil support system.
- Modification of some vibration supports for Reheater 2 and Superheater 2 tube bundles and the installation of additional supports.



5. Don Revane, Bremco Inc's VP operations, points to schedule for one of more than 200 tasks required to complete the HRSG upgrade project

To maximize asset production, both units remained in operation during Bremco's first week on site when its crew went through general safety and lock-out/tag-out training, installed hoists and rigging beams, set up staging and tooling, defined laydown areas, mobilized trailers and personnel, verified test reports for materials supplied by others. Dynegy took Unit 2 out of service first, leaving Unit 1 in operation while Bremco began work on all four tasks simultaneously.

About two weeks later, Dynegy shut down Unit 1, allowing work on both HGSGs. Work ramped up on Unit 1 as it wound down on Unit 2, enabling the latter to begin operation before the Unit 1 work was complete. During the course of the outage, Bremco identified more than 200 individual multi-step tasks that required detailed planning to achieve Dynegy's objectives. Revane, Bremco's vice president of operations, points to the task list in Fig 5 that he used to direct the project from the company's New Hampshire headquarters.

Revane estimated that planning, coordination of activities with Dynegy and N/E, relentless review of procedures before actual work was undertaken, safety and NDE initiatives, rigging plans, job-hazard analyses, qualifying vendors, etc may have required upwards of 20% of the contractor's man-hours. The Bremco executive credited Dynegy and N/E's appreciation of the work involved and their unflinching support as an underlying reason for project's success.

To meet the schedule and budget goals of a large and complex boiler project, such as Ontelaunee's, Revane stressed, it's necessary to always have a Plan B so you can move a defined task in a different direction without delay, if necessary. Dynegy enabled a high productivity work environment by assuring an engineering response to all questions around the clock, the contractor continued. Revane and Site Superintendent Todt couldn't remember a time during the outage that they had to wait more than half an hour for the answer to any question, no matter how complex it was.

This capability was enabled by Dynegy's assignment of Plant Engineer Gassert as the "go-to" person for questions during the day and Ontelaunee's Mark Vogt Jr at night. Terry Long led the re-engineering effort for N/E.

RH interstage attemperator, piping replacement

Removal of the poor-performing attemperator and associated 26-in. piping was first step in eliminating fatigue damage threatening the integrity of the interstage segment of the reheat system and returning it to as-new

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condition. A step-by-step plan for the demolition effort was developed by N/E. It included instructions on where to cut the existing pipe to enable removal of the vertical and lower horizontal sections; how to secure system components not being removed; where to install rigging lugs/shear tabs, or burn rigging holes required; how to attach clamps, hoists, and chains to the rigging beams, etc.

The vertical section was cut just below the upper elbow, at about mid length, and just above the lower elbow. Fig 6 shows one section of the vertical section, about 25 ft long and weighing between 4 and 5 tons, being lowered carefully in an area cordoned off to restrict personnel access. The top priority given safety resulted in an accident-free project.

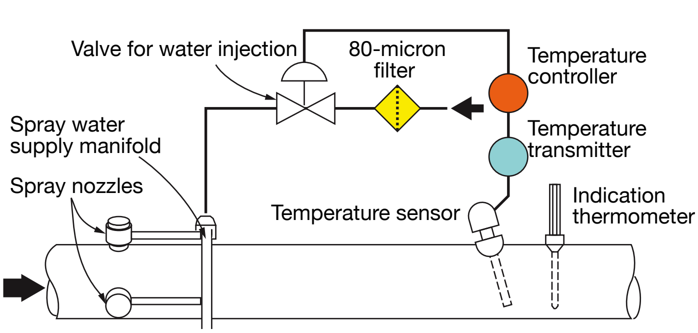
The lower horizontal section and elbow, resting on custom-made carts, is about to be towed out of the plant (Fig 7), where the elbow was removed from the nominal 30-ft pipe for ease of handling (Fig 8).

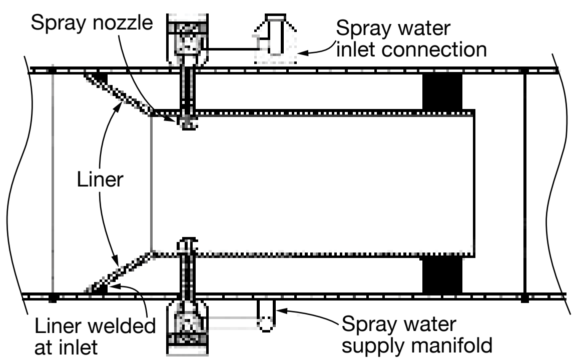
Demo complete, new pipe sections

8

6-8. Demolition of 26-in.-diam interstage reheat line and attemperator required considerable patience and skill. A nominal 25-ft section of the vertical pipe is removed in Fig 6, the horizontal section and elbow in Fig 7; elbow has been cut off in Fig 8

9-10. New section of pipe is wheeled into the plant (left) and prepped for welding (right)





11-12. Replacement attemperator, ring type with five variable-orifice spray nozzles, replaced a problematic mast-type desuperheater

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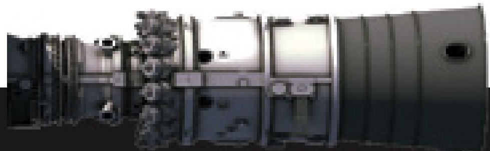

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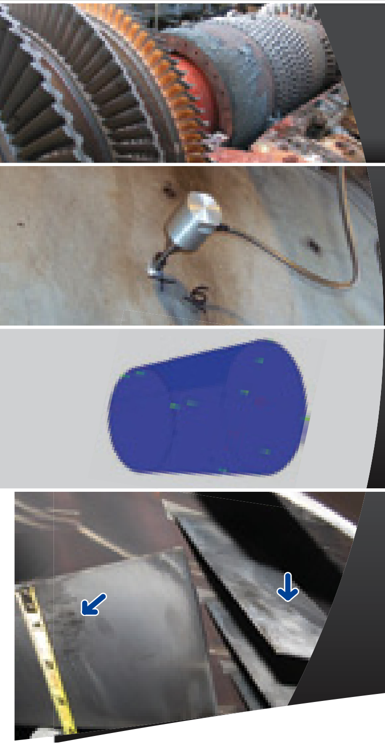
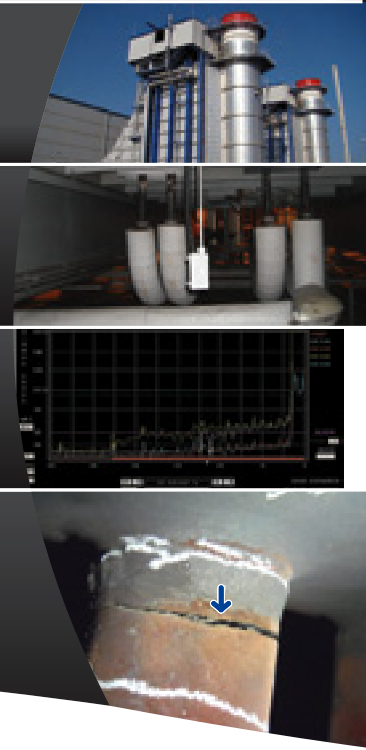
• Non-intrusive sensors • After-market install • Complete forward compressor coverage	**IN SERVICE**	• Non-intrusive sensors • After-market install • 24-7 real time monitoring • Total HRSG coverage or in areas of most concern
• Defect source location • Graphical displays • Local and network alarming	**REAL TIME**	• Trend severity and progression of leak • Locate area of leak before unit removed from service • Local and network alarming
• On-line detection of vane cracking • Insight to unknown condition • Optimize remaining life • Early warning to prevent failure	**RESULTS**	• On-line tube leak detection • Early warning to prevent failure • Manage market exposure and risk • Tube leak repair during planned outage or period of low demand





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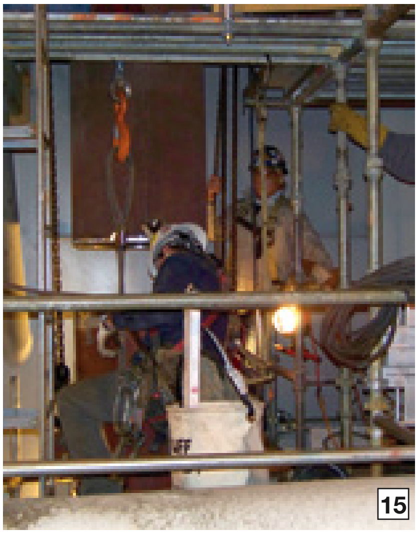
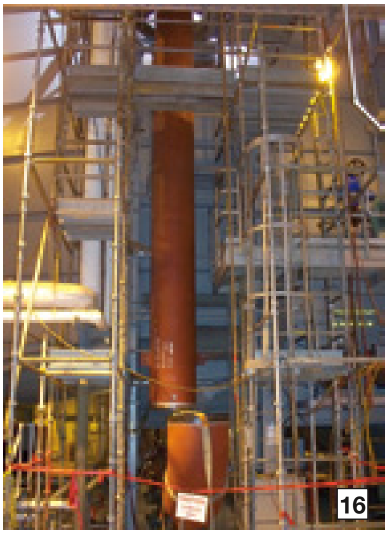
13-17. Top vertical section of new interstage piping, incorporating the attemperator, is hoisted into place in Figs 13-15. Lower section remains suspended over the elbow in Fig 16; welder joins two segments in Fig 17





are brought into the plant (Fig 9) and prepped for welding. Fig 10 shows an E H Wachs clamshell prep tool machining a weld joint consistent with requirements of the *ASME Boiler and Pressure Vessel Code*. A Wachs field rep joined the Bremco team for this purpose because of the critical dimensioning required.

The new interstage attemperator and piping, ordered by Dynegy, were installed by Bremco as directed by the current edition of the National Board Inspection Code. The vertical run of pipe was prefabricated in two sections, each about 25 ft long—the upper segment incorporating the spool piece for the attemperator, provided by Control Components Inc (CCI).

The desuperheater section, supplied with a spray-water connection and temperature element and transmitter, is located about 35 ft above where it was in the original design to maximize the time available for evaporation. A new platform was installed at the attemperator location, complete with lighting, to allow monitoring and maintenance access (refer back to Fig 3).

The attemperator installed at Ontelaunee, is shown in Figs 11 and 12. Five spray nozzles located 72 deg apart around the circumference of the desuperheater are piped into the ring manifold supplied with IP feedwater for attemperation. The use of variable-area spray nozzles assures efficient primary atomization regardless of steam flow. Borescope access is provided by the design to accommodate routine field inspections of internal condition.

The improved atomization offered by the new attemperator has met expectations to date. Maximum temperature differential across the pipe now is within 50 to 100 deg F at combined-cycle outputs down to the minimum load allowed by the plant's emissions permit (perhaps 55% of rated capacity). Further, a temperature differential occurs only during significant changes in load.

The upper section of 26-in. pipe (note the attemperator spray-water ring at far end) is raised into place in Figs 13, 14. Fit-up of vertical members for welding is shown in Fig 15, fit-up of the lower vertical section and elbow is in Fig 16. Fig 17 shows Bremco welder Matt Gray installing the final weld cap on the joint connecting the two sections of vertical pipe. The P22 material is being welded with E9018-CM electrode with the line being held at the required preheat temperature of 300F.

The biggest challenge faced by the contractor was prepping for welding the 16-in. risers connecting the horizontal pipe section to the lower headers (refer back to Fig 1C). Recall that the risers were cut to remove the original 26-in. pipe. The problem was one of alignment: The new horizontal section was purchased with nozzles in the exact position specified by N/E drawings; however, the riser stubs welded into the lower headers had moved from their original positions over time as material "worked" during start/stop cycles. All three of the riser weld joints had to line up within ⅛ in.

Fig 18 shows the E H Wachs field tech (right) and a Bremco employee preparing to prep the 16-in. nozzle for a Reheater 1 header. The nozzle came through the casing at an angle that required a skilled machinist to

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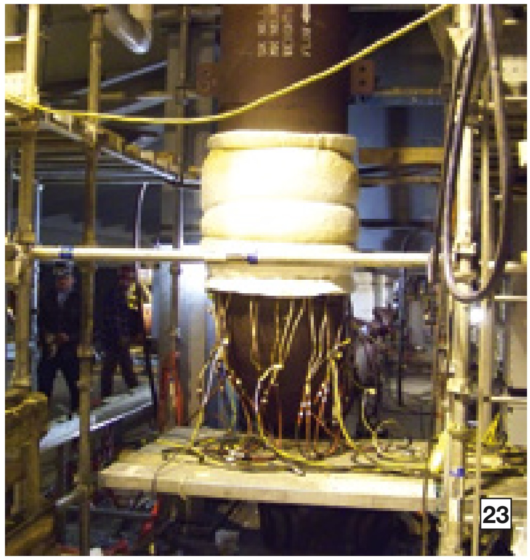


18-23. Weld prepping the risers attached to the lower headers for Reheater 2 was a difficult task. The position of these 16-in. stubs had changed slightly over the years because of thermal cycles. Fig 18 shows the end-prep tool being adjusted to ensure the weld would be "level with the Earth." Machine cut is made in Fig 19 and parallel weld surfaces are verified in Fig 20.

Jacks under the horizontal section of 26-in. pipe (Fig 21) are used to position mating surfaces for tack-welding. Root pass in Fig 22 is ready for inspection. Welds are stress-relieved in Fig 23

assure the weld would be "level with Earth." In this case, fit-up blocks on the machining tool had to be modified to achieve the necessary result. Figs 19 and 20 show the actual machining and final alignment check, Fig 21 one of the jacks required to lift the pipe segment into position for welding.

First step was tack welding, followed by heat treatment. The root pass for the riser serving Bundle C (Fig 22), typical of the critical welds made by Bremco's Welding Superintendent Gary Martin, was manually done using the GTAW (gas tungsten arc welding) process, then checked by Dan O'Gara, certified welding inspector and Bremco's field inspector for Ontelaunee.

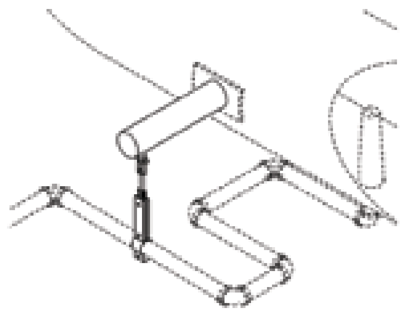
The weld was x-rayed after the root and hot passes to be sure there were no indications before it was filled and capped. Post-weld heat treatment followed. Fig 23 shows electric resistance heaters and insulation blankets on elbow (near field) and riser welds. A second x-ray was taken after the PWHT step. The third-party x-ray technicians told Bremco site personnel they were the cleanest welds they'd ever seen.

Drain modifications

The drain system for Reheater 2 was upgraded to reflect operating experience as well as changes to the *ASME Boiler and Pressure Vessel Code* made in 2007 to accommodate the special needs of HRSGs. These requirements are detailed in Part PHRSG of Section I.

As noted earlier, Reheater 2, as designed, had only one drain at the far end of the horizontal section of 26-in. pipe. It was ineffective because thermal expansion caused water in the pipe to move away from the drain, not toward it. The new arrangement shown in Fig 1C has three 2-in. drain pipes. The automated drain system, controlled by thermocouples in the drain pot's water column, normally sends any water collected to the blowdown tank. Alternatively, the water can be diverted to the oily water separator.

The drain system is not as simple as you might think. Fig 24 shows the layout required to accommodate piping movement. Each of the three drain lines requires a dozen pressure welds. The 2-in. ball valves used in this system to assure positive shutoff were supplied by Conval Inc.



24. The three drains for the horizontal section of 26-in. pipe each required a dozen welds

Spring cans replace rigid supports

A new coil support system was designed by N/E to prevent cracking caused by differential expansion of tube rows in both HP Superheater 2 and Reheater 1 (Figs 2A and 2B). Several bent tubes in both of these heat-transfer sections had suffered cracks at the toes of their tube-to-header welds. By allowing header movement, the added stress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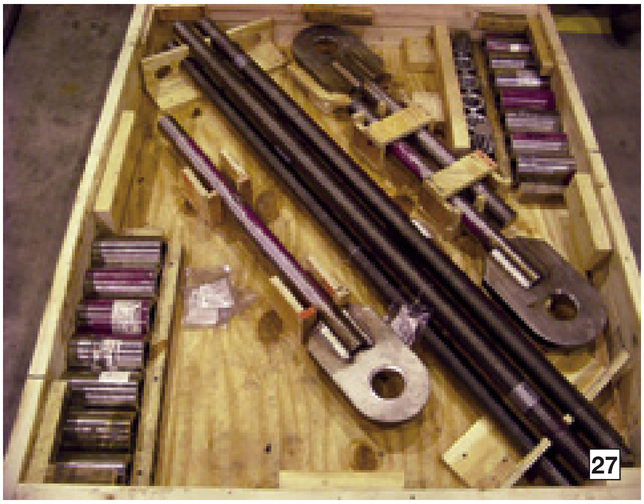


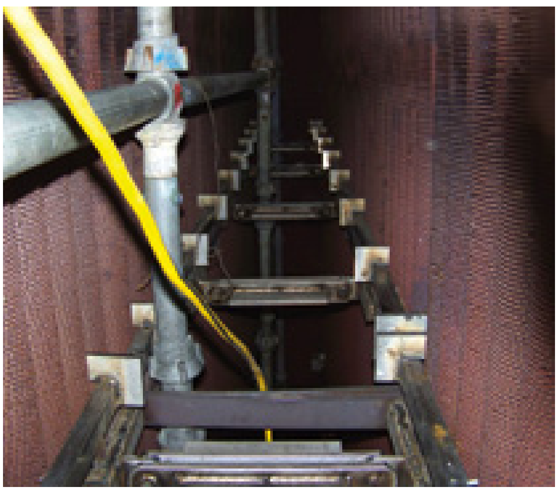
25-28. Replacing fixed supports on the upper headers for Reheater 1 with spring cans is expected to reduce significantly the number of tube failures in the years ahead. Lugs supports are added in Fig 25, spring cans and associated hardware are shown in Figs 26 and 27; the installed cans are in Fig 28

caused by differential expansion between tube rows can be minimized. N/E developed a comprehensive procedure for demolition and installation, along with necessary drawings.

Two spring cans were installed per header following the installation of lug supports (Fig 25). Note that the lugs are tacked into place with a spacer installed to make sure the lugs stay parallel during weld-out. Spring cans are mobilized alongside the kettle boiler (Fig 26) with the necessary hardware (Fig 27). Spring cans as installed are shown in Fig 28.

Tube-bundle restraint system

N/E designed a new restraint system to supplement the vibration supports provided with the tube bundles (alternatively coils or harps) that comprise Reheater 2 and HP Superheater 2. The original supports suffered extensive damage from turbulent gas flows and repairs/modifications were necessary.



29. Vibration supports couple Reheater 2 and HP Superheater 2 coils

The redesigned system helps protect the coils from excessive movement and vibration.

The work is highlighted in Fig 3. The specifics:

- Demo the three lowest levels of vibration supports in each coil comprising Reheater 2 and HP Superheater 2. Replace with newly designed supports (Fig 29).
- Add two levels of mini vibration supports to all Reheater 2 and HP Superheater 2 panels.
- Add four levels of bracing between Reheater 2 and HP Superheater 2 and between HP Superheater 2 and Reheater 1.

Note that Reheater 2 and HP Superheater 2 heat-transfer surfaces are 17 in. apart fin tip-to-fin tip; HP Superheater 2 and Reheater 1 are 4 ft apart.

Detailed step-by-step instructions were provided by the OEM to assure that vibration supports would be installed correctly. To save time on this portion of the work, Bremco, N/E, and Dynegy personnel together developed a method for installing the new supports without having to cut through the casing as originally believed. The three parties, working collaboratively, allowed participants to voice their opinions before final decisions were made—benefitting all. CCJ

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The nitty gritty of aero engine O&M

The first part of the **CCJ's** report on the 22nd annual meeting of the Western Turbine Users Inc, held at the Pasadena (Calif) Convention Center last March 18 – 21, was published in the 1Q/2012 issue, available at www.ccj-online.com. It presented conference highlights and summarized current thinking on several engine-related topics, including:

- The use of HEPA filters to maintain compressor cleanliness without washing, based on Alliance Pipeline's experience.
- Cycles tracking of engines to enable life management of critical parts.
- Details on Black Hills Corp's world-class Pueblo (Colo) Airport Generation Station, home to the latest LMS100 and LM6000 engines in commercial operation when the facility began operating on New Year's Day 2012.
- Rapid removal of water and particulates from turbine oil.

This part of the report digs into the details of top discussion topics aired during the breakout sessions for the LM2500, LM5000, LM6000, and LMS100 engines, as well as during the special technical presentations session conducted on Tuesday afternoon, after the exhibition closed. Sidebar 1 identifies the officers, directors, and breakout-session chairs responsible for the 2012 conference and exhibition.

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Information on venue, program, exhibit space, and sponsorships will be posted at www.wtui.com as it becomes available.
To reserve exhibit space and sponsorships, contact Bill Lewis (wclewis@pplweb.com) or Chuck Casey (ccasey@riversideca.gov).

If you're involved in the operation and/or maintenance of aeroderivative gas turbines manufactured by GE Energy but not aware of the value proposition associated with attending WTUI's annual meeting, a quick read of the material that follows should convince you to attend, without hesitation, the 2013 conference and exhibition in San Diego, March 10-13. Registration for the world's largest and most technically comprehensive forum serving LM/LMS engine users opens November 1 at www.wtui.com.

Breakout sessions

A common thread running through the LM2500, LM5000, LM6000, and LMS100 breakout sessions during the two-and-a-half-day meeting was that current issues typically were carryovers from previous meetings; rela-

1. Western Turbine officers, directors, breakout chairs

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Don Stahl, *Black Hills Corp, Pueblo Airport Generating Station*
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Technical Consultant: Mike Raaker, *Raaker Services LLC*

Breakout Chairs:
LM2500. John Baker, *Riverside Public Utilities, Clearwater Cogeneration Facility*
LM5000. Andrew Gundershaug, *Calpine Corp, Solano Peakers*
LM6000. David Merritt, *Kings River Conservation District*
LMS100. Don Haines, *Wood Group Power Operations Inc, Panoche Energy Center*

Supporting Members:
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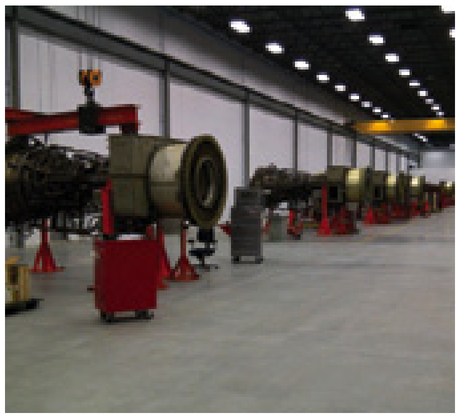
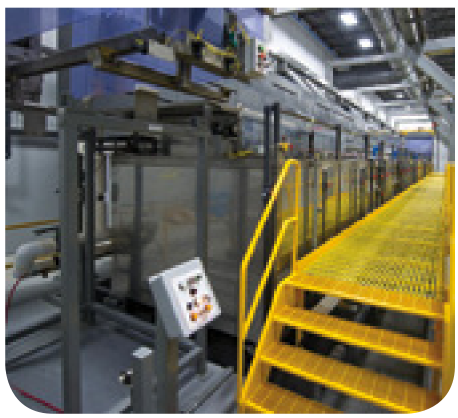


In July 2011, TCT opened a new, custom-built overhaul and repair facility in Airdrie, Alberta. Conveniently located 20 minutes north of Calgary, Alberta, the new facility houses production, project management and support staff for both TCT's General Electric Level 4 services and Rolls-Royce MROC services. This purpose-built facility is 220,000 square feet and is complete with state-of-the-art equipment and tooling. TCT is proud to offer all of its customers immediate induction for all engine types.

In the spring of 2012, TCT will complete construction on a state-of-the-art LM6000 test cell, located in Calgary.

TCT Field Service Office Locations: Houston, Texas; Syracuse, New York; Bakersfield, California; and Cumbernauld, Scotland.



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2. WTUI's depot partners

The success of Western Turbine conferences is underpinned by the technical and financial support provided by the five so-called depots licensed by GE Energy to inspect and repair the four engines addressed by the group.

Representatives of the depots work closely with the WTUI leadership to prepare "lessons" for each of the breakout sessions. Deliverables include notebooks, given to user participants, which review recent service bulletins and service letters issued by the OEM; summarize depot findings since the last meeting; explain causes of performance loss and how to correct them; and provide the fundamentals of critical-parts life management.

The knowledge contained in the notebooks, and that shared by subject-matter experts during the meeting, provide comprehensive, low-cost training for all those involved in the operation, inspection, and maintenance of LM/LMS aero engines. Electric power producers obviously agree with the value proposition offered by Western Turbine participation because each year first-timers comprise between about one-third and one-half of the user attendees.

The depots supporting the Western Turbine meetings are:
- Air New Zealand Gas Turbines (ANZ), Auckland.
- Avio SpA, Rivalta de Torno, Italy.
- IHI Corp, Tokyo.
- MTU Maintenance Berlin-Brandenburg GmbH, Ludwigsfelde, Germany.
- Trans-Canada Turbines (TCT), Calgary.

tively few new problems were reported. That many of the issues discussed were not "new" did not detract from the level of interest, primarily because of the high percentage of first-timers in attendance.

LM2500

John Baker, plant manager of Riverside Public Utilities' Clearwater Cogeneration Facility, a 1 × 1 LM2500-powered combined cycle in Corona, Calif, chaired the LM2500 breakout sessions. The all-important depot presentation was led by Kevin Singh of TCT, with support from Chris Martin of ANZ, Nico Brademann of MTU, and Antonio Errico of Avio. Contributions of the depots to the success of the Western Turbine meetings are acknowledged in Sidebar 2.

Session secretary was Chad Flowe of Charlotte-based Strategic Power Systems Inc (SPS), which compiles the minutes for each session. After approval by the WTUI leadership, these notes are published on the user group's website where they remain available to all registered user members.

The depots' agenda for Baker's session, typical of that for all breakouts, included the following items:
- Engine fleet statistics.
- Recent service bulletins and service letters.
- Review of the OEM's Customer Web Center.
- Depot findings in the last year.
- Critical-parts life management.
- Engine preservation, handling, and transportation.
- Expected maintenance intervals.
- The depot experience.

Singh breezed through a review of the LM2500 fleet operating status and recent service bulletins (SB) and service letters (SL) for the engine (acronyms are defined in Sidebar 3). He reminded user participants that access to SBs and technical documents was via GE Energy's Customer Web Center (CWC). Important to remember is that not all SBs pertain to every engine. Owner/operators should carefully review each publication and determine its applicability for their engines.

Next, recent depot findings were reviewed in detail, starting with the compressor and moving aft.

Compressor front frame (CFF). Delamination, complete in some cases,

3. Acronyms to remember

AGB—Accessory gearbox (also called the transfer gearbox)
AVR—Automatic voltage regulator
CCM—Condition maintenance manual
CCR—Customized customer repair
CDP—Compressor discharge port
CFF—Compressor front frame
COD—Commercial operating date
CPLM—Critical-parts life management
CRF—Compressor rear frame
CWC—Customer web center (GE)
DEL—Deleted part
DLE—Dry, low emissions combustor
DOD—Domestic object damage
EM—Engine manual
FFA—Front frame assembly
FOD—Foreign object damage
FPI—Fluorescent penetrant inspection
FSNL—Full speed, no load
GG—Gas generator (consists of the compressor and hot sections only)
GT—Gas turbine (consists of the gas generator pieces with the power turbine attached)
HCF—High-cycle fatigue
HGP—Hot gas path
HPC—High-pressure compressor
HPCR—High-pressure compressor rotor
HPCS—High-pressure compressor stator
HPT—High-pressure turbine
HPTN—High-pressure turbine nozzle
HPTR—High-pressure turbine rotor
IGB—Inlet gearbox
IGV—Inlet guide vane
IPT—Intermediate-pressure turbine (LMS100)
IRM—Industrial repair manual
LM—Land and marine
LCF—Low-cycle fatigue
LO—Lube oil
LPC—Low-pressure compressor (not on LM2500; just LM5000 and LM6000)
LPCR—Low-pressure compressor rotor
LPCS—Low-pressure compressor stator
LPT—Low-pressure turbine
LPTR—Low-pressure turbine rotor
LPTS—Low-pressure turbine stator
NGV—Nozzle guide vane
OEM—Original equipment manufacturer
PN—Part number
PT—Power turbine (turns a generator, pump, compressor, propeller, etc)
PtAl—Platinum aluminide
RCA—Root cause analysis
RFQ—Request for quote
RPL—Replaced part
SAC—Single annular combustor
SB—Service bulletin
SL—Service letter
SUP—Superseded part
STIG—Steam-injected gas turbine
TA—Technical advisor
TAT—Turnaround time
TAN—Total acid number (lube oil)
TBC—Thermal barrier coating
TGB—Transfer gearbox (also called the accessory gearbox)
TMF—Turbine mid frame and thermal mechanical fatigue
VBV—Variable bleed valve (not on LM2500; just LM5000 and LM6000)
VIGV—Variable inlet guide vanes
VSV—Variable stator vane

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of Teflon stationary oil seals for the No. 3 bearing was reported. The seal body has been redesigned with stainless steel to better resist cracking and general damage, a depot rep told the group.

A user asked: If delamination occurs, will you see Teflon in the sump? "Yes," was the depot response. At previous meetings, users had said they found bits of Teflon in the lube and scavenge-oil filter and that depots had suggested implementing the recommendations of SB 255 Rev 1.

Another participant at the 2012 meeting told the group that his plant had experienced vibration issues because of delamination. Of note was the comment that Teflon breaks down into sand around the seal. The group was asked if any plant was experiencing cold-weather issues because of Teflon delamination. One user with a G4 engine responded affirmatively; he changed the seal.

Peeling of paint from the front frame was acknowledged and it was said that micro FOD/DOD can result from liberated flakes of paint and rust. The subject didn't stimulate discussion at this meeting, but it did in 2009, when at least four users among the more than two score participating in the session reported seeing CFF corrosion. All those plants were at or near seacoast locations.

At that time, the depot representatives suggested that every plant periodically inspect paint condition and check for corrosion. If corrosion was identified, they recommended full paint removal and repainting using a GE-approved process. Several coatings were mentioned, including white polyurethane.

HP compressor rotor (HPCR). There was considerable discussion on the HPCR. Topics included the following:

- Spline adaptor wear. Red paste/sludge deposits have been found blocking the spline-adaptor oil galleries mounted on the Stage 2 disk, with heavy wear to both the adapter and the mating IGB gear shaft. Participants acknowledged that this was an old issue, but one that's still occurring.

  At the 2011 meeting, monitoring of oil pressure and A-sump scavenge-oil temperature was recommended, in addition to semiannual visual inspections, to provide early warning of impending issues. Suggested corrective action included (1) installation of the rugged oil nozzle with improved oil-jet impingement recommended in SB IND-160 and (2) the new spline adapter having four drain holes (SB IND-199), to improve the flow of oil through the spline interface.

  The subject of oil came up this year as it has at previous meetings and attendees once again were urged to use "standard" oil, not the high-thermal-stability (HTS) product some operators believe should be better. The OEM warns against use of HTS oil in SB 10-03 R1. At last year's meeting, a depot representative suggested that owner/operators reference the OEM's qualified product list or ask their oil provider to differentiate between HTS and non-HTS oils.

  This year, a user noted that he had switched to a synthetic oil and is seeing no sludge buildup.
- IGB horizontal gear shaft wear. A user reported light wear on his unit's horizontal gear shaft, attributed to friction associated with the seal oil ring for the inlet gearbox (P/N 9671M82P01/P02). There was no follow-on discussion. At the 2009 meeting, it was said that the light wear on the horizontal gear shaft sometimes experienced was caused by friction of the bronze ring seal and that this occurred most frequently on the early LM2500s. At that time, a Teflon-encased Viton O-ring was a suggested fix. It was said to provide better sealing.
- Spool rub at Stages 14-16 reportedly caused light wear of the abradable coating. Coating was refurbished as a standard repair. There was no further discussion on this point.
- Stage-16 blades. Several incidents of 16th-stage HPC platform cracking and/or tip liberation have been reported in the last few years. Last year, cracking of blade-tip corners was said to have been resolved for LM2500+ units by following the recommendations in SB IND-161 and IND-162, but that platform cracking also has been observed in some of these engines. Base-engine owner/operators were advised to consult SB 180. All users were advised to NDE Stage-16 blades when possible.

An announcement at this year's meeting was that SB 236 addressing 16th-stage platform issues had been issued the day before the conference started.

One participant offered that his plant has had four issues with Stage 16 blades thus far, two causing major outages and two incidents involving minor damage. His plan was to fix the minor damage during hot-section maintenance.

Another user said he kept his engine running at about 7800 hours annually, even with blade trailing-edge damage, and had good luck. When asked he said that he hadn't seen any change in unit performance or vibration level. The OEM advised that operating with damaged airfoils is at the operator's risk. Yet another participant said his plant was not so lucky running with damaged blades; it had experienced significant consequential damage.

HP compressor stator (HPCS). Leadoff subject in this segment was VSV system wear, as it has been for the last few years. The depot representatives urged users to keep the system clean and to replace defective parts immediately. As for frequency of inspections, the depots recommended quarterly, although the OEM's O&M manual specifies 4000 hours or 450 cycles as a guideline.

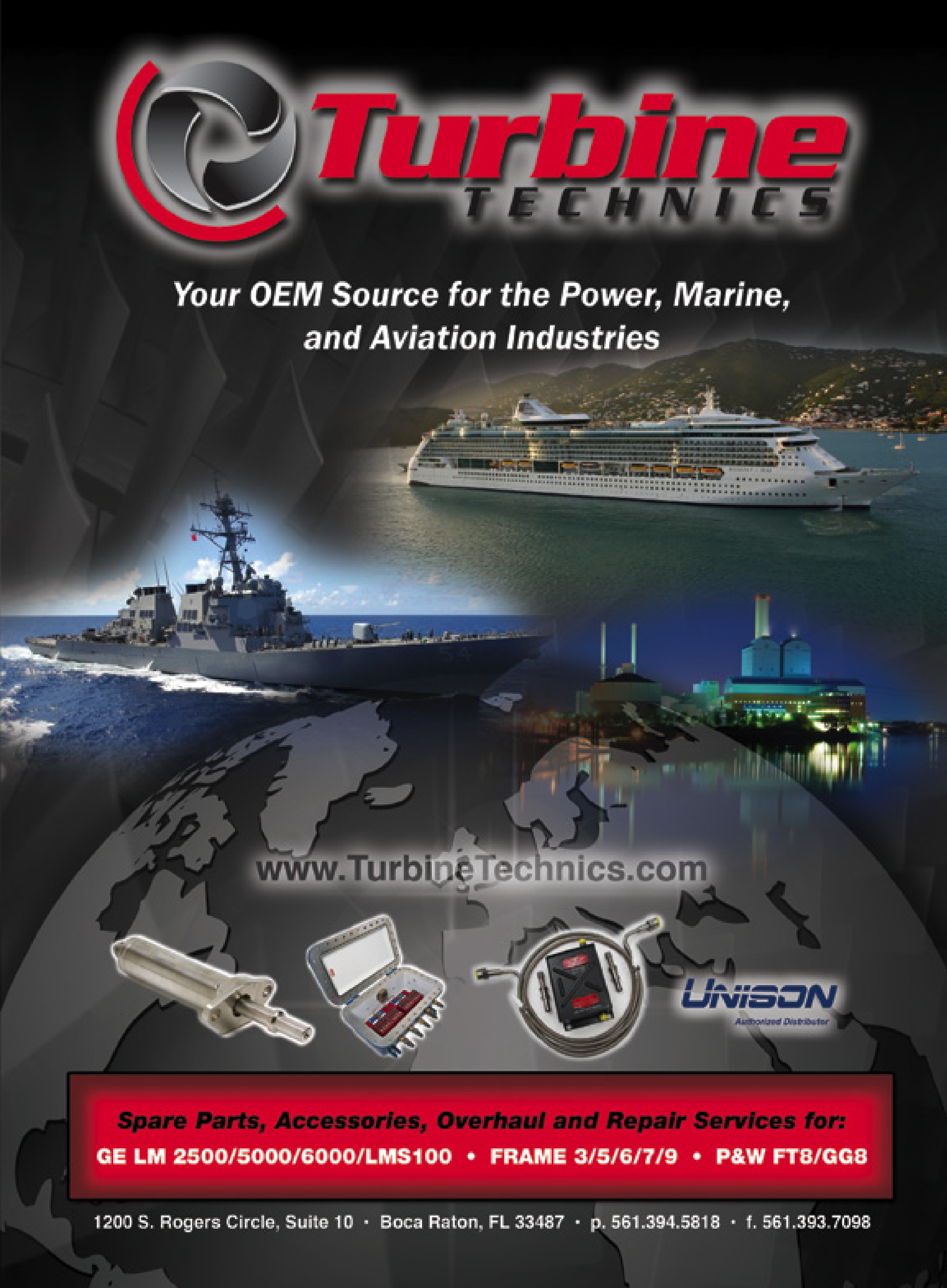
A user noted that system wear typically is found near leaking wash water, where most dirt accumulates. This always seems to be in the hard-to-see places, he continued. Adequate inspection in the field requires time for unit disassembly, to gain access to problem areas. A question from the floor: Can you borescope to see the 6 o'clock area? Response: It's easier to climb under.

VSV lever-arm wear was brought to the floor by a user who observed a visual gap between the lever arms and half rings. He asked, "What methods are used to prevent this?" Answer: Hot water and scrubbing. Another participant mentioned that he pressure washes monthly, which helps mitigate wear. Meanwhile, depot reps said they were working with the OEM to determine the root cause of the gap.

Regarding VSV controllers, one owner said he was having issues with being "ahead of schedule" and that these problems surfaced after only 2000 hours of service. The OEM considered this unusual and recommended working with GE Energy's Woodward Controls group to identify the root cause. Someone else mentioned he was experiencing the same thing, but after 10 years of service.

VSV pump improvements were mentioned. Several VG pumps were removed because of high lube-oil leakage. Pump misaligns because of spline looseness and installation anomalies. Correct installation is critical. Attendees were referred to SB 234, released in 1Q/2012.

Compressor rear frame (CRF). Expandable bolts were introduced as a topic of concern. Experience indicates that the relative motion among diffuser, CRF, and mounting pins contributes to reduced service life. Depot reps indicated that this issue has been around for a while and suggested that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bolts be changed every 4000 hours.

DLE users were asked about their experience regarding this issue. Response was that the whole fleet changed to new-style bolts and no problems were in evidence over the last five years. The OEM said a significant number of its customers haven't followed the recommendations in SB 170 and ordered new bolts.

SAC combustor. Missing/burned material from splash plates was observed. Depot reps noted that the burning was not continuous, but occurred in various isolated areas. The OEM stressed the need for its involvement. Question: Was this a base-load unit? Yes, with a water injection rate of 1:1.

Another participant said he was having a similar problem after 3000 hours of operation on natural gas while running his unit with a water injection rate of 1:1.5. Thinking was that perhaps he was using too much water. Damage did not occur in a specific location at this site either; burning was totally random. Parts were replaced as necessary. The OEM urged verification that the fuel nozzles were correct as installed. Users asked if the OEM was considering a combustor redesign. Answer was "no," current data did not support the need for a new design.

HPT Stage 1 nozzle assembly. Increased NO_x emissions suggested removal of the first-stage nozzle assembly. Outer seal plates were found broken; cause was high cycle fatigue/high-temperature stress. Resulting air inleakage caused hot spots. SB IND-221 was said to offer corrective action.

HPT rotor (HPTR). Hot-section upgrades and life-extension programs were a topic of discussion. The depots said three or four upgrades had been completed. Owner/operators were interested on experience to date. One user said he had two machines upgraded. One experienced cracking at 30,000 hours, the other at 45,000 hours. Both engines were at the depot during the meeting. Come to San Diego in the spring to get the rest of the story.

Turbine mid frame (TMF). Liner wear was one of the first topics addressed. The bottom line: The only way to deal with such wear is to replace the liner. The leaf-seal liberation issue was next. The fix, introduced with SB 229 is a new, shorter leaf seal, which had not been introduced before the meeting.

Depot reps said that seven TMFs had been converted to one-piece cast cases. It was said the cases are easy to replace during an overhaul. One depot said it has had good experience with cast cases, but that they are of a beefier design and available only for units with thick flanges. Recall that some units have thin flanges.

A user asked if a ring was added to the thick flange to make it thicker. The response was "yes." However, it's not available for units with thin-flange power turbines because the bolting is different.

Turbine rear frame (TRF). Chafing damage was mentioned but considered a very minor condition and easy to repair.

Miscellaneous. About a half dozen starter events were recorded over the last 18 months. Bad O&M practices were cited for blame. Corrective action was expensive. Bearing corrosion was another avoidable malady. Corrosion was attributed to water washing. Users were advised to conduct a fired start after washing to dry out the unit if layup was impending.

LM5000

Session chair and discussion leader for the LM5000 breakout session was Andrew Gundershaug, plant manager, Solano Peakers, Calpine Corp; session secretary, Strategic Power Systems' Daniel Murray. Depot representatives were ANZ's John Leedom and MTU Maintenance's Thomas Benisch.

Only 13 users attended the breakout sessions for this engine. The fleet continues to shrink, as expected. At the time of the meeting there were 50 operational LM5000s (six fewer than last year), plus 14 customer spares and nine GE lease engines. The current high-time engine has accumulated more than 180,000 operating hours.

The meeting opened with a general discussion on the level of support owner/operators could expect from ANZ and MTU as the engine navigated its twilight years. Users were told that support was not going away and maintenance manuals and service bulletins were being updated. Also learned was that the OEM's LM5000 program manager position, rumored to have been eliminated, would continue to be supported. The group was assured that issues associated with availability of parts and the lead times for obtaining parts were being addressed. In fact, ANZ had purchased from the OEM parts totaling more than $22 million to improve customer service.

Technical manuals, documentation. Access to SBs and SLs are via the CWC, where owner/operators can register for electronic notifications. That way, when a new SB or a revision applicable to your unit becomes available, you will receive an email with a link to that documentation. Coming SB revisions announced March 19 were the following:

- **215:** LPCR Stage-0 Blade Aluminum Coating (platform installation).
- **216:** Stage-1 Compressor Stator Vane Shroud Improvement (depot repair).
- **217:** Air Collector and Front Frame Interface Improvement (depot repair).

A few items were discussed that the depots would like to see addressed by SBs. Perhaps the most important of these was the No. 1 Bearing Aft Housing Inspection and Repair. This would address holes found that should not be there. A depot visit would be required to make repairs.

LP compressor (LPC). Corrosion has been observed on LPCR Stage-0 blades of leased engines returning from the North Sea. Such corrosion often is found as well in land-based gas turbines of all types and models located on or near the coastline. Two mitigation strategies: (1) Increase the frequency of compressor water washes; (2) cover the inlet when the unit is not in operation.

Shaft-rim bolt-hole cracking seems to be experienced by at least one unit in the fleet annually. Cracks are the result of galvanic corrosion. Suggestion was to try an alternative grease or oil in this area of the engine. But be sure to discuss your choice with the OEM before making a switch. GE is testing torque values for different types of grease.

LPCS Stages 0 to 2/Stage-3 case flange-bolt/nut torque values should be maintained at 130-150 lb-in., and the Stage 3/Stage 4 case values between 100 and 120 lb-in., not the 55-70 lb-in. currently specified in the O&M manual—at least until the OEM can update its manuals.

Discussion migrated to front-frame/air-collector interface issues—specifically, improper seating of the air collector after final torqueing. Inspection revealed bolts were under-torqued. A depot took measurements from flange to skirt on multiple units and variations were noted among the engines inspected. One conclusion was that the feeler-gage check must be 360 deg around the cover. Technicians observed wavy metal in one or more areas of some machines. Depot is working with the OEM to achieve better fit-up.

