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Best Practices Awards

Features

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Second Annual Alstom Owners Group Users Conference
February 4 – 7, 2019
The StateView Hotel, Raleigh, NC
Attendance by invitation only
Contact: Jeff Chapin,
jchapin@liburdi.com

2019 Conference and Vendor Fair
February 17 – 22
DoubleTree Resort by Hilton
Paradise Valley (Phoenix), Ariz
Contact: Tammy Faust,
tammy@somp.co
http://501f.users-groups.com

29th Annual Conference and Expo
March 17 – 20, 2019
South Point Hotel & Spa
Las Vegas, Nev
Contact: Charlene Raaker,
craaker@wtui.com
www.wtui.com

HRSG Forum with Bob Anderson
July 22 – 25, 2019
Hilton Orlando
Contact: Alan Morris,
amorris@morrismarketinginc.com
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2019 MEETINGS
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January 14-15, EPRI TGUG Workshop, Savannah, Ga, Hyatt Regency Savannah. Registration open at www.epri.com. Generator contact: Bill Moore, bgmoore@epri.com. Turbine contact: James Wieters, jwieters@epri.com.

February 4-7, AOG (Alstom Owners Group) Users Conference, Annual Meeting and Vendor Fair, Raleigh, NC, The StateView Hotel. Contact: Jeff Chapin, jchapin@liburdi.com.

February 17-22, 501F Users Group, Annual Meeting, Paradise Valley (Scottsdale), Ariz, DoubleTree Resort by Hilton. Chairman: Russ Snyder, russ.snyder@cleco.com. Details/registration at http://501f.users-groups.com when available. Contact: Tammy Faust, meeting coordinator, tammy@somp.co.

March 17-20, Western Turbine Users Inc, 29th Anniversary Conference and Expo, Las Vegas, Nev, South Point Hotel and Spa. Visit www.wtui.com for more information and registration. Contacts: Charlene Raaker, conference registration coordinator, craaker@wtui.com; Wayne Kawamoto, conference executive director, wkawamoto@wtui.com.

March 19-21, Third International Conference on Film Forming Substances (FFS 2019), Heidelberg, Germany, Crown Plaza Heidelberg City Centre. Chairman: Barry Dooley, bdooley@structint.com. For more information, visit https://iapws-ffs.cvent.com/FFS2019 or contact Tapio Werder at tapio.werder@waesseri.com.

April 28-May 2, CTOTF 44th Spring Conference & Trade Show, St. Augustine, Fla, Renaissance World Golf Village. Chairman: Jack Borsch, john.borsch@ihipower.com. Details/registration at www.ctotf.org when available. Contact: Ivy Suter, ivysuter@gmail.com.

May 14-16, European HRSG Forum, Sixth Annual Meeting, Athens, Greece, Titania Hotel. Chairman: Ladislav Bursik, ladi.bursik@bht-gmbh.com. Registration is open at http://europeanhrsgforum.de.

May 20-24, 7F Users Group, 2019 Conference & Vendor Fair, Schaumburg, Ill, Renaissance Schaumburg Hotel and Convention Center. Details/registration at www.powerusers.org when available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

June 4-6, 501D5-D5A Users, 22nd Annual Meeting. Location and venue to be announced. Chairman: Gabe Fleck, gfleck@aeci.org. Registration and other details at www.501d5-d5ausers.org as they become available.

June 10-13, Frame 6 Users Group, Annual Conference & Vendor Fair, Costa Mesa, Calif, Hilton Orange County. Co-chairmen: Jeff Gillis, william.j.gillis@exxonmobil.com, and Sam Moots, smoots@coloradoenergy.com. Details/registration at www.Frame6UsersGroup.org as they become available. Contact: Greg Boland, Creative Ventures Holding, conference manager, greg.boland@ceidmc.com.

June (target), T3K Annual Conference. Location and venue to be decided. Details at http://swpcdcs.users-groups.com as they become available. Chairman: Bob Lake, bob.lake@fpl.com. Contact: Elizabeth Moore, elizabeth.moore@siemens.com.

June 17-20, Siemens Customer Conference for F, G & H Technology, Orlando, Fla, Hilton Orlando Bonnet Creek. Contact: Dawn McCarter, dawn.mccarter@siemens.com.

July 22-24, HRSG Forum with Bob Anderson, Third Annual Meeting, Orlando, Fla, Hilton Orlando. Chairman: Bob Anderson. Details/registration at www.HRSGforum.com. Contact: Alan Morris, commercial manager, amorris@morrismarketinginc.com.

July 28-August 1, Ovation Users' Group, 32nd 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. Contact: Kathleen Garvey, kathleen.garvey@emerson.com.

August 26-30, Combined Cycle Users Group (CCUG), 2019 Conference and Discussion Forum, St. Louis, Mo, Marriott St. Louis Grand. Meeting is co-located with the Steam Turbine, Generator, and Power Plant Controls Users Groups; some joint functions, including meals and vendor fair. Details at www.ccusers.org when available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

August 26-30, Steam Turbine Users Group (STUG), 2019 Conference and Vendor Fair, St. Louis, Mo, Marriott St. Louis Grand. Meeting is co-located with the Combined Cycle, Generator, and Power Plant Controls Users Groups; some joint functions, including meals and vendor fair. Details at www.stusers.org when available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

August 26-30, Generator Users Group (GUG), 2019 Conference and Vendor Fair, St. Louis, Mo, Marriott St. Louis Grand. Meeting is co-located with the Combined Cycle, Steam Turbine, and Power Plant Controls Users Groups; some joint functions, including meals and vendor fair. Details at www.genusers.org when available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

August 26-30, Power Plant Controls Users Group (CUG), 2019 Conference and Vendor Fair, St. Louis, Mo, Marriott St. Louis Grand. Meeting is co-located with the Combined Cycle, Steam Turbine, and Generators Users Groups; some joint functions, including meals and vendor fair. Chairman: Peter So, pso@calpine.com. Details at www.powerusers.org when available. Contact: Sheila Vashi at sheila.vashi@sv-events.net.

Week of September 9 (target), V Users Group, 2019 Annual Conference. Location and venue to be decided. Contact: Dawn McCarter, conference coordinator, dawn.mccarter@siemens.com.

September 15-19, CTOTF Fall Conference & Trade Show, Rancho Mirage, Calif, Westin Mission Hills. Chairman: Jack Borsch, john.borsch@ihipower.com. Details/registration at www.ctotf.org when available. Contact: Ivy Suter, ivysuter@gmail.com.

October (target), ACC Users Group, Eleventh Annual Conference. Location and venue to be decided. Details at www.accusersgroup.org as they become available. Registration/sponsorships contact: Sheila Vashi, sheila.vashi@sv-events.net. Speaker/program contact: Dr Andrew Howell, chairman, ahowell@epri.com.

October (target), 7EA Users Group, Annual Conference and Exhibition. Location and venue to be decided. Details/registration at http://ge7ea.users-groups.com when available.

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From central to distributed: The inflection point still not clear

At the Distributed Energy Conference in Denver, Oct 15-17, 2018, one of the electric-power industry's most experienced analysts came away with the sense that the "inflection," marking the point at which investment in distributed assets grows faster than that in centralized assets, hasn't yet arrived. And the timing of its arrival still is not clear.

What is clear is that, like acrimonious separations with high-priced lawyers, the debate is far less about technology and engineering challenges and far more about who is going to make money and how—and how much. (Conference details can be accessed at www.distributedenergyconference.com.)

To explain this requires some recent history. In the early 1980s, after the Public Utility Regulatory Policies Act (Purpa) was passed, along with the Fuel Use Act (already in place to prevent utilities from building new gas-fired power stations), many cogeneration facilities and "Purpa plants" were built. Some were large gas-turbine-powered cogen units serving major industrial complexes; some small ones used alternative fuels like biomass, tires, and manure; some were tiny turbine and engine units (micro-cogen), and some were innovative ways to provide thermal and electric energy at industrial, commercial, and institutional facilities.

What proved difficult, though, was a scalable design and business model. In other words, there were many interesting "one-offs" but few repeatable projects. By the mid-1990s, all that changed with the convergence of (1) the lifting of regulatory restrictions on gas, (2) advanced gas-turbine technology, (3) IPP and merchant investment, and (4) growing electricity demand. Sales of gas turbines, in simple- and combined-cycle arrangements, took off, culminating in the famous installation wave of 1997-2002. Approximately two-hundred-thousand megawatts of gas-fired capacity were added to the grid during that period.

At the Distributed Energy (DE) conference, speakers presented on a variety of challenges and trends, most of which have been aired ad nausea over the last 10 or 15 years. But the range and scope of DE projects highlighted (and discussed during the breaks) were instructive.

Clearly, there's no shortage of imagination when it comes to DE. Projects ranged from wind + solar + battery facilities; subscription 20-year wind energy purchases from a non-utility wind developer; utility-owned solar, wind, and storage; 11 MW of solar across 18 sites for a county governmental entity; a campus CHP facility recently expanded with a microgrid (and soon to add storage); a campus fuel-cell CHP unit; and others.

What was not clear was whether any of these DE schemes could be scaled and replicated in the region, state, or nationally. One presenter lauded a project with a 2.5-MW wind turbine/generator, 1.3 MW of solar PV, and a 1-MW/4-MWh storage unit, dubbed a "mid-grid solar wind hybrid." He said there were thousands of attractive locations for this concept. However, he did not mention follow-on projects.

Perhaps it's folly to even think in terms of the earlier advanced GT boom. After all, those were still largely centralized facilities, many with long-term power purchase agreements with a utility or electricity marketing partner. They fit into the historical capacity expansion patterns of the industry and the tendency of regulated utilities (and the banks that cater to them) to prefer a cookie-cutter, least-risk approach to investment.

When you start with each customer's individual needs, criteria, and aspirations, however, can a cookie-cutter approach ever work? Perhaps, if the regulated distribution-oriented utility is controlling expansion. If each customer is truly in control, however, all bets on that horse are off. Consider this analogy: How a colleague has downloaded, arranged, and set the apps on his or her mobile devices

Twenty-three micro-turbine/generators (center of photo at left) are adjacent to the 1-MW battery and power conditioning system—all located in the enclosed area. Battery and PCS details are at right

are probably very different from how you've done it.

Several of the conference speakers insisted "the customer is in control." Really? The industry has been hearing that for two decades. If you have a large load the utility doesn't want to lose, it's probably true. If you have a 12-unit rental property, a small commercial building, or a residence, perhaps not. The truth is that the utility industry and emerging DE component still considers the "customer" in the collective sense, not as an individual.

An old saying goes, "never let anyone get between you and your customer." One speaker noted that the assumptions of the last 100 years no longer hold when it comes to the answer to the question, "Who owns my electric load?" He used the five stages of grief to explain where utilities in the aggregate are today regarding this question. On the scale of denial, anger, bargaining, depression, and acceptance, he thinks utilities are between anger and bargaining.

One of the weapons utilities used to block or stall projects in the Purpa days, and continue to use, is the interconnection (IC) request and analysis. Apparently, it is still a potent weapon. One analyst speaker noted that utilities can block projects by assuming the worst case in the IC evaluation. Even if the worst case is only two hours in the course of a year, the utility can still decline the IC request, at least for projects this speaker is involved with.

We tend to think about California when it comes to DE, mostly because it is said to be the fifth largest economy on the planet (if considered as a country). Whatever works there will, as has been shown in the past, likely be a model for the rest of the nation. A model for a large DE project might be Southern California Edison Co's Pebbly Beach Generating Station and its associated grid serving Catalina Island. The isolated system balances variable loads and NO_x emissions by optimizing diesel operation using 65-MW micro-turbine/generators, a 1-MW NaS battery, and power conditioning system (photos).

But Hawaii is where the pace of the centralized-to-DE transformation is truly ground-breaking, and where the concept at scale likely will be proven first. According to a speaker from the 50th state, one in three Hawaiian homes has rooftop solar PV. Public facilities there have to be energy net zero by 2030.

The state has a mandate of 100% clean energy by 2040, despite the fact that its "grid" is actually six islanded power systems. Almost incredibly, 80% renewable by 2030 has penciled out as the "least cost" path. Keep in mind that renewables are replacing a large component of diesel-based capacity and access to natural gas isn't a matter of collecting, pipelining, and distributing as it is on the mainland.

The one roadblock, he said, is aligning utility incentives with the DE strategy, and noted that the state is considering a new regulatory model that "breaks the links between traditional system expansion and capital investment. That is the key," he said, "to making the transformation to distributed energy resource management (DERM) move faster." Alaska is another state moving more quickly than the rest of the nation to a DE future, for many of the same reasons, based on other presentations at the conference.

For the other states benefitting from a more interconnected grid and lower-cost primary energy resources, the degree to which the utility is embracing or resisting DE will be key to the rate of transformation, and what is left of the customer base once they enter the "acceptance" phase.

It seems most of what is being debated at these conferences is not whether the technology is ready, whether the grid can "handle" massive DERM, or what customers really want, but rather who is going to "control the ball" and make the most money scaling and customizing DE resources to respond to real customer needs and desires. **CCJ**

More tools, more features, fewer connections: Ovation scope expands

There were reasons why David Farr, chairman/CEO of Emerson Corp, parent to Emerson's Power & Water Solutions (PWS) business, delivered the opening address at the annual Ovation Users Group Conference, held in Pittsburgh, July 29 – Aug 2. At least one could speculate, reading between the lines, that it had something to do with financial issues of peer group industrial conglomerates making headlines.

First, he offered five bullet points on what it takes to sustain leadership:

- Be secure in yourself but never become arrogant.
- Do more listening than talking.
- Trust your moral compass and promote truth and integrity.
- Take calculated, well-thought-out risks.
- Continue to learn and drive for change.

While these were geared towards personal leadership, the implications for corporate leadership are obvious.

Farr also talked about winning and commitment, specifically how PWS President Robert Yeager set out a plan 20 years ago to be Number One in this business and how Emerson corporate unwaveringly committed to the power and water sectors after its acquisition of Westinghouse Process Control in 1997. "Bob knows how to win," Farr said. And from the humorous bantering that went on between Bob and David, it was clear that losing isn't well-tolerated in the Emerson C-suite.

Without speaking to it directly, Farr reminded the audience of hundreds of Ovation™ users, and prospects and partners, that Emerson is *not* having the same commitment issues as several other behemoth OEMs of the power industry. "The industry is under a lot of stress," he noted. He went on to describe inexpensive electricity as a competitive weapon and that the industry has to be totally predictable. It wasn't hard to think up a few big names which haven't exactly behaved "predictably" in recent years.

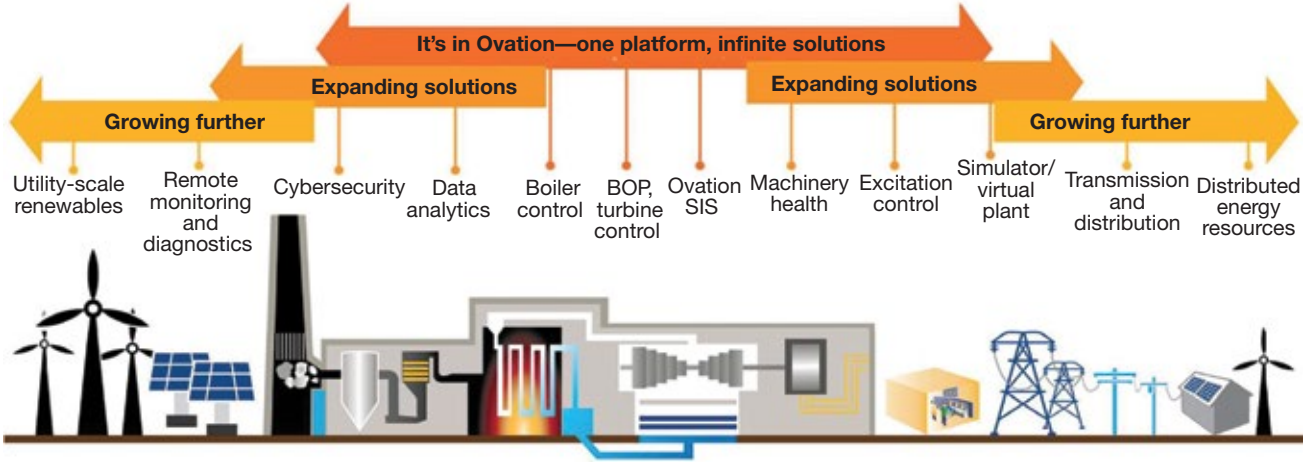
The path forward

Yeager took the stage after Farr and used his time, as he often does, to assume bragging rights for the successes of the last 12 months. This year, however, there were some very notable distinctions.

"We've introduced more new products in the last three years than in the history of PWS," he said (Fig 1). The Ovation version of the "digital twin" now includes over 200 algorithms to simulate systems using real-time data and for monitoring performance and health of equipment. Making the automation platform smarter is one way to address what Yeager identified as the Number One issue facing industry executives (according to a popular annual survey): the aging workforce.

He claimed Ovation being Number One globally. Some of the evidence:

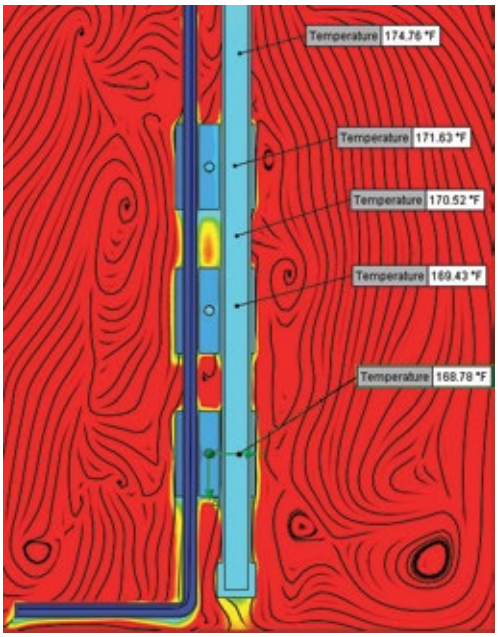
- Ninety-three of the 130 1000-MW supercritical boiler units in China have Ovation automation.
- Three-hundred Ovation systems were added to the global roster in 2018.
- The company now has completed over 400 GE gas- and steam-turbine control retrofits and 30 Ovation generator control systems.
- There are 1.3-million MW of generation capability with Ovation automation, 450,000 MW in the US. Note that these numbers are similar to what was reported last year.
- Twenty-nine Ovation "embedded simulation" projects have been completed and 33 are in progress.
- The first wind turbines are being controlled by Ovation, anchored by its new Compact Controller (formerly the OCC 100, Ovation's answer to the PLC), and the company has announced recent new-build solar