Next issue put before the group was damage to the No. 3 stationary oil seal. It caused internal oil leakage which is conducive to vibration. Evidence of a leak often is found during a borescope inspection: An oil film is in evidence on blades. A depot rep said the Teflon seal had to be replaced on a depot visit. However, a user said he was told that the seal could be changed onsite. The

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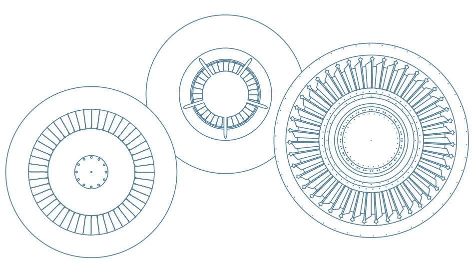

depot rep took a half step backward: An onsite repair was not an easy job, he said, and success depended heavily on proper set-up of the job. There was an acknowledgement that such leaks happen "often" on the LM5000 but no running-time limits were offered for the Teflon seal.

HP compressor (HPC). Rotor vibration (compressor and turbine) often is caused by insufficient internal interference fit between rotor components caused by wear or shrinkage of parts. Suggested course of action: Tear down and take fit measurements; make sure they are in accordance with SL 5000-99-03. Use metal spray or other methods to bring fits back into spec. Plan ahead: Be sure to include fit measurements and corrections into your regular maintenance program.

Distorted, broken, and worn VSV hardware received significant attention. Failure to keep your eyes on such detail can contribute to engine stalls. Regular inspection was urged: More than 4 deg of movement demands replacement of defective parts. Recommendation is to remove all parts and inspect every 12,000 hours. But as the LM5000 fleet continues to migrate to peaking duty, inspections should be conducted more frequently. Users report significant wear at inspection intervals of 4000 and 8000 hours.

Worn pins, missing bushings, elongated pin holes, sheared lever arms, worn bearings, and worn trunnions can be expected. VSV components are relatively inexpensive, so "saving" by not replacing damaged parts is not a sound financial strategy: It increases the risk of costly damage to the HPC.

A comment from the floor was that while external bushings can be replaced in the field, that's only a temporary fix. Both internal and external bushings must be replaced and that requires a depot visit.

HP turbine (HPT). Most important discussion surrounded the failure of air tubes serving second-stage nozzles. Known as "spoolies," these cooling-air tubes typically are found worn because of fretting, dislodged and rotated 90 deg thereby blocking air flow, or simply missing. Associated retaining rings and spring washers typically are dislodged and migrate elsewhere. Attendees were told that other LM engines have a similar issue.

Owner/operators were urged to replace all "spoolies" when exposed in the field and when an engine is sent to the depot. Total design airflow is required to minimize the danger of burning the disk.

LP turbine (LPT). An isolated issue identified with the LPT stator case was cracking on the circumference of the forward nozzle support hook. This was found on an engine in a depot for overhaul and was thought conducive to a catastrophic failure. Metallurgical evaluation was not complete at the time of the conference but the thinking was that replacement with "fresh" metal was necessary. Too much time—47,000 hours in this case—at high temperature was believed to be the underlying cause. One participant noted that engines are making it through the second major but not to the third.

Rim bolt-hole inspection for the first-stage disk was recommended using eddy current to identify any cracking that might have occurred. One disk with cracks was found by a depot in 2011. Refer to SB 5000 IND-0209 for guidance.

Critical-parts life management is a responsibility of owner/operators to protect against physical damage to property and to ensure the safety of plant personnel and the public at large.

Users should maintain cyclic life records of critical parts to enable their timely removal from service. Where such record-keeping has not been done consistently, owners can consult with the OEM regarding a "best estimate" of life expenditure and then collect and maintain follow-on data.

Participants pointed out during the session that they believed LM5000 parts were not made to accommodate the cycling required today. One user experienced vibration at startup following a normal shutdown. He found that running the generator fans for two hours after shutdown caused extended power turbine/generator spin down; thereafter startup was fine. Users were cautioned that the PT lube-oil pump (attached to the gearbox) is not running after shutdown.

The PT requires a sub-core idle warm-up and then a 10-min subcore idle before bringing the unit to synch-idle. It is difficult to restart the LM5000 after a short shutdown. If you can wait eight hours, everything is good the users were told.

Humidity control is very important, the depot reps said, if a unit is scheduled to sit for long periods. Suggestion: Install large plastic sheet over the inlet to prevent moisture from entering the engine. If the unit will be idle for more than a month, owners should follow engine-oil preservation procedures.

Open user discussion. The subject of fire protection systems was raised but discussion was quickly extinguished. A user wanted to know how he could determine if the system was still in workable order and asked if anyone had the original test results for package testing. He was told there was not a product suitable for proper testing.

An owner reported a first-stage nozzle blade failure after 15,000 hours at 1410F to 1425F with full STIG. Unit started daily and ran for 13 hours. The user wanted to know what happened to cause this failure. The answer: End of life. Expect burn-through of first stage buckets and nozzles by 16,000 hours.

"How am I doing?" an owner asked, telling the group that he was able to bring the T44 spread down to 40 deg F. "Exceptional," he was told; most are in the high 90s and above.

Regarding offline water wash, a user asked if sampling of wash water discharged was necessary to verify the cleanliness required. Answer: Not mandatory.

LM5000 STIG interface connection was considered a bad design by a user who was told to add stiffener legs similar to the LM6000 to support the manifolds and piping. This gets the weight off the engine.

OEM/depot, user discussion. Lifetime engine support was a topic of great interest to owner/operators, who had many questions for OEM and depot representatives. The OEM promised "continued" support, saying a budget had been approved for support, parts, and repairs, and that there currently was no plan to take the LM5000 out of service. An OEM rep said that if a strategy of the lifecycle were available, support could be continued five to 10 years.

At least some owners said they didn't have the financial resources to convert to LM6000 and might want to run their engines another 15 years without extreme costs. You could see where this discussion was headed and words appeared carefully chosen.

In brief, the owners had these among other questions:

- What are the inventory levels of critical parts, as well as of non-critical parts?
- Could they be assured no long turnaround times when parts were needed?
- If parts were unavailable, could they arrange for reverse-engineering of parts and give alternative suppliers OEM drawings?
- Would the OEM support less stringent standards so owners could maintain their engines?

The OEM/depot reps responded predictably:

- The depots need the following information from users to better determine the quantity of spares needed: run time, fired starts, hours per start.
- The OEM has been discussing and investigating "conditional" repairs.

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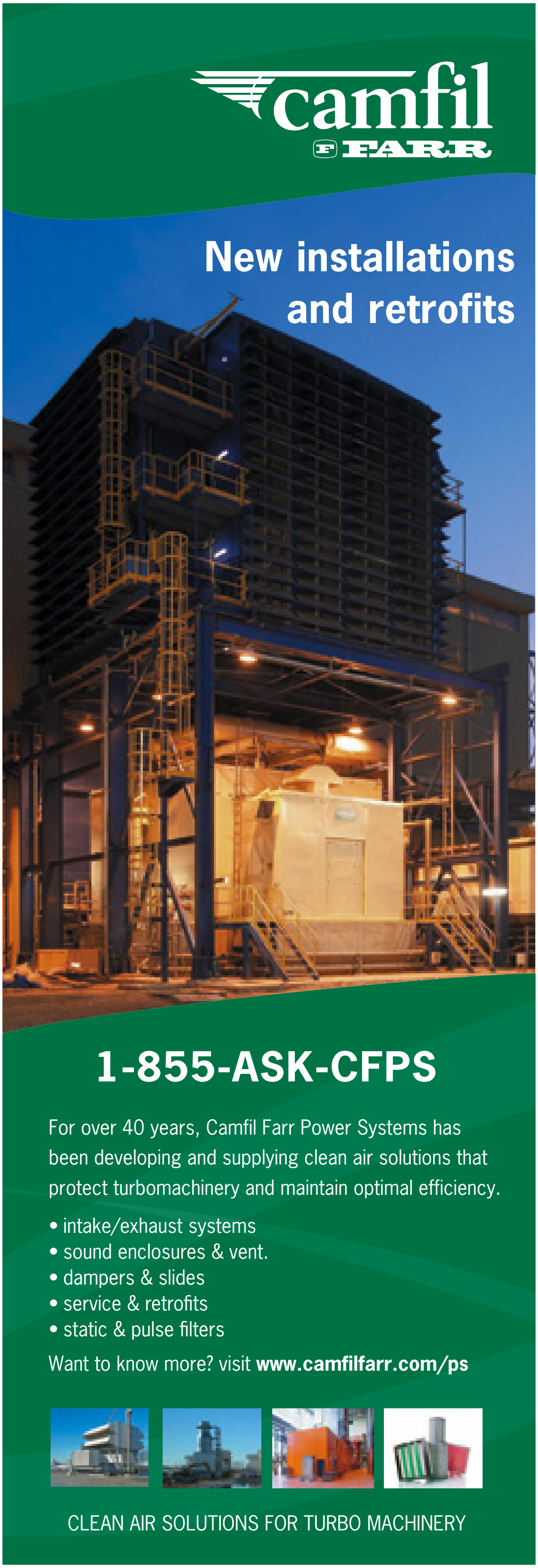


- The OEM is not in the position to authorize support for non-standard parts.
- The OEM is willing to work with a vendor having the quality standards to make needed parts.
- New long-term service agreements are available to LM5000 owners. Plus there are nine engines in the lease pool to support the fleet.

Depot findings: Abnormal events. Several depot findings in the last year were classified as "abnormal events"—including the following:

- LPC coupling nut, cracked/disengaged. The LPC rotor shifted back, stopped only by the PT. Why the nut failed was not completely understood at the time of the meeting. Experts believe the failure mechanism either is hydrogen embrittlement or pitting from moisture developed during operation. As a preventive measure, install a new nut in every unit sent to a depot for repairs. A similar issue was identified with the LM6000 about two years ago and that remains unresolved as well.
- Airfoil separation on HPC eighth-stage vanes. This condition can be identified during a borescope inspection; however, a thorough inspection of the area could take days. It is best to inspect for this condition when the upper casing is removed. A root-cause analysis is forthcoming.
- Cracking and degradation of the HPT outer seal, which apparently was caused by use of an oversize seal, is a manufacturing issue. A final report is pending.
- Debonding of the TMF cooling and vent seal.

Package discussion.

- Inlet-air filter house observations and recommendations: (1) Unit was operating normally with no issues until ambient conditions suddenly changed and turned to mud impurities that had been captured by the filters. The impact of ambient conditions on operations should not be underestimated. (2) Ensure proper calibration of pressure gages, especially differential-pressure gages. (3) Do not "puff" filters with the FOD sock installed. This will clean the debris from the filters, but it will remain in the filter house and re-clog filters. Install FOD socks for about two weeks following a major to help reduce corrosion from acidic environments.
- Lube-oil system. Air/oil separator issues were reported by one user. Investigation found rags in lines at the tank. Suggestion was to cap open lines when removing an engine from service to prevent such problems. Subject of oil sampling was raised. One suggestion was to have a local company sample and analyze the oil monthly. Users were cautioned against bulk changeout of lube oil because detergents can cause engine deposits to break loose and cause problems.
- Fuel system. Test and calibrate fuel nozzles annually. Heat rate is virtually sure to improve.

Engine handling, transport. The group was told that whenever an engine is installed in a shipping container, ensure that the straps over the container are not too tight, to prevent crushing. Fasten the container securely to the transportation trailer from the base of the container.

Storage, preservation. If you plan to keep an engine out of service for a month or more, put it in a properly pressurized container to prevent corrosion damage. Hook up the storage container to nitrogen and blow out all of the air, leaving the container pressurized with a maximum of 3 psig of nitrogen. Follow the OEM's manual for storage and preservation.

LM6000

Session chair and discussion leader for the LM6000 breakout sessions was Bryan Atkisson, plant manager, Riverside Public Utilities; session secretaries, Senior VP Tom Christiansen and Weston Trimble of Strategic Power Systems. More than 150 owner/operators participated in this engine forum, about two-thirds of them first-timers. They were joined by representatives of the OEM and its authorized LM6000 Level-4 service providers—TransCanada Turbines, MTU Maintenance, and IHI Corp.

The breakout sessions at Western Turbine meetings are rigorous. For the experienced, they provide the opportunity to catch up on new issues identified by the depots which should be incorporated into inspection/maintenance routines. For those still getting familiar with the engine, the eight-hour program for each LM/LMS engine, spread over the three days of the annual conference, is an invaluable training exercise.

Two questions Atkisson asked the group before digging into the technical aspects of LM6000 O&M: "Who had an unscheduled outage this year?" By show of hands, 15%. "Who had to remove an engine because of an unscheduled outage?" About two-thirds of those experiencing a forced outage.

Erosion caused by issues associated with the Sprint™ system, on engines so equipped, monopolized the early discussion. Recall that Sprint is an acronym for "spray intercooling," which is used to increase compressor mass flow by cooling the air during compression.

Demineralized water atomized by high-pressure air extracted from the eighth stage is injected via spray nozzles into the compressor. The water flow rate is metered, using the appropriate engine control schedules. Sprint's effectiveness is most pronounced in hot weather. Example: While power output is 9% greater at ISO conditions than for the same LM6000 model without Sprint capability, at 90F ambient it is 20% greater.

On high-pressure-ratio gas turbines like the LM6000, compressor discharge temperature often is the criterion limiting power output because compressed air is used to cool hot-section components. By reducing the compressor outlet temperature using Sprint, the engine can operate on its natural firing-temperature control, thereby boosting output and improving efficiency.

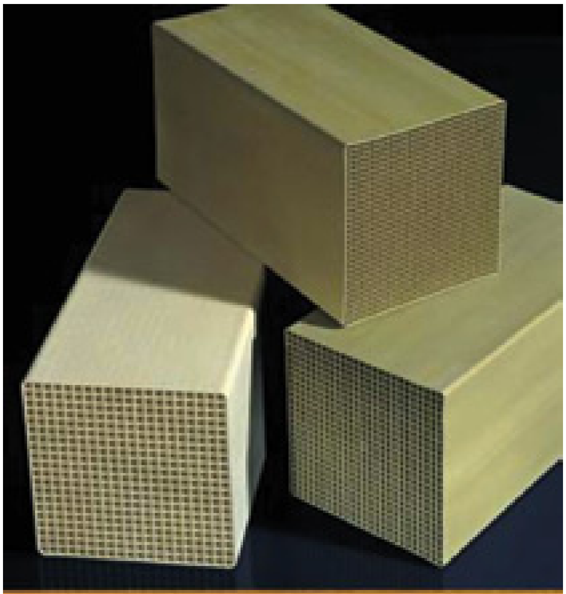
Many users with Sprint-equipped engines have reported erosion of variable inlet guide vanes and of the LPC. Regarding the latter, erosion grooves in the LPC cases of two engines—one with 8000 hours of service, the other with only 3000—were reported at the meeting. The erosion groove formed at the drop-down edge of the zero- and first-stage LPC blades in both cases.

A user asked if the holes in the Sprint nozzles were too large. Not; the spray angle was completely different from that recommended. The group was told that if you change nozzle position, you change the droplet size. A best practice gleaned from the user discussion: Annually, change out Sprint nozzles, or test them to assure that the spray patterns are acceptable.

LPC disk corrosion and pitting have been found in a couple of instances—more often than expected. Current thinking is the wear and tear could be related to moisture in the engines. This issue is important to correct given the cost of replacement wheels.

A photo was flashed up on the screen showing HPT first-stage blades that apparently had taken a beating from FOD or DOD. Suggestion was that in such cases you might want to just run them until replacement is necessary because rejuvenation was unlikely. By contrast, if only flaking was in evidence, rejuvenation might be possible. Advice was to discuss with a depot rep before finalizing a decision.

Next subject was LPT first-stage-blade shroud gap. Only a couple of years ago, if any gap existed, you were supposed to remove the engine from service and repair. But 15,000 to 20,000 hours later the gap typically would reappear. Users pushed for a change in limits because units were being taken out of service based on gap alone and owners thought it unnecessary. Investigation revealed that having a gap was not the problem believed, as long as the wear was uniform. New rule that has significantly improved availability and reduced O&M cost: Repair now is necessary only if wear is not uniform.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Regarding LPT fifth-stage blade shroud wear, this condition has not been reported since the two events that occurred three years ago. Borescope inspections confirm regularly that shroud wear and overlap are not occurring. This is important because loose engagement will allow the blade to vibrate back and forth, a condition conducive to fracture at the base.

Critical parts life management received plenty of air time. A show of hands revealed that only 20% to 30% of the attendees were tracking cycles. Users were urged to track the operating times of parts as accurately as possible. Pushback: A user noted that the OEM's O&M manual still had the life limits of some parts as TBD (to be determined) and asked when the information would be available. Sometime this year was the reply.

From the discussion one quickly concluded that cycles tracking was not something users relished doing. Fingers seemed to be pointing in all directions. Customers are asking the depots for cycles, but the depots said that information is virtually impossible to provide unless owners give them the relevant operating information.

The depots believe cycles tracking starts with the users because they have all the information. Owners are looking for the OEM to track cycles automatically by way of software. The users were told that the new software for the PG and PH models of the LM6000 has the capability to produce counter readings which then must be applied by the user for the applicable part. An OEM rep also said cycles tracking will be offered as an upgrade for older software, except for that on PA and PB engines.

A user asked: "Where do we start with cycles tracking when we don't know the past?" One thought is that it's better to be conservative and replace parts sooner than you might have to; then you can begin accurate cycles counting with new parts. For parts that are original to the engine, you can collect data for a year or two and average it backwards to the installation date if you believe the GT's operating profile has not changed much over the years.

"Are you supposed to pull a part once it has exceeded its cycle limit?" Yes, the owner was told.

Engine preservation. Depot reps suggested to users that they keep logs of engine preservation maintenance, saying they were important both for insurance reasons and for refreshing your recollection of what was done.

Outage preparations. Before every outage, be sure all lifting equipment has been load-tested and is operational. One user remarked, "I think we all load-test the crane before using it. How do we load-test the fixture?" Response: The manufacturer should provide a certificate and unless you overload it, there's no real reason to test the hook. If you think you've overloaded the fixture, the depot rep continued, find a local company capable of testing it.

Another voice: Some fixtures come with manual and/or local guidelines for testing. IND 278, covering weight limits on lift fixtures, is now available via the CWC.

A user was looking for an outage checklist to be sure everything is covered six months ahead of time. His last outage was extended because everything needed was not in place. He was told that checklists do exist—in fact, some have been published in the **CCJ** (search at ccj-online.com).

OEM exchange. Here are several bullet points extracted from the exchange between the OEM and the owner/operators:

1. A couple of users said they did not have access to LM technical documents. This means they're not finding out about improvements. Suggestion was to register immediately on the CWC.
2. Owners now can update SB compliance online if desired.
3. Quarterly bulletins now are issued on what information resources you are missing for your unit.
4. Water washing. There was a question regarding IND 11-103, "Water Wash Guidelines." This was misinterpreted by some users to be a standard for everyone, but water washes cannot be generalized for everyone, the group was told. Water washing is determined by site conditions. Everyone: Be sure to protect electronics underneath the engine against water leaks.
5. Controls demanded considerable discussion time with several specific issues brought to the floor. Most users want to keep up on obsolescence. The OEM said there are three different status designations for its series of Mark controls: enterprise, legacy, obsolete. Discontinued parts still are covered for enterprise but not obsolete parts. Mark V controls will become obsolete in 2014, Mark VI in 2019 (entering the legacy phase now), Mark VIe in 2026.

   OEM reps talked about the benefits of a controls upgrade. Examples: Reliability improves because the probability of having forced outages is reduced; plus, engines are easier to troubleshoot, maintain, and upgrade.
6. PC to PG upgrade kit enables a 10% increase in both air and exhaust flows with no changes to existing mounts. However, a gearbox is required as well as 8 ft of additional space. Time from order to installation is 12 months or less, plus a 45-day outage.
7. Remote monitoring and diagnostics service is now offered. It provides 24/7 support for the operations team, access to technicians, etc, and promises measurable impact on reliability, availability, and operability.
8. HPC blade release. One incident involving a third-stage blade release and two involving releases of fifth-stage blades were discussed. Cracks originated in the dovetail areas; no other hardware or operational anomalies were identified. Examination of remaining blades in the affected rows revealed wear-coating depletion.
9. Splitting of the rubber boot for the radial drive shaft occurred on five units, allowing oil to spill into the packages. Investigation revealed that the supplier changed its manufacturing process. Addition of a solvent to provide reinforcement resulted in poor bonding between layers of Viton. Situation improved by returning to the original manufacturing process and revising the design of boot and clamp for better retention.
10. G39/G40/G42 PC combustor experience continues to demonstrate improved results compared to the G35. Splash-plate burning has been reduced, swirler thermal barrier coating has improved erosion resistance, and the bore wear rate has been reduced. However, swirler cracking still is in evidence.
11. SAC swirler cracking was attributed to environmental attack and thermal stress from NO_x water. Long-term improvement plan focuses on leveraging the PG and LMS swirl cup design to improve durability.
12. SAC TBC loss has been observed after only 600 hours of service, with coating material liberation "beyond normal erosion." Coating release has been attributed to high shear stress at the TBC to swirler interface. Plus, some swirlers examined did not meet specifications. Improvement: The hybrid G42/G32 combustor. Erosion process proceeds faster but it is less damaging as wear occurs. The thinking is that a user would rather replace a combustor with a less effective coating more often than protect the HPT blades against impact damage from liberated large particles of advanced coatings.
13. Accelerated SAC primary-swirler

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bore wear has forced at least one engine out of service in less than 2000 hours. A new coating, T800, has shown promise in trials. No evidence of wear after 4000 hours. Release to the fleet was promised.

14. Two instances of CRF oil leaks were identified with PC units—one after 455 starts and 10,000 hours of service, the other after 393 starts and 4900 hours. Repairs required depot visits. The reported issue was that the "P" clamp "walks" on the heat shield because of thermal cycling and the J-clamp bends. A diagram of the movement can be found among GE presentations on the CWC.

Work is ongoing to validate a new design featuring a wider clamp configured to stop it from catching and walking. If field tests are successful it will be released to the fleet. Discussion revealed that personnel some sites remove the clamp, which has a history of issues. Experts did not support this action, saying that it might be conducive to cycle fatigue of other parts or cause a natural-frequency issue.

CRF oil leaks have been discussed at LM6000 breakouts for several years. Such leaks can cause engine smoking and frame coking, as well as the loss of oil. At previous meetings, there was general agreement that one cause was elongation of loop clamps because of thermal growth and sump-area stresses that contribute to clamp distortion. Investigators found that clamps would slide off the oil-tube wear sleeves and wear through the tubes. A couple of years ago, users were referred to SBs 233 and 236 and told that if the recommended work was done during the next depot visit the leakage incidents would cease.

15. DLE gas-manifold distress. Multiple incidences of C-ring distress were reported in the last year. The problem is separation of the brazed joint on the L manifold. The cause, in theory, is hydrocarbons igniting in the manifold when gas fuel is not flowing. Recommendation: Replace the brazed manifold with one of welded design. Under evaluation: Addition of a check valve at the C-ring outlet to prevent the back flow of combustion air.

    Plants were urged to maintain a leak-free gas fuel system and assure there is no oil carryover from the gas compressor, if installed. Plus, be sure the gas you're receiving meets GE specs published in the O&M Manual, Appendix A1.

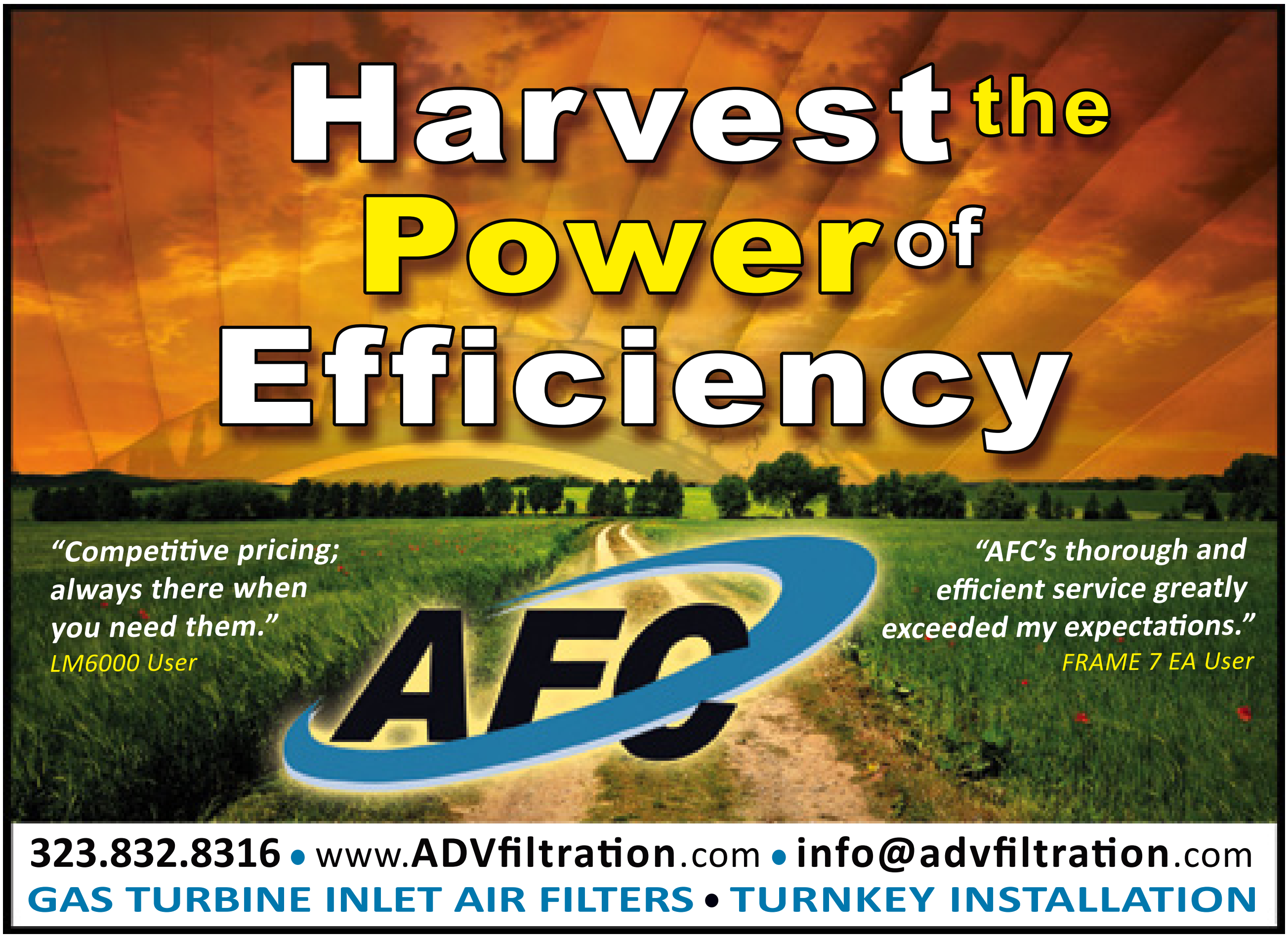
16. Put the LPT fifth-stage blades on your watch list. There were two unscheduled engine removals in the last year attributed to fifth-stage blade issues. While both of these units had accumulated around 40,000 hours of operating time, don't be complacent if you have a low-hours engine, the users were told: One LM6000PC had to be removed in about 5000 hours. PC owners were told there's a one-in-10 chance their engines would be put "on watch" or removed from service because of fifth-stage blade issues.

17. VBV expansion-joint material distress. Tears at the creases of the expansion joint typically are experienced. If tears exceed 3 in., recommendation is to replace the joint. Root cause of the problem is material deterioration; replace with silicone aramid to mitigate tearing.

User presentations. The first presentation in this group reflected a user's first experience in removing an engine (an LM6000PD DLE in this case) for a depot visit. He began by asking two questions:

- Who has not pulled an engine? Half the attendees raised their hands.
- Who has had an unexpected surprise? About 10% acknowledged.

Next, the presenter revealed two issues faced at his plant the first time an engine was removed: (1) Restricted space between the package and adja-



cent building; (2) access platform blocking doors. Action taken: Platform was removed and modified; replaced crushed-stone access path to package with concrete.

The speaker urged his colleagues to review procedures with someone having experience in removing an engine to be sure all lifts, trollies, parts, tooling, etc, that might be needed would be available. His plant was not as well prepared as he and his colleagues thought and a lift had to be rented at the last minute, and a steel structure installed, to facilitate removal.

Surprises incurred during removal and at the depot: Coking on the TRF; oil-sump drain lines had been modified; work was required on the clutch; oil seals required refurbishment. A user asked how it was determined that the clutch was bad. It wasn't, the speaker responded, the depot rep suggested that it be overhauled because no maintenance had been done on it previously. Another question related to the impact of coking. Drain-line diameter was increased by ½ in. to assure proper operation.

Timeline: Engine removal and reinstallation took three days each; the depot visit lasted 10 weeks.

The second case history involved an unplanned depot visit for an LM6000 (converted from an LM5000 about three years earlier) in base-load operation. Engine was borescoped at 21,000 hours and heavy rub damage was found on the leading edges of the LPT second- and fourth-stage seal lips, which was not serviceable in the field. Damage was said to have occurred about six months before the inspection was conducted. There were no prior issues—such as high vibration—that would have indicated a problem with the LPT—no vibration issues, etc.

A combustor/HGP inspection was done during the depot visit, and the B sump clamp inside the engine was modified. Latter action was taken because a sister unit's oil line was leaking. There was no leakage associated with this unit; work was precautionary.

Next user presenter was from a plant where a dozen LM6000s were placed in commercial operation 10 months earlier. He shared issues faced with the new units, including these:

- Evap cooling system. Fuel-valve solenoid control wire termination box was installed in the water path. Water entry shorted the electrical box. There was no fuse protection for the solenoid coils, causing the termination board to short out. Follow-up on a loss-of-suction incident with the evap-cooler circulating pumps three weeks after startup found impellers were set improperly. Couldn't be fixed right away so 6 MW were lost to "no evap cooling available."
- NO_x and fuel-valve driver failures attributed to sloppy installation practices required a team of technicians to check all wiring and connectors and then recalibrate NO_x-water and fuel valves.
- Grounding issues produced erroneous alarms, caused improper response from feedback circuits, etc. "Phantom problems" had to be rooted out and fixed, one at a time.

Questions from the field. The Western Turbine Users serves owner/operators of well over 1000 LM/LMS engines worldwide—machines driving generators and pipeline compressors and others dedicated to ship propulsion. The group hosts an online forum at www.wtui.com, but questions often come directly to officers, directors, and the breakout session chairs. Contact information for these aero leaders is available on the website.

Atkisson collects the questions/comments/ideas sent to him during the year and uses them to drive discussion during the breakout sessions. Here are some of the topics he introduced to the floor during the meeting in Pasadena:

- Passive case cooling system. A plant reported removing it, but losing very little power as a result. Risk mitigation was the reason: A part could wear from thermal stress and get into the LPT case.
- Exhaust diffuser cracking. Several users' engines experienced the issue, but success was elusive and

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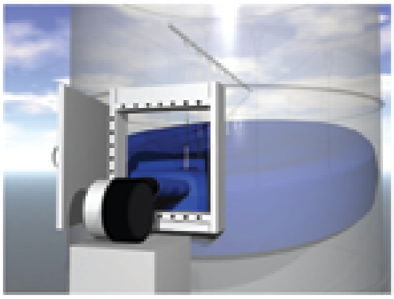

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the crack reappeared. Some owners are comfortable not repairing diffuser cracks because the repairs always seem to be temporary.

- Gas-compressor lube oil carryover to the engine. User said the synthetic oil used even passed through coalescing filters. Addition of secondary coalescing filters appears to have solved the problem.
- Exhaust-spread issues. Discussion was vibrant on the subject. Mention was made of the OEM's "cheat sheet" for plotting exhaust temperature to the T48 thermocouples to help determine if excessive spread can be corrected by change-out of fuel nozzles.
- Water washing. User varies rotor speed during water wash to improve cleaning effectiveness.
- Running on AGC at low loads. One user reported operating at 7 MW and suffering the consequences—wear on first-stage blades, fuel nozzles, and VBV doors, etc.
- NO_x water valves received poor reviews from users. One user said he has changed valves twice in seven years of running and rated that part one of the most unreliable on the engine. The valve supplier just brushed off his findings of metal particles inside the valve and unraveling gaskets with a "dirty and harsh environment" excuse. Fed up, he changed from the OEM's preferred supplier to an alternative supplier. Valves were more expensive, but operating problem-free.

After short discussions on the 11th-stage check valve, an HPC blade failure of the type no one could determine, and a CDP valve failure, IGB sludge became the topic of choice. Opening question: Is there anyone present who needs to do SB 225 and hasn't yet? One hand raised.

An OEM rep cautioned, "If you see sludge, or have wear beyond the 10-mm limit, you have to do SB 225." If you decide to keep running, the risk is that the spline shaft will be damaged and the spline won't engage. Also, if you're having problems, don't keep hitting the start button. When an IGB spline disengages, things are still turning and generating heat which can damage IGB disks.

Some background on the issue may benefit new users. Prior to publication of SB 220, inadequate lubrication often was the cause of gearbox problems. Specifically, inadequate spline lubrication, and relative motion between the horizontal gear shaft and HPC spline adapter, caused wear that resulted in a core speed change or inability to restart. Wear can be identified by the presence of iron oxide sludge during a borescope inspection.

SBs 220 and 225 can prevent this problem. The first document, published six years ago, introduced an oil insert and new oil nozzle. The insert was selected based on successful experience on other GE engines.

SB 225 introduced a new spline adaptor that almost doubles the oil passage area to prevent wear particles from clogging the holes. It also made adjustments to reduce contact between spline teeth. At a Western Turbine meeting several years ago, users recommended fulfilling the requirements of SB 220 because SB 225 requires disassembly of the engine to the modular level. It was considered by users as cost-effective to implement only when related maintenance is required.

A package discussion closed out the LM6000 breakout for 2012. Balance-of-plant issues were included in this lively "ask anything that is on your mind" session. Topics included the following:

- Conversion of belt-driven generator fans to direct drive.
- Rusting air filters and alternatives to galvanized steel frames—stainless steel and plastic. Concern was the production of rust that blows into the engine.
- How to avoid water in lube oil. Shut down the Sprint system (if installed) 10 to 15 min prior to engine shutdown and/or install coalescing filters that are more effective than the ones supplied with the engine.
- Generator lube-oil issues.
- Fuel-system problems during startup. OEM recommended that gas valves are covered during a water wash.
- Flow testing of Sprint nozzles.
- CO_2 system permissives changed to prevent a unit start when the fire protection valve is closed.

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LMS100

Chairman and discussion leader for the LMS100 breakout sessions was Don Haines, facility manager, Panoche Energy Center, Firebaugh, Calif; session secretaries, Sal and Tripp DellaVilla of Strategic Power Systems.

Breakout session chairs invest a great deal of time throughout the year ensuring that Western Turbine members openly share O&M issues to benefit their respective user communities. Example: Haines prepared a detailed handout for all LMS100 attendees that both identified historical problems and described new findings and issues since the previous meeting. This refresher for seasoned participants and backgrounder for first-timers put everyone in the room on the same page at the start of the meeting.

NERC GADS Required Reporting. SPS is here to help.

Strategic Power Systems, Inc. (SPS) has been collaborating with NERC throughout our 25 year history. Mandatory reporting will be required on January 1, 2012 for all thermal units 50 megawatts and above. SPS provides a web-based data entry tool that allows users to enter data once and fulfill requirements for both NERC GADS and SPS ORAP systems.

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Following Haines' opening remarks, Sal DellaVilla presented on the value of user participation in the ORAP® system, which tracks and reports on the availability and reliability performance of the various LM fleets, consistent with WTUI's mission of "advancing the operability and reliability of the GE line of aeroderivative gas turbines." DellaVilla's presentation is available at www.wtui.com; more detail on the Operational Reliability Analysis Program is available at www.spsinc.com.

Currently, ORAP collects monthly operational, event, and counter data for 18 of the 26 LMS100s in the fleet. DellaVilla reported that only one unit is operating base-load, with the fleet average service factor at 18.4%. The majority of the time, the fleet is in a state of ready reserve. Simple-cycle availability and reliability from 2007 through 2011 was 88.4% and 94.1%, respectively. The OEM expects the fleet to grow to 50 engines by mid-2013, the group was told.

As of March 1, the fleet had accumulated 17,500 starts and nearly 110,000 fired hours with the high-time engine just north of 22,000 hours. There were 26 operating units at the time with six more being installed/commissioned (two in Australia, one in Venezuela, and two in California) and five others in transit to plant sites.

Two user presentations followed DellaVilla. Don Stahl, a WTUI board member and plant manager for Black Hills Corp's Pueblo Airport Generating Station, discussed the design, commissioning, and early operating experience for his new plant. It features two 2 × 1 LM6000-powered combined cycles and two LMS100 peakers. For more, retrieve the 1Q/2012 CCJ and turn to p 86 or access www.ccj-online.com and "Google" the plant name.

Stahl was followed at the podium by Haines, who conducted a review of the historical issues at Panoche and encouraged the vibrant discussion session that ensued. Here's a sampling of the issues Haines mentioned and how to deal with each one:

- Eighth-stage anti-icing hose failure. Inspect annually prior to the winter run for cracks, etc. Put the unit on crank, use hands on outside to check for leaks. Remove the clamp on the HPC and conduct a visual inspection.
- VSV loss of hydraulic pressure. A unit trip occurred at about 15 MW while loading. VSV hydraulic supply pressure was decreasing; would not follow demand as HPC pressure increased. Issue was found to be the hydraulic pressure regulator, consisting of two regulating valves and one PRV. The regulator was replaced.
- HPC failure and possible FOD. Inspect unit prior to acceptance for debris, dirt, particles, etc, that can impinge on HPC surfaces.
- Hydraulic pump suction spool installation. Don't over-torque: Rubber spool will deteriorate and disintegrate, going downstream to the HP filter. There should be a visible gap in the flange; a tightly compressed flange is evidence of a problem.
- Over-torqued compression fittings are conducive to miniature fractures which will result in leaks.
- Detronics firmware upgraded to prevent spurious trips.

An OEM presentation reviewed 18 active development programs implemented to address fleet issues and the progress to date. Here's a sample of procedures/processes developed to mitigate three of those issues:

- IPT frame strut tubes. Fractures associated with the IPT frame are being addressed by implementing inspection processes to check for stress cracking.
- Online water-wash procedure, if not performed properly, can result in water accumulation in the rotor system and lead to heavy rubbing. Users were reminded of procedures.
- Second-stage tube fractures caused by stress on joint-IPT frame. SB 104 has developed to address this issue. Other programs being conducted

by the OEM and of interest to owner/operators, include the following:

- Mid-span shroud pad wear on HPC first-stage blades. Recall that this blade row has an interlocking mid-span shroud with adjacent blades sharing a carboloy wear pad. The design is the same as that for the LM6000 blade—same PN in fact—but the wear pattern is different, with the LMS100 pad wearing at an accelerated rate. The OEM is working at figuring out what would drive different wear results.
- Cracking of single annular combustors has been identified at various locations—primarily at the inner overhang. By the time of the meeting, nine combustors had been replaced in the field but there had been no downstream damage (HPT). Investigation is ongoing; the inspection interval has been reduced to monitor the condition going forward. One thought is that water-induced erosion hurts the coating and causes the cracks in and around the dilution holes. An alternative coating has been proposed.
- Plugging issues with intercoolers has been traced to rusting of the carbon steel supply waterbox. Depending on water quality, exposure time, and other variables, the waterbox may rust and cause the blockage of some tubes. Inspect the waterbox periodically and paint if necessary; check tubes for fouling and clean if required.

Special technical presentations

The six special technical presentations conducted Tuesday afternoon in two time slots meant Western Turbine attendees could attend a maximum of two. That was unfortunate because each of the presentations got two thumbs up from the editors.

One, presented by Rob McMahon of Alliance Pipeline, which detailed his company's experience with hydrophobic HEPA inlet air filters, was summarized in an earlier issue (CCJ 1Q/2012); access at www.ccj-online.com using the search function at the top of the page. It is of value to owner/operators of all makes and models of gas turbines.

Two of the six presentations—"User-Generated Package Improvements," conducted by WTUI Directors Brad Hans and Ed Jackson, and "Peaker versus Base Load Operations and Maintenance," by Dale Reed, president, Reed Services Inc—have greatest value to the LM community and are summarized here.

"Tools for Optimizing Gas Turbine SCR Performance," by Larry Muzio and Tom Martz of Fossil Energy Research Corp, is of interest to all power producers controlling NO_x emissions by way of selective catalytic reduction (SCR). A feature article based on their work in the field was published in **CCJ** 2Q/2012 (2012 Outage Handbook). You can access that article at www.ccj-online.com as well.

"Greenhouse Gas (GHG) Impacts of California AB32 and Federal Regs," presented by Jackie Ferlita, director, Element Markets, Huntington Beach, Calif, obviously was of greatest interest to California power producers, but it likely sent a shiver up the spines of attendees from out-of-state electric generators.

Before the Enron fiasco, other states blindly followed California's lead on energy policy and legislation, and while that probably is no longer true, it is worthwhile having an understanding of the carbon market in the nation's most populous state as it prepares to implement an economy-wide cap-and-trade program in 2013.

California's GHG cap-and-trade program is a central element of the state' s Global Warming Solutions Act (AB32) and covers major sources of GHG emissions in the state—such as refineries, powerplants, and industrial facilities. The regulation includes an enforceable GHG cap that will decline over time.

Goal is to reduce GHG emissions to 1990 levels by 2020 and ultimately achieve an 80% reduction from 1990 levels by 2050. An overall limit on GHG emissions from capped sectors will be established by the cap-and-trade program, and facilities subject to the cap will be able to trade permits (allowances) to emit GHGs.

White papers and implementation guidelines for the program, which is said to have started Jan 1, 2012, had not been released by the California Air Resources Board (ARB) at the time of the Western Turbine meeting. An enforceable compliance obligation begins with 2013 GHG emissions. Ferlita said that the cap will begin at around 2% below 2012 emissions and will decline by 2%-3% annually until 2020.

Power generating facilities governed by the program are those emitting more than 25,000 metric tons/yr (an obligated entity). Merchant power producers must offset actual emissions 1:1 by obtaining allowances at quarterly auctions or arranging for carbon offsets from the Climate Action Reserve (urban forestry initiatives, for example).

The editors asked representatives from a couple of California power producers in the audience what the 25,000 t/yr meant to owners of gas-fired LM engines in terms of operating hours. Back of the envelope calculations, assuming between 2% and 3% of CO_2 per lb of exhaust gas during normal operation, translates to between 1667 and 2500 hours for an LM6000 and between 2500 and 3750 hours for an LM2500.

Ferlita said that the majority of allowances will be given freely to utilities and industrial companies in the early years of the program, with a higher percentage of allowances being auctioned over time. Beginning in 2015, the regulations will include all importers of electricity, liquid fuel suppliers, and suppliers of natural gas with GHG emissions greater than 25,000 t/yr. To learn more about the California program, a good place to start is the ARB website at www.arb.ca.gov.

"NERC Audit Interpretation Management," by Chris Siplin of Wood Group GTS Power Plant Services, was a presentation with follow-on discussion of value to all power producers subject to NERC audits. Siplin's prepared remarks were relatively short; his goal was to share with less-experienced colleagues in an open forum, pitfalls to avoid in the audit process.

He began his prepared remarks with the formal audit notification process and how plants are supposed to respond, which includes the preparation of documentation that must be submitted to the audit team. Typically, three or four auditors—including the team leader—will be involved, Siplin said.

Documentation of everything is critical, he told the group; answer all questions with the required detail. Stick to a standard's literal translation, he suggested, and be able to explain your interpretation using the language of NERC as presented in the organization's Glossary of Terms.

Siplin stressed becoming familiar with the Compliance Application Notice (CAN) process, which is vital to responding to any disagreements you may have with the audit team's findings. You will find it detailed under "Compliance Application Notices Processes and Tools" at www.nerc.com and includes five appendices:

- To submit potential issues.
- To prioritize issues.
- To submit comments.
- To submit suggestions to standards.
- To request a high-level review.

One of Siplin's recommendations to anyone responding to a question from the audit team by phone is to follow that up with an email clarifying your response. This will help prevent misinterpretation. Paper trails are critical to success.

Remarks by owner/operators during the open discussion session made it clear that the audits were anything but predictable. While audit teams follow a common set of guidelines their interpretations may be different, so responses that might have been accepted at your last plant might not be accepted at your current one. Also, there are regional differences in rules and interpretations much like there are for the federal court system.

An attendee with familiarity of Texas audits said they are extremely tough—perhaps the most difficult in the country. One audit that he was familiar with generated 120 follow-up items and questions—each requiring the plant to defend itself against a possible violation.