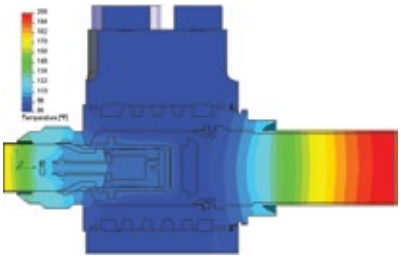


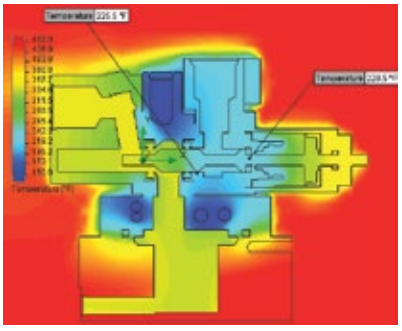
1. Emerson's aspirations for its Ovation™ automation platform, which currently dominates in powerplants, is the complete electricity production and delivery value chain

Maximum Reliability

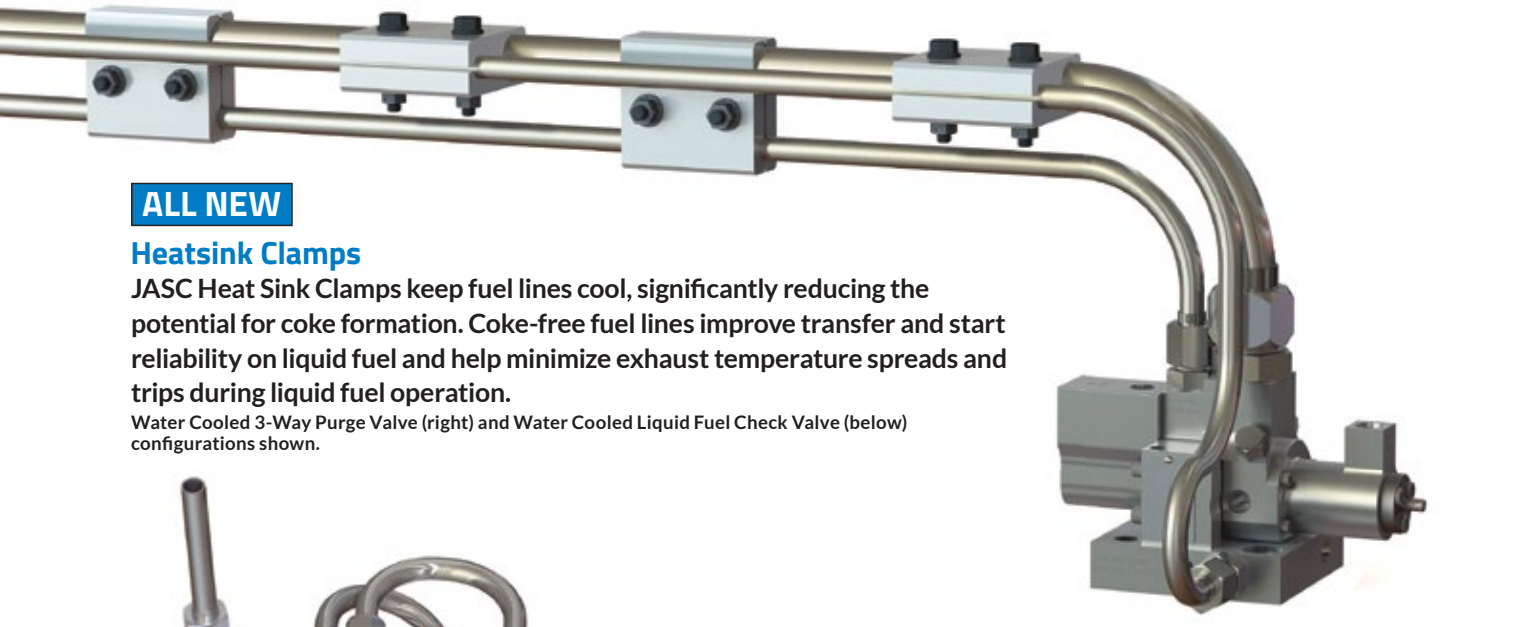
Water Cooling Technology Provides Increased Operating Intervals Between Liquid Fuel Runs







Thermal analysis shows the affectiveness of active cooling (*left*: fuel lines with heat-sink clamps installed, *top right*: water cooled liquid fuel check valve and *lower right*: water cooled 3-way purge valve).

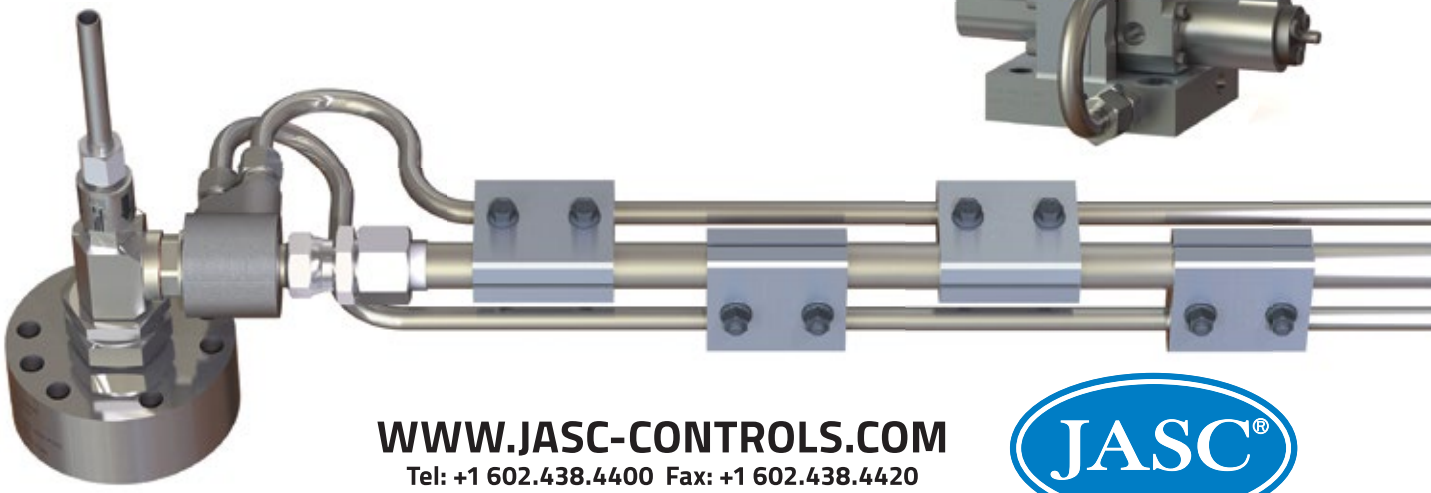


ALL NEW

Heatsink Clamps

JASC Heat Sink Clamps keep fuel lines cool, significantly reducing the potential for coke formation. Coke-free fuel lines improve transfer and start reliability on liquid fuel and help minimize exhaust temperature spreads and trips during liquid fuel operation.

Water Cooled 3-Way Purge Valve (right) and Water Cooled Liquid Fuel Check Valve (below) configurations shown.



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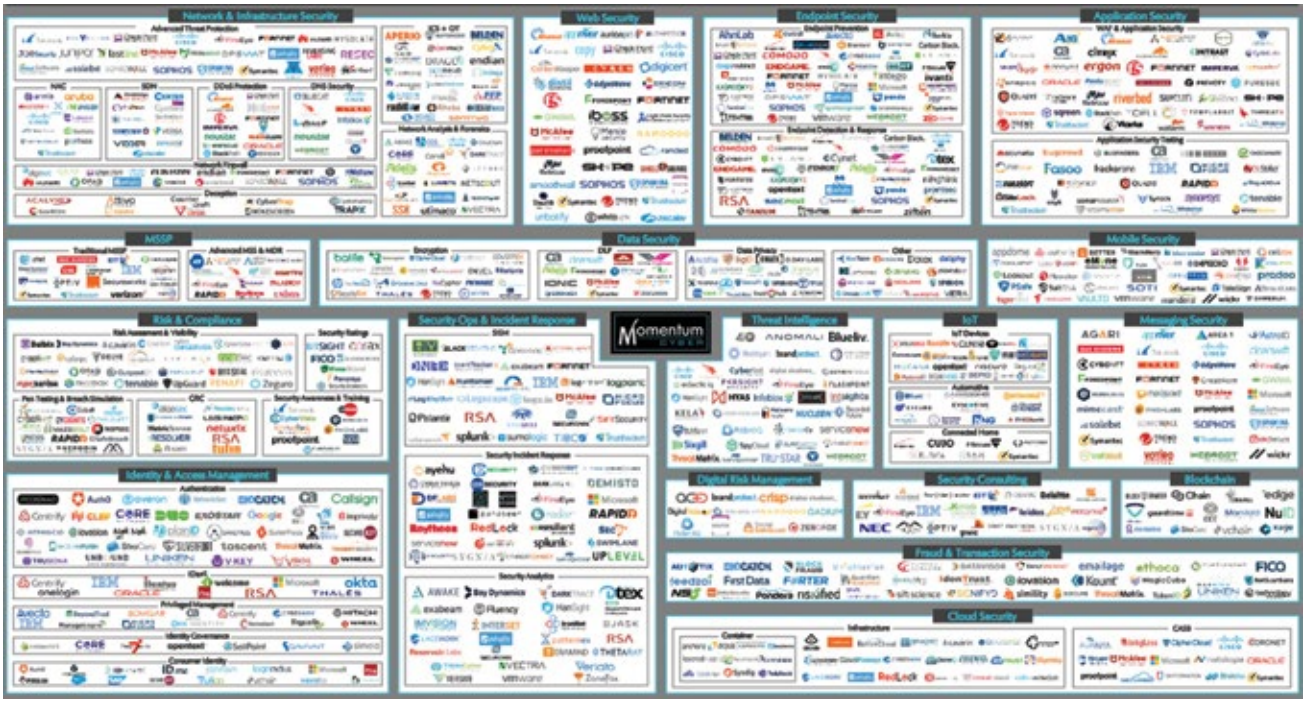

2. Complexity of cybersecurity grows like a cancer, especially given how critical electricity is to the lifestyles to which we've become accustomed

project awards, its first grid-scale storage project, and a unique "grid controller" project in Hawaii.

Perhaps the most interesting announcement, given the times we live in, is that Ovation has been designated as "qualified anti-terrorism technology" by US federal government authorities, which provides significant legal protection to Ovation users whose systems were deployed beginning Jan 1, 2009.

As if to reinforce Farr's emphasis on commitment, Yeager observed that the competitive advantage afforded by technology is short-lived and "customer service is where the edge is found."

Building out the platform

For the hard-core Ovation geek, Steve Schilling, VP technology/R&D, rattled off some of the advancements and improvements in the platform—such as "harmonized Ethernet Link Controller protocols," "microsecond loops with integrated I/O," "updated hardware platform," and many others.

The broader messages for the non-geeks included these:

- Ovation is "getting rid of connections" which makes the system more reliable, and native prognostic, performance monitoring.
- Analytic applications are being built into Ovation embedded simulation and the process historian. Schilling noted, for example, that future releases will incorporate advanced pattern recognition (APR) models directly in the Ovation I/O modules, will be integrated with the

Basic CIS* controls: Key controls to be implemented in every organization—basic cyber hygiene

- Inventory and control of hardware assets
- Continuous vulnerability management
- Secure configuration for hardware and software on mobile devices, laptops, workstations, and servers
- Inventory and control of software assets
- Controlled use of administrative privileges
- Maintenance, monitoring, and analysis of audit logs

Foundational CIS* controls: Technical best practices that provide additional value and security benefits to any organization

- Email and web browser protections
- Limitation and control of network ports, protocols, and services
- Secure configuration for network devices—such as firewalls, routers, and switches
- Data protection
- Wireless access control
- Malware defenses
- Data recovery capabilities
- Boundary defense
- Controlled access based on the need to know
- Account monitoring and control

Organizational CIS* controls are critical to any strong cyber program. They focus on people and processes more than technology and are inherently different from basic and foundational controls

- Implement a security awareness and training program
- Incident response and management
- Application software security
- Penetration tests and "Red Team" exercises

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3. Going from one to six sigma, figuratively, in cyber protection means focusing on organizational issues, much like attention to safety is an on-going commitment from every individual 24/7/365

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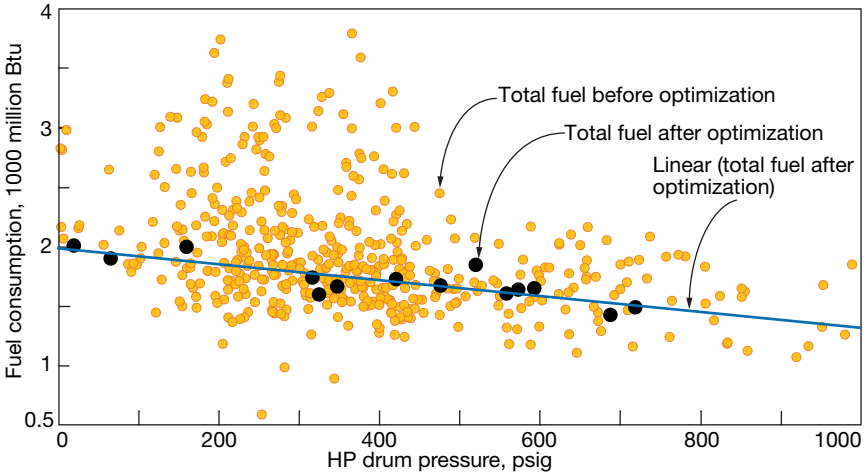

4. Reduction in start variability after overnight cycling optimization is dramatic, considering the growing number of annual starts at this large combined-cycle facility. With overnight cycle sequence automation, cycle startup fuel usage more closely reflects the expected relationship to initial HP drum pressure

PlantWeb digital ecosystem, and identify specific fault conditions and recommendations for staff.

Like string theory

Of course, with digital transformation comes digital vulnerabilities. Cybersecurity continues to suck up more and more of the oxygen in the room. In fact, Schilling likened the cybersecurity dimensions of patch testing, the matrix of supported products, chain-of-custody compliance, device control, asset inventory control reports, and domain "trust relationships" between Ovation and customer corporate IT managers to string theory in physics. "It has 28 dimensions," he joked.

Jaime Foose, who heads PWS's cybersecurity and customer services group, noted that the organization now has close to 40 professionals devoted to 24/7 telephone support for customers in North America and Latin America. Delivering on a promise from the 2017 Users Group, Foose announced the availability of the "Preventive Maintenance Guide," with example checklists for system lifecycle support, segmented by workstations, controllers, network, I/O, the Power and Water Cybersecurity Suite, and others.

Foose added some gravity to Schilling's 28 cybersecurity dimensions. A slide with dozens of cybersecurity firm "brands" for various protective functions (Fig 2) comes across like a work of modern art—each individual brand disappears into a chaotic blur. The underlying message? Leave it to Emerson's cyber experts who understand both IT security and power generation, unlike pure IT firms. Plant managers may want to benchmark their cybersecurity activities to the broad levels and actions shown in Fig 3.

Results speak volumes

As in past years, the industry breakout sessions included user presentations illustrating the benefits of different aspects of the Ovation automation platform.

Case history 1

A 3750-MW combined-cycle facility, with three 3 × 1 units installed between 2009 and 2011, needed faster start times and implemented Ovation's advanced startup automation features. The plant already had experienced close to 650 total GT/HRSG starts in 2018 by the time of the meeting, and the number is projected to surpass 1000 annually going forward. Automating overnight cycling of all nine GT/HRSG trains, with onsite modifications incurring no outage time, is saving close to $1-million in fuel costs alone.

Now there's "one button for a prestart, and one button for a GT start," according to the owner representatives making the presentation, and "we've gone from hundreds of clicks per start to 11 clicks!" They reported that operator acceptance was the most difficult challenge, but now operators use it every day.

The plant has reduced hot-cycle startup fuel consumption by 18%. In addition, each start is "more consistent" and involves much less overall financial risk (Fig 4). Even with six-sigma training for plant personnel to improve cycling performance, too much variability was exhibited across the different plant operations teams.

Other benefits from the upgraded controls include $300,000 per combined-cycle unit from model-predictive control of superheater and reheater temperatures, $600,000 across the units from model-predictive NO_x control and reduced ammonia consumption, 47-MW/min load ramping through model-predictive unit load control, tighter control over the automatic duct-burner system, and efficient comparisons of operator start signatures.

The new techniques were installed, tested, and proven out on one train, then replicated across the other trains. The project took 30 months from conception to completion, noted the owner reps, but an Emerson manager clarified that a "standard scope would be six to nine months" for a project of this type today.

Case history 2

Another utility with an ageing 685-MW steam unit upgraded its station excitation controls with Ovation-based capability. "You don't think much about excitation systems until they don't work," the presenter said. Indeed, one of the project drivers was four unit trips attributed to excitation in one year. The other driver was obsolescence—replacement parts for the original Brown Boveri generator excitation controls were unavailable.

"Emerson not only had a reasonable delivery schedule (less than 12 months), it was the most 'open' of the systems on the market," said the presenter. He also noted that Emerson was good about working through issues such as lack of adequate cooling capacity in some of the cabinets, an overheated transformer phase which had to be replaced, and failure of the excitation transformer. During the last event, oscillography built into the Ovation system protected the generator.

Case history 3

A utility with a 1230-MW plant acquired from investors and equipped with four 1 × 1 combined cycles had as its objective "consolidating to as few control systems as possible," leaving, however, the GT controls to the OEM because of the long-term services agreement (LTSA). The following were part of the project:

- Replaced the Bently Nevada vibration monitoring system with an Ovation Machinery Health Monitor.
- Replaced Alstom P320 controls on the steam turbine/generator.
- Replaced the Alstom exciter cabinet with Ovation.

- Unified alarms to one 40-in. monitor in the control room.
- Added Ovation supervisory M&D for the gas turbines.
- Upgraded the Mark Ve GT controls to Mark VI, with the graphics replicated in the Ovation platform.

Some of the physical plant modifications which came with the project included new gland seal steam valves, instrumentation, and pressure control scheme; instrument calibrations; valve rebuilds; new attemperator valve installed with new automation logic; 6000 I/O points looped and functionally checked; addition of an 800,000-gal fire water tank; and 480-V bus feed rebuilt.

Overall, troubleshooting hours have been reduced, 25-35 minutes have been shaved off of a cold start, and the spares inventory has been lowered. Two "lessons learned" offered to the audience were being more realistic about the project duration and the need for training (no prior Ovation experience at this site), and having a third-party review for the Alstom steam-turbine logic conversion.

Case history 4

A Midwest utility accomplished an Ovation retrofit for a 938-MW Toshiba steam turbine/generator. What makes this project notable is that the unit is only eight years old. The main project driver was that OEM support was "non-existent." The plant was also able to take advantage of a planned long outage involving boiler retuning, and a ST/G major outage.