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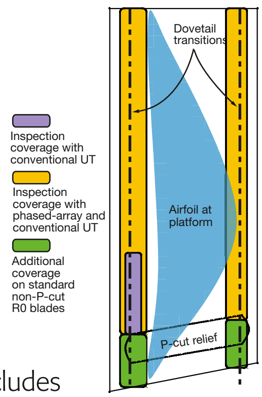

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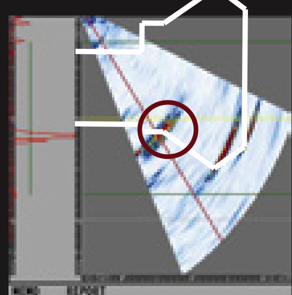
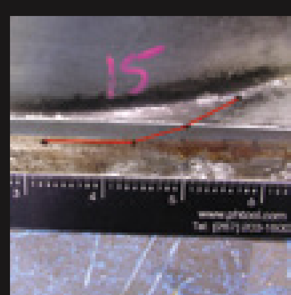

Dovetail Crack Phased Array UT Image



Dovetail Crack Mark-up

1, 2. Platforms were installed to facilitate safe access to chiller-coil drains (left) and air inlet house (right)

User-generated package improvements

The one-hour session on package improvements made by users, chaired by WTUI Directors Brad Hans and Ed Jackson, two seasoned aero users, could have gone on for hours more. This, the best-attended of the three concurrent sessions conducted from 3:30 to 4:30 pm, was designed as an open discussion forum to share ideas among owner/operators.

The co-chairs put up a list of about a dozen and a half topics, introduced each with a slide, said a few words about their experience with a given improvement and encouraged audience participation. It didn't take much encouragement: Discussion was virtually continuous for the hour allocated. When interest in a given topic began to wane, the discussion leaders moved quickly to the next subject.

Below are some of the discussion topics compiled by Hans and Jackson that enabled many users to return home with affordable and proven solutions for improving equipment operability and maintainability, efficiency, safety, etc. This session alone made the trip worthwhile for many attendees and the benefits gained offset the cost of attendance for most of those users.

Maintenance platforms may not be provided with the package to assure easy access to generator and turbine enclosure fans, chiller-coil drains, etc. In some cases where they are provided, the access path is not customized to the site and personnel hazards are created inadvertently.

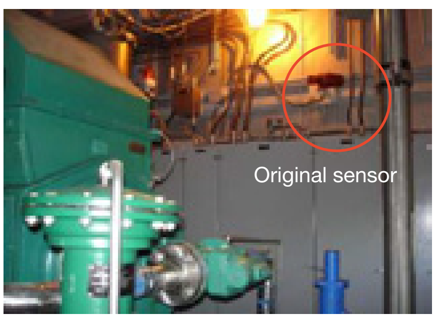
After the constructor leaves the site, it's up to the plant to make necessary safety improvements. One solution offered was platforms mounted to the package roof with safe access (Figs 1, 2). They were engineered and installed by a local company, which prefabricated sections to expedite installation. In Fig 3, a trip/fall hazard is avoided by modifying the marginal ground-level access to an important cabinet.

3. A trip/fall hazard (left) was avoided by modifying ground-level access (right) to a critical cabinet

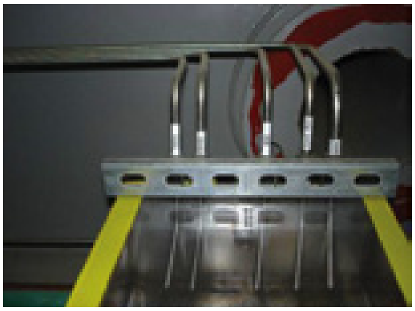
4. Generator-fan lifting device eliminates unsafe working environment

Generator-fan lifting device. For a situation where fan maintenance created an unsafe working environment, plant personnel came up with the idea of a lifting device that mounts in the generator-compartment air intake to remove the belt-driven fan. Engineered and installed by a local company, it consists of three pieces that bolt together, two of which are made of aluminum for ease of handling (Fig 4).

Redundant fire sensors. The



5. Redundant fire sensors help in reducing nuisance trips at little cost



6. Oil drains box helps identify leaking seals quickly and easily

7. Chiller-coils are easy to drain before ambient temperature plummet using flexible hoses

8. Exhaust hood prevents cold air from blowing directly into the generator compartment

9. Damper actuator (left) was replaced by manual operator (right) to improve cold-weather reliability

10. Bird screens prevent roosting pigeons from clogging condensate drains

11. Insulating package base structural members minimizes heat loss and reduces the potential for freeze-up issues

generator compartment, as installed, had one sensor for fire detection. Its failure or spurious activation, possibly caused by electronic noise, could lead to an unnecessary dump of the CO_2 system and a unit shutdown. Plant personnel decided to add a sensor with the goal of reducing nuisance trips (Fig 5). It did that, at minimal cost. Additional coverage of the compartment for early detection was another benefit.

Oil-drains box. Tell-tale drains as originally configured made isolating a problem time-consuming. The drains box shown in Fig 6, designed and installed by Reed Services Inc, makes troubleshooting and identification of leaking seals quick and easy.

Cycles tracking is very important today. Get the details in the Western Turbine article that appeared in **CCJ** 1Q/2012. Go to www.ccj-online.com and type "cycles tracking" into the search function at the top of the page.

"Hands off auto" switches supplied with the unit were failing to make contact when going from "off" back to "auto." Problem can be misinterpreted as a flow switch failure. Replacing with a premium product eliminated vent-fan fail alarms and increased fan reliability.

Chiller coil drains for winter lay-up may have limited accessibility, depending on the manufacturer. One user avoids removal of the drain pan to gain access by connecting flexible hoses to the intermediate-header drains and routing them to an accessible location (Fig 7). The benefits: coil freeze prevention and personnel safety.

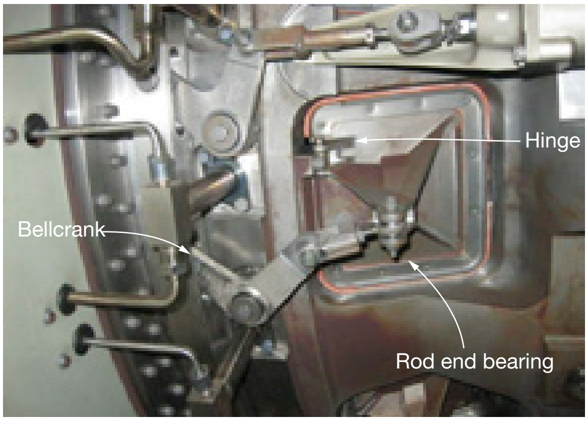
Generator-fan exhaust hood. Package orientation was such that the exhaust hood for the generator fan faced north. Cold air would cause loss-of-start permissive because stators would get too cold. The OEM solution was mechanical louvers; the user solution was a fabricated cover over the exhaust hood that prevented cold air from blowing directly into the compartment (Fig 8). The less-expensive alternative stabilized stator temperatures and avoided the maintenance requirements associated with mechanical louvers.

Damper actuators were continually sticking or failing, resulting in loss of anti-icing capability in cold weather. The practical user removed the actuator and replaced it with a manual operator (Fig 9). Result: Increased winter reliability.

Inlet volute drain. A build-up of water in the inlet volute during crank washes was problematic for one user. If the drain check valve failed, a slug of water could enter the engine. Solution was to install a manual drain valve for the volute upstream of the check valve. A union was installed to facilitate maintenance.

Bird screens. Pigeons roosting in drain collection trays and inlet houses would clog condensate drains and overflow the inlet. Pigeons also would get into Higgot Kane penetrations and tear up the inlet filters. Simple solution: bird screens (Fig 10).

Package base insulation. Interestingly, package sidewalls and roof are insulated but not the base. Despite the package heaters, the bottom of the enclosure remains cold when ambient temperatures are low. Another simple solution: Insulate the base structural members to minimize heat loss and reduce winter freeze-up issues (Fig 11).



12. VBV door and activation components must be monitored carefully for wear

Peaker vs base-load O&M

Aero maintenance expert Dale Reed is a frequent presenter at industry technical meetings, WTUI in particular. During his time at the podium between 4:30 and 5:30 Tuesday afternoon, Reed focused on several known areas of LM engine wear and how maintenance requirements differed dramatically between engines operating base load and those in peaking service. Among the wear areas Reed addressed were the following:

- External GT components
  - VBV door and actuation components.
  - VSV bushings.
  - Starter clutch and seal wear.
- Internal GT components
  - HPT nozzles (vanes).
- Package components
  - AC lube-oil pump.

Referring to Fig 12, Reed discussed VBV hinge wear first. He noted three stages of distress:

- Stage 1. Nylon bushings develop cracks.
- Stage 2. Sections of bushings liberate and increase the clearance between the steel bushing and hinge.
- Stage 3. Contact between the hinge and door is in evidence. This continues with more wear on the steel bushing, hinge, and door.

Such deterioration can be found in less than 800 hr on peakers, Reed said, but might not be seen on base-load units in the first 8000 hr of service.

In the experience of Reed Services Inc (RSI), a bent and broken rod end bearing always is found in conjunction with worn hinge bushings and bellcrank bearings. On peakers, expect to see this at the 10,000-hr mark; base-load units should run about 35,000 hr before this occurs.

Bellcrank wear typically is found on the door at the clevis end of the device. The OEM limit on axial and radial movement is zero (0.000 in.). A Stage 1 condition means wear between zero and 0.004 in. or less and that you should consider maintenance; Stage 2 (up to 9 mils of wear), schedule maintenance; a Stage 3 condition (above 10 mils of wear) warrants a shut down. You can expect the onset of these conditions in less than 10,000 hr on a peaking machine; upwards of 35,000 hr when operating base-load.

The OEM recommends replacement of VSV bushings in 12,500 hours. Reed said both peaking and base-load units should make the recommended replacement interval. However, wear can be expected in less than 4000 hours for peakers, while base-load machines should run about 8000 hours before distress is evident.

Inspect the starter clutch for internal wear every 18,000 hours on peaking engines, every 40,000 hours on base-load GTs. Clean carbon steel every 35,000 hours (2300 starts) on peakers; every 40,000 on base-load units.

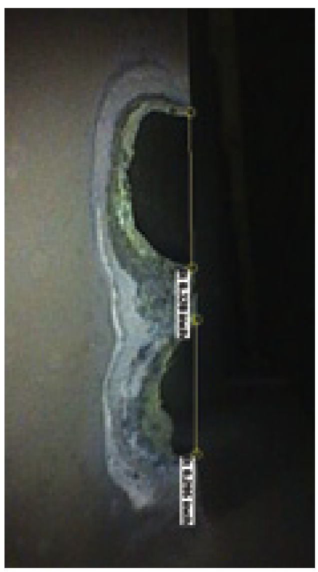
HPT wear is cycles-based—the more cycles, the more wear and tear. Whether the GT is in peaking or base-load service doesn't seem to matter. Reed also said there does not seem to be a correlation between new or overhauled parts in terms of wear.

The aero expert then flashed a series of slides on the screen to illustrate the types of erosion and other damage you can expect over time on S2 nozzles. One of those was Fig 12, which shows distress on the outer platform trailing edge. It started as a crack in the parent metal (right). Erosion then moved forward and exposed the shroud leading edge at the left.

The preliminary stages of heat distress, Reed continued, are evidenced by leopard spots on the convex side of the vanes; coating distress and erosion on the concave side. As shown in Fig 14, vane trailing-edge erosion starts as coating oxidation, then the parent metal is eroded. The condition is easiest to recognize on the convex side of the airfoil.

Regarding the ac lube-oil pump, Reed stressed the need to follow both the manufacturer's installation instructions and good pipe-fitting practices to assure reliable operation and expected life. He did indicate that engine 10-min starts take their toll on these pumps. One example is the reduction in the life of Magnaloy couplings. CCJ

13. Erosion of the S2 nozzle's outer platform trailing edge starts as a crack in the parent metal (right) and moves forward exposing the shroud's leading edge



14. Vane trailing-edge erosion starts as coating oxidation and then erodes parent metal

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The venerable Frame 5

Contents

If the energy industry has an iconic gas turbine (GT), the consensus view probably would be GE Power & Water's durable Frame 5. It certainly has stood the test of time: The first unit in this model series shipped from the OEM's Schenectady factory 55 years ago and Frame 5s are still being built today—albeit by manufacturing associates abroad and at ratings about two and a half times those of the early engines (Tables 1 and 2).

In between, well over 3000 of these machines were assembled and shipped in both single- and two-shaft versions for electric-generation (50 and 60 Hz) and mechanical-drive applications (Figs 1, 2; Sidebar 1). Units in generation service are found in simple-cycle, cogeneration, and combined-cycle facilities (Fig 3). They are installed both onshore and offshore (oil rigs, barges) and may be equipped for single- or dual-fuel firing.

A generation of GE gas-turbine designers and field engineers cut their proverbial teeth on the Frame 5. One of them, Dave Lucier, went on to instruct field service personnel and later manage GE's field engineering program. Just prior to the millennium, he founded PAL Turbine Services LLC to solve problems owner/operators were having with legacy engines and controls, conduct inspections, and manage outages. Lucier has a deep appreciation for things mechanical and electrical, and believes a well-engineered product properly cared for should, in most cases, last as long as the owner has an application.

The Frame 5 is one of his favorite engines, Lucier admitted in a sit-down with the CCJ editors. It's reliable and relatively easy to operate, maintain, and overhaul, he said. The historian in Lucier took over at this point: "You know, of course, that it was a black-start Frame 5 in Southampton, NY, that initiated the restoration of power on Long Island, and eventually New York City, following The Great Northeast Blackout, Nov 9, 1965. The future is nothing without the past," he reminded.

The blackout made utility executives, particularly those east of the Mississippi, realize their systems were at risk without peaking units and black-start engines. Gas-turbine OEMs were inundated with orders. Frame 5 sales remained brisk until the oil embargo of 1973 took its toll on purchases. Note that a large percentage of the early "Fives" were designed to burn oil only; virtually all of the other units in electric-generation service were equipped to fire oil and/or gas.

Reminiscing, Lucier spoke of the frenetic pace of GT activity in the late 1960s and early 1970s, which included his assignment to an installation and startup team for three four-unit power blocs—12 Frame 5s designed to burn oil or gas—at one Midwest utility. He also recalled being trained to provide

Table 1: Frame 5 data have changed significantly over the years

Model rate, MS5001_	Years shipped	Output, MW[1]	Firing temp, F	Exhaust temp, F	Heat Btu/kWh[2]
A	57-61	12	1500	840	15,810
C	61-64	12	1500	835	15,810
D	61-63	12	1500	834	15,810
E	63	12.9	1500	830	15,780
G	63-64	13.4	1500	830	15,120
H, J	64	14	1500	820	14,430
K	65	14	1500	820	14,430
L	66-67	15.7	1600	895	14,440
LA	68-70	17.1	1650	930	14,190
M	69-70	18	1700	965	14,050
R	70-87	19.4	1720	955	13,260
R-N/T[3]	87-??	20.5	1755	970	12,780
N	70-72	24.6	1730	898	12,190
P	72-78	24.6	1730	904	12,140
P	78-86	23.4	1730	901	12,020
P-N/T[4]	87-??	26.8	1765	905	11,860

[1]All ratings based on natural gas fuel [2]Based on fuel's lower heating value [3, 4]In 1987, the HGP of both the P and R turbines was updated and the models renamed PA and RA, respectively. Those models are called P-N/T and R-N/T when they are the result of an aftermarket uprate (N/T means new technology) Source: GER-4196

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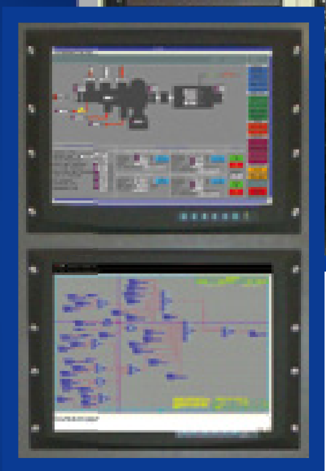

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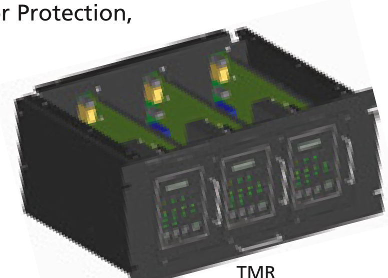

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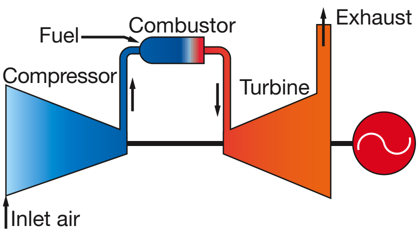
Table 2: Physical characteristics of Frame 5 components

Model MS5001_	Compressor, No. of stages	Turbine, R1 wheel type	Turbine, R2 wheel type/diam	HGP technology	R2 buckets, type	Turbine speed, rpm
A-K	16	Old	Old/large	Pre-old tech	Tie-wire	4860+
L, LA, M	16	New	New/large	Old tech	Tie-wire	5100
M prime	16	New	New/large	Old tech	Tip shroud	5100
M, N/T	16	New	New/large	New tech	Tip shroud	5100
R	16	New	New/small	Old tech	Tip shroud	5100
RA (N/T)	16	New	New/small	New tech	Tip shroud	5100
N, P	17	New	New/small	Old tech	Tip shroud	5100
PA (N/T)	17	New	New/small	New tech	Tip shroud	5100

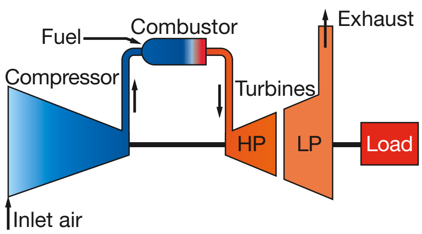
Source: GER-4196

Table 3: Frame 5 control system history

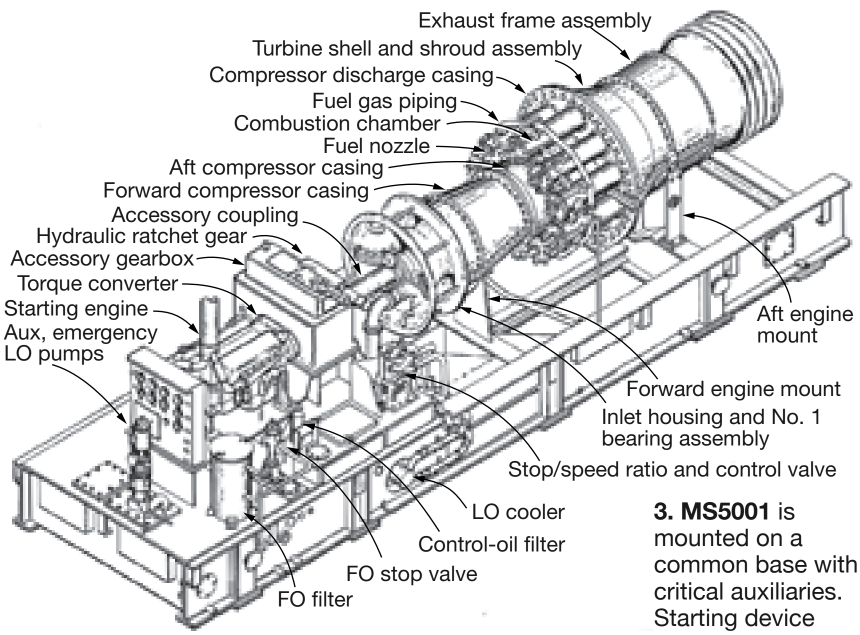
System	Years
Fuel regulator	Before 1970
Mark I	1968-1975
Mark II	1974-1980
Mark III	1978-1985
Mark IV	1983-1993
Mark V	1992-2003
Mark VI	1999-2008
Mark VIe	2004-20??



1. Single-shaft MS5001 gas turbine for electric production has the same arrangement as many other frame engines



2. Twin-shaft MS 5002 sees widespread service as a compressor drive, but also may work as a pump driver or turn a generator



3. MS5001 is mounted on a common base with critical auxiliaries. Starting device can be an engine (shown) or motor

4. First Frame 5 used in a combined cycle is still operating at Wolverine Power Supply Cooperative Inc, Cadillac, Mich. The product name for the 1 × 1 single-shaft configuration is STAG 105

support for engines that relied on Young & Franklin's fuel regulator, as well as those with the first electronic system—GE's Speedtronic™ Mark I—which superseded Y&F's product on the MS5001N (Table 3). "There are still many units operating today with these early control systems," he said.

A Frame 5 was incorporated into a combined cycle before the 1970s, Lucier mentioned while looking through a pile of reference material on his desk. And it's still operating at Wolverine Power Supply Cooperative Inc, Cadillac, Mich (Fig 4). The 21-MW STAG 105 (1 × 1, single shaft) is one of two such combined cycles in the US with more than 40 years of service. The other is owned and operated by Clarksdale (Miss) Public Utilities Commission.

Frame 5s continue to serve their owners well—even engines dating back to the early 1960s. And in view of the high value placed on GTs that can "fill in" for intermittent renewables and provide other ancillary services, the operating lives of many engines are being extended. With a nominal 8- to 10-min start, Frame 5s satisfy the fast-start requirement grid organizations demand, with time to spare in some cases. Although rated capacities and efficiencies of the early units, in particular, are relatively low by today's standards, a paid-for asset capable of operating on low-cost gas and/or No. 2 (distillate) fuel oil for a few hours when required has a place in the generation mix.

As the value of Frame 5s increases in many locations, investments to assure high availability and starting reliability—and possibly to reduce emissions—may be prudent. Controls upgrades usually get top priority based on an informal industry survey. Investments in efficiency improvements take longest to recoup, in most cases.

Experts suggest a thorough inspection of any engine being considered for upgrade before signing a contract. In some cases, the wear and tear of three decades or more of service, or simply standby duty in an engine-aggressive ambient environment, may point to the

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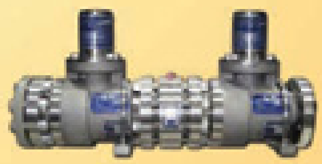

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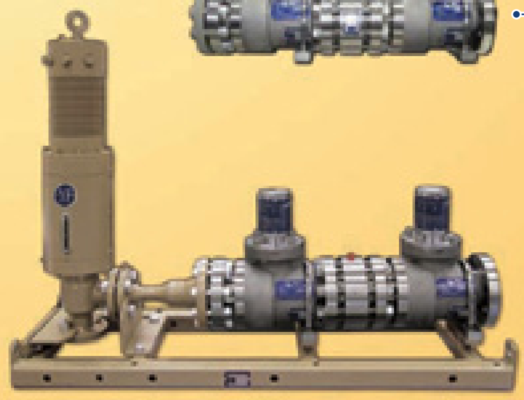

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1. Two-shaft Frame 5s drive compressors, pumps, generators

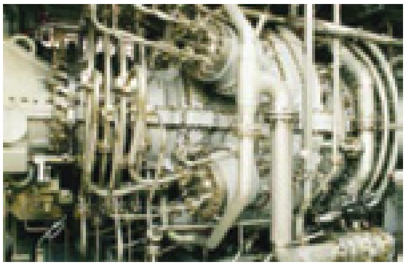
Most **CCJ** subscribers earn their living generating electricity and are very familiar with the MS5001—the single-shaft version of the Frame 5, which accounts for about 85% of the "Fives" built. The two-shaft engine, introduced in the 1970s, was designed specifically for mechanical-drive applications—typically to turn large pipeline compressors and pumps. Occasionally it is selected for electric generation service.

You can find five models of the MS5002 operating worldwide today: A, B, C, D, and E. All can be equipped to burn a wide variety of gaseous and liquid fuels. The simple and robust designs of these engines are conducive to maintenance onsite without specialized tooling or service-shop assistance. The first two-shaft models, the MS5002A (19.6 MW/26,250 hp) and B (26.1 MW/35,000 hp) were developed simultaneously and based on the MS5001M and N compressor designs.

In 1987, the MS5002B was upgraded using advanced materials and design features to resist high-temperature damage and wear and released to the market as the MS5002C (28.3 MW/38,000 hp). The A's 15-stage compressor developed a pressure ratio of 7.4:1; firing temperature 1690F, heat rate 9780 Btu/hp-h. Compressors for the Bs and Cs each are 16-stage with a pressure ratio of 8.8:1; firing temperatures are 1700F and 1770F/heat rates 8830 and 8700, respectively.

The D involved a more comprehensive upgrade than the C to develop its 32 MW/43,000 hp. The machine's most significant feature is the replacement of the 16-stage B/C compressor with a 17-stage version (10.75:1 pressure ratio) derived from the MS6001B design, which many readers are familiar with because of the **CCJ's** coverage of the Frame 6 Users Group.

Extracting more power from the D also required use of a new first-stage nozzle design having a smaller throat area to fully exploit the high pressure ratio of the new compressor, while limiting firing temperature to 1807F to assure high reliability of hot-section parts. Advanced seals for the HP packing, No. 2 bearing, and second-stage shrouds blocks contribute to the performance improvement.

HP rotor assembly for the MS5002E is in the left-hand photo, the engine proper is at the right

The OEM offers a menu of upgrade options to improve the performance of the early machines—converting an A or B to a C, for example. A DLN retrofit may be required in cases where the basic engine upgrade requires the combustion of more fuel. If a DLN is in your future, the Mark II control system typically included with the As and Bs would have to be replaced with a Mark VI or VIe—or equivalent.

The A-D two-shaft Frame 5s each have single-stage turbine drivers on their respective HP and LP shafts. The first powers the compressor, the second the driven equipment.

Design of the MS5002E, rated 32 MW with a simple-cycle efficiency of 36% in mechanical-drive service/35% in power-generation service, is dramatically different than the earlier "Fives." Key features of this engine are listed below.

- Compressor: Scaled up directly from the GE10 gas turbine with more than 100 units installed worldwide; 11 stages; 17:1 pressure ratio; IGVs and first- and second-stage stator blades are hydraulically actuated variable vanes; fourth-stage bleed for LP turbine wheel cooling; seventh-stage bleed for cooling and for surge control during startup/shutdown; compressor rotor has a forward stub shaft, six discs, five spacers, and aft stub shaft restrained in compression by 26 tie bolts.
- Compressor casing: Horizontally split; air-inlet casing supports No. 1 bearing, a combined tilting-pad journal and thrust bearing; inlet case is cast iron, intermediate case nodular cast iron, compressor discharge case (CDC) cast steel.
- Combustion system: DLN2-class system installed on hundreds of gas turbines worldwide; six cans mounted on the CDC, each with five fuel nozzles; combustor operates in premixed mode above about 50% of the engine's rated output and is capable of 25 ppm NO_x on gas.
- HP turbine: Two-stage reaction-type machine copied from the proven MS5002D; both stages of HPT buckets and nozzles are cooled by compressor discharge air.
- LP turbine: Same design as that used on the LM2500+ aero with flow-path profile and airfoils redesigned to accommodate the higher air flow required by the MS5002E.
- Controls: Speedtronic Mark VI.
- Maintainability: Horizontally split casings and removable enclosure roof; power turbine mounted on a special frame that permits axial movement on the base plate; combustors can be disassembled without removing the CDC; bearing Nos. 1, 3, and 4 are easily accessed for inspection; internal crane provided for lifting of main auxiliaries; instrumentation racks are outside the enclosure to facilitate inspection and repair.

The first commercial MS5002E began operating at a fertilizer plant owned by Yara Sluiskil BV in Sluiskil, The Netherlands, Nov 5, 2007. Tests at full load in the premix mode conducted at the end of 2007 and beginning of 2008 confirmed that the unit surpassed the contractually guaranteed electrical by about 1 MW, with 3% less fuel consumption than specified. DLN emissions were 12 ppm during the tests. The Yara engine operates on two fuels with different compositions and demonstrated its ability to adapt to any changes or blends in gas composition with no interruption in production.

scrap heap because of the high cost of repairs or upgrades.

You are unlikely to learn enough about a given machine's condition to support an upgrade investment without removing the upper casing and lifting the rotor for a close-up inspection by one or more qualified experts. This can be done cost-effectively onsite by many third-party firms with access to the skills of retired GE field engineers. Due diligence is highly encouraged.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5. Ascutney gas turbine shortly after installation in 1961. Control cab is at the far left in the left-hand photo and adjacent to the auxiliaries compartment; the air inlet house is at the right and perpendicular to the enclosure. The engine compartment is visible on the other side of the air inlet; the generator and exciter are to the right of the stack

If the service life of your machine is approaching 200,000 factored operating hours or 5000 factored starts, a complete teardown of the turbine section is recommended by the OEM for safety reasons. If that inspection indicates the rotor and its component parts meet GE's standards for continued service they can be certified for another 50,000 hours or more of operation and returned to service.

Third-party services firms also are competing for your business in these so-called end-of-life (EOL) evaluations. Research will point to some firms at least as qualified as the OEM in terms of personnel, tooling, expertise in nondestructive examination (NDE), etc. The advantages of qualified third-parties normally are very competitive pricing and fast turnarounds. As Lucier preaches: Knowledge + Experience = Savvy.

But they are not your only considerations. If you're leaning toward a third party for an EOL exam, be sure to consult with your insurance carrier. A non-OEM probably would not assume the risks associated with "certifying" your rotor for "x" more hours and "y" more starts—if that's what you're looking for. However, they can offer a clean bill of health (if that's the case) and suggest that the rotor should continue to operate reliably for a given period based on inspection findings and industry experience.

There's also a "what if" to factor into your evaluation. What if your third-party services team identifies a defective rotor component—a wheel for example—what do you do? If you want to buy a new wheel, or more probably a refurbished one, where will you get it? Don't expect the OEM to be compassionate. The bottom line: If you opt for a third-party EOL inspection, be sure the company you select has access to qualified rotor parts at pre-negotiated prices.

Feeling comfortable now that your engine has a clean bill of health and *your* economic analysis indicates a certain upgrade makes perfect sense? If so, it could be your naivete showing. Have you considered what EPA might think about your plans? How much do you know about the federal agency's alphabet soup of regulations—including National Ambient Air Quality Standards (NAAQS), New Source Review (NSR), New Source Performance Standards (NSPS), Prevention of Significant Deterioration (PSD), Best Available Control Technology (BACT), Reasonably Available Control Technology (RACT), Reasonably Available Control Measures (RACM), Lowest Achievable Emission Rate (LAER), etc?

This is where the realistic plant manager punts to the company's environmental team. Let it carry the ball from here. Implement your engine improvement plan, or a modified one, only after receiving corporate approval. Environmental regulations are extremely complicated, and ambiguous by design some people believe, to give government the upper hand in legal challenges to any of EPA's decisions. Plus, rules are constantly being changed by court cases: What was acceptable yesterday, might not be tomorrow.

Generally speaking, if your calculations show planned work (not just upgrades) will not increase emissions you should be fine. But be prepared that EPA might not agree with your calculational procedure, for whatever reason. The agency also may find that the new control system you want to install could enable the engine to operate in a manner that would increase emissions—even though you would not operate that way—and deny a permit.

Just when you're getting used to having the environmental cards stacked against you, there's yet another joker in the deck: An NSR trigger means greenhouse gases (GHG) must also be considered in the environmental impact analysis. Talk about a moving target, what's today's BACT for GHG? Tomorrow's?

Frame 5 major surprise

Lucier, off the line after helping walk someone through a knotty combustor problem, returned to his history lesson for the editors, all 20 chapters of which can be read at www.pondlucier.com by clicking on the "Black Start" logo (left side of the "company info" page). An important part of GT history not included in his musings is the transformation in the dissemination of information enabled by the web and the positive impact it has had on owner/operators.

Lucier conducted his entire call via webcam, having the ability to see exactly what problem the mechanic had to deal with and to provide a solution—on the spot. Only a few years ago, this half hour of technology transfer likely would have involved hours of travel time. For a man already at the biblical three score and ten, minimizing the number of nights on the road is particularly important. Much more therapeutic is an evening drive in his Triumph TR6 in the Adirondacks, near Lucier's Lake Placid (NY) home.

GE installed the first of its so-called packaged powerplants for South Carolina Electric & Gas Co in 1961, according to Lucier's history book. The MS5001D was used primarily for peaking and emergency service. "The "packaged" concept was unique at the time," the historian said, "with most of the primary and auxiliary components located on the same 36-in. I-beam base, together with the engine, during factory assembly."

The "package" concept facilitated factory testing, shipment to the plant site via rail car or truck, and field installation. GTs for these plants were built in Schenectady and tested there at full speed/no load (FSNL) on liquid fuel. The speed reduction gear and generator were built in the company's Lynn (Mass) works. Mechanical coupling and alignment of the principal components were done in the field. Control cabs, built in Salem, Va, also were connected onsite.

Sister units to the South Carolina engine were installed by Central Vermont Public Service Corp (CVPS) in Ascutney in 1961 (Fig 5) and in Rutland in 1963. Interestingly, these GTs are only a couple of hours by car from the offices of PAL Turbine Services and Lucier's team has worked at both locations over the years.

Serendipity. A month after sitting down with Lucier, personnel from Genex Turbine Technologies, Manchester, Conn, told the editors at a meeting of the Combustion Turbine Operations Technical Forum that CVPS had hired Genex to overhaul

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2. Backgrounder on CVPS Frame 5s

Hydro aside, half a century is a long time for any generation asset to operate productively. Central Vermont Public Service Co's Rutland and repowered Ascutney MS5001D peakers hit the Big Five-O next year for a couple of reasons: (1) They are meeting grid expectations for the capacity and black-start services provided under contract, (2) The utility has invested, as necessary, for repairs and upgrades to keep the engines competitive. Here's a snapshot of a few entries from the log books for these units:

- Control systems for Ascutney and Rutland were replaced by Innovative Control Systems Inc in 2005 and 2006, respectively, to assure continued high reliability. The company had provided hundreds of PLC-based controls solutions before it was purchased by Emerson Process Management's Power & Water Solutions unit a couple of years ago.
- Ascutney's exhaust silencers and stack were replaced several years ago with upgraded stainless-steel components.
- Both Ascutney and Rutland operate on low-sulfur distillate oil today. Rutland burned Bunker C for several years after commercial start. The auxiliary skids for both machines have been upgraded over the years. Flow dividers are of the free-flow type—that is, fuel flow creates the turning power. Model 903 Cummins diesels, which replaced the original VT8-430 Cummins recips in the 1980s, crank the units. Both GTs can be started remotely (units are unmanned) and have ratchet-type turning gears. An operator is dispatched after a unit is started.
- As for problems, Rutland had fuel-nozzle issues—specifically coking after restart. Replacing the nozzles solved the problem, so a root-cause analysis was not pursued. The utility has not had the opportunity for a long run on the unit since the 2009 major inspection. One reason: Fuel oil is expensive and kilowatt-hour sales would not be profitable.
- Rutland had vibration issues, so the rotor was disassembled and rebalanced. One cause of vibration, blade migration, was corrected by skim-cutting the locking wedges for each stage.

6. Fifty years later, the back side of the Ascutney enclosure (left) shows stack, and roof and side of the engine compartment, have been removed to access the rotor for a shop visit. Cables from the unit transformer to the grid were disconnected to allow safe crane access (right)

7. Engine removed, connection to the auxiliaries compartment is visible along with lube-oil piping

its Ascutney unit. Already planning this report, the editors were invited by CVPS to Ascutney for a first-hand look at the work being conducted (Figs 6, 7). Oil-only Ascutney and its sister unit at Rutland provide non-spinning-reserve fast-start (10-min) capacity and black-start services to the grid.

Mechanical Engineer Randy Johnson managed the major inspection for the utility. CVPS hired a turbine services firm for disassembly and reassembly and contracted with Genex for refurbishment of all stationary components and bucket repairs. Rotor and casing work was subcontracted by Genex to Elliott Co's Pittsburgh Service Center. Johnson's goal was to apply lessons learned from previous majors to the Ascutney project (Sidebar 2). Most recent experience was the Rutland Frame 5's second major in 2009. The first was in 1986.

Johnson described the Rutland GT as being in "pretty fair shape." First-stage buckets and vanes were "rough," tip rubs were in evidence, bearings

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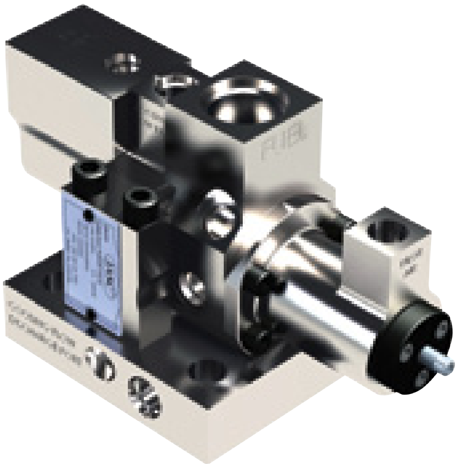

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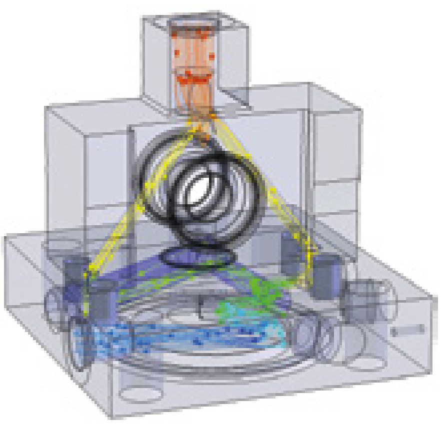
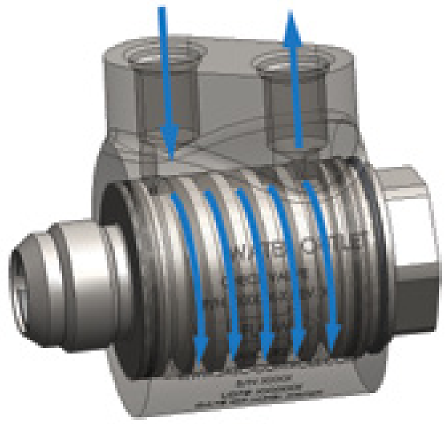


Three-Way Purge Valve Water Cooling Flow Path



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JASC INSTALLATIONS

3. How to remove buckets rusted into turbine discs

Materials of construction, ambient environment, and operating regimen sometimes combine to create a cementitious rust that locks buckets into turbine discs. Removal, as experienced during the Ascutney overhaul, can be virtually impossible. The firm servicing AECI's Unionville Unit 2 rotor experienced a similar difficulty when it was sent to the shop.

Induction heating coil is installed to expand the turbine wheel and facilitate removal of rusted-in buckets

The first thought was to slowly rotate the turbine rotor through a heated solution formulated to penetrate the rust between the bucket roots and wheel dovetails. This method didn't meet expectations. Next, a specialty contractor tried its luck using induction heating to expand the disks and dry ice to shrink bucket roots (photo). Success! The buckets came out as if there was grease on them, one plant person said.

Later, the rotor and buckets were grit-blasted. Minor tip rubs on the first-stage buckets and the few indications found on the rotor disks were blended out. On reassembly, machinists found that the fit between the blade roots and disc dovetails was within the OEM specification and no work was required. However, the locking device had excessive play. In effect, the turbine disc had "shrunk" because of material loss. A 30-mil coating was metal-sprayed on the disc, thereby enabling proper fit-up of the locking device without any machining.

8

9

10

8-10. Original Ascutney distance piece and turbine section were scrapped **(8)**. R1 fir trees were no longer fit for duty as close-up image reveals **(9);** the second-stage wheel also shows the wear and tear of a tough life **(10)**

needed work. PAL provided a technical advisor for engine disassembly, which was done by utility personnel. Shop work was contracted to Dresser-Rand Turbine Technology Services (Leading Edge Turbine Technologies Inc at the time of the Rutland overhaul).

A lesson learned that was applied to the Ascutney major: Use outside labor for engine disassembly and reassembly. Utility mechanics had a heavy work load at the time of this project and there was thought to be a schedule advantage in using outside labor more familiar with GTs than the hydro-oriented CVPS mechanics. The lesson learned at Ascutney is that MS5001Ds are much different than the latest "Fives" and it is difficult to bring together an experienced team for this particular model. Johnson said someone told him that of the 30 MS5001D engines produced only four remain in service—including the two at CVPS.

Rated 13.3 MW when originally installed, Ascutney had roughly 14,000 factored hours and 5000 factored starts when the decision was made to conduct the major in June 2011. To maintain the degree of operational readiness required by its grid contract, Ascutney had been conducting two test runs a month for several years—one FSNL, the other loaded. In a typical year the unit might be called on to run about a half dozen times and deliver power for six to eight hours after each start. The limited run time causes significant wear and tear on the turbine wheels. Plus, the high-moisture environment of lush southern Vermont is conducive to corrosion.

So it was not a complete surprise when CVPS got the word from Genex that the buckets for both turbine stages (the Frame 5 has only two turbine stages) were frozen into their respective wheels (Sidebar 3). In addition, both stages revealed tip damage from casing rubs and the angel wings exhibited wear from mild rubbing. To illustrate how "frozen" the buckets were in the wheels, it took about 12 hours to remove three first-stage airfoils. A simple visual examination showed the R1 fir trees were no longer fit for duty (Figs 8-10).

Note that the assembled rotor (compressor section, distance piece, and turbine section) had been removed from the package and trucked from Vermont to Pittsburgh. The original generator and exciter remained in place, properly heated for protection against moisture ingress. The generator had never been disassembled although it had been inspected and cleaned, with no issues identified.

The preferred option would have been to replace the Ascutney first-stage wheel and perform the EOL inspection as suggested by the OEM, because the unit had reached 5000 starts. But a replacement wheel could not be located. Johnson thought the second-stage wheel could have been salvaged and the tip rubs trued-up, but that became a moot point. Meanwhile, destacking of the compressor section hit a snag when those wheels got hung up on the through-bolts because of severe corrosion.

Ageing assets can present unforeseen problems. By contrast, the major on Rutland, about an hour drive from

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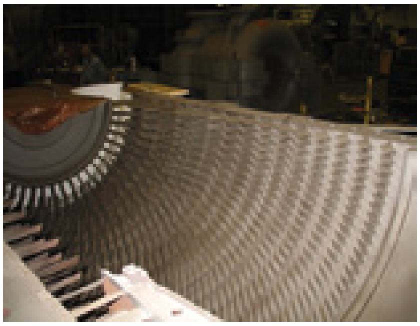
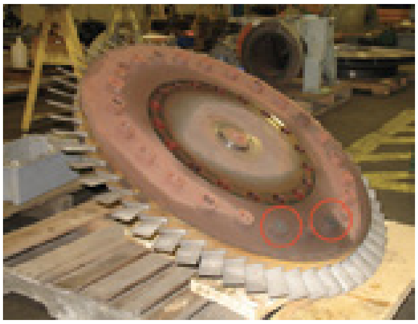
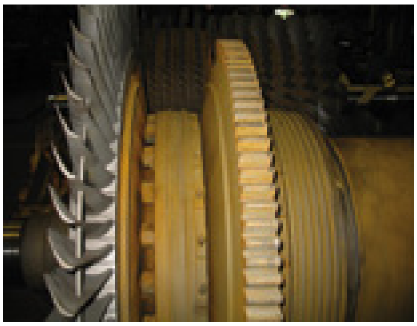



11, 12. The replacement MS5001D was in reasonably good condition as indicated by tight, unscathed compressor vanes (left) and the top compressor case for Rows 10-16 (right)




13, 14. A couple of marriage bolts sheared off during the unbolting process (left). Optimal solution was to swap out the affected 16th compressor stage on the replacement unit with that from the original Ascutney machine (right)




15, 16. Fir trees in the first-stage turbine wheel were grit blasted after buckets were removed (left); second-stage wheel was cleaned with buckets in place (right)

17. Shroud blocks were cleaned up and rated "fit for duty"

18. Ninth-stage hookfit area, prone to cracking as Frame 5s age, was in good condition

Ascutney, two years earlier went smoothly. No one expected the Ascutney rotor to be in such poor condition. There also was some casing damage requiring repair.

What to do? Good luck and a little help from your friends count when "smarts" aren't enough. Team Genex was hot on the trail of an MS5001D when the editors phoned during a trip south early this year to inspect a unit installed in 1963 and retired in 2007 with 7566 fired hours and 1866 starts. After reviewing the results of a borescope inspection report and making an external inspection of physical condition, Genex gave the machine two thumbs-up and bought it. The entire unit from the compressor inlet to the generator coupling, casings included, was loaded onto a truck and shipped north.