Scope included complete logic conversion from the OEM-supplied controls to Ovation, supervisory I&C, overspeed protection, main turbine and boiler-feed-pump turbine drives, fully automated turbine startup, rotor stress calculator, and other "integrated enhancements." A similar retrofit project was conducted for a large utility in the Southeast. The presenter noted that they still "have a few issues to work out."

Case history 5

A peaking gas-turbine facility with four simple-cycle units in Wisconsin added diesel engine/generators, black-start capability, and replaced an "obsolete vibration monitoring system." The Bently Nevada racks were replaced, but the existing GE/Bently sensors were re-used. A new set of controllers for each unit was added, along with the Emerson PeakVue product integrated into the Ovation system. According to the presenter, there are "no longer any data links to maintain." CCJ

Annual meeting focuses on equipment inspection, operation, maintenance

The annual Combined Cycle Users Group (CCUG) conference and vendor fair, held in Louisville, Ky, Aug 27-30, 2018, proved once again to be an excellent barometer of what's on the minds of those charged with making sure gas-fired combined cycles (CCs) start and stop when they are supposed to, make money for their owners, and attain or surpass the performance metrics expected of them.

Among the broad themes you'll take away here:

- Staffing and expertise issues continue to plague the industry, especially OEMs.
- Need for flexible systems grows, as do the maintenance consequences of greater cycling imposed on plants not designed for it.
- Impact on existing facilities of the latest H and J machines coming online, as well as early storage units, is imminent. These new GTs are nimble and several percentage points more efficient than predecessor models. Batteries can, theoretically, respond for grid services close to instantaneously.
- Shift in regulatory burden from environmental to physical and cybersecurity.

Many of these themes amplify what was learned through the 18 one-on-one vendor and user interviews conducted by the editors last spring over a two-day period and reported in the 1Q/2018 issue ("Acute levels of uncertainty pervade the industry," p 22).

The staffing issue was aired right out of the gate by the regional utility executive who kicked off the opening plenary session: "We're about to lose 40% of our generation staff; while contractors are filling in, there's a real skills gap." More than one presenter lamented about the man-hours required to deal with NERC issues, yet another burden on already-lean staffs.

To dig deeper into the topics summarized here, access the meeting presentations on the Power Users website at www.powerusers.org. If you're an owner/operator and not registered to use the group's library, sign up today online. Recall that Power Users is the umbrella organization for managing and coordinating the technical programs for the industry's leading user groups—including 7F, Combined Cycle (CCUG), Steam Turbine (STUG), Generator (GUG), and Controls (CUG).

Highlighted plants

Some of the first Mitsubishi J-class gas turbines are now in early commissioning at a 2 × 1, 925-MW site, one of several new power stations equipped with the latest and largest GTs. According to the presenter, the J machine features a 5800-Btu/kWh heat rate in CC mode, and 63% cycle efficiency. Plant will run "totally merchant" at an expected capacity factory of 85%. Each unit can achieve 50% load in 30 minutes.

Somewhat astonishingly, the plant, once it goes commercial, is planning only one outage late in 2019 "to get warranty claims done." That performance goal was even more stunning after hearing that "the OEMs and EPCs lack expertise with these machines, their outages, and the models used to control them."

About 80% of the plant's staff comes from coal-fired plants, as there is little gas-turbine experience available in that region. More than 500 resumes were received for 19 hourly positions, 24 total. "Everyone must be cross-trained," the presenter said, implying that the staff is beyond lean, and "the plant manager is responsible for training, especially training hourly employees to be managers."

In that vein, most of the presentation was focused on intensive training to recruit and retain employees even at the risk of losing them to the plant down the road. "The only thing worse than training employees and having them leave is not training them and having them stay."

GTs + storage? One conclusion you might draw from a presentation on a UK facility is that the next asset plopped down at your CC may not be a GT, but a storage unit instead. According to this presenter, such a hybrid plant can meet all grid services—frequency response, spinning reserve, black start, energy arbitrage, and voltage regulation, as well as earn payments in the capacity market.

This five-year-old 1300+ MW, 3 × 1 facility added a 49-MW battery which started operating in the first quarter of 2018. The first revenue stream derives from delivering near-instantaneous response to frequency changes. Winning in the capacity-market auction provides a second revenue stream. Salient features of the battery: 34 MWh stored energy, 20-year asset life (battery cell replacement at 10 years), and 20 containers totaling 150,000 lithium-ion cells.

Lest you think adding storage to gas-fired plants won't happen here, recall that the whole "dash for gas" originated in the UK in the early 1990s. Also, as the presenter mentioned, FERC 841, "Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators" came out earlier this year, essentially intended to create a level playing field for storage assets in regional US electricity markets.

Outage best practices

One of the most enlightening items, coming under an informal session titled "Best Practices for Outages," is the existence of the website, ISNetworld. Perhaps it is better placed under the heading, "the world is fully knowable" (at least on the Web).

ISNetworld, launched in 2001 with process industry clients as early adopters, is a source for managing contractors from one location. Like similar sites which aggregate performance data from facilities and redistribute it to the participants, this one aggregates reported information on contractor performance.

Apparently, you can review stats, monitor performance, and research

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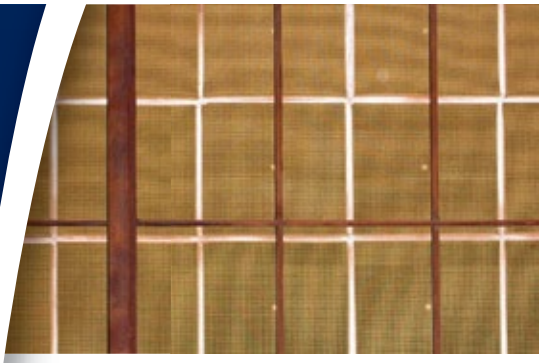

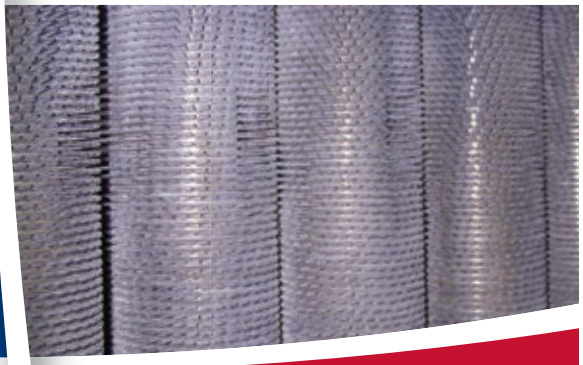

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contractors before they are selected or show up at your site. From the website: "By collecting and reviewing safety, insurance, and regulatory information, ISNetworld streamlines the contractor qualification process for 550 hiring clients worldwide."

Other outage best practices noted during the session included the following:

- Warn contractors that nothing goes down the plant drains.
- Add 480- and 220-V receptacles (drops). Plants often are deficient in drops to minimize the installed cost.
- Add 480-V heat-trace panels in cold-climate locations.
- Map out laydown and layout spaces before the outage begins.
- Badge each contractor, and monitor and track them.
- Avoid background checks at low-impact NERC CIP facilities.
- Add physical security at the plant entrance. One site was said to employ a local cop—appropriately armed so he doesn't get any lip.

Discussion topics

The open-discussion sessions at CCUG the last few years have featured a padded wireless mic "cube" tossed to the next person who wants to add to the discussion. The moderators are practiced at the toss, based on the accuracy of their throws. Here's a punch list of topics, generally arranged in order of the animated discussion around them:

Attemperator inspections and frequency. One attendee said that this is one of the toughest services in the whole facility and few undoubtedly would dispute that claim (see below). One attendee with a "high-cycling probe-type attemperator" said they inspect it every two years. A second described a failure on the attemperator line at the sleeve, the root cause was leak-by. "It doesn't take much water to cause stress and shock," he said. A third said they had had poor experience with one OEM's design.

Remedies included revisions to the control logic to reduce attemperator cycling, doing external spray tests to check the spray pattern (only a few raised their hands to indicate they did this), and use of a specially designed rig offered by Fisher Valves & Instruments to do the spray tests.

HRSG liner failures/liberation. One attendee said his plant had significant HRSG liner failures in the first year of operation, and another responded that he'd been "dealing with this his whole career." The liners are held in place by studs which tend to fret and fail from flow energy vibration. If this leads to cracks in the casing, you may experience problems with steam drum supports, he added.

Software/hardware for operator rounds. This essentially was a discussion about replacing paper with digital records; responses were all over the map. Several commercial products were mentioned, including RoundsKeeper (Instamation Systems), MAINTelligence™ (DMSI-Design Maintenance Systems), and eLogger (eLogger Inc).

If you are gearing up for the switch, know that one plant rep said it "took months" to go from paper to electronic and another said it took a year. A few of the interesting comments include: "ledger books are no longer used at our plant, "we don't have enough people to take reams of data by hand," "even though we have electronic records, we still keep hard copy logs," "we stress the training value of what the operators log," and "still need operators to see and hear the equipment."

Welding issues with P91 is a perennial topic at this forum, and many others. One attendee cautioned that most of the P91 components come from Asia and you need to add hardness strength in the formulation to compensate for later repairs. Another attendee noted that you can weld repair P91 twice before you have to replace it. A third said his company had developed a qualification procedure for onsite welding of P91.

Obsolete equipment. A facet of the discussion addressed the fact that OEMs declare components obsolete when that may not be the case. One plant rep lamented that they had "lots of obsolete stuff even after only 13 years." Control system software and hardware seemed to be a category unto itself.