Genex's subcontractor broke the casing, losing only at most 10% of the bolts, and found the flanges in relatively good condition. The unit was cleaned and inspected, and critical measurements confirmed (Figs 11, 12). However, the as-received rotor had a degree of imbalance and balance-weight locations did not follow normal industry convention. Logic suggested breaking the marriage coupling and balancing each of the rotor components separately.

However, as the saying goes, no good deed goes unpunished. Three marriage bolts sheared off during the unbolting process and extraction of the segments would have been especially difficult (Figs 13, 14). So the 16th compressor stage from the original Ascutney rotor was removed swapped-out with that on the replacement rotor. A new set of matched marriage bolts was required, but the compressor through-bolts were salvaged.

Best practice for marriage-joint repairs on this machine, according to shop personnel, was to skim-cut or grind to correct axial and radial runouts, then do a light grind on the dummy journal (on the 16th stage under the marriage joint) to be sure it's "true." Finally, use balance weights to meet runout specs.

On the turbine end, the first-stage buckets were removed and sent to Genex for reconditioning, including repair of angel wings. Genex also repaired other hot-section parts—including liners, cans, transition pieces, first- and second-stage nozzles, second-stage diaphragms, etc.

With the buckets out of the wheel, fir trees were grit blasted and inspected; no cracks were found. The second-stage turbine section, including blades, was cleaned up as-received (Figs 15, 16). The work scope was designed to accommodate the planned operating regimen (a nominal 30 annual starts and 60 run hours) at optimal cost; there would have been no commercial advantage gained by removing the R2 buckets and cleaning the fir trees as was done for R1.

The rabbet-fit area and faces were dressed while light machining maintained concentricity at the marriage

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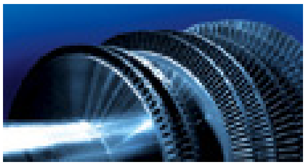


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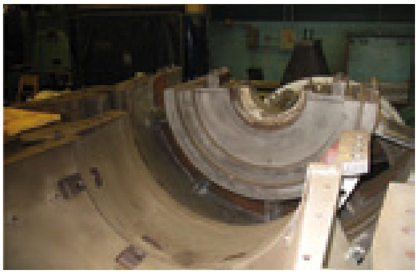
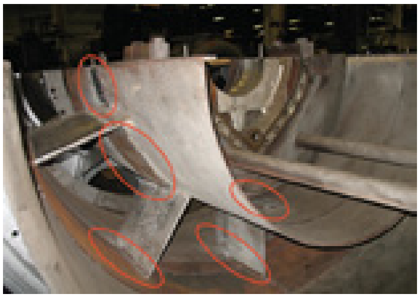
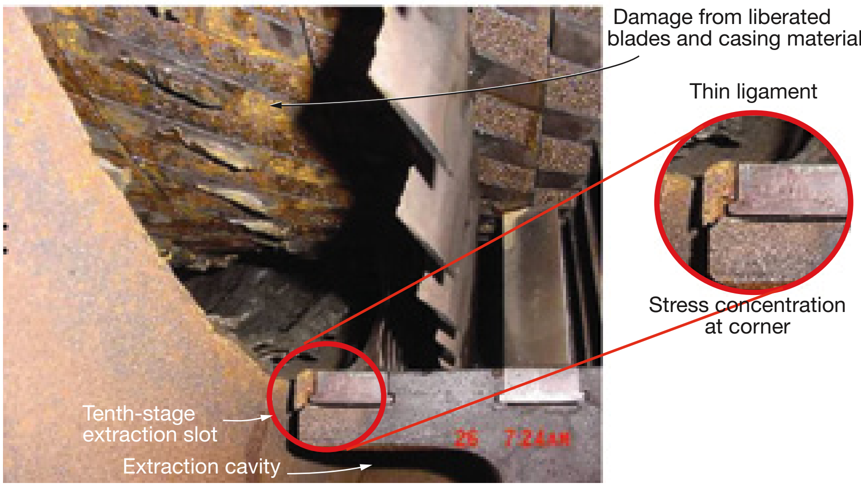
joint to assure a proper interference fit with liquid nitrogen used to shrink the turbine end. After the reconditioned R1 buckets were installed in the wheel with new seal pins and rock was verified within OEM specs, the turbine was balanced at low speed. The turbine and compressor sections then were rejoined and, after checking runout, the complete rotor was balanced at low speed.



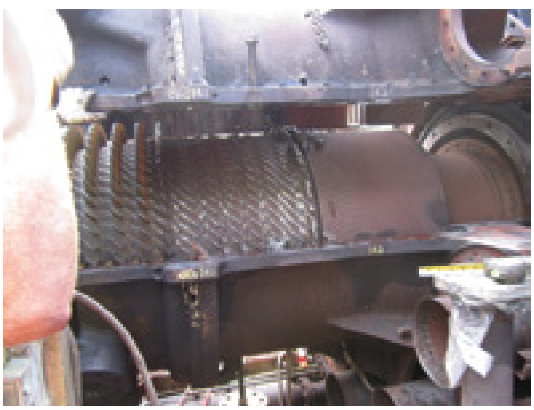

19, 20. Condition of the exhaust end of the lower casing half was fair (left), as was the upper half of the exhaust casing (right)




21, 22. Exhaust-end patch repairs were sufficient as there was no major damage (left). Even the diffuser, which was missing a couple of pieces of metal, could be repaired adequately by scavenging parts from the original GT (right)



23. Thin ligament is susceptible to cracking, allowing stator vane to work free and go downstream doing major compressor damage



24. Compressor is corncobbed downstream of Row 9 (left)

25. Casing crack generally is visible to borescope technician looking inside the 10th-stage extraction cavity (below)

Turbine nozzles were in reasonably good condition; only a grit blast was necessary. Shroud blocks were removed and inspected for cracking. The blocks on the replacement engine were in much better shape than the original Ascutney machine (Fig 17). After cleaning up some dents and dings, shroud blocks were cleared for duty. The ninth-stage hook-fit area, which is prone to cracking as Frame 5s age, was in good condition (Fig 18).

General condition of the exhaust end of the unit was fair (Figs 19, 20). Several small patchwork-type repairs were required on the exhaust housing, as one would likely expect (Fig 21). A segment of the exhaust diffuser was damaged and it was repaired with a section from the original turbine (Fig 22). Journal and thrust bearings were rebabbitted and seals replaced. Shaft journals just required polishing.

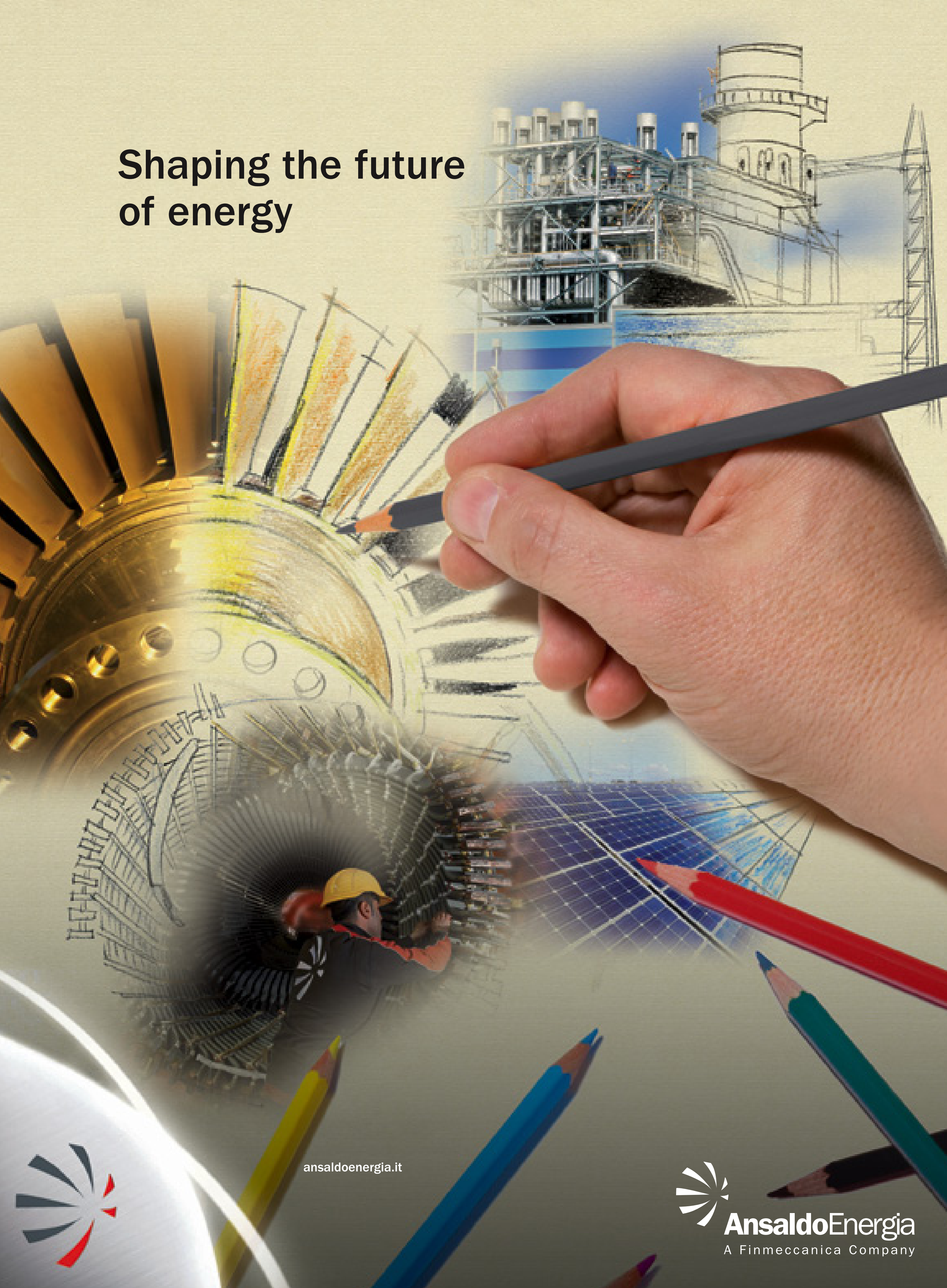
Weak ankle

The Frame 5 is a beast. In horse terms it can be compared to a Clydesdale, but one with the ankle of a thoroughbred. The Five's ankle is the thin ligament at the 10th stage extraction slot in the compressor section. It forms the hook that holds one side of the ninth-stage compressor stator vanes in place. Fig 23 shows the area of interest as well as the damage caused when the casing cracks, allowing the vane to work free and one or more airfoils to go downstream. Fig 24 illustrates the damage south of the ninth stage in greater detail.

Rodger Anderson, manager of GT technology, DRS Power Technology Inc, Schenectady, NY, and previously a lead design engineer for GE's gas turbine division, has seen this type of failure in many Frame 5s over the years. He says it is the result of a gray cast iron casing weakened by (1) corrosion, (2) the uplift loading on the ligament area created by airflow through the compressor, and (3) the numerous start/stop cycles associated with peaking service. Recall that gray cast iron has poor tensile and fatigue properties.

The casing cracks before failure, Anderson continued, and the vane loading will propagate the crack. Thus regular checks of casing condition in the extraction cavity during borescope inspections can warn of impending failure (Fig 25) and enable corrective action before serious damage occurs—as shown in Figs 26 and 27.

Option 1. The compressor expert offered three hook repair options for users to consider depending on the extent of cracking. Option 1 is an effective least-cost approach for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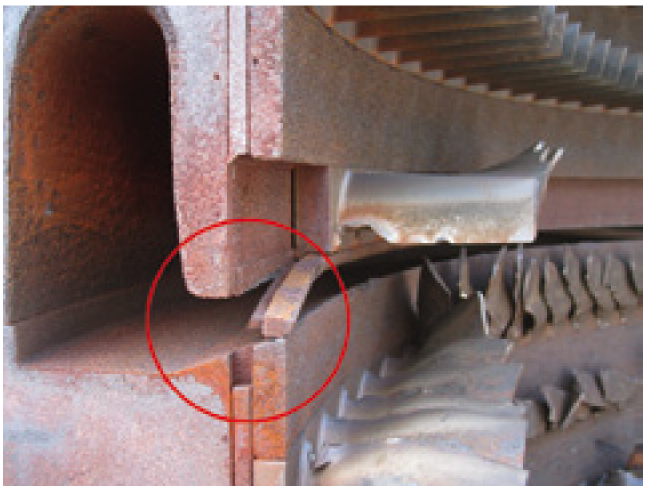
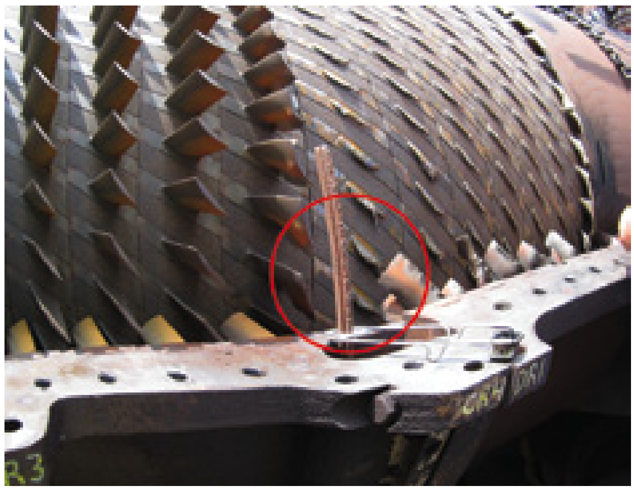
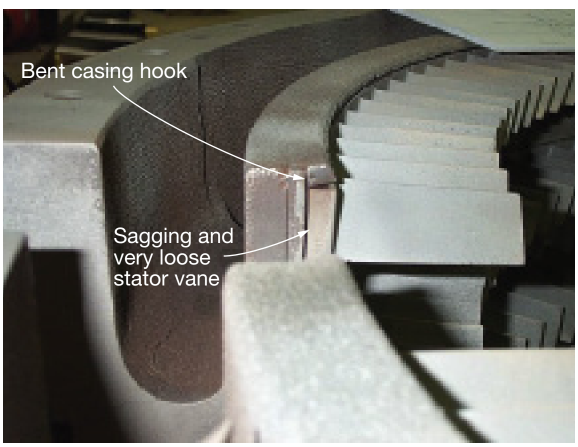


26. Hook portion of casing "peels" away, allowing vanes to go downstream. Tenth-stage extraction cavity is at left



27. Segment of hook broke off from the casing allowing several vanes to come loose and destroy downstream airfoils

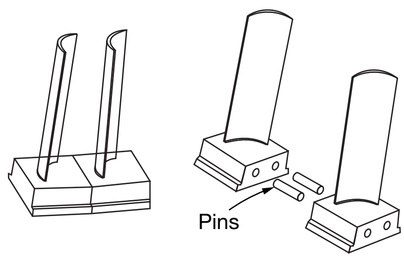


cracks less than 6 in. long at either (or both) of the horizontal-joint locations. Here's how Anderson approaches this repair:

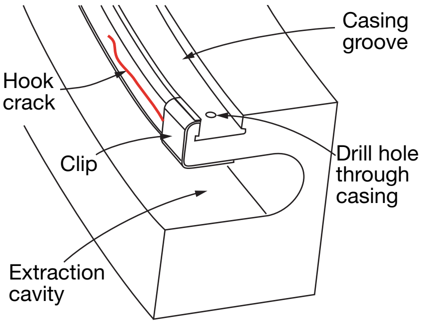
- Lift the upper half of the compressor casing about 2 ft above the horizontal joint and support it in that position.

28. Bent casing hook was noticed before any damage was done. In-situ repairs are possible at this point

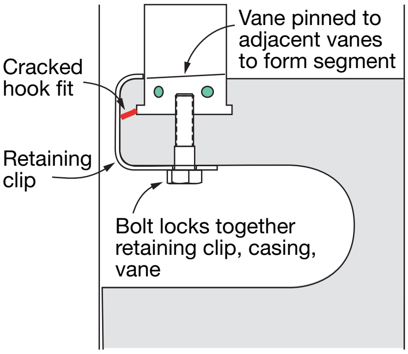
- Inspect hook fits on both sides of the upper and lower halves of the casing at the 10th-stage extraction groove. If your inspection confirms



29. Pinning creates a rigid vane segment and is an economical solution for hook cracks less than about 6 in. long



30. Short cracks can be repaired in-situ. Vane closest to the horizontal joint is bolted to the casing



31. Bolt anchors vane closest to the horizontal joint to the casing groove. Retaining clip holds in place the free end of the cracked hook fit

32. Patch ring is bolted to casing

borescope findings that any open crack is less than 6 in. long (Fig 28), remove stator vanes from the horizontal joint through two vanes beyond the end of the crack—as many as five airfoils in total.

- Drill the square bases of the vanes to accept the spring pins shown Fig 29 to create a rigid vane segment. This is the technique Anderson developed to prevent fretting wear caused by loose vanes in casing grooves. More than 120 turbines worldwide are running with over 80,000 pinned vanes. Fleet hours total more than 3 million; multiple fleet leaders have passed 50,000 hours. Reliability is 100%—meaning there have been no vane failures or shim liberations since the first vanes were pinned more than 10 years ago.
- Drill and tap a hole in the center of

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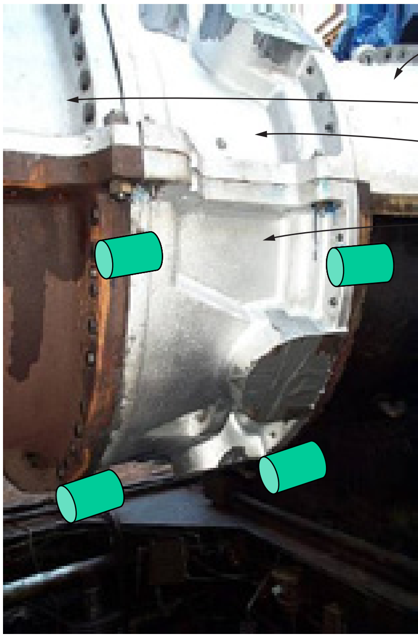
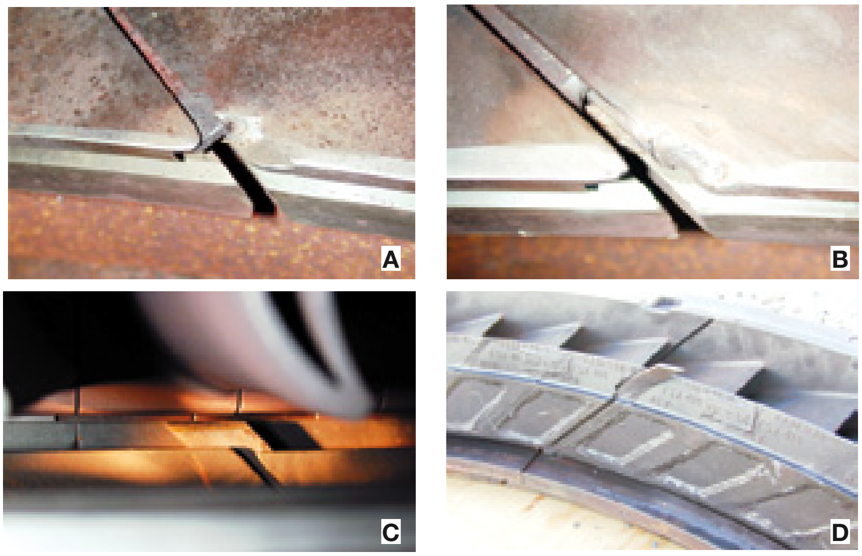


33. Rollers are bolted to the lower halves of the compressor discharge and forward compressor cases to guide and support the lower half of the mid compressor case as it is rolled to the upper-half position for removal

34. Mid compressor case is bolted together in the shop where two 180-deg patch rings are installed and fastened to the casing with counter-sunk flat-head bolts to form a new hook for the ninth stage

36. Half of each nozzle ring has five segments with five airfoils per segment (left); support ring is at right



35. Seal between adjacent nozzle blocks looks almost normal in A, except for the cracked weld. Seal has migrated downstream about an inch in B. Downstream side of seal, seen with borescope before machine disassembly, is approaching the first-stage rotating buckets in C. Seal migration is more pronounced in D after nozzle blocks have been removed from the unit

37. Rubbing was observed on platforms of first-stage buckets, but there was no indication of significant damage

the back side of the platform for the vane at the horizontal-joint location and then drill a hole through the extraction-cavity wall to align with that hole (Fig 30). A bolt anchors the vane to the bottom of the casing groove (Fig 31). A retaining clip is installed as shown to hold in place the free end of the cracked hook fit. In cases where vanes on opposite sides of the horizontal joint are bolted in place, elongated holes in the casing are necessary to accommodate expansion.

Option 2 is Anderson's solution for a crack in the upper half of the casing that exceeds 6 in. in length. The upper casing half is removed using a mobile crane and shipped to a machine shop where a 180-deg patch ring is installed at the 10th-stage extraction groove. Of course, the enclosure roof and side panels, as well as some of the combustion hardware, must be removed to lift the upper casing. The patch ring is described in Fig 32.

Option 3, the most extensive solution, is used when a 360-deg patch ring is required or desired. After the upper casing is removed in the manner described for Option 2, the lower casing half is removed by rolling it around to the upper-half position using the mobile crane (Fig 33). Both casing halves are bolted together in a capable shop and machined for a 360-deg patch ring (Fig 34). Back at the plant site, the lower casing half is rolled back into place and bolted to the forward and aft cases. Then the upper-half casing is lowered into place and bolted to complete the assembly.

Inspect regularly

It's not difficult to convince yourself that a robust Frame 5 relegated to capacity, black-start, voltage support or other grid service—logging perhaps a dozen starts and 50 or so hours of run time annually—doesn't need borescope inspections on a regular basis.

But that would be a mistake. Gabe Fleck, an electrical engineer with Associated Electric Power Cooperative Inc (AECI), Springfield, Mo, and the chairman of the 501D5/D5A Users, explained how periodic borescoping prevented catastrophic damage in one of his company's legacy engines several years ago.

AECI installed in rural Missouri, in 1976, two oil-fired MS5001Ps equipped with Mark II control systems for the primary purpose of maintaining voltage stability in an area served by one transmission line. For 30 years following COD, the unmanned Unionville GT Power Plant averaged two fired starts per month and about 40 operating hours annually—primarily to confirm reliability. The units very rarely ran with the express purpose of supplying kilowatt-hours to the system. In fact, Fleck said he couldn't remember one time in the last decade that they did.

The engines typically are inspected every two or three years, the gas-turbine expert continued. Several borescope inspection ports are provided on the Unionville Ps for this purpose—two on each side of the engine, one on each of the 10 combustion cans. Back in September 2005, Fleck went on, Florida-based Advanced Turbine Support Inc checked the machines from the IGVs to the exhaust plenum.

Borescoping of Unit 1 gave no reason for immediate concern but inspection of Unit 2 did. The most important of the technician's findings was that spot welds retaining the inner seals provided between adjacent first-stage nozzle segments had cracked in two instances (Figs 35, 36).

This allowed those seals to migrate downstream into the space between the first-stage nozzles and buckets (rotating blades). Rubbing was observed on platforms of first-stage buckets, but there was no indication of significant damage (Fig 37). Note that when a weld breaks, the seal does not just come loose and travel downstream; the resistance fit restricts its movement to small increments over a period of time. The seals are about 7 in. long and slightly less than a quarter of an inch wide; the gap between nozzle and bucket is 0.345 in.

Vendor selection. Fleck stressed the importance of proper due diligence in the selection of a borescope inspection service. Another vendor might have missed the traveling seals, he said, but ATS knew exactly what to look for on these particular machines. "We started out monitoring a first-stage nozzle shim for a Florida utility," the inspector recalled. "For two years we watched the shim move back and forth between the trailing edge of the first-stage nozzles and the leading edge of the first-stage buckets.

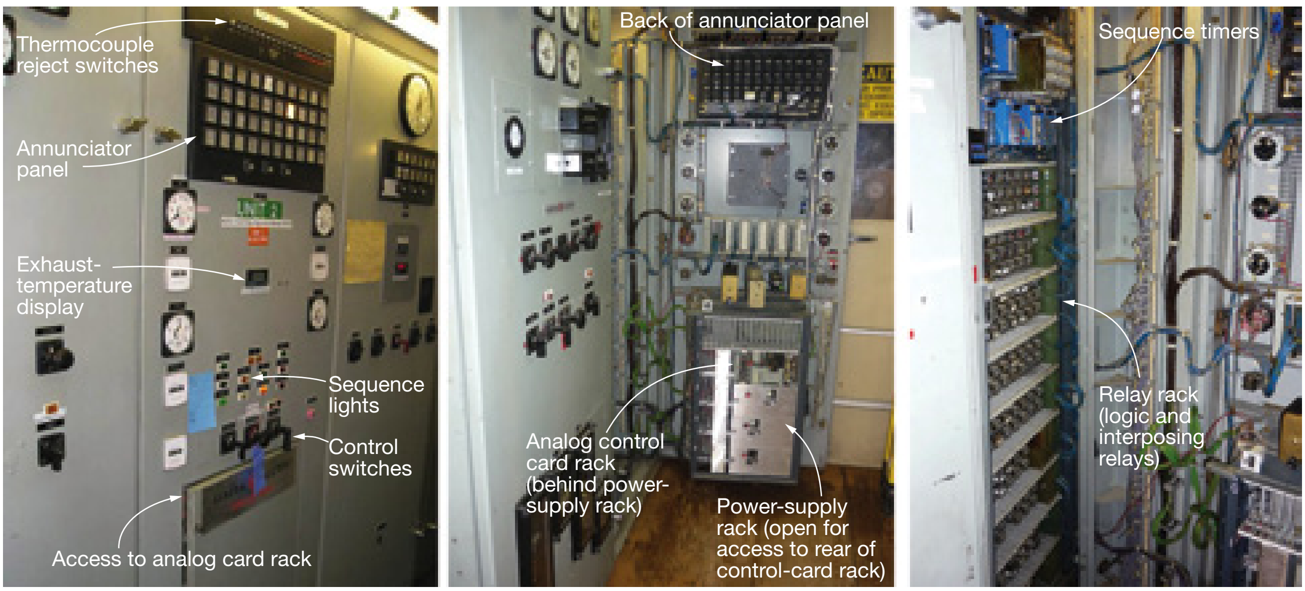
Initially, the customer and we thought that there wasn't enough room for the shim to come out—that it would just continue to move back and forth in the seal slot. However, we learned over time that shim contact with the rotating buckets was actually pulling the shim out from between the nozzle segments. Upon confirming this, the unit was removed from service and repaired."

Based on this experience, ATS implemented an inspection program for all Frame 5s that requires the checking of each shim to see if it is moving and/or if the tack weld holding it in place is cracked. The company also inspects closely first-stage buckets for signs of rubbing.

Since finding the first migrating seal, ATS inspectors have identified loose seals on several more units. Still more might have been found if all customers had been diligent about removing all 10 fuel nozzles. Some choose to pull only two to four nozzles, despite knowing this type of damage might be overlooked.

The "traveling seal" problem dictated a shop visit for this rotor, where severe rusting made removal of buckets from the wheels particularly difficult. Fleck explained that the Unionville peakers operate in a high-humidity environment and that about half of their lifetime starts had been for reliability testing.

Company procedures called for a



38. Speedtronic I controls are fading from view in the electric power industry, possibly heading for the Smithsonian. At left is the front of the control system cabinet, the rear view of the panel door is in the center, and the inside of the cabinet is at the right

one-hour test, mindful of fuel cost, emissions concerns, cost of personnel to conduct the tests, etc. However, an hour was not sufficient to heat-soak turbine components and the resulting moisture took its toll over the years. New procedures call for cranking each engine once in the first and third calendar quarters, and starting each once in the second and fourth quarters and running for three hours each time.

Controls retrofits

Most Frame 5s earn their keep providing black-start, emergency capacity, peaking power, and other ancillary services. One look at the heat rates associated with the various models of the MS5001 (last column in Table 1), and the fact that many of these engines built before the mid-1970s are oil only, tells you most users are not competitively bidding kilowatt-hours.

In the market segments typically served, reliability is of greatest importance and controls upgrades are viewed positively—even by parsimonious owners. They know that once in a while you have to spend a buck to assure a revenue stream. Those users interested in performance upgrades are referred to GER-4196, "Performance and Reliability Improvements for MS5001 Gas Turbines" and similar documents, available on the Web. There are far

too many performance-improvement opportunities offered by the OEM to do the subject justice here.

There's usually good reason to consider a controls replacement on virtually any "Five" that is 30 or more years old (Fig 38). It can be tough getting parts/service for fuel regulator and Speedtronic I and II systems. When the financials support a controls upgrade for your units, there are two basic options: a PLC-based system or a DCS.

After speaking with several owners, the editors learned that with control-system cost pretty much a tossup among third-party suppliers, selection comes down to schedule, the capabilities of plant personnel, and spare parts. The supervisor of a municipal plant said his city's power and water departments shared personnel and the water infrastructure was controlled by Rockwell Automation/Allen-Bradley PLCs. With a knowledgeable labor pool already available, a DCS didn't get serious consideration.

Another owner with several generating plants controlled by Emerson Process Management's Ovation™ said savings in spare parts, plus having experienced technicians available on-call to service the Frame 5 peakers, supported the decision for a DCS. Yet another user told the editors that opting for a DCS provided schedule benefits.

Patrick Nolan, Emerson's director of gas-turbine solutions and an expert with 25 years of experience in managing businesses dedicated to engineering, installing, and commissioning both PLC- and DCS-based controls upgrade solutions, told the editors the two types of systems can be installed in about the same amount of time because as much as about 90% of each application is "standard." The remaining 10% has to do with customer preferences.

Nolan said, "Users can ensure a successful controls retrofit with relatively little upfront work at the procurement stage. Specs are relatively standard from user to user and best achieve their goals by being functionally descriptive rather than hardware-centric." To keep the project affordable, he recommended that users resist the temptation to specify a unique solution. He advised procuring such projects on a turnkey basis to hold down costs.

Some customers want to manage the installation activities themselves and have the control-system bidder only provide a technical advisor. Nolan advised owners to carefully consider the benefits of this, explaining that the lowest cost is achieved when the supplier is responsible for the entire package. Modernization of Frame 5 controls is a "very standard application," for experienced vendors, he added.

The cost/benefit of additional upgrade enhancements is strongly influenced by the particular vintage and model of turbine. The controls expert encouraged users to address the main problem items—such as variable-displacement pumps for the fuel systems on old Frame 5s—and not to unduly drive up project costs with "nice to haves" that may not directly improve overall life-cycle costs.

PLC controls

Kentucky Utilities Co recently upgraded the controls on three 20.7-MW MS5001Ms installed in 1969-1970 at the Heafling Gas Turbine Plant in Versailles, Ky, near Lexington. Production Supervisor Greg Wilson told the editors that reliability concerns with these black-start peaking GTs, each having about 30,000 fired hours of service, motivated the controls upgrade.

Petrotech Inc, Houston, was the winner among several bidders, offering a PLC-based system with Allen Bradley components familiar to many utility personnel. An eight-week outage was needed to convert all three oil/gas-fired units from Speedtronic I to a system underpinned by programmable logic controllers. Local electrical contractors handled the field wiring and instrumentation under the supervision of a Petrotech technical adviser.

The primary goal of the project, said Petrotech's Steve Cernik was to upgrade the turbine control systems to increase reliability and safety and

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to facilitate troubleshooting, maintenance, and normal operation. Wilson confirmed that the new control system has been in service for several months and is meeting expectations.

The Petrotech system controls starting, synchronization, operation, and shutdown. It enables the three GTs for full automatic black-start and non-black-start sequencing and control in both local and remote modes. Bumpless transfer between liquid and gas fuels also is assured. The control system also allows running on mixed fuel if desired.

Startup sequence for the new control system generally proceeds as follows:

- Shutdowns/relevant alarms clear, operation selector in appropriate position.
- Local/remote start command.
- Lube-oil pump, cranking motor/diesel start and unit accelerates to cranking speed.
- Ignition and flame detection.
- Warm-up complete, unit accelerates to 50% speed.
- Diesel engages, idles for five minutes and shuts down.
- Turbine accelerates to 100.3% speed.
- Synchronization is next—by manual means or by using the autosynchronizer to modulate turbine speed. Breaker closes.
- Load increases to pre-selected value if this feature is activated, or spinning reserve otherwise.
- If in isochronous mode, controller matches frequency set point.
- If in droop mode, controller matches a load set point—unless base, peak, or peak reserve is located. In this case, the controller will match the corresponding temperature or maximum-load set point.

In addition to the normal start sequence, a fast-start sequence shortens the amount of time required to get the units in service by reducing the warm up time and increasing the rate of acceleration.

39. Ovation™ cabinet is designed to drop into space available after Speedtronic I controls are removed. Compare the front panel with the left-hand photo in Fig 38 and the right-hand view here with the center and right photos in Fig 38

DCS solution

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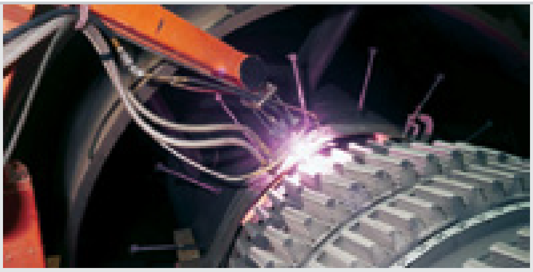

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in the Ohio city. Utility personnel take great pride in their system's service record. In 2011, the overall average service availability index was 99.99%: The average Piqua electric customer experienced fewer than two outages of less than 33 minutes each.

Krieger knew the company's enviable record was at risk given the age of the control systems married to its two simple-cycle gas turbines; nuisance shutdowns had become problematic. Piqua is a member of American Municipal Power Inc (AMP), a nonprofit corporation that owns and operates power generation and delivery facilities to provide its 129 member companies reliable, competitively priced electricity. The city also participates in the PJM Interconnection LLC's demand response program, so its generating units must start when required to avoid financial penalties.

The kilowatt-hours provided to Piqua's customers are produced by several projects the city holds minority interests in through its AMP membership—including renewables. Primary purpose of the two oil-only legacy gas turbines—a 21-MW MS5001N (Unit 8) and a 15-MW W191G (Unit 9)—is system reliability. They are black-start capable and can support critical loads in the city if the grid fails and Piqua disconnects to run in island mode.

Years back, the city generated its own power, but that stopped in the 1990s when its 60-MW coal-fired unit was shut down. The Frame 5 was purchased new in 1971; the 1960s-vintage W191 was pre-owned and relocated to Piqua in the late 1980s.

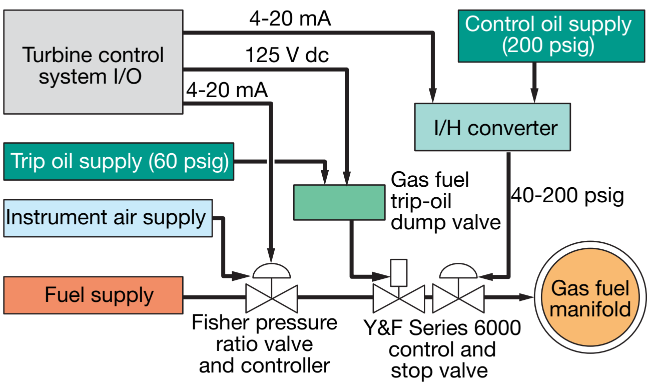
The city engaged Kansas City-based Sega Inc in spring 2011 to provide guidance in drawing up bid documents with detailed specifications for a new Frame 5 control system. Emerson Process Management Power & Water Solutions was awarded the competitively bid project. But before the project could get underway, the thin ligament at the 10th stage extraction slot cracked during a normal unit shutdown, releasing ninth-stage stator vanes and destroying the back end of the compressor (refer back to the section, "Weak ankle").

A major overhaul was initiated promptly, with Sulzer Turbo Services hired to repair the rotor. The company got high marks for its work on the project from Krieger. One of the enhancements Piqua selected was coating of the new compressor blades to protect against corrosion pitting during the long periods the machine sits exposed to a humid ambient environment. The exhaust diffuser and flex seals also were replaced at this time with stainless steel components from Braden Manufacturing LLC; installation was done by ProEnergy Services.

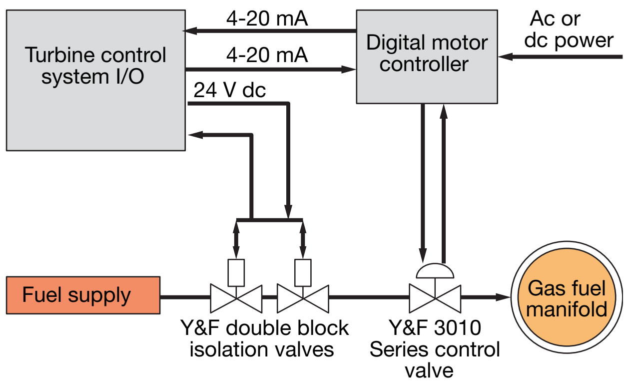
In parallel with the major overhaul work, Emerson replaced the Frame 5's Mark I turbine and generator controls with an Ovation turbine control system. Krieger commented that the Frame 5 was an easy machine to upgrade. A small crane was used to pull the Mark I package (Fig 38) from its housing and the Ovation cabinet was skidded right into the space vacated (Fig 39).

The Ovation system—including controller, I/O modules, power supplies, touchscreen interface, and turbine-control application software—was pretested in Emerson's shop before being shipped to the site. It monitors about 200 I/O points for the Frame 5. Krieger said that Emerson recommended several "no-brainer" enhancements that were implemented, including the following:

- Remote control capability.
- Modern screens that enable operators to know why the unit trips if it does.
- Fuel oil system upgrade, including a new fuel valve with upstream/downstream pressure transmitters.
- Excitation system upgrade.
- Power monitoring through a protective relay with Modbus serial communication.
- Rewiring of the turbine base.
- New thermocouples.
- Flame detection system upgrade.



40. Problems with the original fuel control system were traced to contaminated air and hydraulic oil needed for valve operation



41. Upgrade of the fuel control system from pneumatic and hydraulic actuation to electric dramatically improved reliability

- Compressor-discharge pressure transmitter.

Asked what he thought of the new system, Krieger said simply, "When we call for a start, it runs."

Fuel system upgrade

Ageing fuel control systems, like the ageing turbine control systems discussed in the previous section, often have a negative impact on engine reliability. Sometimes only after upgrading to today's technology can you appreciate the advancements made since your Frame 5 entered service. A case in point is two gas-fired MS5001 machines that generally have operated base-load since entering service in 1967.

The owner, who asked not to be identified, had upgraded the engines' control systems to Emerson Process Management's Ovation™ before tackling the fuel systems earlier this year. Both upgrades have met expectations. The user's comment after the fuel system was modernized: "It was a simple 'push button and watch' startup—the first of its kind here in many years."

The original fuel control system, supplied by the OEM, was standard for the day (Fig 40). The equipment replaced and upgraded was provided to GE by Young & Franklin Inc and Fisher Governor Co. Today the latter, known simply as Fisher®, is a subsidiary of Emerson. Issues affecting the original equipment included the following:

- Contamination of instrument air, which interfered with position tracking by the Fisher pneumatically actuated pressure control valve.
- Normal wear and tear of the actuator for the Y&F Series 6000 combined control and stop valve contributed to hysteresis, which was not easily corrected because of poor support for low-pressure mechanical servo valves. Note that the Y&F valve is controlled hydraulically from the 40-200-psig control oil system via an I/H (electric current to hydraulic pressure) converter.
- Varnish in the hydraulic oil system, which caused unit trips and failed starts.
- Wear of the I/H converter supplied by Tri-Sen Systems Corp, for which there was little-to-no support. Failure of the I/H converter to operate as expected directly affected engine starting and operational reliability. Replacement of the hydraulically

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and pneumatically actuated valves with Y&F's electrically actuated alternative simplified the fuel control system and eliminated the least-reliable devices—specifically, the solenoid trip-oil dump valve and I/H converter (Fig 41). Prior to conversion, servicing of the fuel control system was required annually; calibration and cleaning of the instrument-air controller and I/H converter was necessary triennially. The mean time between service calls for the new system is projected at 10 to 20 years with no calibration of the isolation valves or gas control valve required.

End-of-life inspection

OEMs tell users gas turbines have critical parts with finite lifetimes and that replacement of these parts may be necessary to assure reliability and safety moving forward. Rotors are a primary target of this initiative. Their lifetimes depend significantly on service history. Today, the only way to reliably determine if an ageing rotor is in sufficiently good condition to continue operating is to disassemble it and to nondestructively examine individual wheels, bolts, etc.

GE's Technical Information Letter (TIL) 1576, issued in 2007, requires rotors with 200,000 equivalent operating hours or 5000 equivalent starts (whichever comes first) to undergo a comprehensive inspection. Hours-limited rotors that pass inspection, with or without rehabilitation or replacement of critical parts, can be certified for extended service (50,000 or more hours). The OEM's current position reportedly is that rotors having accumulated 5000 starts are at end of life no matter how good they might look.

Generally speaking, Frame 5s owned by electric utilities and independent power producers probably would bump up against the starts limit first because of their widespread use in peaking service. Those used in cogeneration service at refineries, chemical, and other process plants likely would be hours-based engines, as would "Fives" driving gas pipeline compressors.

According to GE presenters at user-group meetings, rotor life limiters fall into two categories:

- Low-cycle fatigue (LCF) cracking/fracture, and
- Creep rupture.

The first is the result of service-induced accumulated cycling and usually identified in areas of stress concentration and at locations of (1) initially acceptable forging inclusions or (2) inclusions that could not identified using the nondestructive examination (NDE) tools available when the rotor was manufactured. Note that operation at low ambient temperatures and age-related embrittlement of the rotor material can reduce fracture toughness.

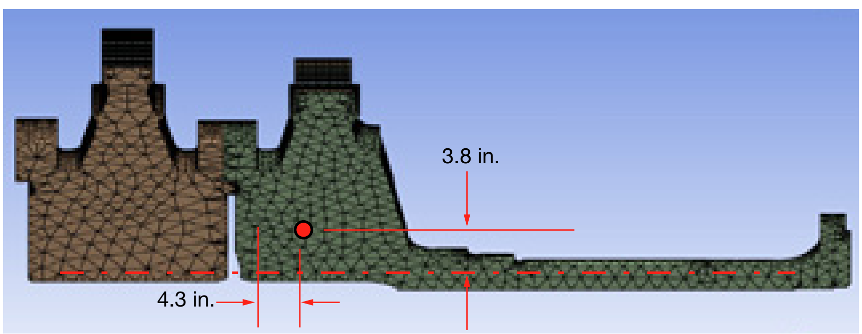
Creep rupture is a time-dependent life limiter influenced significantly by temperature and stress. This is why it's particularly important to maintain wheel-space temperatures within OEM guidelines. Crack growth can be time- or cycles-dependent, thereby creating the potential for crack propagation to be a mixed-mode life limiter.

OEMs and NDE. When it comes to discussion of NDE tools for deciding whether your rotor gets a "thumbs up" or "thumbs down," the OEMs offer much less detail in public forums than third-party service providers. Perhaps the latter must dig deeper to provide owners the level of detail they and their insurers need to decide on retirement or continued operation. When OEMs conduct inspections their decisions on rotor life, in effect, are "rule of law." What owner or insurer is going to question the OEM's view?

To illustrate the level of detail an OEM offers on its rotor life inspection process, consider the following publicly available information:

- Visual inspections.
- Dimensional inspections.
- Magnetic/fluorescent particle inspection.
- Eddy current inspection.
- Ultrasonic testing.

A third-party view on GT end-of-life (EOL) inspections was provided by Paul Tucker of First Independent Rotor Service of Texas (FIRST),



42. Flaw identified during the phased-array ultrasonic inspection of a Frame 5P gas turbine is located in the bore region of the second-stage turbine wheel

Humble, Tex, and Gary Hensley of Veracity Technology Solutions, Tulsa. Tucker and Hensley were two of the principals in the first third-party consortium to conduct EOL inspections of GE frames following the release of TIL 1576. Some believe Tucker, who worked in GE rotor shops for more than two decades before striking out on his own, and Hensley, who previously was responsible for the development of NDE tools for Siemens, may have done their first Frame 7 EOL inspection before the OEM did one.

The results of that work were reported at the CTOTF Fall Turbine Forum in 2007. The 7C rotor inspected came from a 1× 1 STAG 107 combined cycle installed at Arizona Public Service Co's West Phoenix Generating Station in 1976. It had more than 6000 actual starts at the time of the inspection and is still in service today.

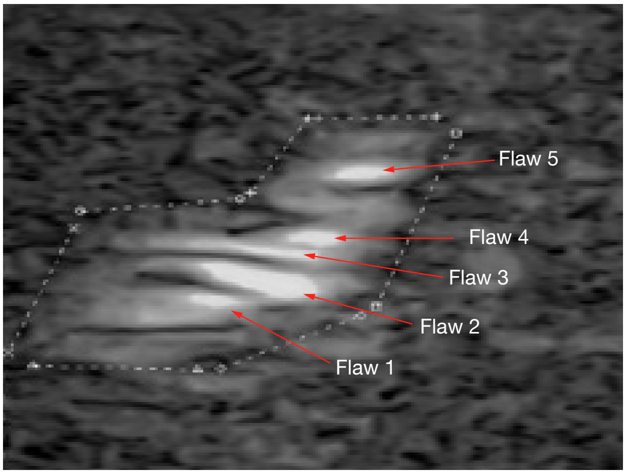
The rigorous EOL inspection program—including visual, magnetic-particle, ultrasonic, and eddy-current NDE, as well as metallurgical and dimensional verification—revealed no reportable indications. This led the inspection team to conclude, based on inspection-process fidelity, inspection methodology/criteria experience, and the excellent inspection report, "that it is more than reasonable to assume no defects would grow and propagate into anything near critical flaw size in the next major inspection interval."

Tucker and Hensley discussed with the editors ongoing work in EOL inspections, which at the moment, focuses on several Frame 5s. Inspections conducted to determine if an engine is fit for duty include the following:

- 100% three-dimensional boresonic inspection for internal flaws.
- Eddy-current inspection for creep.
- Hardness and replication for grain structure.
- Critical diameters measured for bore shrinkage.
- Finite element analysis (FEA) when flaws are identified.

Regarding the last point, FIRST and associates have developed rotor-component fracture models to perform FEAs when needed. Tucker said that FIRST's critical flaw-size and fatigue-life estimations enable the company to analyze flaws with its models to see if flaw characteristics are detrimental to machine operation. He said the models can determine if specific flaws will fail, and if so, when in terms of hours and/or starts.

For Frame 5P EOL inspections currently being conducted in FIRST's shop, technicians are checking compressor wheels for Rows 13 to 16, the distance piece, and both the HP and



43. Closer examination revealed flaw in Fig 42 was a cluster of indications (above)

44. Condition of turbine wheel serrations was typical for a 26-yr-old Frame 5 with 86,000 fired service hours (left)

45. Ultrasonic inspection is conducted of the turbine first stage without disassembling the rotor

LP turbine disks. In one of the machines, a phased-array ultrasonic inspection revealed a flaw in the bore region of the second-stage turbine wheel (Fig 42). Closer examination revealed five significant indications in a cluster formation (Fig 43). Two of the indications (Flaws 1 and 2) were of significant concern because of sharp projections emanating from their blunted ends.

A detailed FEA showed the flaw was located in a region of high shear stress at a significant stress gradient and that the region of concern was above the material's yield strength, based on the information available to the inspection and analysis team.

A more exacting analysis would have been possible

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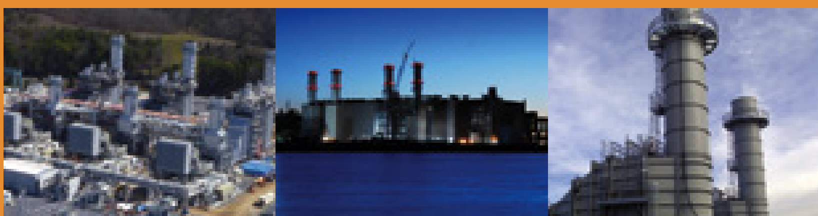

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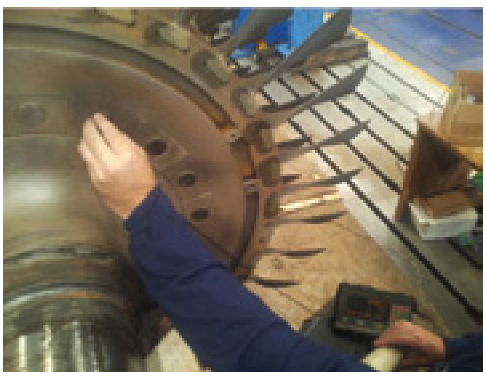
if FIRST had information pertaining to the residual–stress state inherent in the disc as a result of the hot-spin process performed during its manufacture. Note that a hot spin reduces the wheel's operational tensile stress by locking in a compressive residual stress in the bore region.

Absent that, and stress-strain data to accurately reflect the plastic behavior of the disc material, the company recommended that the disc be removed from service.

Not all flaws are show-stoppers, however. For example, a flaw was found in the 16th-stage compressor wheel of a rotor with 4800 starts. FEA showed it to be "non-detrimental." Tucker said that the material used for compressor wheels is more forgiving than that used in the manufacture of turbine discs. At this point he stressed, "What you might find is not always bad," mentioning that some users he speaks to believe a material defect means the part must be scrapped. Not true, Tucker continued, it's not a "gloom-and-doom" thing.

Inspections conducted by FIRST and its alliance partners nominally take five days, a fraction of the time typically quoted by the OEM. However, analysis of any flaw that might be found can add a couple of weeks or more to the schedule. Tucker suggested that owner/operators do an EOL inspection earlier rather than later—during a major or when you're going to replace compressor blades.

Having a baseline condition assessment enables users to better manage the lives of their rotors. Plus, if it appears that one or more components will have to be replaced in the future, knowing earlier allows owner/operators to plan for that eventuality and to order refurbished or new parts on a standard delivery schedule.



46. Compressor through-bolts are ultrasonically checked to determine their condition.

Tucker mentioned ongoing work by aimed at developing a new protocol to enable specific rotor-in-place tests for EOL evaluations. If that work is successful it would eliminate the need for unstacking the rotor in a shop unless a flaw is found or other work is required.

Some preliminary work in this area was described to the editors by Veracity President Kevin McKinley. He said Veracity was tasked to develop a set of inspections for a Frame 5P (86,000 fired hours; COD 1986), that together with metallurgical data, would enable its owner to have an accurate condition assessment without disassembly. The three inspections listed below were specifically requested by the user.

- Advanced Impedance Plane Analysis eddy-current inspection of R1 and R2 turbine fir trees to look for evidence of creep cracking, as well as other material deficiencies related to unit operation (Fig 44).
- Single-element and linear-array ultrasonic inspection of accessible areas of the R1 and R2, including fir trees (Fig 45). Additional 3-D modeling of the volumetric inspections was conducted to increase the probability of detecting any subsurface anomalies.
- Ultrasonic inspection of through bolts (Fig 46).

Veracity recommended additional inspections—such as 100% eddy-current inspection of all rotating and stationary compressor airfoils—but the user opted instead for penetrant inspections of compressor blades done by plant personnel. CCJ

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The venerable Frame 5

Coordinate generator, engine overhauls, upgrades

By **Paul Heikkinen** and **Phil Karwowski,** TurboCare Group

The Frame 5 gas turbine originally was manufactured by General Electric Co and subsequently produced by GE and its licensees—including Bharat Heavy Electricals Ltd, John Brown Engineering Gas Turbines Ltd, Hitachi Ltd, Alstom Power, and Nuovo Pignone SpA (later acquired by GE). Introductory Frame 5s were rated at 10,750 kW (Fig 1), with current versions up to 26,800 kW in single-shaft configuration and 31,100 kW in the twin spool arrangement (see previous article for gas turbine details).

Generators from many manufacturers have been coupled to the Frame 5. In addition to the engine suppliers listed above, one may also find generators manufactured by Brush Electrical Machines Ltd, Meidensha Corp, AEG-Kanis Turbinenfabrik GmbH (later acquired by Siemens AG), and others. The majority of these generators are air-cooled, employing either OAC (open air cooled) or TEWAC (totally enclosed water to air cooled) variations; however, some applications may use hydrogen cooling. Typical voltage is 13.8 kV at 60 Hz and 11 kV at 50 Hz, although it is not uncommon to find voltages from 4.16 through 15 kV.

Inspection, testing

Hot-section component improvements have allowed users to extend their gas-turbine inspection intervals well beyond those that had been recommended by the OEM up until only a few years ago. Fig 2 compares yesterday's intervals with today's for the Frame 5PA.

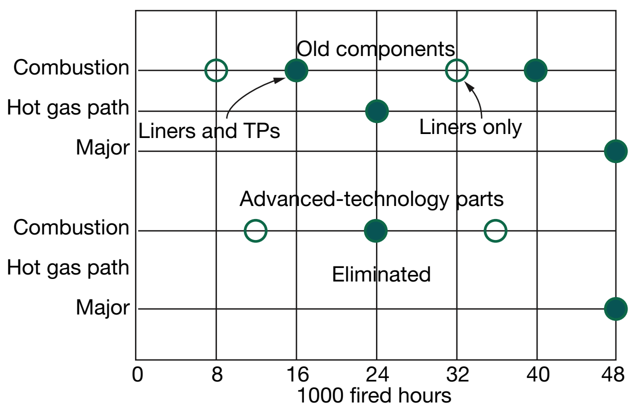
The inspection schedule for advanced technology parts fits well with what generator experts recommend for their equipment, making it both logical and good operating sense to align generator and GT maintenance activities. For backup units that run infrequently, owner/operators might consider inspecting their generators at three-year intervals aligned with the scope recommended in Table 1 for "rotor-in" testing.

Important to note is that insurance-industry experts have advised against conducting ac high-potential testing as part of regular inspection and maintenance activities because these tests can be destructive. Industry trends suggest that a controlled dc over-voltage test—such as stepped-voltage testing and ramped-voltage testing—are more appropriate for maintenance assessments.

Issues identified at lower voltages can be corrected before proceeding to rated voltage multiplied by a factor for conversion to ac. However, ac high-potential testing is appropriate for proof-testing a generator that has been rewound either in the factory or the field.

During a combustion or a hot-gas-path (HGP) inspection, when the generator rotor remains in the stator, it is always good practice to measure and record stator and rotor electrical data—such as insulation resistance (IR), winding resistance, and Polarization Index (PI). Also, check to insure that resistance temperature detectors (RTDs) and thermocouples are functioning.

1. Generator section is lowered into position at Central Vermont Public Service Corp's greenfield Ascutney plant in 1961. It is believed to be one of only four MS5001D generating sets still in service. CVPS owns two of the four



2. Suggested maintenance intervals are compared for a Frame 5PA equipped with original parts to one with advanced-technology parts. The generator inspection program recommended in Table 1 is in alignment with the engine overhaul program using the latest hot-section parts. Estimated maintenance intervals are based on base-load operation (one start per 1000 fired hours) while burning gas

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Table 1: Inspection checklist for Frame 5 air-cooled generators

Component	Activity	During 12,000-hr combustion inspection (rotor in)	During 24,000-hr HGP inspection (rotor in, upper end shields off)	During 48,000-hr major inspection (rotor out)
Rotor	Electric testing	Impedance test Winding resistance Insulation resistance Polarization Index	Impedance test Winding resistance Insulation resistance Polarization Index	Impedance test Pole balance Winding resistance Insulation resistance Polarization Index
	NDE			Retaining-ring NDE Retaining-ring hardness
	Mechanical testing		Borescope under rings	Rotor TIRs Journal diameters/surface finish
Collector rings	Electrical testing			Insulation resistance
	Mechanical testing	Visual inspection	Visual inspection	Collector-ring hardness Collector-ring diameters/surface finish
Exciter (brushless)	Electrical testing	Insulation resistance	Fuse inspection Diode testing Capacitor testing	Fuse inspection Diode testing Capacitor testing Insulation resistance of shaft components Stator winding resistance
	Mechanical testing	Visual inspection	Visual inspection	Fasteners and locking hardware
Stator	Electrical testing	Insulation resistance Phase resistance measurements Polarization Index	Insulation resistance Phase resistance measurements Polarization Index	Insulation resistance Phase resistance measurements Polarization Index Dc controlled over-voltage testing Power factor and tip-up testing
	Mechanical testing		Visual inspection	Wedge tightness mapping Building bolt/through-bolt torque
	Core testing			El CID testing
Instrumentation	Electrical testing	RTD element resistance RTD insulation resistance Thermocouple continuity	RTD element resistance RTD insulation resistance Thermocouple continuity	RTD element resistance RTD insulation resistance Thermocouple continuity
Enclosure	Visual inspection	Visual inspection	Air in-leakage/sealing Moisture ingression Oil leakage inspection	Air seal inspection Water supply connections Oil seal clearance inspection
Bearings	Electrical testing			Bearing-pedestal insulation resistance Bearing insulation resistance
	Mechanical testing			Bearing babbitt bond Bearing clearance
Cleaning methods (stator)				Hand cleaning CO_2 blast cleaning Solvent cleaning

Historical records should be established and trended to provide a foundation for decision-making. For example, if the IR value of one phase is lower than the other two phases, and it does not change over time, then the likelihood of a developing maintenance issue is reduced.

Electric generators naturally operate best when clean and dry, so pay close attention during inspections to enclosure sealing, oil-seal clearances, resistance-heater operation, and paths of moisture ingress. These small steps can help extend the operating life of the insulation systems. Test heaters and their attendant control systems during planned maintenance.

Stator cleaning can be accomplished with CO_2 blasting, solvent cleaning, hand cleaning, or a combination of these methods. Rotor cleaning is best done in a qualified shop. In all cases, be certain to test for lead paint and asbestos before initiating any cleaning or repair activities. If the generator tests positive for hazardous materials, remediation should be performed only by trained abatement specialists.

When planning a GT major inspection, it's a good idea to consider cleaning and pressure-testing the generator air cooler. Factor the cooling-water source into your thinking.

Generally, all stator maintenance and repair work can be accomplished in the field— from testing and cleaning, through stator recore and full rewinds. A complete stator re-wedge can usually be done in a few days, which is well within the outage windows allotted for the gas turbine.

If insulation distress is apparent, keep in mind that with today's reverse engineering capabilities and fast manufacturing cycles, it is possible to do a complete in-place stator rewind in about 45 days—that is, from initial identification of a winding issue, to stripping the unit, to final high-pot testing and turnover for mechanical assembly. These schedules are supported by pre-defined insulated copper, resin-rich mica tape insulation systems, and flexible-coil former technology.

For loose cores, tightening is often performed in the field without adverse effects. Pre-tightening and post tightening El CID testing can verify core

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Table 2: Upgrade economics for Frame 5 air-cooled generators

Upgrade	Engineer's estimate, $1000	Typical turnaround, days	Upgrade payback	Maintenance payback	Degree of life extension
Stator rewind	1200	45-60	Strong	Strong	High
Stator recore	1000	45-60	Moderate	Strong	High
Rotor rewind	350	30-45	Moderate	Strong	Moderate
Retaining-ring replacement	300	21	Weak	Moderate	Low
Retaining-ring insulation replacement	20	14	Weak	Moderately strong	Moderate
High-speed balance	40	5	Weak	Moderate	Low
Heater replacement	5	2	Weak	Moderately strong	Moderate
Collector-ring replacement	75	14	Weak	Moderately strong	Moderate
Bearing and seal replacement	50	21	Weak	Moderately strong	Low
Add online monitoring (flux probe and PDA)	50	4	Weak	Moderately strong	Low
Replacement generator (new)	2500	365-548	Strong	Strong	High

3. Generator stator rewind "zero hours" a major component of the classic Frame 5 generator. With the proper winding redesign, output can be increased

4. Generator rotor rewind rejuvenates the rotating element. An increase in the temperature class of the associated insulation system from Class 130 (B) to Class 155 (F) benefits the user by extending service life and uprate potential

integrity during this process.

If stator-iron damage is identified, repair or replacement of the core depends on the extent of damage. In the past, core replacement was almost always performed with the stator positioned vertically. However, in some plants, the cost of stator removal for re-core is prohibitive. Horizontal stacking methods have been used frequently to repair cores in-situ, saving the cost of a heavy lift and also reducing the critical-path schedule.

Maximizing productivity

A typical Frame 5 generator has an expected lifetime of 30 to 40 years; some machines last longer, others fail sooner. Timely upgrades can boost productivity and help your unit achieve a long and productive life. Enhancements are available for minimizing the chances of an expensive failure, reducing the cost of maintenance, boosting output, etc. It basically comes down to economics: Is the payback worth the cost of the upgrade and the peace of mind that comes with it?

What follows are some upgrades and maintenance best practices for you to consider:

Stator rewind. Your vintage generator may still have its original asphalt mica folium stator windings, complete with hardwood wedges, string-tied end windings, and circuit ring cabling (Fig 3). With regard to return-on-investment, a stator rewind, whereby the windings are wound back to zero-hour, is perhaps the most beneficial upgrade of all. Another benefit: You generally can expect a 10% to 15% improvement in kilowatt-hour production with the switch from Class B to Class F insulation materials.

Rotor rewind. The original rotor winding insulation system in your classic Frame 5 probably consists of large flake mica and Class B-rated binders. Anticipate that your original end-winding blocking contains asbestos. Again, abatement, performed by a hazardous material specialist is important.

The original main field winding may or may not be suitable for reuse. Determining factors include tensile strength, yield strength, amount of physical distortion, etc. A complete rotor rewind, using an all-new Class F-rated insulation system would provide benefit in extended service life and uprate potential (Fig 4).

Retaining-ring replacement. Retaining rings arguably are the most critically stressed components within a generator. The stresses in the rings (especially at the fit areas) alternate between compressive load at standstill, and tensile load at speed. Your vintage generator may still have its original rings.

Replacement rings are forged from 18Cr18Mn alloy and can be of the ventilated or non-ventilated designs (Fig 5). This modern material is mechanically superior and much more corrosion-resistant than steels used in early Frame 5s. The 18-18 material typically is in stock, so if an issue arises suddenly, new rings can be manufactured without affecting the rotor rewind and/or recondition critical path.

Retaining-ring insulation. Current practice is to manufacture new retaining- ring insulation from a single piece of spun-wound epoxy-glass. The multiple layers of insulation and epoxy used previously are less forgiving to process variations. During rewind

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5. Upgrading retaining rings to modern 18Cr18Mn (18-18) material improves the reliability of these critical components while reducing the potential for stress corrosion cracking

6. Replace insulation each time you remove the retaining rings from the rotor. Table 2 shows the cost is relatively insignificant

7. Collector-ring replacement affords the opportunity to take advantage of modern insulation systems. Collector-ring diameters and dust groove depths may be brought back to OEM dimensions

operations, modern insulation can be manufactured to give a precise fit, preventing looseness and gaps which can allow the end arms to expand radially outward (Fig 6).

Collector-ring replacement. Collector rings can be remanufactured and replaced during rotor rewinds and/or reconditioning activities (Fig 7). This area often is overlooked. When replacing collector rings, new and improved insulation is added between the collector hub and the rings. The axial and radial lead insulation systems often are replaced during a rotor rewind. A word of caution after replacing the collector rings on the rotor: Make sure the brush rigging is realigned concentrically with the restored diameters to prevent rubs.

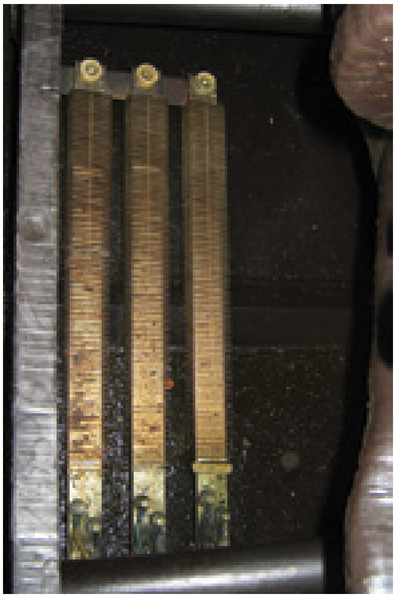
High-speed balancing, seasoning, overspeed testing. Although rotors can be rewound in the field, the inability to high-speed balance and conduct sophisticated electrical tests after the work is done increases the risk of startup issues (Fig 8). For example, during high-speed balancing, it is possible to test for shorted turns using the RSO (recurrent surge oscillograph) process, flux probe testing, and/or ac impedance testing. The rotor also can be tested for a running ground by performing an at-speed IR test.

Various examinations are conducted at standstill, as well as at operating speed and temperature, to insure that shorts and grounds do not develop. More expeditious and less expensive corrections are possible, since they are found before the generator is reassembled. The time requirement for field balancing is often eliminated or reduced to only a touch-up balance move. TIRs recorded before and after balancing insure mechanical fixity of all rotor components.

Overspeed confirmation (at either 110% or 120% of rated speed) insures the mechanical integrity of all components. After fully reconditioning a rotor, coupling faces and diameters should be restored to design conditions.

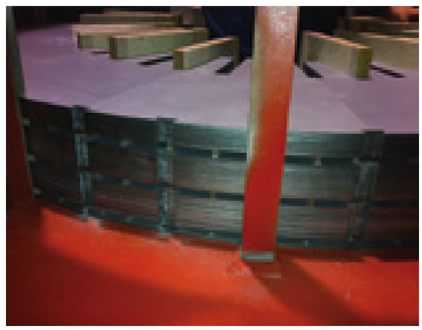
Resistance heaters. The operation of resistance heaters should be verified

8. High-speed balancing, seasoning, and overspeed testing greatly reduce the potential for rotor-related issues during startup



9. Resistance heaters are relatively inexpensive and simple devices that sometimes are overlooked despite their importance to the well-being of the generator

10. Bearing and seals with improper clearances should be repaired or replaced to avoid internal oil leakage, which contaminates the generator and causes major maintenance headaches



11. Core repairs and replacement restart the clock on another critical generator component. Modern silicon steels and advanced insulations are available with this upgrade

(Fig 9). If the generator stator temperature is maintained above the dew point, condensation is prevented. RTDs and heaters should be tested and replaced when not functioning properly.

Bearings and seals. It is always good practice to ultrasonically inspect the bearing babbitt for proper bonding to the shell and to check bearing clearances. Seals should be tight to keep moisture out of the bearing system, and prevent oil leakage into the generator stator (Fig 10).

Core repairs and replacement. Your vintage generator probably still contains the original stator iron. Stator cores can be completely replaced in the field (Fig 11). In the past, stator laminations were punched using large dies. Today, laminations can be cut precisely and quickly using laser technology. Modern silicon steels also are much more efficient and reduce core losses. Plus, the latest inter-laminar insulation coatings are electrically superior and mechanically tougher than those of yesteryear.

The new iron can be installed with the stator positioned vertically, or horizontally using spider-like fixtures and blocks of hardwood to align the new laminations during stacking. The iron is compressed using hydraulic jacks as the core is built out. A new stator core will provide associated renewed service life, as well as a degree of uprate potential.

Wrap-up

Your vintage generator may be a classic—between 20 and 40 years old—perhaps even an antique (over 40). But it was designed conservatively, constructed with craftsmanship, and built to last. Maintaining your unit in top condition begins with proper operation; know your capability curve and abide by its parameters. Conduct routine electrical, mechanical, and NDE assessments. Perform all associated maintenance. Remember that generator longevity demands clean and tight windings. Take advantage of today's upgrades when the economic equation points in that direction; extend your vintage Frame 5 generator's life and possibly increase its capacity. With such enhancements, your classic will stand the test of time. CCJ

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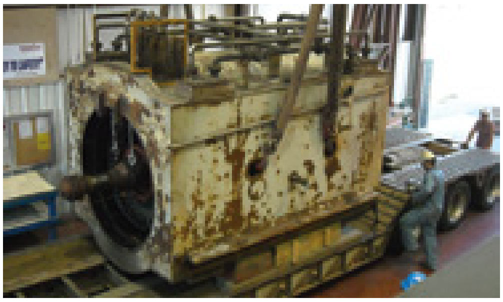
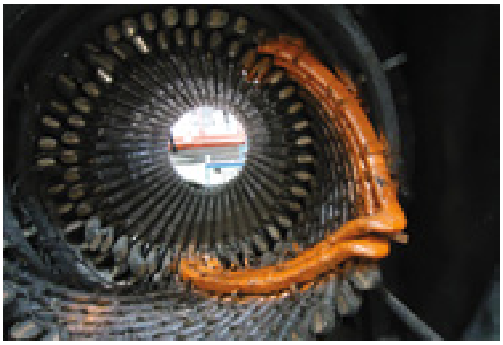
Rebuilding a classic in

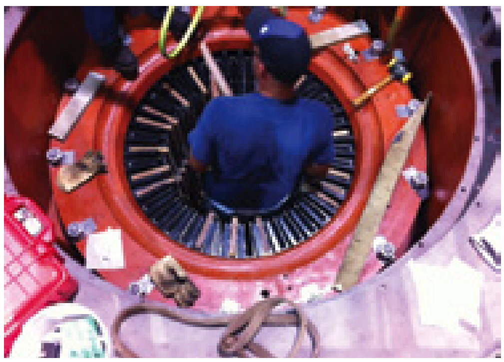


1 Classic Frame 5 generators typically arrive at the shop in poor condition. Mechanical, electrical, thermal, and environmental aging influences have taken their toll. Stator and rotor winding insulation systems usually are obsolete. Plus, retaining rings, collector rings, core iron, and the end-basket support system are dated and should be upgraded.

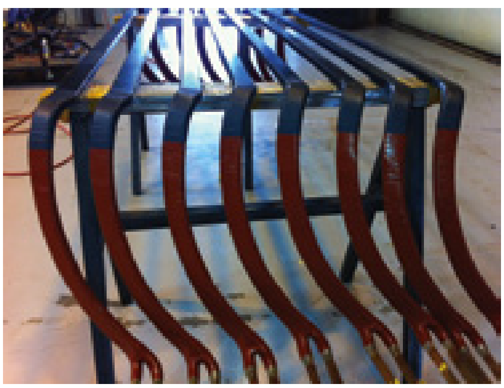


2 A classic commonly contains asphalt-mica stator windings. The straight-section outer binder, strand insulation, and/or end connection putty may contain asbestos; test prior to demolition. If positive, use only trained abatement specialists. As the stator windings are extracted, critical dimensions are taken for the engineering and redesign process.

3 Once stripped of the original windings, the stator housing and core iron are grit-blasted clean. Great care is required during this operation, because the stator laminations are susceptible to "smear" damage. Perform a near-flux core loop test to requalify the iron for reuse.



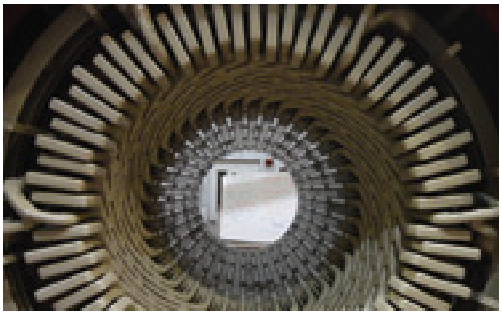
4 A full core replacement can be performed with either stamped punchings or laser-cut laminations. The lamination steel used should be either grade M6, Cold-Rolled Grain-Oriented (CRGO), or M15, Cold-Rolled Non-Grain-Oriented (CRNGO), with C5 core plating as the interlaminar insulation.



5 The original two-turn full diamond coils are upgraded to two-turn, 360-deg Roebel half-coils, which are far superior to the original windings in many ways, including these: They have more copper (lower I^2R losses), more conductors in-hand (lower eddy-current losses), and a Roebel transposition (lower circulating-current losses), as well as a modern resin-rich mica thermosetting insulation system.

15 steps

6 The new and improved windings are installed into the stator core iron together with the following upgrades: End-basket support system, vertical slot fillers, side packing, stator slot wedge system, encapsulated end connections, circuit ring bus, new RTDs, new heaters, a flux probe, and partial-discharge monitoring system.

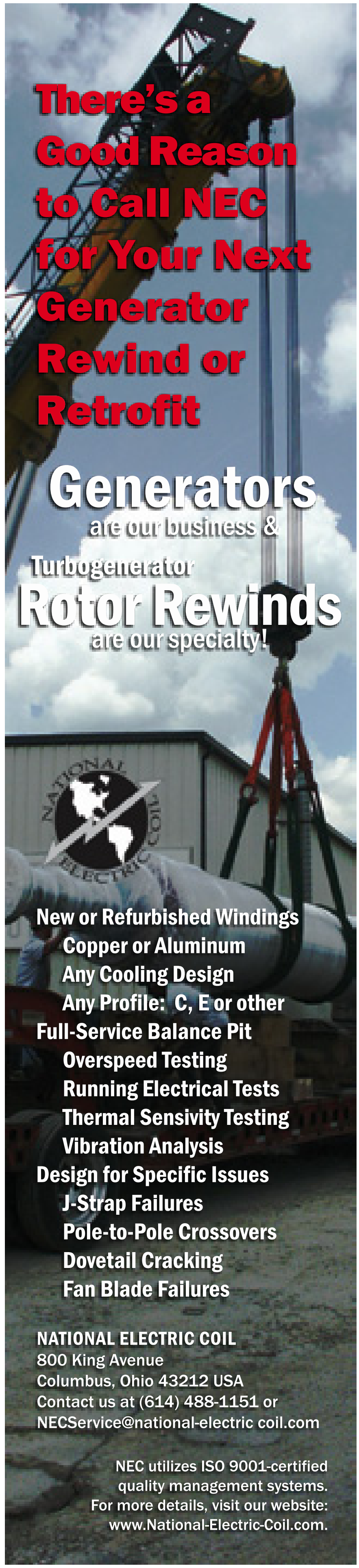


7 A comprehensive acceptance program is conducted following a stator-winding upgrade and includes successful completion of an El CID core test, wedge-tightness mapping, insulation resistance, Polarization Index, controlled over-voltage, ac and dc high potential, power factor and tip-up, and phase resistance.

8 The rotor is dismantled down to a bare forging, taking steps to avoid the release of asbestos-bearing materials, if present. Copper samples are removed from the main field winding and lab-tested for composition, tensile strength, hardness, and yield strength. Main field windings generally are suitable for reuse.

9 Rotor components—such as the rotor body forging, retaining rings, blower hubs, and rotor body wedges—are cleaned down to grey metal. Each individual part is subjected to requalifying nondestructive testing, which may include dye-penetrant, ultrasonic, eddy-current, and magnetic-particle examinations. Nonconforming parts are either repaired or replaced.

10 The reconditioned and requalified main field coils are wound back into the rotor-body forging. The latest turn-to-turn and ground-wall insulation systems are incorporated into the process. Slip-planes, critical to unimpeded axial thermal expansion and contraction of the windings, are designed into the upgraded main field winding system.



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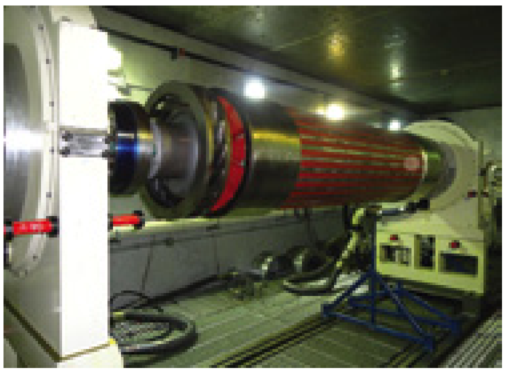
Rebuilding a classic, Steps 11-15

11 Specially designed and fabricated slot and end-winding compression fixtures are installed on the newly installed coils, forming a symmetrically round and dimensionally concentric main field winding. The rotor is then induction-cured, to set and stabilize the associated adhesives while seasoning the windings.

12 All new top creepage blocking is installed along with the rotor body wedges and a new permanent end blocking system. Should resin-load materials be used, the end windings are compressed once again, and the rotor windings are subjected to a second and final induction curing process.



13 The rewound, reassembled, and fully upgraded rotor is placed in the high-speed balance facility. There it is balanced to operational speed, subjected to a minimum 10% over-speed run, and at-speed electrical testing—including insulation resistance, ac impedance, RSO and/or flux probe.

14 The generator rotor now is completely upgraded, uprated, and "zero houred." With all new turn-to-turn, ground wall, and retaining-ring insulation systems, modern 18Cr18Mn retaining rings, and new collector rings, the classic Frame 5 rotor is better than when it was new and ready to begin its second life cycle.

15 The Frame 5 generator is a true classic in every sense of the word: simple in design, rugged in construction, and easily acceptant of modern upgrades and uprates. Rebuilding of vintage machines typically makes better economic and business sense than buying new. Owners can expect years of relatively maintenance-free service.

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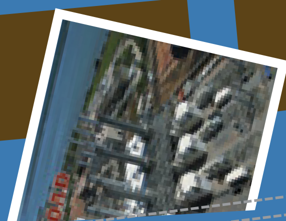

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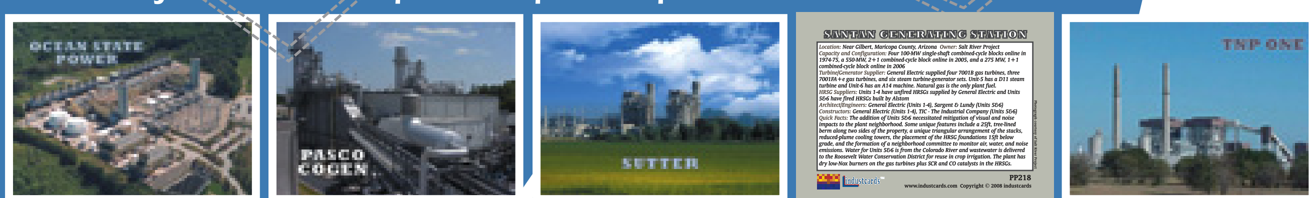

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The 2013 International Conference marks the second gathering of technical experts and end users to focus on all aspects of FAC in fossil and combined cycle systems. The inaugural conference held in 2010 was attended by 170 people from 21 countries and featured a technical program with 40 papers. The conference will be linked to the 2013 FAC Conference, May 21-24, 2013, organized by Électricité de France, which focuses on FAC in the nuclear power industry.

The 2013 International Conference on Flow-accelerated Corrosion (FAC) in Fossil and Combined Cycle/HRSG Plants will be held on March 26-28, 2013. Total attendance is targeted at 180 people. The conference will include an Exhibition Area and is seeking exhibitors and sponsors to support various conference activities. An Expert Panel and Roundtable Discussion is planned for the morning of March 29.

Who should attend the conference?

Anyone involved with FAC, including researchers, industry personnel (including engineers, chemists, operators and managers), and technical product and services organizations will benefit from attendance.

SummaryAgenda

Day 1: Tuesday, March 26
07:00 Registration/Exhibition Open
08:00 to 17:00 Conference Sessions
17:30 to 19:30 Social and Networking Gathering

Day 2: Wednesday, March 27
08:00 to 17:00 Conference Sessions
17:30 to 20:00 Conference Reception and Buffet in Exhibition Area

Day 3: Thursday, March 28
08:00 to 17:00 Conference Sessions
17:00 Conference Adjourned / Exhibition Closed

Day 4: Friday, March 29
08:00 to 12:00 FAC Experts Panel and Roundtable Discussion

Call for Conference Papers

The conference will consist of both invited and contributed technical papers. Abstracts must be submitted by September 30, 2012, to guarantee consideration by the conference chairmen. Authors will be notified of acceptance by October 31, 2012. Authors of accepted papers should be prepared to submit the completed paper and/or presentation materials by February 15th, 2013.

Person to receive abstracts: Barry Dooley via bdooley@structint.com

Subjects to be covered during the conference include:

- FAC in Fossil Plants
- Conventional Fossil Power Plants
- Combined Cycle Plants with Heat Recovery Steam Generators
- FAC in Other Industries (Refineries, Pulp and Paper, Dairies and Food Supply Systems, Industrial Steam Plants, City Steam and Water Supply Systems, Geothermal, etc.)
- Cycle Chemistry Influences on FAC
- Materials Aspects of FAC
- FAC Research Activities
- FAC Damage Mechanisms
- FAC Modeling
- Programs for Management of FAC
- Predictive Methods
- Inspection and NDE Technologies
- Repair and Replacement
- Life Management
- End User Experiences

Conference International Advisory Group Members

- David Addison, Thermal Chemistry, New Zealand
- Bob Anderson, Competitive Power Resources, USA
- Dr. Geoff Bignold, GJB Consulting, UK
- Professor Albert Bursik, PowerPlant Chemistry, Germany
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- Stan Walker, EPRI, USA
- Daniel Zinemanas, Israel Electric, Israel

For information as it becomes available, and to register, visit www.facfossilhrsgconference.com

Minimize operational risk with an onsite chemist

By David Addison and **Judy Weir,** Thermal Chemistry Ltd

Powerplant chemists are responsible for minimizing corrosion- and deposition-related failures in combined-cycle facilities. Their demonstrated positive impact on operations contributes significantly to plant efforts aimed at achieving top performance—a fact that often is not fully appreciated by station management.

The "unseen" nature of cycle chemistry work is one reason. Mechanical and electrical issues, by contrast, are quite visible, often causing equipment to fail and, on occasion, plants to shut down. The consequences of poor plant chemistry and chemistry control may not surface for years because of the delayed-development characteristic of the issues. Examples: Heat-recovery steam generator (HRSG) and steam-turbine damage mechanisms, such as under-deposit corrosion and stress corrosion cracking, respectively, can result in failures months or years after the initiating chemistry event or events.

Traditionally, combined-cycle plants have had small staffs because of their relatively high degree of automation and aggressive pro formas. Many of these plants have no chemist, or only a part-time position, or third-party management of cycle-chemistry functions. Each of these circumstances presents a degree of risk to long-term reliability.

Often the chemist's role, as viewed by plant operations and engineering personnel, is to collect samples and adjust chemical analyzers at the wet rack—and very little else. This is a gross understatement. The chemist's role is complex and multi-faceted, and when carried out correctly, contributes to improved plant reliability.

Another common misconception about the chemist's role in a combined-cycle plant is that it's an "easier job" than at a coal-fired steam station because there are no coal/ash chemistry issues to deal with. However, combined-cycle chemistry is at least as complex, if not more so, than that for a coal plant. Reasons include multiple boiler pressure stages, blended flows, mixed chemistry programs, etc. Plus, combined cycles are much more difficult to inspect and repair than a conventional steam unit.

Staffing levels are another consideration. A typical coal plant generally has four to five times the personnel assigned to a combined cycle of equivalent output. This means the combined-cycle chemist is sure to be assigned several part-time roles as well—such as health and safety, environmental compliance, etc—which impact the time available for core/strategic chemistry functions.

Key take-aways

- You can't run a large combined-cycle plant well without a chemist: Corrosion and deposition problems eventually will catch up with you.
- Routine, strategic, and troubleshooting chemistry functions must be conducted regularly: World-class plants do this.
- Operators will run your plant better if a chemist is onsite. A qualified "house" chemist assures better procedures, better training, better results.
- The most effective chemist will be adept at "talking the management talk."
- The full-outsource model for chemistry services usually looks good financially, but science often is lacking. Consider outsourcing carefully, very carefully.

Key areas of cycle chemistry

For the chemist to fulfill his or her core mission of preventing corrosion- and deposition-related failures consistent with plant operating objectives, proper attention must be given to the routine, strategic, and troubleshooting aspects of cycle chemistry.

Routine chemistry incorporates the core cycle-chemistry functions that must be handled daily by a chemist, chemical technician, operator, or contractor *to prevent issues today*. They include ensuring:

- Instrumentation is working correctly.
- Dosing systems are operating properly.
- The correct grab samples and chemical data are being collected for analysis.
- Compliance with operating limits.
- Makeup water is being supplied within spec.

Strategic chemistry. Routine chemistry is only one aspect of what a chemist needs to do to protect a combined-cycle plant against corrosion- and deposition-related problems. Strategic chemistry, a second aspect of the job, focuses on the long-term chemistry functions that must be accomplished to *prevent issues tomorrow*. These are among the "unseen" activities a chemist responsible for—ones equally important as those activities that fall under routine chemistry. Strategic chemistry includes the following:

1. Development of site-specific cycle-chemistry guidelines for:
   - Establishing chemical regimes for the various plant areas, stating set points, limits, etc, and how the chemistry will be achieved.
   - Identifying the person responsible for ongoing monitoring and maintenance of chemistry-related plant and equipment.
   - Deciding on the operational and/or maintenance changes required to ensure chemical limits are met.
   - Compiling a troubleshooting plan to address possible chemical problems that could occur in any plant area.
2. Conduct routine corrosion-product studies to determine cycle-chemistry program effectiveness and to help identify potential flow-accelerated corrosion (FAC) locations.
3. Conduct routine mechanical- and vapor-carryover testing to deter-

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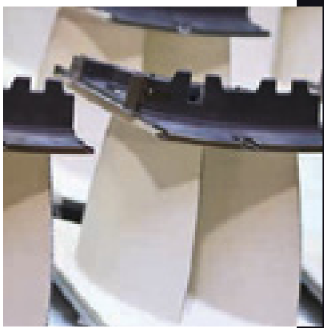

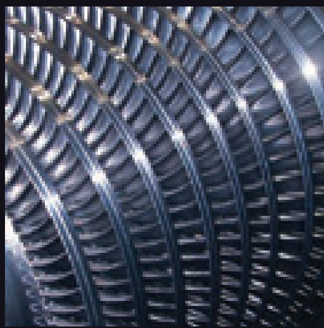

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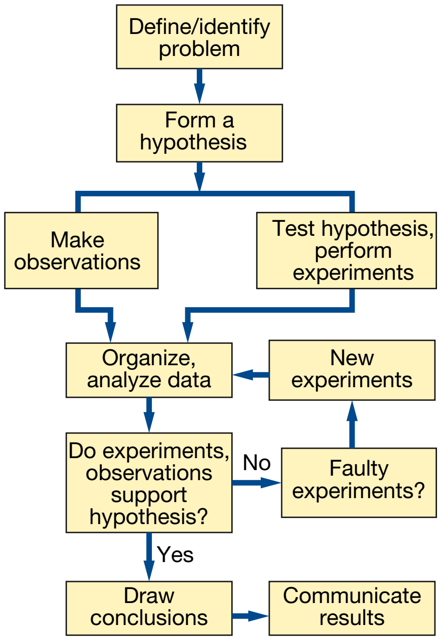
4. Develop a management plant to ensure plant-specific FAC-related risks are being managed correctly and effectively.
5. Analyze operating data to support acceptable long-time cycle-chemistry performance. This requires that all online chemical analyzer data be transmitted to the plant control room and archived.
6. Make inspections to assess the internal condition of the overall plant and to link the online cycle-chemistry data analysis to the actual physical condition of the major equipment.
7. Conduct training for plant engineering and O&M personnel to ensure cycle-chemistry information is distributed and used correctly throughout the organization, and the chemist's role is clearly understood.

   The plant benefits tremendously by having operators who understand the importance of cycle chemistry and how to deal quickly and effectively with process upsets—such as one caused by a condenser tube leak—which seem occur most often in the middle of the night. Regular operator chemistry training is essential; refresher training is recommended annually or more frequently.
8. Participate in ongoing professional development to assure that the chemist's technical skills and abilities remain sharp. Expert information can be obtained by regular review of the latest literature/guidelines and by attending appropriate training courses and chemistry conferences.
9. Developing cycle-chemistry strategic plans to ensure future improvement projects are identified. The chemist needs a strategic plan consistent with the overall site operational and engineering plan that identifies where plant chemical functions are predicted to be over the next five to 10 years, and where improvements should be made. Include in this plan the work to "design out" future failure areas as determined by analysis of collected data and a review of the state-of-the-art and current best-practices guidelines.



1. The scientific method is a robust methodology for the investigation and understanding of chemistry-related problems which may be overlooked, misunderstood, or ignored during investigations by non-scientifically trained persons

For new combined-cycle projects, the chemist should be intimately involved with the specification and design of any chemistry-related unit operations. Involvement in upgrade projects may include writing of technical specifications and specific project-management assignments—such as the management of HRSG chemical cleaning activities.