Another thread in the discussion was having spares in inventory. "Things can break when you do an upgrade," someone said. And then a word of advice: "Replacing obsolete components requires management of change documentation!" Most plants probably wished they had this option, uttered by one attendee: "Declare it surplus and have purchasing handle it."

Leaks from the top of HRSG casings. The discussion began with infrared (IR) thermography surveys, one attendee noting "from top to bottom." Another said they use contractors for IR surveys but that "you have to work with them for HRSG roofs." A third attendee pulled no punches: "HRSG designs are crap. They catch water, they have no railings, they pose all kinds of safety issues." Another noted that you have to be a contortionist to access for welding repair. Be aware that it's sometimes hard to see cracks as they can "seal up in cold weather" when materials contract.

Under-insulation corrosion. Most of this discussion centered around identifying problem areas in piping and vessels using an eddy-current "lite" program to "semi-quantitatively assess wall thickness through 8 to 10 in. of insulation for main steam piping lines. Because the technique does not distinguish between outside and inside loss, you have to follow up with a magnetic-flux leakage inspection technique to measure loss. The EC-lite technique helps avoid stripping insulation in places with no loss.

Film forming amines. The question was, is there any impact on the steam turbine when this technique is used to reduce iron transport? One respondent who had looked into this answered that they had found no impact. Dig into this subject by reviewing "Film-forming substances: The next frontier in cycle chemistry," 1Q/2018, p 6).

Desuperheater replacement. A plant rep who described replacing one manufacturer's unit with that from another vendor reported performance was good but that they experienced packing leaks. They also relocated the positioners outside of the enclosure so they would not overheat and technicians could work on them more comfortably.

NH_3 injection-grid mods. A California plant re-engineered the vertical manifolds by drilling extra holes on the edges to redistribute flow while plugging other holes. This reduced ammonia slip from 5.2 to 1.8 ppm. The original grids were not properly designed, the rep said, and that you need a system perspective to properly address SCR issues.

Remotely monitoring HRSGs and ST/Gs. One rep for a third-party operator said they had partnered with a consulting firm for daily monitoring and management of "PI points," but that it was not real-time. Another referenced the owner's remote M&D center staffed by two analysts who look at the data and hold weekly calls with the plants. "Most of what is caught are instrumentation issues," he stated.

Online leak testing. One plant rep said they are doing this quarterly because "they find problems routinely." Another said their company protocol was annually.

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1. Erosion of HP-bypass pressure control valves is "not specific to any OEM, not a problem with most units, but a *BIG* problem with some," according to one of the industry's top HRSG consultants. At left, water and/or wet steam accessed the plug shown through perforations in the surrounding cage, creating an artistic-like erosion pattern. At right, the destructive effects of erosion are clearly visible at the bottom of the plug

The speaker offered three case studies, the first in which the HP-bypass PCV began leaking through after only a couple of early runs, although he conceded the plant endures some unique operating modes. In the second case study, leakage began in less than two years of operation, despite valve modifications to arrest erosion. In the third case study, it was discovered that the valve was opening at the wrong time in the start sequence.

"The bypass lets you control the ramp rates, but erosion and subsequent leakage is the probable consequence," he stated. The presentation wrapped up with this question: Are there alternative methods of depressurizing under bypass conditions? An idea tossed out for discussion was an additional bypass around the original HP steam turbine bypass designed for mixed flow.

2. Weld cracks and bulge in attemperator "pup" piece (A) led to design changes shown in (B), but after another failure and forced outage, plant decided to replace it with the design shown in (C), being installed (D), and welded in place (E)

Human performance

Gas-turbine sites at one utility are participating in a company-wide human-performance initiative (HPI) to make reducing or eliminating human errors and organizational process shortcomings part of the company culture, much like safety programs. The rep noted that a study of "significant events" showed that 80% are caused by human error, and only 20% are because of equipment issues. A significant event is a forced outage, a derate of more than 20%, or a reportable safety or environmental incident.

Although no direct link to staffing and expertise was made in this presentation, it is clear that an HPI program can go a long way towards ensuring that plant personnel are properly trained and experienced and work processes don't fail them. Get the details in "Human performance events become opportunities at NV Energy," 3Q/2017, p 34,

Valve erosion

A renowned HRSG consultant tackled HP-bypass pressure-control-valve (PCV) erosion (Fig 1), opening his talk with "none of these valves can survive if you put water through them." Magnetite entrained in the water, picked up in idle piping lines, will increase the erosion rate a hundredfold. Once erosion occurs on the plug and seat, steam will leak, overheating the downstream carbon steel pipe.

Attemperator failure analysis

A rep from a 1 × 1 CC in the western US delivered the type of presentation attendees come to CCUG for: A detailed, richly illustrated (Fig 2) root-cause analysis of a hot-reheat final attemperator which failed twice, once in 2015 and again in 2017. Providence kept this from becoming a catastrophic failure event.

After reviewing the commercial and operating history of the plant, the presenter told how a foreman was milling around and saw steam pouring out of the main-steam-line lagging. Taking the plant down and removing

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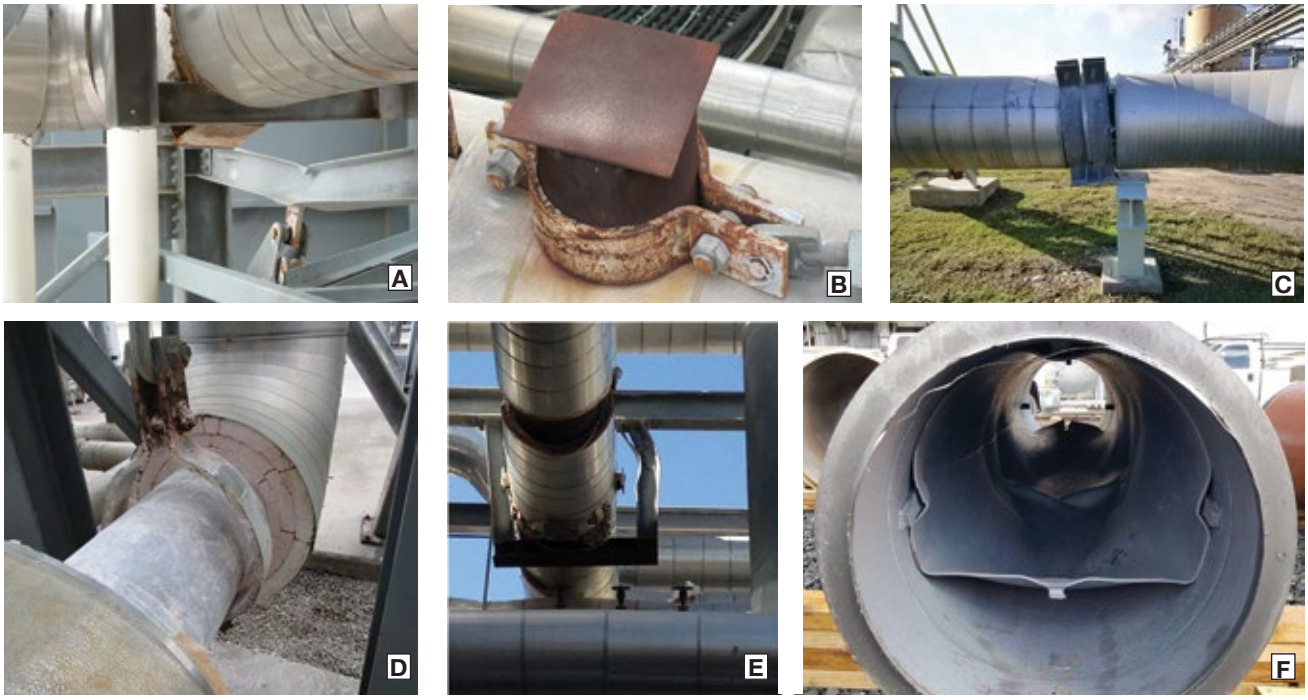

3. Formal piping inspection programs have uncovered such things as pipe beam buckle and failure (A); loose axial restraint pipe clamps (B); poor application of pipe shoe for HP steam line, deteriorated insulation, loss of clamping force, and support migration following a transient event (C); defective clamp bolt and nuts and oversized clamps (D); water-hammer damage on hot-reheat bypass line (E), and attemperator liner failure (F)

the insulation revealed a bulge at the top of the attemperator "pup" piece (a length of Sch-60 straight pipe welded to the attemperator piece and the P91 main steam line) and a 4-in crack.

It turned out that the attemperator had no liner (thermal sleeve); it was significantly oversized, along with the temperature control valve; there were pipe support issues; the post-weld heat treatment (PWHT) was too long and violated code; the original Type-422 stainless steel nozzles were replaced with Inconel nozzles; and metallurgical lab analysis showed that pipe cracking was caused by thermal shock.

A redesigned attemperator was specified with three nozzles rather than four and a body length of 9 ft instead of 3 ft (to eliminate the pup piece and reduce the overall number of welds). All piping with PWHT was removed and replaced. Unfortunately, two years later, weld failures recurred. After grinding out the area and weld repairing, staff began to get concerned about the number of heat treatments and creep life.

A third ring-type attemperator replacement was specified and installed during an outage this year. Even during this work, issues arose with prolonged PWHT, purge dam failing, coordinating large radiography test (RT) crews, and more weld failures prior to PWHT. This may be yet one more example of expertise issues plants are grappling with.