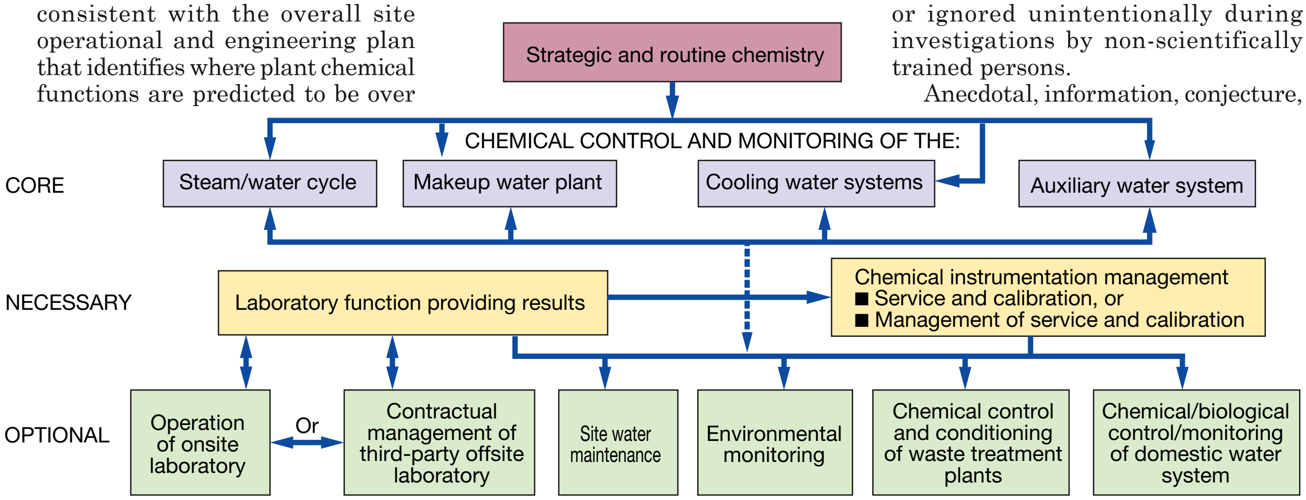
Troubleshooting chemistry involves the investigation of issues that must be conducted now to better understand today's problems and to avoid new ones tomorrow. These include such things as:

- Undertaking root-cause-analysis (RCA) investigations of failures and ensuring that remedial actions are implemented.
- Providing cycle-chemistry input to assist in investigations of plant problems—often to eliminate chemistry as a possible root cause.
- Using the "scientific method" to assure the correct outcome. This demands the following:
  1. Understanding the difference between causation and correlation as they relate to data analysis.
  2. Developing testable hypotheses.
  3. Eliminating bias and preconceived ideas that could influence the final outcome of the analysis.

Whatever name is used—be it troubleshooting, incident investigation, or RCA—they all require the investigation and resolution of significant plant problems or failures with a chemistry component. This often is carried out as part of a multi-disciplined team that also may include engineers, operators, and plant management. Such activities are closely aligned with strategic chemistry, but also contain aspects of routine chemistry, as additional sampling and testing often is required as part of the investigation.

It is the chemist's responsibility to introduce the *scientific method* to the other participants (Fig 1). Often underused and underrated in a combined-cycle environment, the scientific method will validate critical findings. It provides a robust methodology for the investigation and understanding of chemistry-related problems which often are overlooked, misunderstood, or ignored unintentionally during investigations by non-scientifically trained persons.

Anecdotal, information, conjecture,



2. A strategy proven successful for strategic and routine chemistry at a combined-cycle plant differentiates among core, necessary, and optional activities to assure that the most vital job functions are addressed first

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preconceptions, and poor understanding of the plant and its processes often lead to incorrect RCA results and the high probability of repeat failures. Important to remember: Never rely on anecdotal information.

Principal activities

The chemist's responsibilities in a combined-cycle plant can be divided into the three groups of activities described below and illustrated in Fig 2 for a hypothetical F-class plant with a full range of water-treatment requirements:

- **Core** activities are the critical functions that must be conducted to ensure high availability and reliability over the long term. They include both routine and strategic chemistry functions. The chemist is intimately involved in guiding the management of the chemical regimes implemented in the core areas to minimize corrosion and deposition.
- **Necessary.** Support activities required for accurate completion of core functions. Without them, the information analyzed in the core activities would be meaningless. The chemist is directly concerned with the product (or outcome) of these activities, and in many cases, will be involved directly in their management—supplying technical advice and input. Consider laboratory tests, for example. Regardless of who does the analysis, the chemist is responsible for ensuring the results are accurate and timely so the correct chemistry is maintained.
- **Optional** activities depend on the type and size of combined-cycle plant and what business decisions site management has made in the areas identified in the chart. The chemist only may be involved in managing interfaces between the core and optional activities. In some generating facilities, the chemist can have more involvement in the chemical management of these optional activities, including the responsibility for managing those assets.

Communication

A chemist must communicate with many different business units and people at both the plant level and at headquarters while pursuing his or her routine, strategic and troubleshooting chemistry activities. The most important communications are at the top of the list immediately below, the least important at the bottom.

- Station management.
- Station operations.
- Chemistry-related contractors and consultants.
- Station engineering.
- Instrument and maintenance technicians.
- Station/corporate environmental specialists.
- Health and safety.
- New plant/project business development.
- Corporate engineering.

The highest-priority communication target for the chemist is plant management, primarily because it is the plant manager who ultimately controls the budget and all plant activities. The chemist must clearly and effectively communicate the following information to plant management:

- Establish short-term (routine) and long-term (strategic) chemical requirements for the plant budget.
- Confirm that routine chemistry activities are being completed.
- Identify strategic chemistry risks, along with clear recommendations for the minimization of those risks.

Excellent communications skills are necessary to carry out successfully best-practice chemistry activities, which require the following:

- Both verbal and written instructions/requests/feedback/results, etc.
- Clarity in explaining complex terms and problems to plant management, complete with detailed descriptions of what is needed to resolve those

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problems with minimum impact on plant operations.

- A good grasp of the complexities of cost/benefit analysis and how to explain the outputs of that analysis.

PM critical to success

A chemist's success depends significantly on the degree of management support received—including the following:

- Sufficient budget for routine and strategic cycle-chemistry activities.
- A commitment to professional development and technical training for the chemist.
- Timely communication of changes to the plant operating environment—such as new cycling patterns and non-chemistry-related plant maintenance requirements that could impact cycle chemistry.

Staff vs outside chemist

It is becoming more common at combined-cycle facilities worldwide to combine the day-to-day chemistry activities with a chemical supply contract—a third-party package that theoretically eliminates the need for a chemist on the plant staff. This model often includes chemical supplies for both the HRSG and cooling-tower water along with regular site visits by a technical rep to do sampling and review of cycle chemistry.

Such arrangements are viewed favorably by budget-conscious plant managers and accountants. However, cost/benefit analyses of these contracts rarely are conducted using real cost data derived from the long-term consequences of not having a trained chemist (or technicians or operators trained in chemistry) on staff.

The use of a third-party chemical supply and services company in place of a dedicated in-house chemist has some inherent risks that plant managers and owners should be aware of—including:

- A focus on routine chemistry aspects only, with little or no attention to the strategic and troubleshooting chemistry needs of the plant. More robust terms might alleviate this shortcoming.
- The level of technical support and training of the service providers may be insufficient for the overall cycle-chemistry needs of the plant.
- Insufficient time is spent onsite, and usually there is no, or very little, follow-up on any cycle-chemistry issues identified. Information is collected but not analyzed.
- There can be a reluctance to raise complicated cycle-chemistry issues with plant management because of the potential repercussions and possible loss of the business contract.

If a chemical services/supply company is hired, its personnel should work with the plant chemist and report directly to him or her. This model has provided the greatest observed degree of success in relation to effective cycle-chemistry management.

Chemist staffing

The optimal cycle-chemistry-related staffing level for a given combined-cycle facility requires some analysis because it depends on plant design and configuration. Here are recommendations for three hypothetical plants:

- Plant 1: Up to 250 MW, multiple small gas turbines, single- or double-pressure HRSGs, water treatment plant, cooling tower. Staffing: one full-time chemist.
- Plant 2: 300-400 MW, single-shaft, triple-pressure HRSG, water treatment plant, once-through seawater cooling. Staffing: At least one full-time chemist plus half of a support technician's time; or support from a chemical service/supply company in place of the staff technician.
- Plant 3: 300-400 MW, single-shaft, triple-pressure HRSG, water treatment plant, air-cooled condenser or cooling tower. Staffing: At least one full-time chemist and a full-time support technician; or support from a chemical service/supply company in place of the staff technician.

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400 MW, add at least one more support technician or equivalent support from a chemical service/supply company. For plant 1000 MW or larger, two full-time chemists are recommended. These positions probably would be split into routine and strategic chemists. Thus, a 1000-MW+ combined cycle would have two chemists and two technicians, and possibly a graduate chemist/trainee support technician. CCJ

David Addison (david.addison@thermalchemistry.com) works with utilities and independent generators to resolve cycle-chemistry issues. Prior to launching Thermal Chemistry in spring 2008, he was senior project chemist at the Electricity Corp of New Zealand's (today, Genesis Energy) Huntly Power Station. Addison has a Bachelor's degree in chemistry and a Master's in materials science.

Judy Weir (judy.weir@thermalchemistry.com) is a powerplant chemistry consultant specializing in the design of new utility water treatment plants and cooling water systems and in the improvement of existing facilities. Training of chemists and operators is another of her responsibilities. Weir has two Bachelor's degrees in applied science (biology and chemistry).

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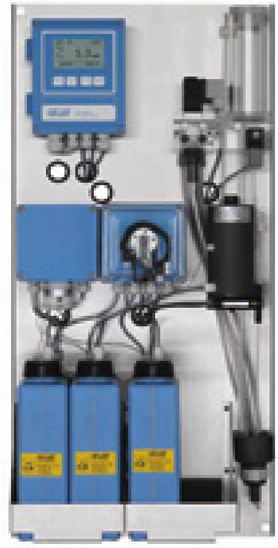

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Note: The 501F and 501G Users Groups are co-locating their conferences again this year and will have some joint sessions and a joint vendor fair.

2013 BEST PRACTICES Awards

Combined-cycle, cogeneration, and simple-cycle generating units powered by gas turbines

Deadline for entry: January 18, 2013

The editors of the COMBINED CYCLE Journal have tweaked the categories for the magazine's annual Best Practices Awards program, focusing them on industry issues to maximize the value of the solutions presented in the entries. Some general categories for years past, like design and management, have not attracted much interest of late and Senior Editor Scott Schwieger, who manages the program, and the CTOTF Leadership Committee, which provides the judges, collaborated on the changes.

At virtually all of this year's user group meetings, the concerns of owner/operators with grid requirements for fast-start assets, right-staffing and skills development, performance improvement, and Version 4 of NERC CIP standards, among others, took center stage. The new entry categories listed below enable users to share ideas on these timely subjects for the benefit of all.

The bullet points that accompany each category are "grey-matter triggers" to stimulate thinking on possible subjects for your entries. They are not meant to be specific subjects for entries, although they might be in a few cases. The administrative rules for the awards program essentially remain the same, the most important being the deadline for entries: January 18, 2013.

ENTRY CATEGORIES

1. FAST STARTS

- Engine/fuel system/controls/emissions uprates/improvements/enhancements to enable fast starting of existing gas turbines in both simple- and combined-cycle service.
- Improvements/enhancements to enable other grid ancillary services—such as black start, synchronous condenser, etc.

2. NEW SKILLS/WORKFORCE DEVELOPMENT

- O&M staffing plan (permanent employees) for the next 10 years in terms of numbers, skills development required, etc, for peaking and combined-cycle facilities.
- Training program for single plant or fleet (rotating staff).
- Multi-skills training—e.g., operator/mechanic.
- Specialized training—e.g. controls, cycle chemistry, etc.
- Capturing intelligence.
- Training for simple-cycle facilities running more.
- Finding time for combined-cycle training at high capacity factors.
- Scenario training—e.g., what-if problem solving, how to respond to off-normal and emergency conditions.
- Retraining programs.
- Qualifying employees for advancement.
- Repurposing coal-plant personnel for peaker and combined-cycle duty.

3. NERC CIP V.4 COMPLIANCE

- Implementation process.
- Self auditing process.
- Preparations for NERC auditors
- Personnel training.
- Document control/reporting.
- Physical security—e.g., complying with minimal impact on plant O&M and outages.
- Cybersecurity initiatives.
- Planning for V.5.

4. PERFORMANCE IMPROVEMENTS

- Starting reliability.
- Availability.
- Emissions reduction.
- Thermal performance monitoring program.
- Benchmarking.
- Data retention and analysis.
- Diagnostic and analytic tools.
- On-staff or contract service for monitoring.
- Program for identifying/correcting deficiencies; trigger points for action.
- Staff awareness/training.
- Condition-based maintenance program.
- M&D center.

5. PLANT SAFETY PROCEDURES

Goal is to identify successful procedures for assuring compliance with critical safety standards developed by such industry organizations and professional societies as:

- NFPA (56, 70E, 85, 850, etc).
- ASME Boiler & Pressure Vessel Code.
- IEEE.

6. OUTAGE MANAGEMENT

- Planning process.
- Outage safety programs.
- Pitfalls to avoid from previous outages.
- Personnel responsibilities—plant staff, fleet specialists, contractors.
- Improving upon past performance—e.g., reducing outage cost, shortening the schedule.
- Planned-outage strategy—e.g., shut down or run 1 × 1 while working on one GT and HRSG.
- Forced-outage strategy.
- Pre-outage inspection program to fine-tune outage scope.
- Review process for OEM alerts.

7. O&M—GENERATORS, TRANSFORMERS, HIGH-VOLTAGE ELECTRICAL GEAR

Best practices for:

- Inspection.
- Maintenance.
- Repair.
- Upgrade.
- Safety.

8. O&M—MECHANICAL: MAJOR EQUIPMENT, BALANCE-OF-PLANT

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- Inspection.
- Maintenance.
- Repair.
- Upgrade.

9. NATURAL DISASTER PREPAREDNESS/RECOVERY

In the wake of Hurricane Sandy, and the continuing challenges that face the East Coast during the recovery period, this category aims to spread best practices and lessons learned from this storm—as well as experience from previous hurricanes—while they are still fresh in the mind.

- Pre-storm procedures.
- Evaluation of flooded equipment.
- Repair equipment onsite/offsite.
- Recommissioning.

JUDGING/RECOGNITION

All entries will receive industry recognition by way of a profile in a special editorial section on Best Practices published in the Q1/2013 issue of the COMBINED CYCLE Journal. A panel of judges with asset management experience will select for formal recognition at an industry event next spring, the Best Practices they believe offer the greatest benefit to the industry given today's demanding goals of improving performance, reliability/availability, and safety, and reducing costs, while satisfying the requirements of ever more challenging regulations promulgated by EPA, NERC, OSHA, regional grids, etc.

RULES

1. Entries accepted only from employees of powerplant owners and third-party firms with direct responsibility for managing the operation and maintenance of gas-turbine-based electric generating facilities in the Western Hemisphere.
2. Maximum of four entries from the same power plant.
3. Entries must be received by midnight January 18, 2013 via regular mail/courier, fax, email, or online submission (http://www.ccj-online.com/best-practices/enter).

TO ENTER

1. Award category (select one):
   - Fast starts.
   - New skills/workforce development.
   - NERC CIP V.4 compliance.
   - Performance improvements.
   - Plant safety procedures.
   - Outage management.
   - O&M: Generators, transformers, HV electrical.
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   - Natural disaster preparedness/recovery.
2. Title of Best Practice.
3. Challenge: Description of business or technical challenge motivating the development of a Best Practice.
4. Solution: Description of the Best Practice.
5. Results: Document the benefits gained by implementing the Best Practice. For example, percent improvement in starting reliability or plant availability, dollar or percent saving in annual operating cost or reduction in annual maintenance cost, improvement in man-hours worked without a lost-time accident, etc. Please limit your response for Section 5 to the equivalent of three pages of single-spaced 12-pt. type. Add photos, drawings, tables, etc.,
6. Na me of plant.
7. Plant owner.
8. Plant personnel (and their titles and company affiliation) to be recognized for developing and implementing the Best Practice.
9. Contact for more information (name, title, company, phone, fax, e-mail).

Refer questions/submit entries to:

Scott Schwieger, senior editor, COMBINED CYCLE Journal, 7628 Belmondo Lane, Las Vegas, NV 89128.

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Presentations by Shuman, Tucker get meeting moving on a fast track

Knowledgeable opening-day speakers passionate about the technologies in their fields of expertise are critical to the success of user-group conferences. They stimulate thinking and discussion that can keep participants energized until the closing bell. The steering committee (sidebar) for the Frame 6 Users Group invited two of the industry's best—Alfred Shuman and Paul Tucker—to participate in its 2012 Conference at the Hyatt Regency in Greenville, SC, June 25-28.

Shuman, a senior consulting engineer for PAL Turbine Services LLC, Clifton Park, NY (near Albany), and Tucker, the founder/president of First Independent Rotor Services of Texas (FIRST), Humble, Tex, are experts on GE legacy frame gas turbines with decades of hands-on experience each.

Both presenters had their challenges and both handled them well. Shuman's presentation, "When Bad Things Happen to Good Turbines," focused on damage suffered by machines primarily because of carelessness and a poor grounding in fundamentals. With half the audience first-timers and the other half hard-nosed senior O&M personnel, you can see Shuman's dilemma: How to hold the attention of attendees with deep experience during a "basics" presentation that left some others with a "wow" look.

But the consulting engineer is a teaching pro who moved quickly through the material and kept the users engaged with a steady stream of questions that piqued the interest of the experienced, some concluding they didn't have *all* the answers.

Tucker's primary challenge was being the first speaker after a relaxing lunch. Tough to recapture the morning's energy, but he is one of the industry's top rotor experts and this group has many high-hours engines. So attendees representing units in cogeneration service, in particular, wanted to learn about turbine-rotor end-of-life evaluations.

Note that the Frame 6 Users attracts more O&M personnel from the energy-intensive process industries than any other gas-turbine user group. For example, participants at this year's meeting included representatives of Total Petroleum, Chevron, Shell, Foster Wheeler Martinez, Huntsman, BASF, Formosa Plastics, ExxonMobil, LyondellBasell, Berry Petroleum, etc.

Good turbines, bad happenings

Shuman began by reminding the owner/operators that no one is immune to making mistakes and that review of past errors helps keep you on your toes. Perhaps

Learned at

6 Frame 6 Users Group

Next meeting:

June 2013

Details, when available, will be posted at www.Frame6UsersGroup.org

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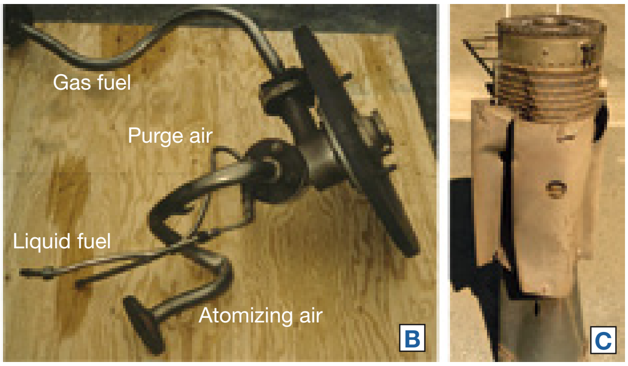


1. Failure of bolts (A) allowed combustion can cover to blow off **(B)**, causing collapse of liner and flow sleeve **(C)**

2. Portions of failed ductwork bolts were sucked into the inlet air stream and carried into the compressor, damaging airfoils. Note that the compressor shown is for a 7B. Shuman said he used pictures from Frame 5s, 6s, and 7B-EAs in his presentation, but that the damage illustrated has affected virtually all GE frames

no one in the room knew this better than the speaker, who started his career as a machinist's mate on the USS Nautilus (SSN-571), the world's first nuclear submarine, more than four decades ago.

Shuman can talk "mistakes" for hours on end from personal experience and because he has access both to PAL Turbine Services' extensive files on equipment dos and don'ts dating back half a century and to its silver-domed staff of 15, only two of whom have fewer than 30 years of industry experience. Judging from the employee resumes at www.pondlucier.com, many knowledgeable retirees build rewarding second careers at PAL. If you get to the site, visit "Turbine Tips" for a catalog of best practices and "The Turbine Cowboy" to share field engineering experiences.

Bolting. The retired sailor's fourth slide had the headline "WWII Liberty and Victory Ships." Everyone realized at that point, Shuman wasn't your typical industry speaker. By show of hands, about half the attendees said they had no familiarity with Liberty and Victory ships (too young, obviously), the first all-welded merchant vessels to serve in the war effort. The takeaway from the ship experience was the failure of many welds attributed to embrittlement—caused, in large part, by contaminants and excess hydrogen in welds.

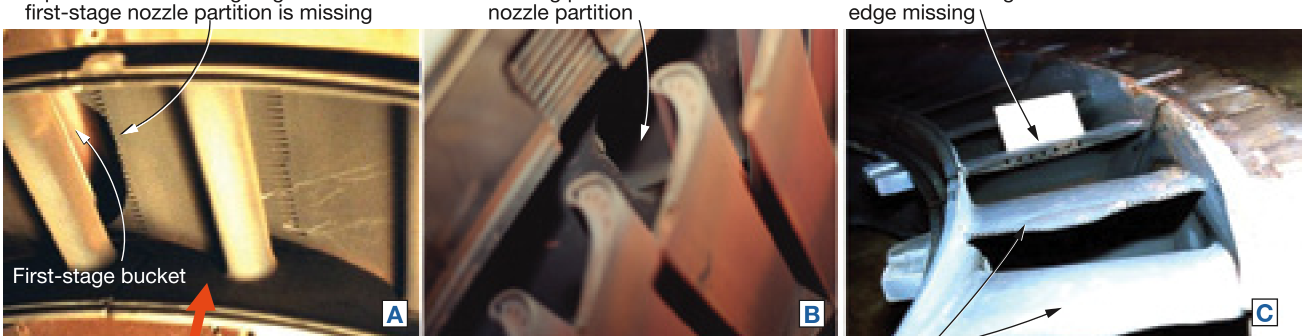
Shuman's message had nothing to do with ships or welding, but rather to the use of cadmium- and zinc-plated bolting. Don't use cadmium-plated bolts in the combustion, turbine, or exhaust sections of your gas turbine, he said. Above 450F, the cadmium melts and attacks the grain structure of the bolts and they fail. The failure mode is called "liquid-metal embrittlement," which is similar in nature to hydrogen embrittlement.

The combustion-can cover in Fig 1, complete with fuel nozzle and pigtails, launched when bolts failed because of embrittlement. The missile blew off the combustion compartment door, and the large pressure differential created when the cover went airborne caused the liner and flow sleeve to collapse.

Rusted bolting in turbine air-inlet ductwork can harm compressor components. Shuman couldn't figure out how to get his favorite photos of ships at sea in this segment of the presentation, just several pictures of compressor damage from failed ductwork bolts as illustrated in Fig 2. The ex-sailor stressed the need for first-class hardware and its proper installation to prevent bolts from going downstream into the compressor.

Ductwork must be inspected and maintained regularly, Shuman said. Holes in the rusting metal allow water and foreign material to enter the inlet house and get sucked into the compressor. Bolts holding sections of ductwork in place are inserted from the outside, he continued, with nuts on the inside tack-welded to their respective bolts. Any water leaking along a bolt, which is virtually impossible to see, eventually eats through that bolt allowing the nut and part of the bolt to enter the air stream. Your maintenance plan should include sealing of bolt penetrations as well as repair/repainting of rusting ductwork.

Shuman pointed to the inlet bell-

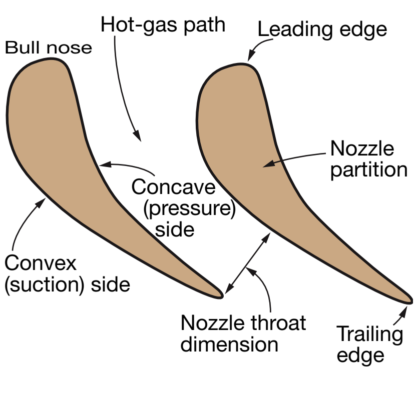


3. Gone missing is a portion of the trailing edge of a first-stage nozzle partition **(A)**. The same damage is shown looking upstream from behind the first-stage buckets in **B**. Another view of the missing trailing edge is in **C**, which also shows how the trailing edges of adjacent vane partitions have been pushed upstream by the FOD mouth in a cutaway slide and told the group that the pressure drop in that area increases air velocity to Mach 0.5, so any material entrained in the air stream goes into the compressor with conviction. He also mentioned that the delta P across the inlet throat produces a 23-deg-F drop in air temperature. This is why you can have icing and associated compressor-blade damage when the ambient temperature is above freezing.

Cautions with open casings. Ask labor to tell supervisors when tools, parts, or other foreign objects fall into open casings. Everyone knows this, but the message must be reinforced daily during outage reviews, Shuman said. "Stress that no one will be fired or censured, as long as the incident is reported promptly." He then offered two case histories of when bad things happened because of the failure to remove tools from inside the engine after an outage.

In the first incident, the output of a 7EA following a hot-gas-path (HGP) inspection was significantly less than before the outage. Compressor discharge pressure was higher than expected. Testing indicated a problem in the turbine section. The combustion section was opened and an inspector snapped the photo in Fig 3A from inside the wrapper. Note that a portion of the trailing edge of one first-stage nozzle partition was missing. Fig 3B shows the damage looking upstream from behind the first-stage buckets. Fig 3C offers another view of the missing section of trailing edge and shows how the trailing edges of other vane partitions have been pushed upstream by the foreign object.

Shuman said that the high compressor discharge pressure was caused by a tightening of the nozzle throat area because of FOD (Fig 4). He pointed out that the nozzle throat is the tightest orifice in the HGP and that even small deviations from its critical



4. Nozzle throat dimension is the tightest orifice in the hot-gas flow path

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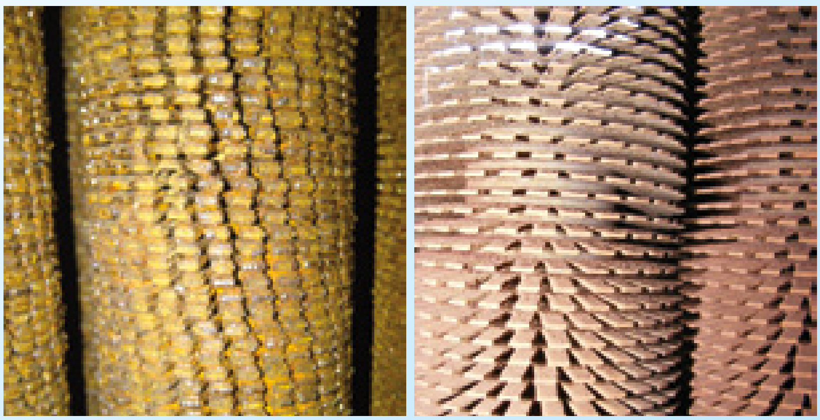

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dimensions can upset engine behavior. The speaker offered a diagram of the nozzle throat area with dimensions that should be verified by owner/operators or their contractors.

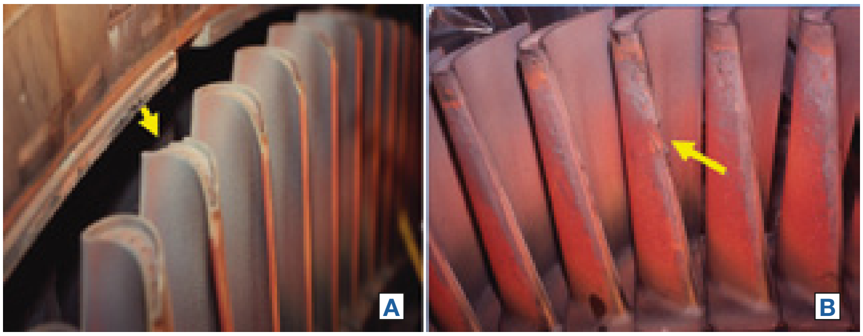
The control system, reminded Shuman, relies on readings of several variables—including ambient-air and exhaust temperatures, exhaust spreads, and compressor discharge pressure and temperature—to tweak unit operation. When the data imported don't match what the control system expects, it makes adjustments. In this case, the control system reduced fuel flow because the damage had restricted air flow through the unit.

The missing bullnose in Fig 5A and the denting of the leading edge of the first-stage bucket highlighted Fig 5B were caused by FOD. Examination revealed that one or more foreign objects tore through the nozzle partition shown in Fig 3A and then banged up some first- and second-stage buckets.

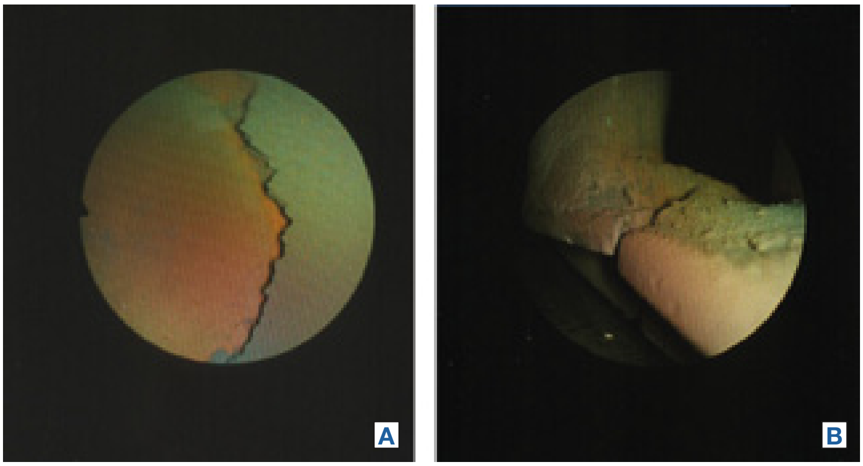
"Splatter" created by the thermal and physical destruction of FOD and liberated HGP components deposited on first- and second-stage buckets (reddish deposits on buckets in Fig 5B). Metallurgical analysis revealed multiple materials in the splatter; one was tool steel which had no business being in the engine. The "ah ha" moment came when the outage manager remembered that feather wedges used to align the combustion liners and transition pieces were made of tool steel. They had not been removed, as specified, before the engine was buttoned-up.

Second incident. A Frame 6B, restarted after a major overhaul that included replacement of all HGP parts along with a refurbished CDC (compressor discharge case) inner barrel, was expected to show a significant improvement in unit performance. Instead, plant personnel saw a reduction in power output of about 9%. Tuning and other adjustments did not help.

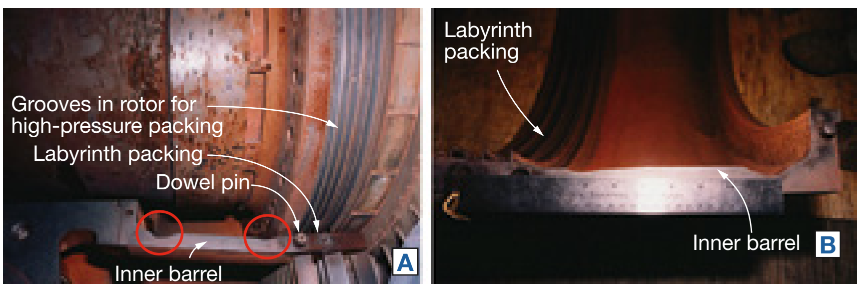
Performance tests were conducted and a borescope inspection ordered.



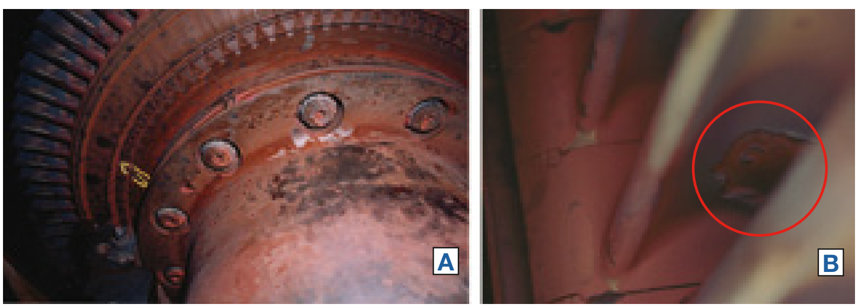
5. FOD damage to the bullnose of one first-stage bucket is shown in **A**, denting of another R1 bucket in **B**. Important to note is the reddish "splatter" on the buckets in **B**. That term describes the tiny particles of metal created by the thermal and physical destruction of FOD and HGP components which were deposited on both first- and second-stage turbine buckets



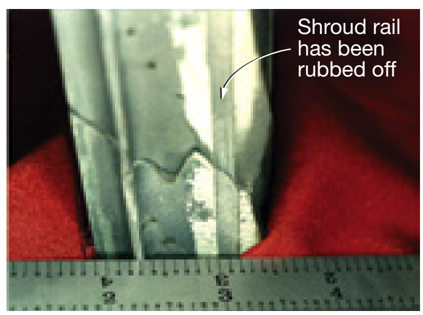
6. Borescope inspection revealed splatter on the pressure side of first-stage buckets near the platform **(A)** and on the leading edge of the second-stage bucket shroud **(B)**. The machine was opened based on these inspection results



7. FOD caused serious gouging of the inner barrel. Note that the close-up in **B** is of the upper casing half with the photo taken in the opposite direction of that in **A**.



8. First-stage buckets reveal splatter (grey) from FOD **(A)**. Photo was taken looking at the first-stage wheel where it interfaces with the distance piece. Close-up in **B** shows splatter deposit on the pressure side of a first-stage bucket



9. Second-stage-bucket shroud rail has been rubbed off by contact with shroud blocks because of too-tight clearances

Results of the latter were disturbing. Splatter was found on the pressure side of some first-stage buckets, near their platforms. Melted metal also had been sprayed on the leading edge of the second-stage bucket shroud (Fig 6). The engine was opened immediately.

Severe gouging was found on the inside of the inner barrel and the rotor was banged up (Fig 7).

Splatter on the first-stage buckets was easy to see with the machine open (Fig 8). Analysis of the splatter revealed material from the inner barrel and an unknown foreign object. Best guess as to what the foreign object was: A hammer!

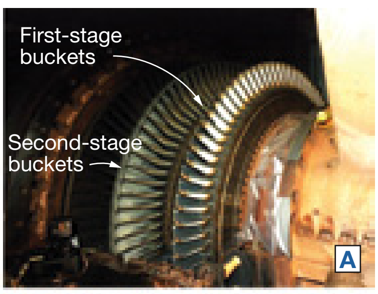
Accurate clearance measurements are critical to avoiding bucket rubs and consequential damage caused by rubbing. The effects of out-of-round turbine casings and too-tight turbine clearances are the root causes of rubs, which typically occur at slow speeds during the first start after an outage.

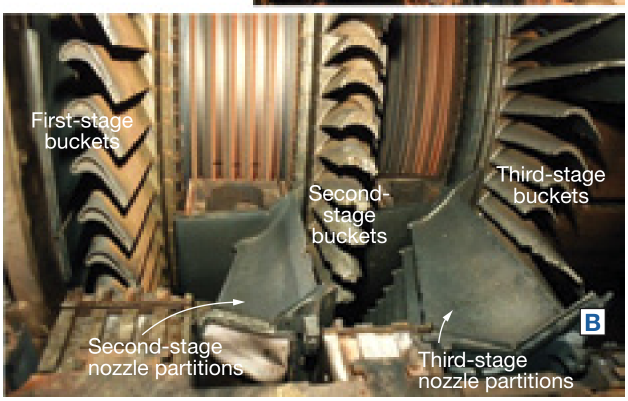
As the heat of friction causes metal to melt, globules high in carbides are formed. The hard carbides contribute to more rubbing with the rails on some bucket shrouds being completely worn off (Fig 9). When this occurs two things happen: (1) The shroud structure is weakened, and (2) sealing is compromised and gas bypasses the buckets, reducing performance.

Shuman suggested that some owner/operators may not fully understand the true costs of tradeoffs made during reassembly. "To measure is to know," he said emphatically. Even if you are going to change out turbine nozzle partitions and buckets during an outage, it's important to check all internal clearances after opening the unit and again before closing it.

Turbine, compressor, and bearing clearances are where the "rubber meets the road," he added. The OEM's design engineers view clearance diagrams with their specific tolerances as the bible for establishing performance and reliability parameters. Shuman stressed that the person taking the clearances must have a good understanding of how and where to take accurate measurements, recognizing that this task is one of the most important of the outage.

Ignore the OEM's recommendations at your own risk. Experienced speakers, especially ones working their way through multiple technical topics, know their audi-





10. Frame 6B turbine was in excellent condition when opened for the unit's first outage **(A)**, not so for the second outage **(B).**

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11. Collateral damage was suffered by the exhaust frame outer barrel

ences begin to tire after a half hour or so of "lecture," despite repeated attempts at humor. How to recapture the attention of listeners can be challenging. Shuman used the "shock" technique—few words and lots of pictures of damage no one wants to see when they open their unit.

One of his shocker topics was the Frame 6B bucket shroud-lift phenomenon. Some attendees were not aware that legacy second-stage buckets, in particular, are prone to creep and if operated unchecked might grow to a destructive length.

Terse lead-in to this topic: Unit was open for an HGP inspection; owner chose not to the follow the OEM's TIL (Technical Information Letter) recommendation to change to new buckets because of potential cracking on airfoils. Instead, the user repurposed a set of buckets from another unit at the site which had marginal shroud-lift readings.

Fig 10A shows what the unit looked like at the first outage, Fig 10B after saving money by not buying new turbine parts. Note that R1 buckets are only lightly damaged, but the second and third stages were chewed up badly. Plus there was collateral damage to the exhaust-frame outer barrel (Fig 11). There were more photos as well, most close-ups of ugly metal. Attention regained.

Reconsider eliminating the plant chemist position. Everyone is under pressure in the highly competitive power generation business: Cut people, reduce expenses, produce more kilowatt-hours. Plant chemists are an easy target for elimination: They can't operate the plant from the control room, they never have a wrench in hand. What do they do, anyway? Now ask yourself, "What does a fireman do when not putting out fires? Please read the article on p 98, "Minimize operational risk with an onsite chemist."

Corrosion was Shuman's next topic. He told that group that contaminating reagents can enter the hot gas path via ambient air, fuel (both oil and gas), evaporative cooling, etc, stressing that contaminants from all sources are additive in concentration and impact. The contamination example he presented illustrated the importance of water chemistry in maintaining a healthy GT environment.

Simply put, steam injected for NO_x control was attemperated before it entered the turbine to reduce combustion-zone temperature. Water for attemperation was provided from the condensate/feedwater system which contained the oxygen scavenger hydrazine.

A "hydrazine event" allowed an excessive amount of the chemical to enter the gas turbine where it leached out cobalt in the airfoils and turned first-stage buckets and nozzle partitions to scrap. Fig 12 shows the characteristic blue color of cobalt oxide. A seasoned chemist might have avoided use of oxygen scavengers altogether, as recommended by many experts in the field, or at the least had the appropriate instrumentation in place to warn of such an event.

Haste makes waste. This phrase can be traced to biblical times, so it's apparent that the human species is a slow learner. Shuman's last "lesson" concerned an overhaul team that thought it wise to rush the back end of a 6B major "to meet the schedule."

Repair of the resulting damage took 10 times the hours it would have taken to do the job properly the first time. Cost of the extra field labor hours and outage time were in addition to the cost of repaired and replaced compressor components. Photos revealed where retaining keys should have been locked in place, rubbing damage was experienced in the dovetail slot—caused by rotation of blade rings in service. Rubs and dings also were found on blades and vanes—a cornucopia of issues.

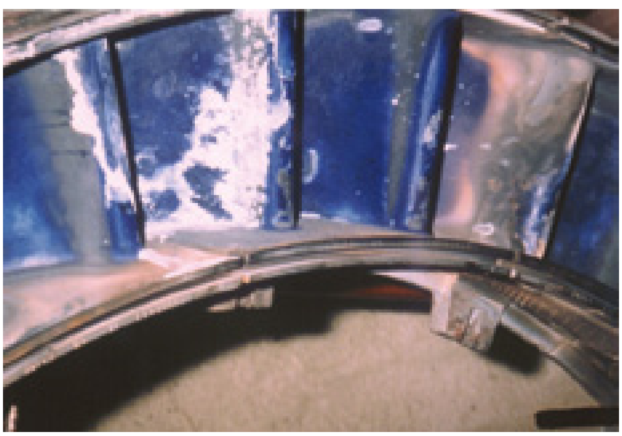
Wrapping up, the overhaul expert advised that if schedule is causing an inordinate rush, stop to think, review the situation, and act accordingly. Don't make mistakes that are avoidable; work safely, work smart. Following good engineering practices always trumps false economy, he stressed. Finally, account for every single tool and every part before closing up the GT. Then, before starting the engine, conduct a borescope inspection "to be sure."

End-of-life inspection

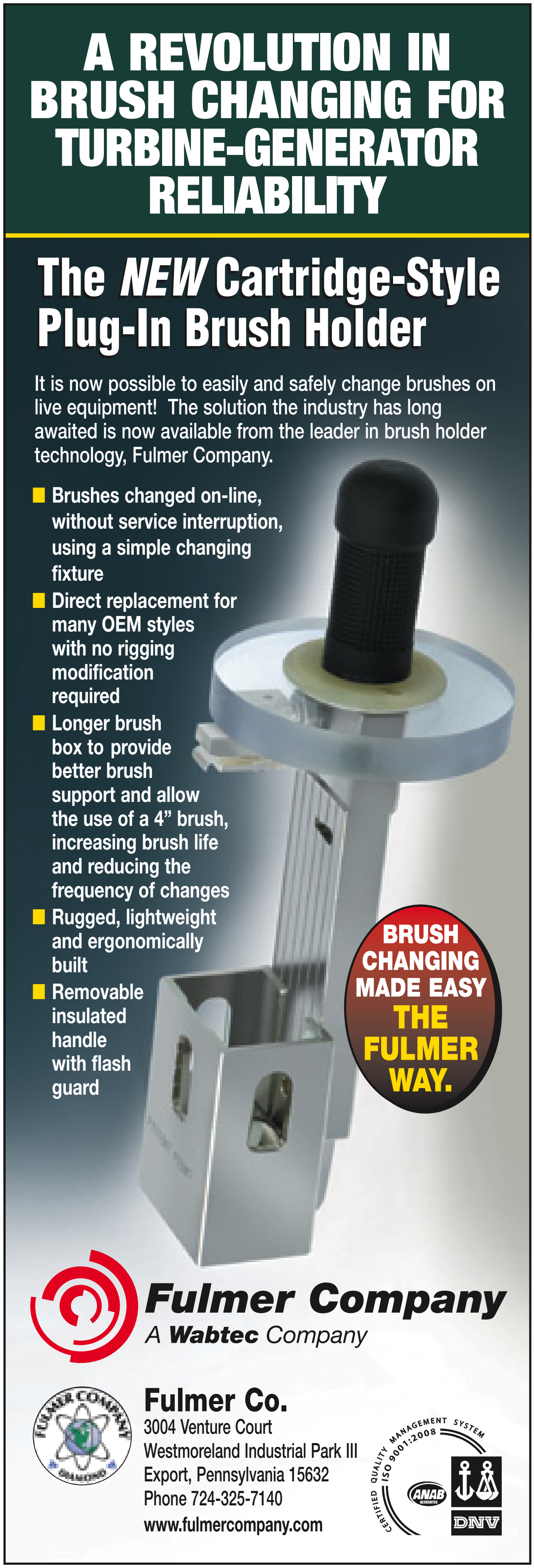
OEMs tell users their gas turbines have critical parts with finite lifetimes and that replacement of these parts may be necessary to assure reliability and safety moving forward. Rotors are a primary target of this initiative. Today, the only way to determine if an ageing rotor is in sufficiently good condition to continue operating is to disassemble it and to nondestructively examine (NDE) individual wheels, bolts, etc.

For readers unfamiliar with the Frame 6, the fleet was launched in 1978 by General Electric Co with the 31-MW MS6001A. To date, the 1200-plus units shipped worldwide by the OEM and its manufacturing associates for either 50- or 60-Hz power generation service have accumulated more than 60-million operating hours. Most engines serve in simple- and combined-cycle configurations, but a significant number also underpin cogeneration systems.

Industry shorthand refers to the engine as the "6B," only nine "A" models having been built. The first "B" that went into operation 31 years ago reflected a 5.7-MW increase in output over the first "A" and a 170-



12. Hydrazine leached cobalt from first-stage buckets and nozzles, destroying them



deg-F increase in firing temperature to 2020F. After four model upgrades, the PG5681B offered today is rated 41 MW at a firing temperature of 2084F. This design is now 12 years old. From the beginning, the single-shaft, two-bearing unit has employed a 17-stage compressor and three-stage turbine.

A focal point of the 2012 Conference was rotor lifetime assessment, a subject that has been on the Frame 6 Users' program for the last couple of years. Several owner/operators active in the group have engines north of 150,000 hours and wanted to know what they should be doing to meet the intent of the OEM's TIL 1576, issued in 2007.

The document requires rotors with 200,000 equivalent operating hours or 5000 equivalent starts (whichever comes first) to undergo a comprehensive inspection. Hours-limited rotors that pass inspection, with or without rehabilitation or replacement of critical parts, can be certified for extended service (50,000 or more hours). The OEM's current position reportedly is that rotors having accumulated 5000 starts are at end of life no matter how good they might look.

The steering committee, co-chaired by Jeff Gillis of ExxonMobil Chemical and Sam Moots of Colorado Energy, incorporated into this year's program a comprehensive and balanced look at rotor life management. It included the following:

- A formal presentation by the OEM on the subject.
- A special GE roundtable on compressor and gas-turbine life management.
- A user's experience with the OEM's rotor lifetime assessment process.
- A third-party service provider's methodology for, and experience in, conducting rotor end-of-life inspections.

The user speaking on his company's experience with GE's lifetime inspection service began with a backgrounder on the equipment inspected and the scope of the inspection. His plant's three 6Bs were commissioned in 1989 and had accumulated 180,000 fired hours in base-load service on natural gas using steam injection for NO_x control.

First step in the inspection process was complete rotor disassembly. Next came nondestructive examination (NDE) of CrMoV steel wheels installed in the turbine and aft compressor (rows 14-17), and the distance piece. Inspection efforts focused on dovetail slots, rabbets, wheel bores, and bolt holes. Ground rules specified that all indications found had to be evaluated by the OEM's engineers. Those evaluations might allow continued use as-is or require blending, repair, or component replacement.

The user purchased a new rotor and installed it in Unit 1. The original Unit 1 rotor was installed in Unit 2 after inspection and refurbishment. The Unit 2 rotor, in turn, was installed in Unit 3 after it was inspected and refurbished. A decision regarding the disposition of the original Unit 3 rotor is pending. The speaker said the OEM's schedule for the end-of-life (EOL) assessment typically is nine weeks, broken down as follows: two to three weeks for de-stack and clean-up; two weeks for the EOL inspection; three to four weeks for reassembly, assuming only minimal machining is required to correct any minor deficiencies identified.

The user next presented inspection results for one unit to give his colleagues a view of the types of NDE techniques employed and the level of detail sought. Here's what he said:

- Visual inspection and replication. Pitting was found in the bore from the compressor 16th stage through the second-stage turbine wheel, but it was not life-limiting. No microcracking or variations in grain structure were identified. Corrective action: Bore surfaces were reconditioned/honed to eliminate stress concentrations and bore fatigue damage.
- Magnetic particle inspection of each component produced no findings.
- Hardness readings all were within the OEM's serviceable tolerance ranges; no concerns.
- Ultrasonic testing of bore surfaces of all components covered in the scope of work produced no limiting findings. Some indications were found imbedded into the distance piece. They were considered "birth defects." Fracture assessments determined no anticipated propagations to failure within 750 starts—decades of useful life for a base-load unit.

The bottom line: The OEM certified this rotor for 750 total starts and 300,000 equivalent operating hours.

FIRST's Tucker. The third-party view on EOL inspections was provided by Paul Tucker and Gary Hensley, an NDE expert affiliated with Veracity Technology Solutions, Tulsa. Both were principals in the first third-party consortium to conduct EOL inspections of GE frames following the release of TIL 1576. Some believe Tucker, who worked in GE rotor shops for more than two decades before striking out on his own, and Hensley may have done their first Frame 7 EOL inspection before the OEM. Results of this inspection are profiled in the Frame 5 report, p 78.

The pair discussed ongoing work in EOL inspections, which at the moment, focuses on several Frame 5s. Tucker pointed out that while he and Hensley had not yet conducted a lifetime assessment of a Frame 6 engine, this machine is similar in many respects to the Frame 5s and 7s they have done.

Inspections conducted by FIRST/Veracity to determine if an engine is fit for duty include the following:

- 100% three-dimensional boresonic inspection for internal flaws.
- Eddy-current inspection for creep.
- Hardness and replication for grain structure.
- Critical diameters measured for bore shrinkage.
- Finite element analysis (FEA) when flaws are identified.

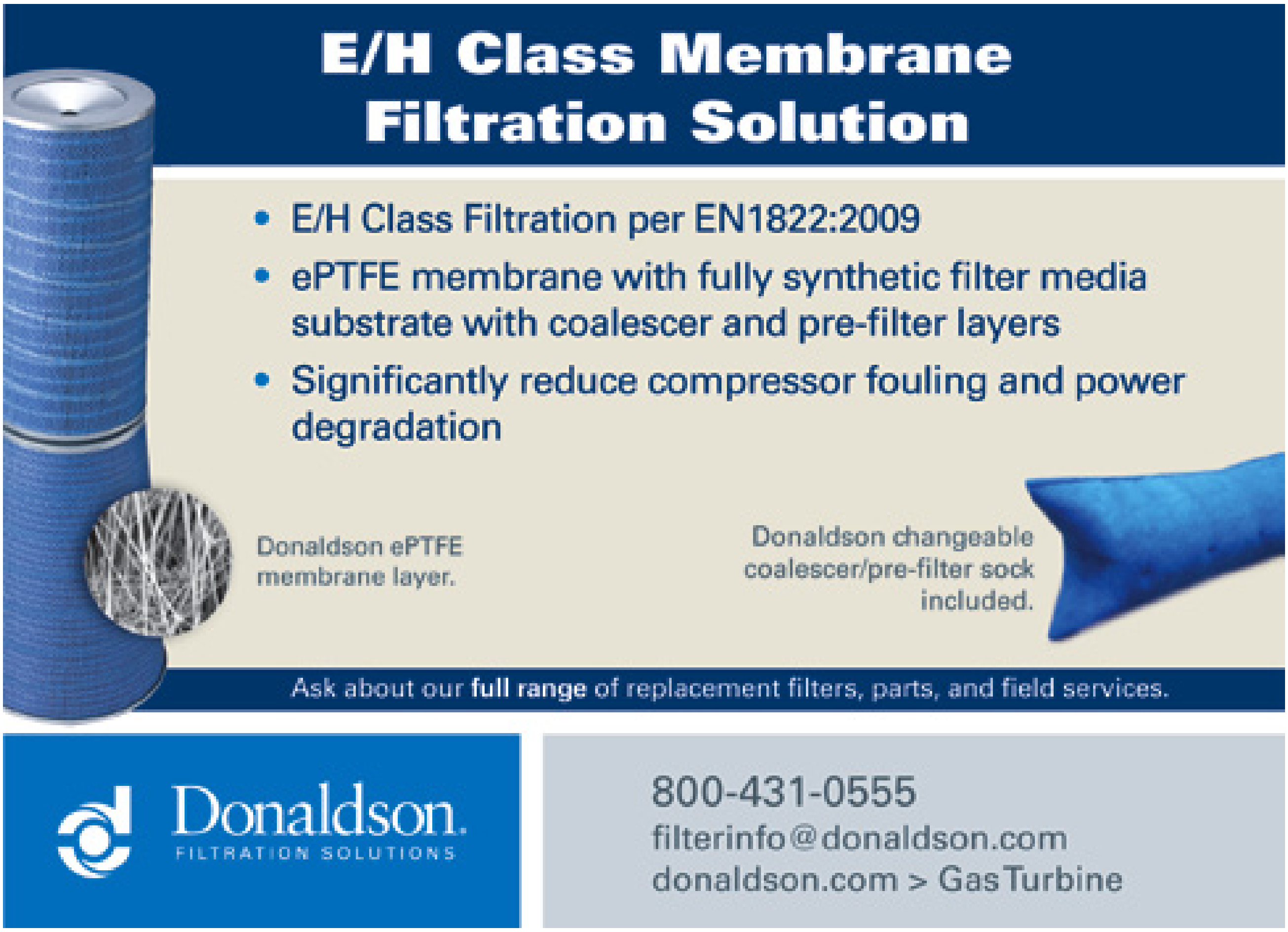
Regarding the last point, FIRST and associates have developed rotor-component fracture models to perform FEA analyses when needed. Tucker said that FIRST's critical flaw size and fatigue life estimations enable the company to analyze flaws with its models to see if flaw characteristics are detrimental to machine operation. He said the models can determine if specific flaws will fail, and if so, when in terms of hours and/or starts.

Inspections conducted by FIRST/Veracity nominally take five days; however, analysis of any flaw that might be found can add a couple of weeks or more to the schedule. It was at this point that Tucker suggested to the Frame 6 owner/operators that they do an EOL inspection earlier rather than later—during a major or when you're going to replace compressor blades, he said.

Having a baseline condition assessment enables users to better manage the lives of their rotors. Plus, if it appears that one or more components will have to be replaced in the future, knowing earlier allows owner/operators to plan for that eventuality and to order refurbished or new parts on a standard delivery schedule.

A question from the floor: If you do not find defects during an EOL inspection, how long will the rotor last? Tucker responded by saying that creep life is the user's greatest concern and asked rhetorically, "What margin of safety is built into the hours and starts numbers specified in TIL 1576? A factor of two, perhaps?"

The robust coverage of EOL inspections at the 2012 Conference reflected the group's interest in the subject at the previous meeting in Scottsdale, Ariz. There Greg Snyder, director of engineering for Dresser-Rand Turbine Technology Services



13. End-of-life inspections require an array of specialty NDE tools and knowledgeable technicians

(D-R TTS), Houston, and Rich Curtis, VP engineering for Eta Technologies LLC, Coventry, Ct, outlined a rotor life evaluation program that their companies had developed jointly.

Perhaps the greatest value of the Snyder/Curtis presentation was the checklists it provided users responsible for managing rotor evaluation programs. The checklists can assist in evaluations of the various service providers—including the OEM and third-party shops like D-R TTS. They also can help in writing specifications: You don't want to forget something important because you "didn't know."

Of course, some owners will just accept the OEM's hours and starts EOL limits and purchase a new rotor. Snyder acknowledged that a new rotor is the path of lowest risk, but it is the highest- cost option and the commitment lead time is considerable.

He next described the process the D-R TTS/Eta Tech team uses to enable retire/restore/replace decisions. It begins with customer inputs, critical for evaluating the impacts of prior and projected future operation. Here's some of the information you will be asked to provide:

- Operating hours: base load, part load.
- Starts: number and type (slow, normal, fast).
- Trips/load rejections.
- Shutdown time between restarts.
- Ambient environment data—for example, temperature, air cleanliness, location downstream of cooling tower plume, close proximity to saltwater, etc.
- Operating paradigm—for example, seasonal.
- Design configuration.

Assuming you have the requisite experience to have the turbine rotor removed from your gas turbine and shipped to a qualified repair shop with the capability for proper disassembly, you should come up to speed on the various inspections (and reasons for them) and engineering assessments necessary for decision-making.

Many detailed parts inspections were recommended by Snyder and Curtis, some requiring special skills in nondestructive examination (NDE) and metallography. They next reviewed the key considerations for the rotor-lifetime-extension inspections, including:

- Rotor construction.

- Original manufacturing and inspection processes and accept/reject criteria for the latter.
- Alloys of construction and original heat treatments.
- Failure/damage history for your turbine model (fleet) and your unit.

The inspection team you engage will "worry" about residual subsurface flaws from the manufacturing process, small subsurface defects linking to critical flaw size under low-cycle-fatigue (LCF) loading, creep damage, metallurgical changes over time, and the effects of prior "events" experienced by your unit.

Inspection tools include state-of-the-art volumetric ultrasonic testing using phased-array probe technology, advanced three-dimensional signal processing, and digital data archiving; plus, eddy current, fluorescent magnetic particle, visual, dimensional, metallurgical, and hardness measurements (Fig 13).

Critical areas to inspect include:

- Wheel bore regions.
- Bucket dovetail fits.
- Bolt holes.
- Bolt-circle contact faces.
- Rabbet fits.

The engineering phase of the rotor evaluation effort uses established analytical processes and methods for life assessment. Probabilistic evaluation also is part of this effort to assess sources of variation and the risk of a missed defect during the next interval. Engineering capabilities of the firm you select should include reverse engineering, finite element analysis (thermal and mechanical), materials testing and characterization, and analysis of LCF, creep, and crack propagation.

An assessment of in-shop repair capabilities—weld processes in particular—also should be part of your due diligence effort.

Optimal tip clearance

The segment of Alfred Shuman's presentation on damage caused by bucket rubs was a fast-moving alert for attendees (refer back to Fig 9), more than half of whom had not attended Lloyd Cooke's presentation on subject of tip clearance at the 2011 meeting. Cooke, an expert on hot-parts repairs at Liburdi Turbine Services Inc, Dundas, Ont, Canada, told the group that excessive turbine-bucket tip clearance raises your fuel bill because of lost performance, while insufficient clearance increases the cost of maintenance. The goal, he said, is optimal clearance.

Cooke noted that a gap of 40 mils between bucket tips and shroud blocks decreases power output by 1%—or about 400 kW for a typical 40-MW Frame 6B. This could penalize a base-load engine $100,000 annually, possibly more, depending on the cost of power.

Perhaps the best way to optimize tip clearance, Cooke continued, is to specify a high-strength casting (single crystal or directionally solidified alloy) for first-stage turbine buckets and apply an "engineered blade tip" of different material during airfoil manufacture. The latter is designed for superior oxidation resistance and sometimes contains embedded abrasive particles to grind into abradable coatings on shroud blocks, thereby creating the optimal clearance. The tip is applied as a powder metallurgy or sintered pre-form material and fused to the tip in a vacuum furnace.

It's not uncommon for a turbine bucket to suffer rub wear and high-temperature oxidation at the tip, Cooke told the group. Original alloys and conventional coatings are unable to prevent oxidation in high-performance engines. To compensate for metal loss—which can open tip clearances by as much as 30 to 60 mils—application of an oxidation-resistant weld alloy was recommended by the metallurgist.

He suggested a nickel-based alloy with higher aluminum content than the original casting—specifically Liburdi's L3667, which is applied using an automated welding process. More than 15 years of experience with this material, Cooke said, shows repaired buckets can achieve a full 24,000-hr service interval with no metal loss. Buckets then are repairable for additional service—possibly up to more than 100,000 hours.

To minimize second- and third-stage clearances, he presented the details on the company's honeycomb seal mod for outer shroud blocks and the advanced cutter teeth it welds to buckets. These solutions have been used by Liburdi on 7EA and 7FA engines.

Cooke pointed out some of the deficiencies of the OEM's original cutter-tooth design, which was conducive to friction heating of the rail and transfer of rail material to the honeycomb seal. He showed how the Liburdi pre-grooving solution with a Stellite cutter installed on one quarter of the buckets provided sufficient clearance between honeycomb and rail on both sides and top surfaces to prevent overheating.

Next topic: Shroud blocks. Mature engines suffer turbine-casing distortion over time, Cooke said, and Shuman reiterated. Casing radial dimensions, and tip clearances, are tighter at split lines because of the rigidity of bolting flanges. Inspections reveal that shroud blocks at top and bottom dead center usually are not rubbed because there is excessive tip clearance at these points and close to them.

Thus, the strategy of simply restoring bucket tip heights is defeated by shroud rubs incurred because of out-of-round casings. The Liburdi solution here is to tailor shroud-block thicknesses to accommodate casing distortion by forming a close-to-cylindrical arc for the turbines blades. Cooke explained how casing measurements are taken to determine shroud-block radial adjustments.

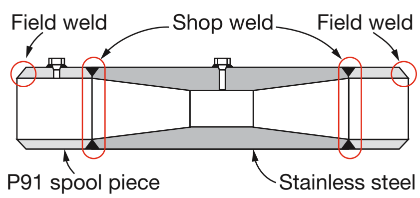
The composition of shroud coatings was the final subject of the presentation, which had not been reported on previously by the **CCJ** editors. Early shroud-block coatings, Cooke said, were dense MCrAlY or ceramic thermal barrier coatings (TBCs). Both were not truly abradable and contributed to bucket-tip metal loss when there was contact between the airfoils and the shroud.

Today's shroud coatings typically are abradable—that is, friable and sacrificial during a rub. But they must be oxidation resistant as well. High-porosity TBCs applied by air plasma spray can be used for internally cooled F-class blocks. But they are not appropriate for uncooled E-class blocks because of their high hardness.

A high-porosity MCrAlY top coat applied to uncooled E-Class blocks by air plasma spray is recommended because it is both abradable and oxidation resistant. The first part of the two-part coating consists of a MCrAlY bond coat for oxidation resistance and adhesion. The 25% to 35% porosity top coat is achieved with polyester sacrificial fill.

HRSGs, steam systems

Frame 6 meetings dig deeper into heat-recovery steam generators (HRSGs), and steam systems in general, than any of the other model-specific gas-turbine user groups—probably because of the engine's widespread use in cogeneration systems at process plants. Recall "Re-engineering, new surface



14. Flow elements that have been problematic were supplied with stainless-steel venturis and welded into P91 piping

boost reliability, efficiency, operational flexibility," published in the 2Q/2011 issue, which profiled the redesign/rebuild of a 20-yr-old HRSG at Huntsman Petrochemical Corp by Abilene-based Rentech Boiler Services Inc (access article at www.ccj-online.com).

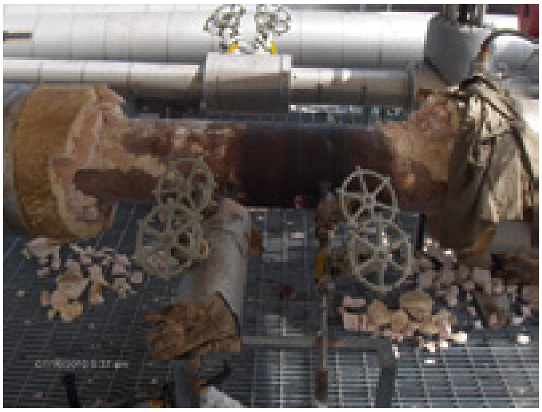
A discussion on dissimilar-metal welds in steam lines and HRSGs that took place at the 2011 meeting after the Huntsman presentation and not covered in the **CCJ** until now is important from the standpoint of personnel safety. Two attendees from a Gulf Coast process plant began asking questions about HRSGs and steam systems—specifically about the experiences of others regarding flow elements supplied with stainless steel venturis shop-welded on both ends to P91 pipe using Inconel weld metal filler (Fig 14). No response, so the natural follow-up question was "Why do you ask?"

Turns out their plant suffered a catastrophic failure of a shop weld on a 16-in. flow element in a nominal 1500-psig/900F main steam line (Fig 15). Remarkably, no one was injured, but damage was extensive. It took approximately 45 days to restore the facility to an operable condition and allow for safe startup.

Root cause analysis (RCA) revealed that the P91 pipe was buttered with a deposit of 0.25 in. of Inconel 182 and then welded to the Type 316 stainless steel throat. The fracture occurred at the edge of the P91 pipe weld, at the interface with the buttering layer. Cracking in the heat-affected zone was identified as the failure mechanism. Also important: The line blew less than two hours after the leak was identified.

15. Catastrophic failure of a shop weld on a 16-in. flow element in a nominal 1500-psig/900F main steam line miraculously injured no one

The editors recalled writing on this particular subject as part of their coverage in CCJ ONsite of a 501F Users Group meeting. However, the weld failure described at that conference was identified before any physical damage was done (Fig 16). Three of



16. Failure of this dissimilar weld was spotted before any collateral damage occurred

the four flow elements installed at the combined-cycle plant were found to have cracks of at least 11 in. (circumferential length) on the bottom side of the upstream shop welds. The plant's assessment was that the different coefficients of thermal expansion caused weld cracking under cyclic operating conditions.

The user representing the affected plant urged attendees to inspect all welds joining dissimilar metals—at least by checking for hot spots in the insulation. He recommended that any multi-metal flowmeters found should be replaced with flow elements made entirely of P91. The prevailing wisdom during the construction boom of the late 1990s/early 2000s suggested that stainless venturis offered erosion resistance that P91 might not.

Wonder why so few people in the generation sector appeared unfamiliar with the dissimilar-metal weld issue regarding flow elements? Reason was no clear line of communication from the manufacturer of the flow elements to the end user. One supplier, Fluidic Techniques, Mansfield, Tex, a division of FTI Industries Inc, reportedly sent an advisory several years ago to OEMs and EPC contractors that purchased its product with dissimilar-metal welds. The manufacturer did not know the names of the plants where the flow elements were installed.

Alstom is one OEM that alerted its customers with Service Information Letter (SIL) 2008-01, "High-Pressure Steam Flow Meters with Stainless Steel Venturi in Heat Recovery Steam Generators." It clearly states at the top of the two page bulletin, "Warning! Potential for Personal Injury and Equipment Damage." The bulletin presented background on the issue, plus a technical discussion and recommended actions.

Recommendations of knowledgeable parties were generally similar. Specifically, the affected Gulf Coast process plant suggested the following corrective actions:

- Identify all dissimilar-metal welds in critical service for inspection and evaluation.
- Eliminate the use of dissimilar-metal welded joints where possible.
- Implement flowmeter design changes to allow radiographic examination of body welds. (The failed flow element was of a geometry that did not allow for radiographic inspection.)
- Implement site procedures for welding 9%-chrome (P91) material.
- For any dissimilar-metal applications remaining in service, monitor with periodic inspection and develop a replacement plan.

Alstom in its SIL recommended against making a repair to a cracked dissimilar-metal weld in a flow element. Also, that the replacement or temporary repair (installation of a temporary spool piece) should be performed in accordance with standard practices and approved weld procedures.

The company suggested limiting personnel access to the area around a suspect flow element until it can be replaced.

Finally, the Alstom advisory noted that based on its long-term experience with dissimilar-metal transitions in the high-temperature circuits of conventional utility boilers, these welds are vulnerable when in cyclic service, but under base-load conditions can provide tens of years of trouble-free service.

Outage management

Outage management is a hot topic at most-user group meetings because it's not easy to remember everything you should do to ensure a successful gas-turbine overhaul, and how you should do it. With about half the owner/operators attending the 2012 Conference first-timers, one of the veterans offered his experience in outage planning as a segue to an open discussion on the subject.

Start planning 12 to 18 months ahead of the outage, the speaker said. This may sound like an extraordinarily long lead time, but some parts have normal delivery times of one year. If you have little history at the plant, he continued, gather up all the knowledge you can on the GTs: operations and mechanical history, parts lives, parts upgrades from the original installation, etc. Establish your goals, your expectations after startup—including output (At what ambient temperature?), emissions, vibration, oil leaks, etc. What guarantees are you looking for? What terms and conditions?

Background information and goals in-hand, it's time to begin planning the outage. Some of the things that must be done to move forward include:

- Select an outage team leader and identify team members and their specific responsibilities.
- Decide what equipment will be addressed during the outage: gas turbine, generator, HRSG, steam turbine (if installed), etc.
- Take a first cut at the scope of work: mechanical, instrumentation, electrical, inspections.
- Conduct an inventory of spare parts (mechanical, instrumentation, electrical), (1) verifying the condition of new/repaired parts in the warehouse, (2) identifying parts needed and ones that must be repaired, etc. Obtain quotes for needed parts, making sure they can be onsite before the outage starts. Assign a planner/scheduler to track all parts ordered and sent for repairs.
- Flesh out the workscopes outlined earlier, have team members review, incorporate changes, finalize. Develop bid packages incorporating the final workscopes.
- Decide which companies will be asked to bid, when the outage must start and when the plant is needed back in operation, what the work schedule will be (days only, two 10-hr shifts, work every day, etc).
- Schedule a day to meet with all bidders selected. Communicate expectations, review scope, conduct field walk-through, establish firm due dates for bids, stress the need for bidders to submit schedules for their work within the outage window and to provide labor rates for disciplines required.
- Select the successful bidders.

Have your gas turbine borescoped after you complete the outage work and before you restart to verify once

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more that there are no loose parts or tools inside the machine. Remember the examples Shuman presented above on the two units heavily damaged after multiple people signed off that the units were ready to operate.

There's a temptation to "tune out" during some discussions, perhaps on borescope inspections, because they sound like the same thing you've heard a dozen times before. But there's always something new brought to the floor and the challenge is to "remain engaged" to pick up on that material.

Example: One of the users alerted the group to the fact that there are two sizes of borescope holes in Frame 6s that he has—and the plug for one fits through the hole for the other. The user discovered this when the small plug fell through the larger hole into the machine and the upper casing half had to be removed to recover the "foreign object." Plant best practice: Do not remove a borescope plug if one is already out.

Safety

Fire protection. Make sure package doors are closed and sealed, otherwise your fire protection will be compromised, a user told his colleagues. Another mentioned the need for operators to enter his plant's package regularly to check gages. Doors remain open and are tied off as a safety precaution when operators enter, he added.

Someone else said that wouldn't work at his plant: New machines are designed to trip when you open the package door—as a safety precaution. For units relying on CO_2 as the extinguishing medium, package entry is prevented unless the CO_2 system is temporarily disabled.

Jam-up and sticking of package louvers was reported by several attendees. Proper louver operation should be tested at least annually, one suggested. They must be able to close in the event of a fire. Liquid lubes can glob up and inhibit operation over time, he said. Experience with dry powder lubricants has been acceptable, reported several plant personnel. Lots of "helpful hints" were offered, such as how to prevent wasps from building nests in CO_2 dispersion nozzles.

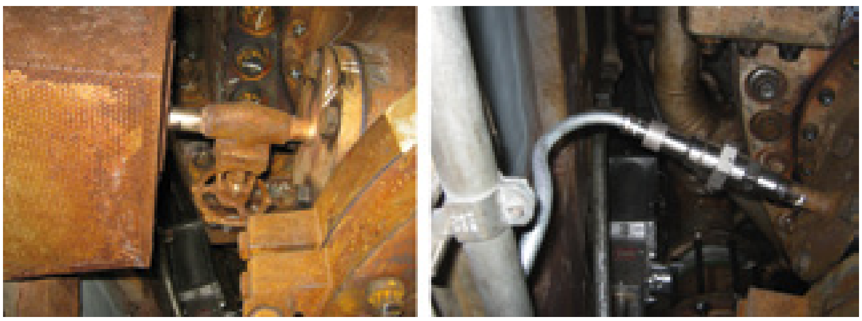
Fall protection received some air time. Discussion focused on poor footing in the neighborhood of the compressor inlet plenum as the cause of several injuries. Floor is curved there on some machines because of the nature of the inlet scroll installed, and it can be difficult to maintain balance to exit the air inlet area after adjusting inlet guide vanes, for example.

A couple of the long-term members of the group recalled that the purpose of the scroll—conceived by one of the founders of the Frame 6 Users and later adopted by the OEM as an upgrade—is to even out the flow stream entering the compressor and prevent failures of IGVs in the areas 45 deg from the vertical in the lower half of the unit. Not everyone agreed on the value of the scroll; a couple of attendees thought it inhibited maintenance access and felt they would be better off without it.

An arc flash discussion extinguished quickly. Not much mentioned other the proper attire and face protection. At one plant, operators wear Level 2 fire-retardant clothing all the time, so they always are protected. Safety precaution enforced at another plant: Only electricians are allowed to open breaker boxes.

Alternative fuels are pertinent to this group because many Frame 6 engines are installed in refineries and chemical plants. An attendee was investigating the use of a byproduct gas containing a high concentration of hydrogen.

Colleagues offered some suggestions and contact info for follow-up discussions. Another user discussed the two byproduct fuel trains at his



17. Water-cooled flame scanners (left) can cause nuisance trips, and concerns persist regarding possible damage to the turbine from leaking coolant. Conversion to a fiberoptic flame scanner (right) eliminates such concerns

plant—one containing hydrogen, the other CO. Neither fuel is available all the time, he said, and transitioning between the two can be challenging. Nitrogen purge was cited as critical to safe transfer.

One gleaned from the discussion that at least some systems for burning byproduct fuels, to accommodate availability and specific concentrations of combustibles, are unique and custom instruction in handling and combustion are necessary to assure a safe work environment. If burning alternative fuels in your gas turbine is a concern, consider burning them in the heat-recovery steam generator, rather than the gas turbine, assuming a boiler is installed.

Fiberoptic flame detector. Some users have reported that liquid-cooled flame scanners can cause nuisance trips because the sight tube turns into a condenser during startup and water droplets can form on the sensor lens and refract UV radiation. There also are concerns of potential damage to the turbine from leaking coolant. Conversion to a fiberoptic flame scanner eliminates such concerns and is relatively easy the group was told by one user (Fig 17).

Control of exhaust-end temperature motivated discussion. Too-high temperatures pose operational problems and a safety hazard, an attendee said. Varnishing of bearing oil and tunnel fires were cited. One incident reported: A fire was caused by spark ignition attributed to an overloaded fan wire. The spark set on fire lube-oil-soaked insulation (caused by a leak).

A major concern is instrumentation wiring in the exhaust end of the unit, which can have a thermal rating in the neighborhood of 300F—below the operating temperature in some overheated bearing tunnels. If sensor wiring is compromised, the fire protection system will not be activated and the fire will continue to burn.

LOTO. One takeaway was a pitfall of having too many lockboxes. At one plant with individual lockboxes for the gas turbine and HRSG, personnel identified a safety issue when GT tests were scheduled while maintenance was ongoing in the boiler. Fix was to consolidate lockboxes.

Black-start arrangements were a lively discussion topic. Attendees generally agreed there were many variations in circuitry among similar plants. Point was raised that the OEM has no standard black-start package and it often is left to the EPC contractor. Suggestion was to review this system if you change plants to make sure you know how it works; make changes as necessary to assure operational safety.

Confined space entry. In the past, one attendee said, if your head was out of the confined space your whole body was considered out; today, if any body part is in the confined space your whole body is considered

in the confined space. Some plants do not require a permit for confined-space entry and this was said to be fine with OSHA.

There was general agreement that the inlet plenum is a confined space. Consensus view to assure safety was lock out of the IGV before entering the inlet plenum. Pulling of actuator pins might be the best way to do this.

Compressors

The compressors open discussion covered the "waterfront." One user said his plant replaced its galvanized filter house with one of stainless steel to prevent more galvanized surface from peeling off and entering the compressor. In addition, the old trash screen from which bits of stainless-steel wire had been liberated was replaced by a Nimonic 50 screen, thereby eliminating unnecessary dings on compressor blades.

When replacing a filter house, another user offered, do not replace in-kind—redesign it. In many cases, you'll find the original filter house is one with marginal air-flow entry area and by opening-up the design you can reduce the pressure drop through the unit. If you go this route, a suggestion was to consider HEPA filters and size accordingly. Users with experience reflected a positive attitude toward HEPA filters.

Effectiveness of fogging, location of fogging nozzles, importance of droplet size, and plate-out of zinc on compressor blades were among the usual discussion points—and ones of greatest value to first-timers.

One user seemed concerned about the wear and tear on first-row compressor blades attributed to water droplets created by the fogging system installed at his plant. A colleague asked, "How much can you make by selling the excess power produced with foggers in service? He suggested conducting an economic analysis. His plant, he related, is on its fifth row of first-stage blades. The cost of new blades in his situation is relatively low compared to the revenue gain.

Compressor efficiency was another timeless discussion topic. Protruding shims pulled out/cut off/pinned were part of the initial exchange, as was take-up of IGV gear backlash. Lifetime of compressor blades then was debated. Several users in the room had more than 150,000 hours on their blades, none over 200,000. Others suggested that just because the blades were in one piece didn't mean they shouldn't be replaced.

Measuring of compressor efficiency was suggested. A couple of users contended that first-stage blades with long service hours tend to get flat spots and this costs you power. Replacing the row in such instances may squeeze another megawatt from a Frame 6.

On the subject of compressor washing, an attendee said his plant switched from one 30-min wash daily to two 15-min washes and that was beneficial. Someone else mentioned the OEM saying that 90% of the benefit of online washing was realized in the first 15 minutes. CCJ

Berry receives 2012 John F D Peterson Award

The Frame 6 User Group's John F D Peterson Award, given annually in recognition of extraordinary contributions to the organization and the gas-turbine sector of the electric power industry, was presented by the steering committee to Scott Berry of Indiana Municipal Power Agency. Berry, a former plant superintendent, and an active member of the Frame 6 steering committee for six years, currently oversees IMPA's compliance with NERC reliability standards and environmental regulations.

Borescope inspections offer insights for condition-based maintenance

Plant managers, particularly those responsible for combined cycles, need all the help they can get. Their jobs have become ever-more demanding because of increasing regulation, relentless corporate pressure to reduce costs, loss of experienced personnel to retirement, etc. One hands-on plant director recently told the editors that he never made it down to the deck plates during the last engine overhaul because of the mountains of NERC, OHSA, EPA, company, and other paperwork that had him handcuffed to the desk. First time that ever happened, he said.

In addition to all the regulatory and company forms and reports that demand "immediate" attention, there's a steady stream of OEM advisories flowing into the plant. Those require the plant manager's attention as well, because properly working equipment is critical to a positive bottom line.

Perhaps one of the reasons top management doesn't have a deeper appreciation for plant personnel is because the OEMs have senior staff convinced that after a relatively short "break-in" period, their gas turbines will work well until the first overhaul—years away in most cases. Then perform as planned until the following overhaul, and so on. Anyone who really knows generating equipment is aware that the classical "bathtub curve" doesn't apply here and damage occurs over time depending on the mode of operation, quality of parts and repairs, degree of unrealistic expectations, general "abuse," etc.

There are many variables that can be monitored to warn of impending problems—such as exhaust-temperature spreads, compressor discharge temperature and pressure, power output, lube-oil temperature, etc. However, there are things that can go wrong in an engine that cannot be identified easily—or at all—using operating data. These include spalling of coatings on hot-section parts, tip rubs of turbine buckets, clashing of rotating and stationary airfoils in 7EA compressors, etc.

Your "eyes" in such cases are inspection experts equipped with the latest borescopes and nondestructive examination (NDE) tools. Technicians with intimate knowledge of an engine's internals are the plant manager's first line of defense against catastrophic damage: They know what to look for and where to look.

The leading inspection companies are continually developing new techniques for identifying issues earlier than had been possible previously. Some also have tools for taking corrective action in-situ. User-group meetings are ideal venues for catching up on such advancements and experience with them.

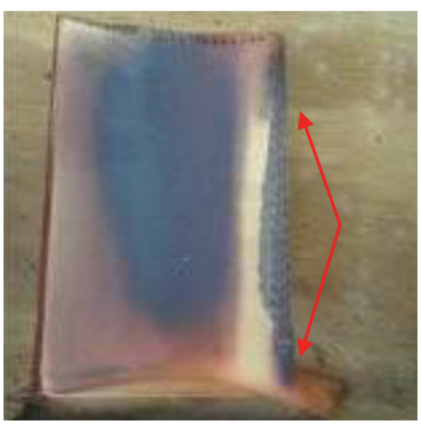
1. **Complete loss** of bucket tip cap is rare

To illustrate, what follows is a summary of the inspection results and recommendations presented by Rod Shidler, president, and Mike Hoogsteden, field service manager, Advanced Turbine Support LLC, Gainesville, Fla, this fall at the CTOTF™ and 7EA Users Group meetings. ATS is believed to conduct more inspections of gas turbines than any other third-party services provider.

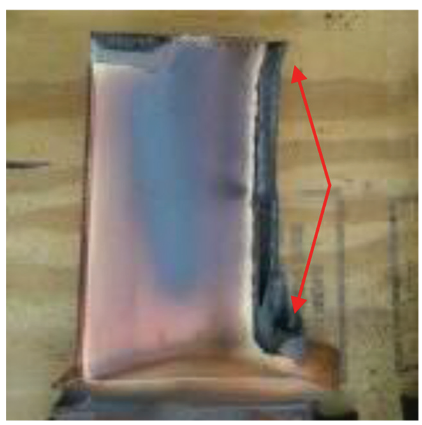
Tip-cap inspection

Shortly after the 7EA Users Group meeting at the end of October, Hoogsteden reported that ATS had perfected a specialized method for inspecting, without turbine disassembly, 7FA first-stage buckets for tip-cap damage or loss (Fig 1). This is important because such damage is conducive to a reduction in airfoil cooling. When that occurs, the expected end result can be a loss of coating on the leading edge of the affected bucket (Fig 2), or in extreme cases, the loss of the entire leading edge (Fig 3).

ATS technicians inspected all 92 first-stage tip caps on each of six



2. **Coating loss** from leading edge of first-stage bucket was attributed to tip-cap damage



3. **Leading-edge cap loss** occurs after the protection provided by the coating is gone

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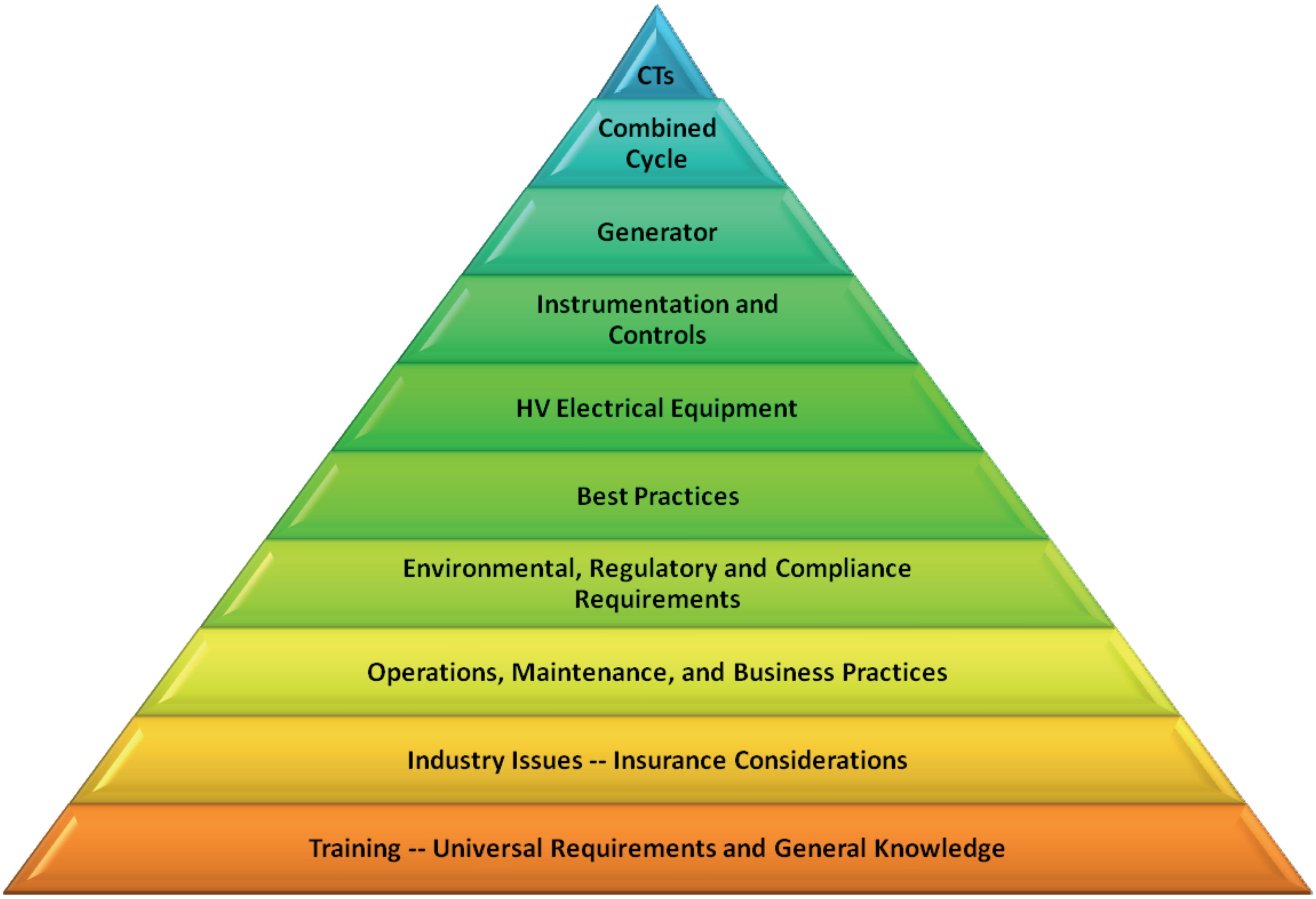
Consider Your Whole Plant



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4. Blocked cooling hole at leading edge of tip cap

5. Bulging and material separation at leading edge of tip cap. Note debris protruding through opening where the material has separated

6. Bulging and material separation viewed from the trailing edge

engines in the early fall. Four units were fine, two had buckets with damaged tip caps. Checking first-stage tip caps adds about four hours, depending on findings, to a typical 10- to 12-hr engine inspection. Hoogsteden said bulging and material separation of the tip cap, and plugged cooling holes, are likely precursors of eventual failure.

It's unlikely that damage to a particular tip cap would be reason to remove the GT from service, but the findings serve as an alert and enable users to better schedule an outage for repairs. Figs 4-9 illustrate the damage found in six different buckets in the two affected machines.

Clashing: No TIL yet

The annual conferences of the 7EA Users Group traditionally begin with a State-of-the-Engine report by Advanced Turbine Support LLC. At the 2012 meeting, Hoogsteden's presentation indicated that the number of issues identified annually in the ageing fleet is increasing. It's more important than ever, he said, to perform inspections regularly and properly to prevent "issues" from developing into catastrophic losses. Then the service manager stressed the need for owners' engineers to review promptly documented findings and to develop and implement programs to mitigate identified risks.

For many attendees, the highlight of the presentation was ATS's five-step clashing mitigation procedure that Hoogsteden introduced to the group. Recall that clashing—the term used to describe contact between rotating blades and stationary vanes in Frame 7 compressors (Fig 10)—has been a hot topic for years at the 7EA meeting.

ATS inspectors have documented clashing damage to the trailing edge of R1 rotor-blade platforms and the leading edge of S1 stator vane tips for the last five years. More importantly, accurate measurements of the damage have been taken over the last three years and records maintained for each affected vane, using the OEM's stator-vane numbering system. In several cases, data have revealed increases in clashing damage over time.

Absent a Technical Information Letter (TIL) on how users should address clashing damage, ATS offered the following procedure:

1. Check for clashing damage during your regular semi-annual or annual borescope inspection.

2. Perform an in-situ red-dye penetrant inspection on the trailing-edge platforms of rotor blades, stator-vane tips, and on the convex side of stator vanes where damage is in evidence.

3. Blend/crop in-situ the affected airfoils. The extent of the repairs is determined by the type of damage identified during the first two steps.

4. Apply in-situ an approved lubricant/rust inhibitor to the platforms of damaged stator vanes. Note that current industry thinking is that vane lock-up attributed to rust and other airborne debris is at least partially responsible for clashing.

5. Monitor/trend results. Appropriate intervals for follow-on inspections would be determined by the extent of the mitigation process implemented.

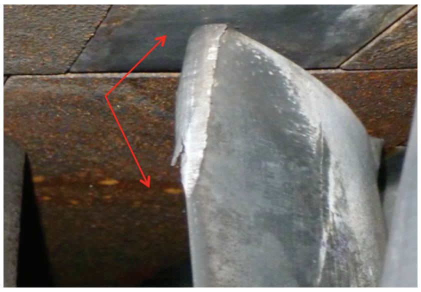
TIL review. Hoogsteden spent most of his time at the podium discussing what ATS believes are the OEM's most important TILs regarding the 7EA compressor. Much of this information had been presented previously and covered in past issues of the **CCJ**, but more than half of the 120 or so attendees were first-timers and the review was particularly valuable. The following is a list of the TILs covered and the issues they addressed, with publication dates in parentheses:

- 1132-2R1, spring and thrust washers for variable inlet guide vanes (Dec 15, 2004).
- 1562, stator-vane shim migration (Jan 30, 2007).
- 1854, compressor R2 and R3 tip loss (Aug 27, 2012).
- 1090-2R1, R17 blade movement

7. Another view of bulging and material separation at the tip-cap leading edge

8. Bulging and material separation on the suction side

9. Damage here is at the trailing edge



10. Tip damage on the leading edge of this S1 stator vane was caused by clashing

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New Release! UDI Combined-Cycle and Gas Turbine (CCGT) Data Set

The **UDI Combined-Cycle and Gas Turbine (CCGT) Data Set** links plant contact information with ownership, location information, and unit equipment details for simple-cycle, combined-cycle, and cogeneration gas-turbine based electric power stations worldwide.