Such experience is common. The presenter mentioned another user he was familiar with which had five attemperator failures early on in plant operation. He offered these lessons learned:

- Health and safety. Hexavalent chrome may be present during grinding and welding.
- Involve site personnel in determining RT site exclusion zones.
- Maintain strict control over RT crews and schedule.
- Attemperator lead times are long; even an expedited delivery took 20 weeks.
- Limit P91 heat treatments to three or less.
- PWHT and welding of P91/F91 are poorly understood by many in the industry. Verify procedures!
- Hardness testing may not be accurate in predicting material condition.
- Have a contingency plan for purge dam issues.
- Problems maintaining vacuum will show up at the attemperator piping.
- There is value in performing pre-PWHT weld inspections.

Glycol sleuthing in cooling water

If you ever detect glycol odor emanating from your storm water drain, you might want to request this presentation from a plant in the Northeast. After operators noticed the closed cooling water (CCW) system tank levels dropping (despite refills), and detecting glycol odor in the system (water/propylene glycol mixture), sampling at the stormwater drain and the downstream retention pond confirmed presence of glycol.

Unfortunately, at this unit around 3000 ft of the CCW piping is underground.

The situation turned into an environmental event: Biological oxygen demand (BOD) at the water discharge to the receiving body was permitted at less than 30 ppm, but the leaking glycol drove it two orders of magnitude higher.

Troubleshooting included walking down all the above-ground CCW piping and equipment, isolation of supply and return lines, acoustical analysis (not helpful), hydrostatic testing with pressurized air, and even invasive digging in the HRSG area. But the critical clue turned out to be that the CCW temperature was found to affect leakage rates; lower temperatures, less glycol.

By driving the temperature as low as it could possibly go, the plant located CCW fluid coming from the ground around the CW piping associated with the GT lube-oil cooler. Maybe you guessed it: The piping was located under the turbine floor.

A 24-in hole was bored into the floor and the leak was discovered on the supply side of the cooler. The CCW system was taken out of service, a larger area of the turbine floor was removed, the entire system was drained and a permanent repair was made. All of the glycol-tainted pond water had to be treated as well.

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4. Warming system for a D11 steam turbine can be installed within a 10-day window, according to Arnold Group (left). It can bring the turbine from a cold state to hot-start condition within 2 to 2.5 hours (right)

Formal HEP assessments

An attendee from one of the largest owner/operators of gas-fired power stations in the US described the evolution of his company's centralized high-energy covered piping system (CPS) program, adhering to or exceeding ASME B31.1 Power Piping Code requirements. The program includes flow-accelerated corrosion assessments and NDE recommendations.

Primary program elements include these:

- Baseline assessments conducted within three years of COD, preferably in the first year.
- Five-year follow-up hot and cold assessments of balance-of-plant, non-boiler external, and boiler external piping 2.5-in and larger (Code requires 4 in. or larger); main steam, hot reheat, cold reheat, and boiler feed water; and piping that operates above 750F or 1025 psig.
- Annual O&M piping inspections conducted by plant personnel: Visual assessments from casing to casing—including piping, supports, and in-line components (flow meters, valves) for overall integrity, evidence of water hammer, improper slopes, etc.
- Each site has an assigned CPS program coordinator.
- Documentation includes just about anything that might impact the condition of the piping, from original P&IDs to records of transient events and operational data.
- Standardized reporting format using hyperlinks from spreadsheets (home-grown system).
- Consistency in selection and use of third-party contractors to perform the work.
- High stress areas for NDE assessments are prioritized.
- Subset, but separate, program for P91/Grade 91 components.

If you want to understand the value of such a formalized approach, look at the Fig 3 photos; they illustrate what you might expect to find during such assessments. By the end of last year, this owner/operator had conducted a baseline assessment and at least one follow-up assessment (five-year interval) of all plants in a fleet which includes 92 gas turbine/generators and HRSGs and 47 steam turbine/generators.

Vendor thumbnails

HRST Inc. For those suffering with economizer issues, an HRSG expert from HRST told the audience about its Shockmaster® economizer, an all up-flow single-pass design that can be installed in two weeks or less. It solves the problem of pass-to-pass temperature differences. The first unit went into service in 2007 at a site experiencing numerous economizer failures. Since the replacement only one failure has occurred. Numerous other units have been installed since then.

HRST also offers its return-bend economizer support upgrade. Among the pearls of HRSG operating wisdom dispensed during the presentation were rapid cooling of steam drums does more damage than rapid heating; small numbers of cooler tubes among many hotter tubes leads to numerous failures; warped tubes can still last a long time; and economizer drains should be blown down at 50 to 100 psig once per month before the cold season.

AAF International explained its GT inlet heating system to expand the lower end of the GT operating range from 35% to 30% turndown and achieve greater flexibility. Heating the air intake by 24 deg C will improve part-load efficiency (though at the expense of an increase in parasitic load). Plants can avoid cold starts by remaining at the minimum emissions compliance level (MECL) for several hours or overnight. There's a significant savings in fuel consumption, too. A two-year payback for the inlet heating system was reported by a plant in Italy.

PSM. A representative from Ansaldo Energia/PSM addressed plant needs for flexibility and optimization, and minimizing operator variability, with solutions that don't require gas-turbine hardware upgrades. The company's AutoTune product, which replaces the OEM's tuning expert who typically shows up seasonally, can be used with Mark V and VI, TXP, T3000, and Ovation control systems. Importantly, it does not override the GT controller.

More than 50 AutoTune systems are operating today, said the rep. PSM also works with Emerson, provider of the Ovation automation platform, to address balance-of-plant issues, new sensors, and valve response issues.

Siemens spent part of its allotted "Siemens Day" describing its exhaust-gas attemperator, which "decouples the GT from the steam cycle" if there is no bypass stack available. Simply, water or air is added into the exhaust which improves peak shaving, enhances cold-start performance and efficiency, decreases startup fuel and emissions, and enables GT operation above the limits imposed by the HRSG. Note that the water option will consume demineralized water and one attendee observed that care must be taken that no water impinges on the downstream SCR catalyst.

The physical configuration involves eight attemperators distributed along the circumference of the exhaust duct downstream of the thermocouples. Each attemperator has five water injector nozzles.

GE. Both Siemens and GE, during each OEM's respective session, empha-

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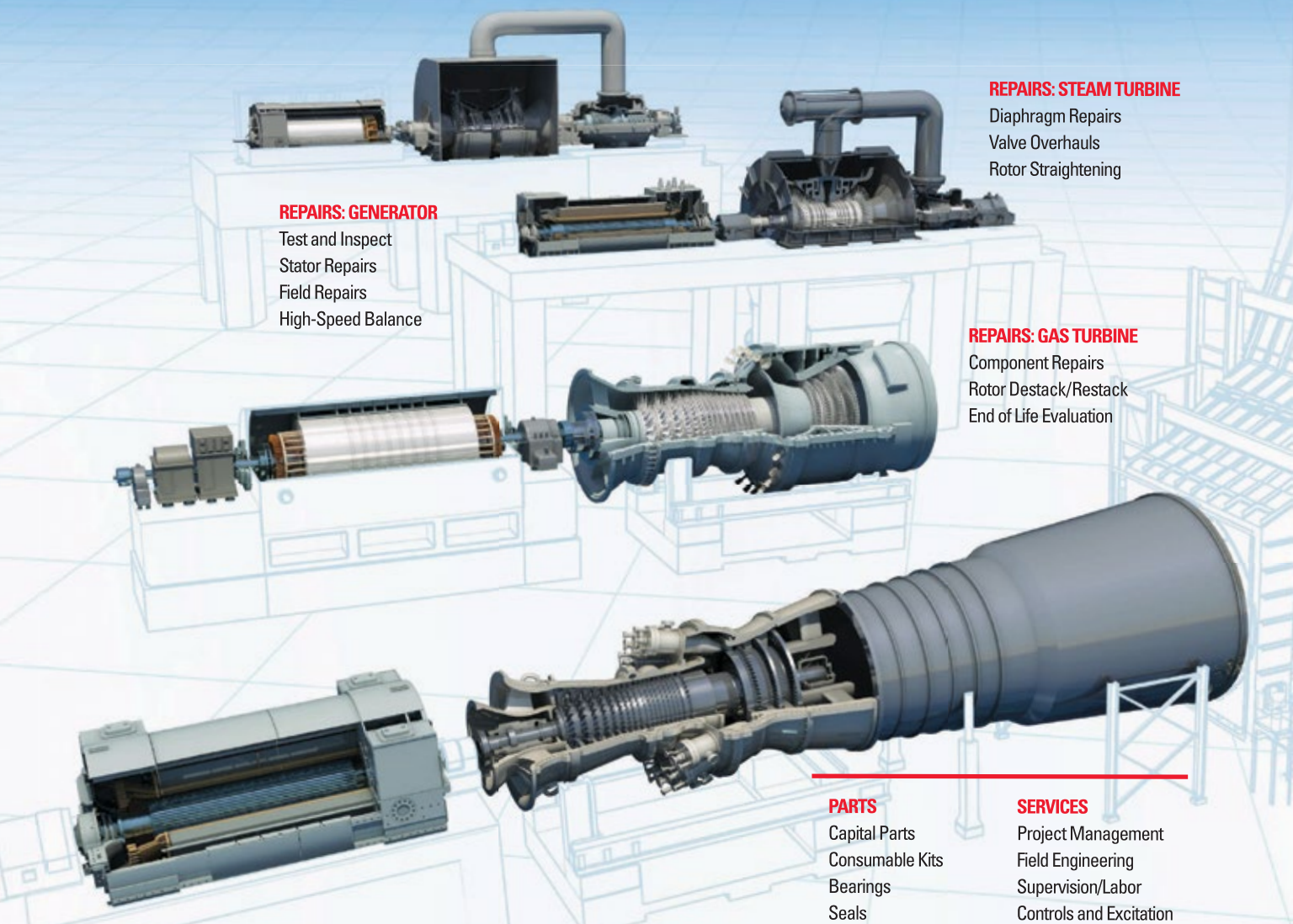

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sized system-wide optimization strategies and digital-based solutions. GE's top service guys dwelled on FieldCore, their field-service company, described as a "work-in progress," and a "massive new organization" intended to make up losses in revenue from new-build with field-engineering and outage-management services.