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(Mar 3, 1993).

- 1744, stator-ring rail and CDC hook-fit wear in stages S17, EGV1, and EGV2 (Sept 27, 2010).

Photos incorporated into Hoogsteden's comments on typical IGV damage, illustrating rubs against the inlet bellmouth and bending of inlet guide vanes, had already appeared in CCJ ONsite (www.ccj-online.com, use the keyword search function to locate). Shim migration has been discussed extensively over the last several years in the CCJ. That information also can be accessed by using the Google-like search feature. Hoogsteden gave the group an ATS rule of thumb: When a shim protrudes 250 mils or more into the flow stream (Fig 11), it almost always can be removed. If removal is not possible, the shim should be trimmed flush in-situ with the stator-vane platform.

The service manager mentioned that the week prior to the 7EA meeting, an ATS inspection team found ½-in. cracks on two pristine rotor blades—that is, there were no tip rubs and no discoloration in evidence. Hoogsteden said the company's recommendation was to do a dye-penetrant exam during each inspection to monitor crack growth.

Tip grinding is not necessarily the solution, he added, recalling indications of cracking on 18 blades during the unit's first inspection following tip grinding of that blade row in the shop. A red-dye check adds only a little time to a regular borescope inspection because all R1 and R2 compressor blades, and about 85% of the R3 blades can be accessed in-situ.

Regarding TIL 1090-2R1, Hoogsteden said the biggest concern is how much the R17 rotor blade is moving forward. The Friday before he addressed the 7EA users, an ATS inspector reported that upstream movement of an R17 rotor blade spacer allowed it to contact the rotor, despite double staking. Blade and spacer movement shown in Figs 12 and 13 was 100 mils; maximum allowed is 10 mils.

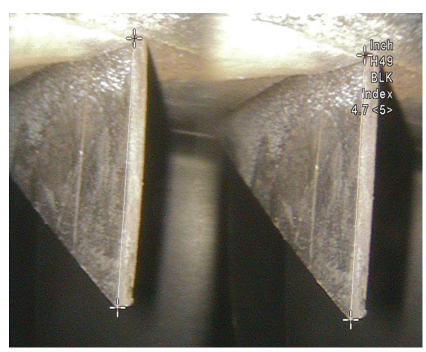
7FA bucket platform cracking

Put first-stage-bucket platform cracking on your inspection hit list, Shidler and Hoogsteden told owners of 7FA Models 7231 and 7241 at CTOTF's 2012 Fall Turbine Users Conference in San Diego. They mentioned a relatively rare "find" the previous weekend: The pressure-side platform crack shown in Fig 14. Although Hoogsteden said ATS had found cracking previously on the pressure side of 7FA first-stage turbine bucket platforms, the amount of separation shown here together with the offset is not typical.

Cracks that go unnoticed are virtually sure to grow and could lead to liberation of a portion of the platform as the photo in Fig 15 indicates. Downstream turbine damage can be expected. Figs 16 and 17 illustrate that skilled inspectors can get up close to any flaws identified for precise measurements. This information then can be referred to engineering for further analysis and decision-making.

TIL 1854

TIL 1854 was issued in late August: Have you read it, yet? If not, don't worry. It was rated "optional" by the OEM. TIL 1854 addresses tip losses on 7EA Rows 2 and 3 compressor blades caused by heavy rubs and/or corrosion pitting. Conclusions drawn from operating experience and engineering analysis suggest that casing distortion over time, as well as hot restarts after



11. S1 stator shim located at vane segments 1-2 (right side, upper casing) protrudes well into the flow stream

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The CCUG's online forum, hosted at http://ccug.users-groups.com, enables owner/operators to communicate with user colleagues 24/7 to share experiences, get advice/referrals, locate parts, etc. The only requirement is registration to verify professional credentials. This forum focuses on plant- and fleet-wide issues that go beyond the gas turbine, which is covered by the various GT user groups. Subject areas include HRSGs, steam turbines, balance-of-plant equipment, NERC CIP, training and development, transformers/switchgear, high-energy piping systems, emissions control, plant electrical, safety best practices, renewables integration, plant control systems, etc.

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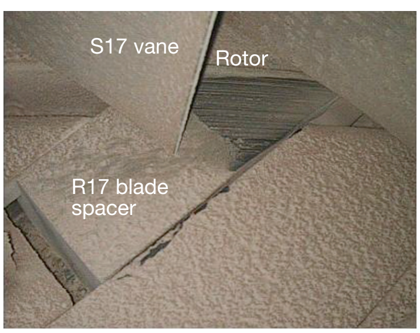
shutdowns of between one and eight hours, are responsible for the rubs.

Damage ranges from scoring of the casing to rolled material at the top of the airfoil. Fatigue damage caused by heat generated during rubbing is conducive to blade-tip liberation when high-cycle fatigue conditions exist. A user told the editors that the foregoing has been known for years. Inspectors manning the booth for ATS confirmed that fact and brought up some borescope images on the company laptop showing an R2 tip liberation and rolled material that had been taken two years earlier (Figs 18-20).

The reps said this particular unit had three R2 tip liberations and had one R1 stator vane damaged by flying metal. Team ATS suggested dye-pen inspections of airfoils that had suffered tip rubs to gauge the level of damage. A quick read of 1854 did not bring to light any such recommendation by the OEM. ATS said it could dye pen R2 blades during a borescope inspection.

12. Upstream movement of compressor S17 rotor blade

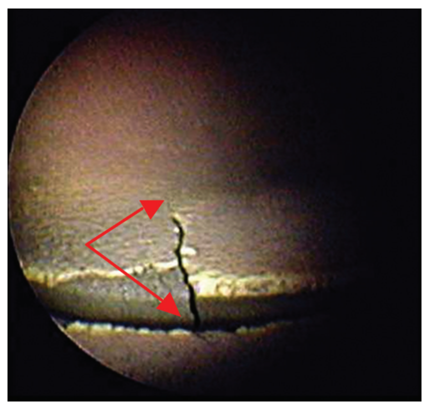


13. Upstream movement of R17 blade spacer allowed it to contact the rotor

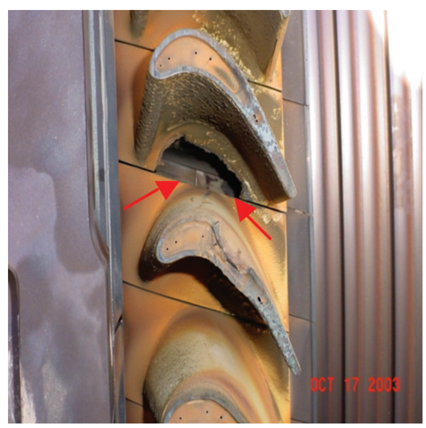
TIL 1724

Another thing ATS representatives were telling 7FA owner/operators at the CTOTF fall conference was that they could have corrosion in the quarternary fuel annulus, which is located in the forward combustion casing of late-model frames—those equipped with DLN2.0 and DLN2.6 combustion systems.

Inspection and cleaning were recommended by TIL 1724 to reduce the risk of operational issues—includ-



14. Pressure-side crack in first-stage bucket platform



15. Material lost from platform went downstream

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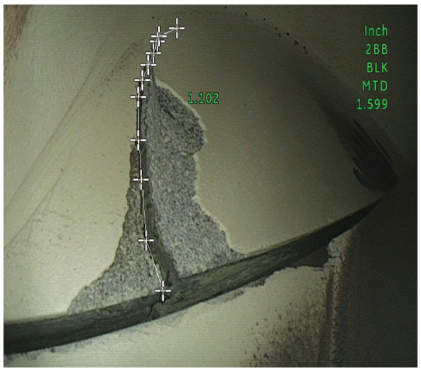
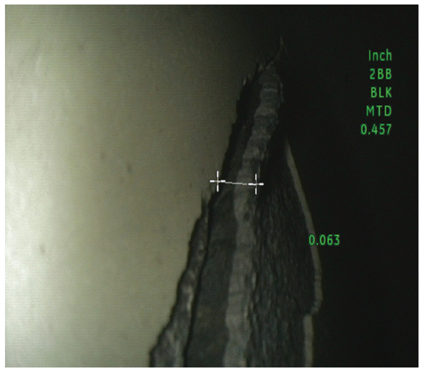


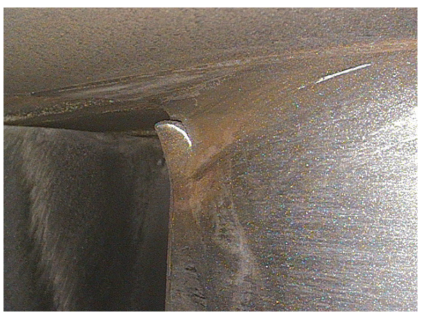
16. Crack and material separation with measurement



17. Elevation view showing separation and offset with measurement

18. Second-stage rotor blade tip liberation (trailing edge)

19. Second-stage rotor blade with rolled metal



20. First-stage stator vane tear on trailing edge (suction side)

21. Condition of the quaternary annulus before cleaning

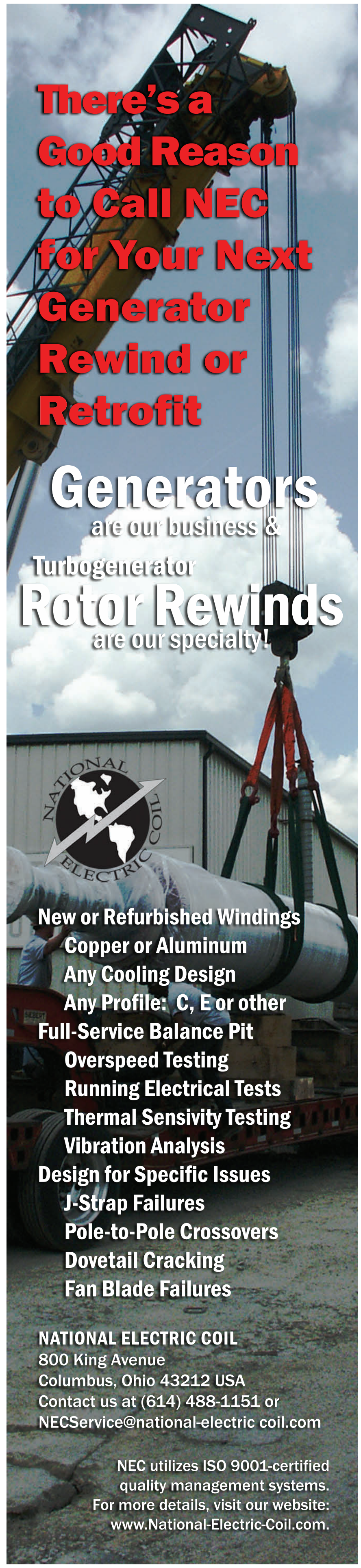
22. Quaternary annulus after cleaning with ATS' dry in-situ procedure

ing elevated dynamics, high exhaust spreads, and even unit trips. The ATS inspectors said the quantity of corrosion byproducts deposited in the annulus can range from almost nothing to accumulations extending to near the top of the conduit. Significant accumulations, after removal, have been known to fill a 2-gal bucket. The amount of steam used influences the rate of corrosion-product formation.

Recommendation: Schedule inspection of the quaternary fuel annulus during your next planned CI or hot-gas-path overhaul, or during the annual borescope inspection—whichever comes first.

If the annulus is found to have significant corrosion buildup, ATS suggests cleaning during the following scheduled outage. Be sure to take representative wall-thickness measurements after that activity.

Company reps said ATS has developed a dry cleaning process that removes more than 95% of the oxidized scale within the annulus (see before/after photos, Figs 21-22) and also takes wall-thickness readings for future comparisons. It takes about eight hours to complete the cleaning, which can be conducted in parallel with any other inspection. CCJ



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Shop tours, robust discussion highlight 16th annual meeting

Robust presentations and group discussions, and tours of three manufacturing and repair facilities, combined to make the 501D5-D5A Users' 16th Annual Conference and Vendor Fair a valuable learning experience. A significant portion of the technical exchange between the OEM and owner/operators, and among the two-score users in closed sessions, focused on rotor-related issues—vibration in particular. The 2012 meeting was held in early June at the Charlotte (NC) City Center Marriott.

The steering committee for this group is chaired by Gabe Fleck of Associated Electric Co-op Inc, Springfield, Mo. He is supported by Vice Chairman Barry Mayhew, maintenance manager, Cardinal Power, Ontario, Canada, and Director Lonne Grote, lead O&M technician at Rocky Road Power Plant, East Dundee, Ill.

Although the D5 and D5A fleets are not large, Siemens Energy Inc provides them the same level of technical support it gives to its F-class fleet, judging by the quality of the OEM's presentations and the first-hand knowledge of the engineering leaders making those presentations.

The first D5 was installed 30 years ago. Today there are 89 units in service, with the fleet leader reporting more than 235,000 operating hours. There are 61 D5As in service, the first achieving commercial status in 1996. The fleet leader has more than 110,000 operating hours. Interestingly, given the relatively low price of gas, the D5s are not running as much as they were a year ago; the D5As are slightly behind last year's run times.

D5-D5A Users

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Feb 6 – 7, 2013 • Orlando

17th Annual Conference and Vendor Fair
June 4 – 6, 2013
(team-building event June 3)

Details, as they become available, at www.501d5-d5ausers.org

To register, contact Chairman Gabe Fleck at gfleck@aeci.org

OEM presentations

Technical topics addressed by the Siemens service engineering team included the following:

Rub distress attributed to a loss of turbine axial clearance has been observed on some R2, R3, and R4 blade platforms. Keep in mind that the turbine cylinder grows faster than the rotor on startup. Rubbing may occur because the vanes, which are attached to the case, move downstream somewhat while the rotor blades hold a fixed position. A root-cause investigation has suggested cutback modifications to increase axial clearances between stationary vanes and rotating blades and these mods have been implemented in a few engines. Field experience is being tracked.

R4 shroud wear has been observed on some D5A turbine blades, particularly those made of U520 material and having significant operating hours. Blade material was changed to IN738 about seven years ago to improve manufacturability. Hard-facing of shroud contact pads may mitigate the problem. Field tests are in progress. Users were urged not to mix U520 and IN738 blades in a given row.

Importance of rotor belly bands in preventing the loss of cooling air from between adjacent turbine wheels was stressed. Keep in mind that reduced cooling air flow to rotor components accelerates component degradation because of higher metal temperatures. If wear/cracking of the original two-piece belly bands is experienced, suggested solution is removal and replacement with a proven three-piece design which can be installed in the field.

Cracks have been observed in the exhaust baffle seals on some units. One concern is the possible recirculation of hot exhaust gas, which could cause overheating of the turbine casing and/or thermal distortion of the exhaust cylinder and some structural elements. Replacement of the seal in-kind requires removal of the exhaust manifold, a time-consuming job. A new seal has been developed, based on F-class experience, which does not require removal of the existing baffle plate for installation. Field testing of the prototype design is in progress.

A vibration improvement program initiated by Siemens to assess issues experienced by some engines in the 501D5-D5A fleet was said to have the OEM's highest priority. The effort was initiated following the user group's 2011 meeting and is being guided by a committee that includes both Siemens engineering managers and user representatives.

Independent consultants are assisting Siemens in the evaluation and specialist teams were formed to conduct a root-cause investigation, perform engine testing, model rotor dynamics, evaluate data collected, and make operational recommendations. The comprehensive interim report presented by a half-dozen subject-matter experts at the Charlotte meeting identified promising corrective measures and next steps.

Users unable to attend the conference can access the OEM's presentations via the Customer Extranet Portal. If you are an owner or operator of a D5 or D5A and not registered to access material on the CEP, and need help navigating the registration process, contact your plant's Siemens representative. The information you'll find on the portal is vital to reliable and efficient operation of your engine.

User presentations

User presentations and candid discussion are the lifeblood of user-group meetings. Several owner/operators presented at the Charlotte meeting. Below are a few notes on four of the presentations. Users registered on the group's website can access these presentations online. If you're an owner or operator of a D5 or D5A, the registration process is simple; contact gfleck@aeci.org if you experience problems.

Exhaust-bearing vibration spikes caused by coking of lube oil in the bearing. This was a particularly interesting presentation, one perhaps of value to owner/operators of gas turbines other than the D5. The affected engine, a D5 in base-load service (only two or three starts annually), experienced plugging of its bearing cap exhaust line with coked lube oil.

This led to coking in the bearing along the shaft which caused vibration interpreted as a rub. Plant personnel could not clean out the flex line from the bearing cap to the vacuum manifold line on a regular basis because the unit was running all the time. But when they did, using a homemade Roto-Rooter type of device, vibration levels returned to normal.

Identifying the root cause of the vibration issue and correcting it took a great deal of effort over a period of years. The complete story includes (1) replacement of two vibration probes originally located downstream from the bearing cap with four probes on the bearing cap to warn of plugging earlier, (2) replacement of the original flexible vacuum line off the bearing cap with stainless-steel pipe having a smooth internal surface, and (3) addition of a dedicated exhauster to serve the bearing, thereby enabling regular cleaning of the vacuum line to avoid coke formation.

Important to note is that when the vacuum line coked up, oil squeezed by the labyrinth packing and ran along the shaft until it dripped onto the insulation below. Fires resulted—more than a dozen over the years. The speaker said the dry chemical extinguishing medium and oil created a real mess. This scenario apparently is in the past now with the bearing running normally and within spec regarding lube-oil temperature.

1. Gas-turbine assembly area at the Siemens manufacturing facility can accommodate seven engines

2. First 501FD4 rotor made in Charlotte was delivered to a customer in Mexico

Next step for plant personnel is a thorough check of the exhaust frame and associated seals for proper alignment and condition during the upcoming outage. Thought is that the higher-than-desired temperature in the bearing tunnel probably is caused by leakage of exhaust gas into that space.

Closing keys broke off R1 compressor stage and went downstream, causing FOD. Vibration levels offered no indication of the event or resulting damage. The broken keys, attributed to high hours on turning gear, were found by OEM personnel during the investigation of another matter. A 27-day round-the-clock outage was needed to make the necessary repairs.

A R4 turbine-blade failure that caused six adjacent blades to snap off (at about 10% of their respective heights from root) and bring the rotor to a complete stop from full speed within two minutes was announced with a loud bang. Resulting vibration caused the bearing oil line to rupture. The engine's R4 turbine blades were of the latest generation, installed in 2006. The peaker had 400 starts and only about 2000 hours of service on the blades when the failure occurred.

The owner has not yet completed its accident analysis, but believes the failure might have been caused by a combination of shroud wear (see second bullet above in the section on OEM presentations) and a casting anomaly. Thinking is that blade vibration attributed to shroud wear from high turning-gear hours magnified the anomaly, causing the blade to fail. Corrective action taken includes implementation of intermittent turning-gear operation, hard-facing of shroud contact pads, and the addition of root springs.

Considerable discussion on the need for more rigorous nondestructive examination (NDE) of castings ensued. Some users expressed dissatisfaction with the way rotors are being bladed today and suggested that all blades in a given row should come from one vendor and one casting run. Indication was that most blade rows mix and match among casting suppliers and heats. Another thought was to digital x-ray all castings before proceeding further with manufacturing.

With lunchtime fast approaching, Chairman Fleck squeezed in one more user presentation, that by a user reporting on the performance of OEM turbine vanes upgraded by a third party. No time for details or discussion at this point. The takeaway: Third-party mods—specifically, the addition of cooling holes—offered better performance than vanes with the original cooling configuration.

Discussion among users

User-only discussion sessions can cover a great deal of territory at a well-managed meeting. Here are a few notes from Charlotte:

Strut shields. One user was planning to have new shields fabricated. The originals suffered so much cracking and fatigue over the years, he said, further attempts at weld repair were pointless. High exhaust tunnel temperatures were identified with the D5 but not the D5A. A colleague suggested that tunnel temperatures be maintained below 400F to avoid cracking.

Strut-shield integrity is of concern, the first operator said, because if exhaust gas gets by the shield and attacks the strut, damage can cause a shift in the exhaust casing which conceivably could migrate and encroach on R4 turbine blades. Discussion followed on how best to replace struts. Consensus thinking was "one at a time" and to follow procedures developed by F-class users. Replacing all struts was considered a two- or three-day job.

Weld repair of exhaust-cylinder cracks: Use Inconel 82 wire. Wire matching the material characteristics of the exhaust cylinder material doesn't work reliably.

Varnish mitigation always is a topic associated with seemingly endless discussion. At the 501D5-D5A meeting that certainly would have been true if the floor leader didn't limit the exchange. Experience with various types of oils, "proper" testing methods, etc, all were noted. One must ask: Does anyone ever really solve a varnish problem?

Mashing of fins in rotor air coolers was another discussion topic. Replacing bundles of copper/nickel tubes with ones of stainless steel was a solution for one user.

Vibration on engine start received significant air time. Most users participating in the discussion experience vibration levels higher on starts than during normal operation. Numbers above 8 mils were experienced by one user on starts; a couple of attendees thought that too high. Vibration during normal operation was below 3 mils, which colleagues considered normal.

An attendee mentioned that the resonant frequency of bearing pedestals was at 3500 rpm and this could be associated with the high startup vibration. Yet another user said he has two of the same engines side by side and they have dramatically different vibration profiles. Example: One suffers high-vibration episodes when ambient temperature exceeds 100F. Conceivably, most or all vibration issues will be resolved as the OEM's vibration improvement program moves forward (see last bullet in section on OEM presentations).

Proper greasing of trunnions was stressed: Grease them often, grease them well was the advice.

Proper specifications was another subject introduced. In some cases, the dissatisfaction of contractor performance can be traced to specifications lacking appropriate detail. When this occurs, expectations are not met. Consensus of the group was that specifications should be developed by personnel on the deck plates with expertise in the equipment requiring repair, inspection, upgrade, etc.

Shop tours valuable

You could call 2012 the "Year of the Shop Tour." Most of the user groups dedicated to gas-turbine owners and operators got out of the classroom for a half day or so to see firsthand what's going on in the manufacturing centers and repair shops serving the industry. Hundreds of millions of dollars have been invested in expanding and upgrading these facilities over the last several years to satisfy global demand and to transition, to the degree possible, from worker-intensive processes to automated machining centers, high-technology nondestructive examination (NDE), etc.

A visit to a modern manufacturing center dispels the notion that skills lost through worker retirement were going to cripple the industry. To the contrary, retirements may have facilitated the transition to hands-off manufacturing controlled by sophisticated software and machine tools. This is not to say skilled machinists are no longer needed; they most certainly are. However, today you need fewer of them today than in the past.

If you haven't visited a shop within the last decade or so, it's almost unnerving to stand on the floor of a modern turbine/generator manufacturing center and watch product flow, with a minimum of human intervention, into special shipping containers to protect against damage. There are relatively few workers in view and the building is quiet, spotless, well lit, air conditioned, with no dust or odors in the air.

Direct involvement of shop personnel on most visits is particularly valuable. Sanitized canned presentations by a tour guide are old school. Today you get to listen, for example, to the coating specialist at his or her workstation on what they do to assure quality of your hot-gas-path (HGP) parts; you have the opportunity to ask technical questions and get the answers you need to make better decisions for your plant and company. Worker pride is clearly in evidence at every tour stop. Not attending a user group meeting with a planned tour is a valuable opportunity lost.

Fleck and his steering-committee colleagues took maximum advantage of the Charlotte location to arrange tours at Siemens, Liburdi, and Pioneer Motor Bearings. The outreach program was very well received by attendees.

Siemens' new manufacturing facility in a word: Wow! Experienced powerplant personnel are not easily impressed. Then they get the opportunity to visit the new Siemens facility and minds must be recalibrated regarding the capabilities of American manufacturing for the global electric power industry both in terms of quality and quantity. You don't *have* to be impressed with the more than one million square feet of shop space under roof, the 100-ft-high manufacturing bays, and the latest automated machine tools and inspection techniques, but if you're not "show me better," as the saying goes.

The 501D5-D5A visitors were told to keep a sharp eye for ongoing construction in the facility, which will employ more than 1800 upon completion. But there was so much manufacturing in progress it was difficult to believe the mega-shop was not finished. Charlotte has three basic products: gas turbines, steam turbines, and generators (Figs 1 and 2). Capacities offered extend from 150 to more than 1600 MW depending on the machine and its application. The shop also is a center of excellence for mods, upgrades, and major repairs and does some critical parts manufacturing as well (such as gas-turbine transition pieces).

Part of the overall facility is more than 40 years old—Westinghouse Electric Corp built the first 550,000-ft^2 shop space in 1969 to make LP turbines for nuclear powerplants—but that has been upgraded and spruced-up. Siemens acquired Westinghouse in 1999 and announced plans to add more than 400,000 ft^2 to the Charlotte manufacturing complex in March 2010. The integrated facility hums round the clock every day of the year.

Here are a few of things recalled by the editors following the tour:

- Rotor and compressor component manufacturing incorporates the latest lean-flow principles. There is no reverse flow on the shop floor, distance between work stations is minimal, zero-gravity lifts are used to the extent possible.
- Rotor manufacturing is conducted in an aisle about 200 yards long and adjacent to the rotor service center, which includes incoming inspection. Everything needed to assure success in rotor manufacture and repair is located on the shop floor—including offices, machining, heat treatment, all tooling, NDE, etc.
- At the component level, one skilled employee typically handles the operation of two or more machining centers.
- The generator section of the shop gave the impression of a wartime mobilization unit with perhaps more than two dozen rotors in various stages of manufacture (or repair). There were rotors for 50- and 60-Hz machines with far-off destinations, in some cases, according to workflow paperwork. The tour leader guessed that only about one-third of the generator rotors produced might be for domestic service. Process flow through the generator rotor manufacturing area was continuous and straight ahead like the GT rotor line.
- With such high bays throughout the shop, storage facilities for machine parts, tools, etc, are vertical.
- The GT assembly area was particularly impressive, having the capability to build seven 200-MW-class units simultaneously and ship upwards of one gas turbine a week if necessary. Only 501FD4s were being assembled during the user tour. These engines are distinguished by their relatively short rotors compared to earlier versions of the 501F. Thirteen-stage compressors are the reason. Recall that earlier versions of the 501F compressor had 17 stages. The new machines also have inlet guide vanes on four stages instead of the traditional one.
- Siemens went the extra step to accommodate the D5 and D5A users by putting out on the shop floor various pieces of combustion equipment for "show and tell," including some cutaways to get a first-hand feel for the hardware that would be discussed in the classroom the following day.

3. Liburdi's Rob Rowland explains the use of inspection arms for dimensional measurement (of a vane ring here) and model formation. Fit-up of transition pieces is verified in jig behind and to the right of Rowland

Liburdi operates two businesses from its Mooresville facility that support power producers: turbine services and welding equipment/services. Most of the users on the tour knew Liburdi because of its reputation for quality repairs of HGP parts (see "Optimal tip clearance," p 118).

The North Carolina shop specializes in the repair of fuel nozzles, combustion baskets/liners, transitions, nozzles/vanes, blade rings, and shrouds. The visitors observed Liburdi's in-house capabilities—equipment, procedures, and qualified personnel—for removing coatings, providing state-of-the-art NDE and metallographic techniques, etc (Fig 3). The company's LPM® (Liburdi Powder Metallurgy) process also was reviewed along with its machining (manual, CNC, and EDM), welding, heat treating, and atmospheric plasma-spray capabilities.

Sister business, Liburdi Dimetrics, makes automated orbital welding equipment for sale or rent. The company offers a wide range of GMAW, GTAW, and hot-wire orbital weld heads and power supplies for precision joining of tubes, piping, and bellows. R, PP, and S stamps enable Liburdi to support training, certification, and welding activities for powerplant maintenance and new construction.

Pioneer Bearing's plant opened in 1990, specially designed to facilitate the manufacture and repair of large babbitted journal and thrust-bearing assemblies. One cause of bearing damage that plant owner/operators are seeing more frequently today is arcing attributed to stray shaft currents. First step in dealing with such damage is to the repair the bearing; second step is to install a proper shaft grounding system.

Work in progress when the users visited included babbitt being poured. The gas-turbine O&M specialists in attendance knew that the dynamic behavior of rotating machines could change over time but some may not have realized that bearings sometimes can be modified to provide a smooth-running machine, reducing requirements for special maintenance and restricted operations.

A good complement to the shop tour is the presentation Technical Services Manager Fred C Wiesinger Jr made to attendees of the CTOTF's Combined Cycle Roundtable at the group's 2012 Spring Turbine Forum in Williamsburg, Va. There was no classroom-style presentation on the care and feeding of fluid-film bearings at the 501D5-D5A Users meeting.

Wiesinger's presentation, available for viewing by any user registered with the CTOTF Presentations Library (it's easy to register), covered bearing casting processes, NDE to verify proper bonding of metals, importance of proper lubrication, inspection, damage identification, analysis, and investigation, and several case studies. It is worthwhile reading whether or not you were on the tour. CCJ

BUSINESS PARTNERS

FAC 2013, March 26-29

The program for the Second International Conference on Flow-Accelerated Corrosion in Fossil and Combined Cycle Plants has been compiled from 45 abstracts received and evaluated by an advisory group of distinguished experts (ad, p 96; www.facfossilhrsgconference.com).

Conference Chairs Barry Dooley and Kevin Shields of Structural Integrity Associates Inc said "this clearly indicates the continuing concern about FAC around the world." They added, "All the important aspects of FAC will be addressed at FAC 2013: cycle chemistry, NDE/inspection, modeling and software, mechanisms, and laboratory studies."

About 200 people from two-dozen countries are expected to attend the meeting in Arlington, Va. A large percentage of delegates will be from operating plants, enabling a valuable exchange of experience and ideas with peers. Looking over preliminary program, the editors have compiled the following bullet points, which might encourage your participation:

- "Fossil Plant FAC Experiences and Programs" (three of the 12 sessions on the agenda) includes first-hand experience from the US (Progress Energy, Xcel Energy, NRG Energy, Associated Electric Cooperative Inc), South Africa, UK, Israel, Canada, and Brazil.
- "FAC in Air-Cooled Condensers" includes a presentation by Dooley and Xcel Energy's Andy Howell, both members of the steering committee for the ACC Users Group (www.acc-usersgroup.org). A Olszewski and J Barnett of Constellation/Exelon also are on the program to talk about FAC assessment and mitigation in ACCs.
- "Combined Cycle/HRSG FAC Experiences and Programs" (two of the 12 sessions) features input from Canada, Germany, US, The Netherlands, Spain, and ANZ. The presentation by Siemens Energy's M Rziha will include discussion of FAC potential in once-through HRSGs, which are receiving considerable attention because of the current interest in fast-start plants.

GT component repairs, January 8-10

"Metallurgical Aspects of Industrial Gas Turbine Component Repairs," an intensive three-day training program taught by Hans van Esch of TEServices, will be held in Houston, January 8 – 10. The course, conducted semiannually, gets "two thumbs up" ratings from most participants.

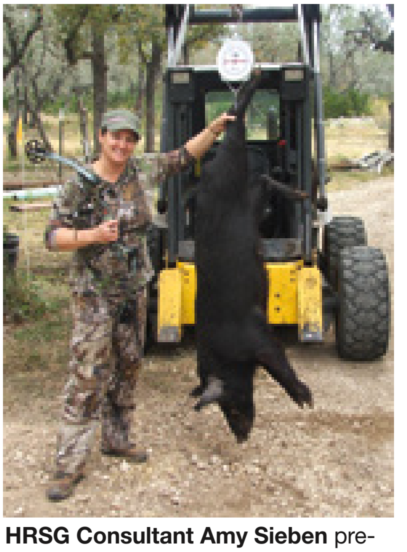
Purpose of the program is to help owner/operators understand the jargon of hot-section repair shops, make metallurgically sound decisions regarding the repair and coating of IGT components, create work scopes and RFQs, select the best vendor, and learn how to monitor repair, coating, and inspection processes.

CCJ contributors have diverse personal interests

As you read through the pages of the **CCJ** you might come away with the idea that the magazine's contributors are a bunch of dull engineers totally wrapped up in their professional pursuits. Nothing could be further from the truth. Here's the evidence:

- Amy Sieben, who helps keep readers informed on HRSG design, inspection, operation, and maintenance, has opened her own shop, ALS Consulting LLC. Power industry services include HRSG analysis, water chemistry, inspection, troubleshooting, and innovative solutions. Sieben can be reached at info@ALSconsultingllc.com, 651-785-8516.

  To relax before launching into her new career as an independent engineering consultant, Sieben spent 10 days in Texas hunting and making sausage. The deep freezer is now full. Hunting is nothing new for Sieben; last year she chased big game in Africa.
- David Addison (3183), a prolific contributor on water chemistry (article, p 98), relies on high-tech bikes for transportation in his native New Zealand. At the end of November, he reeled off a 156-km race in 4:16 to place 88th out of 4200 riders—all while concerned about a volcanic eruption on the race route (certainly an incentive for speed). As this issue goes to press, Addison is on his way to cover the Australasian HRSG Users Group meeting in Australia for the Journal.



HRSG Consultant Amy Sieben prepares to make sausage

Water Chemist David Addison doesn't just look serious, he is

- Dave Lucier, general manager, PAL Turbine Services LLC, has his name sprinkled throughout this issue, and others, because of his encyclopedic knowledge of legacy GE frames. His spare time is spent restoring and racing sports cars.
- Paul Tucker, president of Texas-based FIRST and Technical Bolting Solutions, who shared his expertise in the Frame 5 and Frame 6 articles in this issue, spends his free time bass fishing.

Visit www.teservices.us/train.html or write van Esch at hvanesch@teservices.us.

HRSG Academy, January 22-24

The highly acclaimed HRSG Academy, conducted by HRST Inc for North American owner/operators, will be held next at the Driskill Hotel in Austin, January 22-24. For more information, visit www.hrstinc.com; or contact Brenda Peterson at 952-833-1427, info@hrstinc.com.

Reasons for attending:

- Better understand your HRSG design.
- Learn where to inspect and how to anticipate HRSG problems.
- Learn HRSG fleet trends and happenings.
- Share lessons learned among attendees.
- Better prioritize future inspection and maintenance tasks.
- Course notebook for future reference.

USERS 501F GROUP

2013 Conference

March 18 - 21
Westin Charlotte
Charlotte, NC

Discussion topics include compressor, combustor, and hot-gas-path issues, control system and other upgrades, personnel safety initiatives

Meeting participation is limited to members of the 501F Users Group and all meeting information and registration information is sent from our website.

Participation in the user's group is limited to companies who either have an equity interest in, are currently operating, have under construction, or have a valid contract for delivery of future 501F units manufactured by Siemens or Mitsubishi. Within the companies that meet these criteria, group participation is limited to individuals who are directly involved in the operation, maintenance, or construction of the unit. All information is broadcast to users through the group's website. Users interested in joining the 501F Users Group should open http://501F.Users-Groups.com and navigate to the "Membership" menu option.

Exhibitors: Contact Caren Genovese, meeting coordinator, at carengenovese@charter.net

Note: The 501F and 501G Users Groups are co-locating their conferences again this year and will have some joint sessions.

Company news

Siemens Energy Sector announces the following:

- Contracts for the combined-cycle conversion of two simple-cycle plants (Ensenada de Barragan and Brigadier Lopez) from Argentina's Union Temporal de Empresas. Total increase in generating capability will be 420 MW with no additional fuel consumption. Commercial operation is expected in fall 2014.
- Startup of the first of three 274-MW H-Class gas turbines at Florida Power & Light Co's Cape Canaveral Next Generation Clean Energy Center in Port St. John, located near NASA's Kennedy Space Center. Three more SGT6-8000H gas turbines also will be installed at FPL's Riviera Beach Next Generation Clean Energy Center for operation in 2014.
- A modification of its business strategy and organizational setup with respect to renewable energy. The company plans to divest its solar business activities (solar thermal and PV) and is currently holding talks with potential buyers. Siemens said it will focus its renewable-energy activities on wind and hydro power, slimming down the Energy Sector in the process.

Emerson Process Management Power & Water Solutions helped Dorado Power Ventures' 1 × 1 Termovalle combined-cycle plant return to commercial operation just months after devastating floods in December 2011 left 6 ft of water in some areas and destroyed the facility's Ovation™ control system. Emerson replaced all I/O, controllers, workstations, and related equipment, allowing the 205-MW Cali (Colombia) plant avoid financial penalties that could have been levied by the Colombian regulatory organization (Fig 1).

The Ovation control system monitors and controls the plant's dual-fuel W501FC DLN engine, steam turbine, HRSG, and balance-of-plant equipment and processes. Emerson also provided two fully integrated Ovation DGC excitation systems—a static system for the gas turbine and a brushless system for the steamer. Tightly coupling the excitation systems with the Ovation plant architecture allows operators to control and monitor the excitation systems from the existing Ovation workstations.

Swift Filters Inc, Oakwood Village, Ohio, manufacturer of oil filters for the power generation industry commits to building a new manufacturing facility with 42,500 ft^2 of space, more

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1. Termovalle shows no sign of the devastating flood following commercial restart

than tripling the size of the company's current plant.

Turbine End-user Services Inc (TEServices), Houston, celebrates its 10th anniversary of service to industrial gas-turbine users. The company provides engine owner/operators technical support, training, component management, repair and bid specifications, verification of component repairs, selection and audit of repair and coating vendors, etc. The company and its founder, Hans van Esch, are well known for the semi-annual three-day training course, "Metallurgical Aspects of IGT Component Repairs."

MTU Maintenance Berlin-Brandenburg recently celebrated the repair of its 1000th industrial gas turbine—an LM6000 for Thailand-based Rojana Power Co.

Hamon USA Corp appoints Peter Dawes president of Hamon Deltak Inc. Dawes will lead the company as

Contact Susie Carahalios today at:
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it expands its presence as a manufacturer of large heat-recovery steam generators—units capable of serving gas turbines up to 350 MW. Dawes' career includes stints as a VP for Alstom Power and as manager of mechanical engineering for ABB. He began his career as a design engineer for GE Aircraft Engines.

Cutsforth Inc aims at expanding its capabilities by breaking ground for the construction of a 10,000-ft^2 facility to serve DC Manufacturing, a division of the company. Cutsforth is, perhaps, best known for its innovative design of brush-holders for exciters, truing of collector rings, and other products/services for generator owners.

Mee Industries Inc announces the launch of a mobile version of its website to facilitate access to company information on gas-turbine inlet-air cooling applications. It will allow users to view the website optimized and formatted to fit the screen of any web-enabled smart phone or tablet.

Alstom was selected by Dominion Virginia Power to provide three state-of-the-art HRSGs for its new 1300-MW Brunswick County Power Station. These steam generators will be coupled to Mitsubishi 501G gas turbines and be the largest HRSGs supplied by Alstom for the North American market. Three more boilers will anchor Dominion's 501G-powered Warren County Power Station.

Products/services

Swan Analytical Instruments, Wheeling, Ill, discusses these three products in its latest releases:

1. AMI Sodium P, for automatic and continuous determination of dissolved sodium in steam, condensate, and feedwater over the range of 0.1 to 10,000 ppb. Features include the following:
- Reliable reagent delivery system without moving parts.
- Continuous sample flow monitoring and reagent addition.
- Simple calibration routine—one or two points.
- Logger, event, and calibration history stored in the AMI transmitter—up to 1500 data points.

2. AMI Codes-II CC is a colorimetric process analyzer (DPD method) for measurement and dosing control of disinfectants—such as free chlorine, monochloramine, total residual chlorine, and combined chlorine. Complete system includes measurement and control electronics, photometer, flow indicator, reaction chamber, reagent dosing system, and reagent containers. Integrated pH measurement with temperature compensation is available as an option.

3. AMI silica, for online continuous measurement of silica in feedwater, steam, condensate, and makeup water. Features include the following:
- Automatic zero before every sample measurement.
- LED photometer, long-term light source stability.
- Selectable measurement interval, low reagent consumption.
- Measurement range up to 5000 ppb.
- Sample flow monitoring and low-level reagent detection.

Consolidated Fabricators, Auburn, Mass, a division of Braden Manufacturing LLC, announces a new approach to the design and manufacture of replacement doors and panels for gas-turbine enclosures. The company's Smartdoor™ products are used to replace leaking, worn out, corroded, and/or damaged GT access doors (Fig 2).

The new enclosure doors feature bolted, formed plate exteriors, eliminating problems associated with the typical welded construction of OEM doors. Previous welded designs created unprotected perimeter surfaces, making them a major source of corrosion and climate exposure. In addition, welded designs limited drainage and allowed greater thermal transfer, contributing to higher surface temperatures.

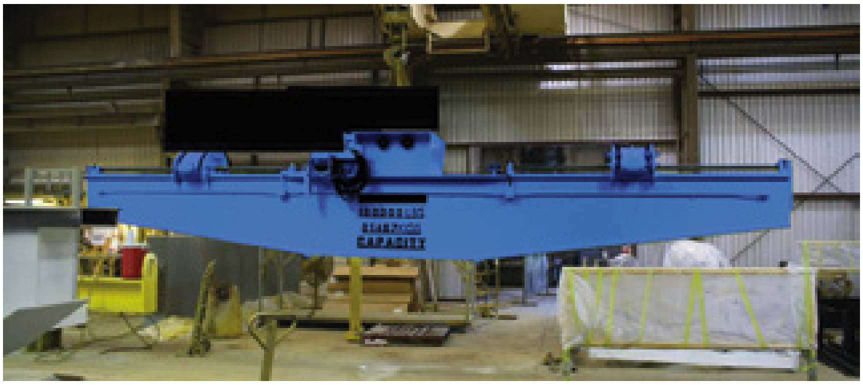
The bolted construction of Smartdoor products allow easy re-insulation and repair onsite. Insulation tubes are standard to simplify the process. Additionally, the doors feature a unique tadpole gasket, which reduces leaks by being secured

2. Smartdoor™ is designed to replace leaking, worn out, corroded, and/or damaged GT access doors with a superior design capable of long life by a clamping bar to create a uniform-pressure seamless door seal.

TestOil Cleveland, Ohio, updates its testing process for filter debris, increasing the laboratory's ability to identify wearing machine components—thereby providing better diagnostic and prognostic information about impending failures. A new filter washing instrument is critical to this enhanced capability. An optical particle count on the debris stream collected from the filter also is performed.

Ludeca Inc's (Doral, Fla) Vibconnect RF is said to be a highly reliable, wireless condition monitoring system for machine components. The sensor unit monitors machine vibration, bearing condition, and temperature, and transmits the relevant information for evaluation.

Meggitt Sensing Systems, Londonderry, NH, introduces a partial-discharge monitoring system for monitoring, logging, and reporting PD activity in generators, motors, and cabling systems. The company's solution provides for early detection of PD pulses by using coupling capacitors for direct measurements, thereby enabling existing RTDs embedded in the windings to be used as additional PD sensors.



3. Lifting beam is designed to handle 7FA rotors

Conval Inc, Somers, Ct, offers Clampseal® fire-safe forged globe valves in Y, angle, and T-pattern configurations and in ½ through 4 in. sizes for pressure ratings up to ANSI 4500 with NPT, butt-weld, or socket-weld ends. The innovative product contains a simple mechanism that compensates for thermal expansion, which together with other design features, enables the valve to meet API fire-safe standards by extremely high margins.

First Independent Rotor Services of Texas now offers a lifting beam (Fig 3) and shipping skid for 7FA rotors, providing both onsite and in-shop assistance. The lifting beam, which can handle up to 90 tons, permits the operator to adjust the beam center of gravity as needed without having to bring down the beam to man height. This time-saving feature uses electrical pendants with pushbutton controls to adjust either or both saddles.

The shipping skid has pedestals machined to fit 7FA journals while allowing for installation of ½-in.-thick softeners to prevent journal damage. The pedestals can be made adjustable upon request.

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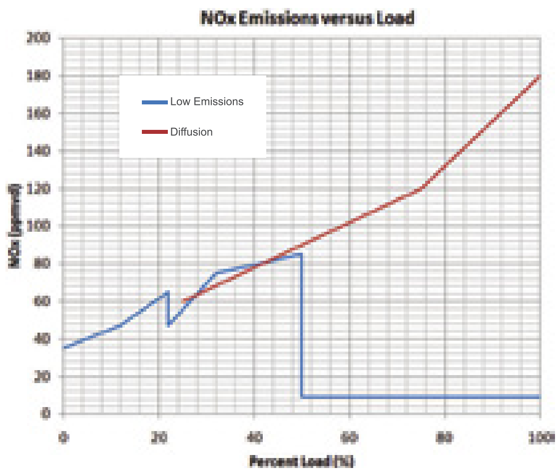

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