GE-supported options delineated to the audience included OpFlex AutoTune, Variable Load Path, and Turbomax for ST/G stress control automation. Most of these involve modifications, enhancements, changes, and/or refinements to the control strategies, hardware, and software.

Physical options, described in CCJ previously, include heating blankets (Fig 4) and ST/G shell warming (with hot air, those units with double shell). Clearly, both behemoth OEMs are seeking to drive more revenue from facilities with performance consulting around enhanced monitoring, analytics based on digital software and new sensor technologies, financial and weather forecasting models, equipment health advisories, startup advisors, dashboards with key performance indicators, and digital "twins" (simulator capabilities to test and diagnose control strategies, anticipate issues, etc).

Krowech, Mayfield career achievements lauded by CCUG

Krowech

Mayfield

The Combined Cycle Users Group annually recognizes industry professionals who have demonstrated excellence throughout their careers in the design, construction, management, operation, and/or maintenance of generating facilities powered by gas and/or steam turbines.

The group's 2018 Individual Achievement Award was presented at its annual meeting in Louisville, at the end of August, to Robert Krowech, PE, CEO emeritus, HRST Inc, and to Dr Robert Mayfield, plant manager, Westmoreland Generating Station (Tenaska Inc).

Krowech grew up on a farm in northern Minnesota where repairing machinery was part of life. After a tour in Vietnam, and with engineering degrees from the University of Minnesota in hand, Krowech began his career in the power industry at a leading supplier of heat-recovery steam generators. Twenty years later he left that company as chief engineer to found HRST Inc, today a leading provider of HRSG aftermarket products and services.

His efforts in developing and standardizing the HRSG inspection process and various analysis techniques have effectively created industry standards. In more than four decades of HRSG engineering, he has obtained 10 patents—including steam separators, self-energizing penetration seals, and boiler-cleaning apparatus and methods.

Krowech's deep knowledge of HRSG design, fabrication, and operation has contributed significantly to the development of engineers capable ofsolving some of the industry's most challenging problems.

Mayfield retired from the US Navy as a submarine commander about 20 years ago and launched a second career in the power industry. Highlights thus far include a stint with a gas-turbine OEM, 15 years as plant manager of a 3 × 1 F-class combined cycle in Virginia, and his current assignment as plant manager of a 2 × 1 J-class combined cycle still in commissioning.

The team of O&M professionals Mayfield led in Virginia are high achievers. They received the "Decade of Excellence" award from CCJ for their many outstanding contributions to the periodical's Best Practices program, were recognized as a model OSHA VPP Star site, and received the Virginia governor's Volunteer and Community Service Award.

Mayfield is a relentless champion of education and professional training/development. After serving on four nuclear submarines, he instructed on nuclear engineering and reactors and was appointed academics director of the Naval Nuclear Power School. In the civilian world he was an adjunct professor at the national Graduate School of Quality Management, Stratford Univ Richmond Campus and Univ of Phoenix Richmond Campus.

An advocate for STEM (Science, Technology, Engineering, and Math) and CTE (Career and Technical Education), he was appointed by the Virginia Board of Education as chairman of the CTE Advisory Committee and as vice chair of the Virginia Career Education Foundation.

Mayfield has published the books "Actionable Intelligence" in 2010 and "Knowledge Management in the Digital Age" in 2017, as well as numerous papers in the areas of knowledge management, STEM, CTE, and workforce and economic development. **CCJ**

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Owner/operators wrestle with emergent issues at inaugural meeting

Welcome the 7HA Users Group into the pantheon of power-industry organizations seeking peer-to-peer interaction to solve problems expeditiously and provide a collective check on official OEM positions regarding fleet- and plant-level issues.

Representatives from well over a dozen facilities and five countries, responsible for 30+ machines, attended the inaugural 7HA Users Conference, in Fort Worth, Tex, Sept 12-13, 2018. The table illustrates machine operating stats as reported by the participating owner/operators. Obviously, it is early days for the technology with respect to commercial operations.

The scene was reminiscent of the early 1990s when the F-class technology emerged in commercial settings, dozens of units were sold worldwide, engines began operating before any appreciable operating experience had been gained with the fleet leaders, and before long, units were being air-lifted from around the world to have serious deficiencies addressed.

You can read about that experience in "Flaw in Design of Turbines Results in Massive Recall from Utilities All Over," by William M Carley of the Wall Street Journal, May 6, 1996.

We don't preface this article this way to create ill will among users and OEMs, but to remind the community that the evolution of high-energy, highly engineered, cutting-edge power systems is rarely a smooth process. To get to today's landscape of F-class machines humming around the world doing what is expected of them, for example, the industry had to get through a tumultuous early to mid-1990s period which deeply affected all five major large-frame OEMs at the time. Now there are three.

What follows is an exclusive industry report from the 7HA Users meeting. All technical issues are described generically out of respect for the extreme sensitivity owner/operators face managing the OEM relationship. GE was there in full force, though, with the meeting structured as first day devoted exclusively to owner/operators, and the second day to the OEM response, followed by a plant tour. CCJ was invited to attend only the part of the OEM session that had nothing to do with addressing issues.

The material, to the extent possible, is organized in priority of fleet issues and/or issues affecting multiple sites. Then a punch list is provided—issues experienced by one or two sites. Learning through open and transparent discussions among the folks who live and die with the equipment is the fastest route to commercial success with the technology.

Keep in mind that the 7H machine has established new industry records for power output, efficiency, emissions, and turndown flexibility. Some of these achievements are noted in the sidebar.

Post-commissioning operating data reported at inaugural conference organized by GE H users[1]

Unit	Model	COD	Starts	Operating hours	Trips
A	7HA.02	04/2018	69	3700	8
B	7HA.02	04/2018	54	3700	6
C	7HA.02	07/2017	85	10,400	17
D	7HA.02	07/2017	69	10,158	3
E	9HA.01	09/2017	1	8500	1
F	7HA.01	09/2017	19	-	-
G	7HA.01	09/2017	32	-	-
H	7HA.01	09/2017	22	-	-
I	7HA.01	03/2018	10	-	-
J	7HA.01	03/2018	11	-	-
K	7HA.01	03/2018	21	-	-
L	7HA.02[2]	08/2018	54[3]	1350	-
M	7HA.02[2]	09/2018	43[3]	1350	-
N	7HA.02[2]	05/2018	50	3200	21
O	7HA.02[2]	09/2018	15	650	3
P	7HA.02[2]	06/2018	52	-	-
Q	7HA.02	-	15	9160	5
R	7HA.02	-	10	9230	4

[1]Not the total experience with GE H machines
[2]Single-shaft combined cycle
[3]Starts between first fire and commissioning

First-stage bucket failure

As if on cue to accentuate the importance of such conferences, the first speaker noted that one of its machines had, just days earlier, experienced a first-stage turbine (S1B) bucket failure after less than 10,000 operating hours. All four units (at two sites) being operated by this company were then shut down as a precaution.

Days after the conference, Reuters reported on September 20 that four GE HA-class machines in the US were shut down because of an "oxidation issue" and the company expected that all 51 machines shipped to date would be affected. The article also noted the fix, according to an OEM spokesperson, would require "minor adjustments." Users at the meeting said GE had "acknowledged that this is a fleet-wide issue."

Others have reported that the oxidation affects a key alloy in the blade and shortens its life. GE, already dealing with existential corporate and Wall Street level complications, was dealt yet another blow by this event.

The bucket issue also has

GE's 7HA.01 and 7HA.02 gas turbines feature 14-stage compressor sections with three stages of variable stator vanes (left in photo) and four-stage turbine sections (right in photo). The 12-can DLN 2.6+ combustion section, the latest engines featuring axial fuel staging, is between them. The Dot 01 is designed to produce 290 MW net at 42% efficiency in a simple-cycle configuration, 880 MW net at 62.6% efficiency in a 2 × 1 combined-cycle arrangement. For the Dot 02, the simple-cycle numbers are 384 MW at 42.5%, with combined-cycle output and efficiency at 1184 MW and 63.3%

thrown into some turmoil the delivery schedule for machines to US customers, according many present at the conference. One, with a commercial operating date (COD) a few years out, said that the buckets destined for their machine, what were to be the first "Gen II" S1Bs, were now being diverted as replacements in the failed units. This action has postponed COD.

Users wondered aloud whether this "fix" would be the right one, since there is no commercial operating experience with Gen II hardware. The next opportunity to "look at them" in the first machine incorporating them, said the site representative, was not expected until a scheduled outage many months out.

Another operating site rep said the OEM was 9-10 months behind on spare parts and that they were "desperate for spare stage 1 blades," and needed to "get through the fall on someone else's blades." A third site was expecting its S1B replacements in 2019. A fourth noted that they were getting a mix of Gen I and Gen II hardware. Finally, a site with several thousand hours on its HA.01 machines reported that the dampening pins for its first-stage buckets already had been replaced twice.

AFS failure

Some HA combustors feature axial fuel staging (AFS), of which a key component failed and caused damage at one site. The GT was operating at 298 MW when the failure occurred. It not only caused internal damage to the combustion system, but also breached a combustor can into the turbine compartment, triggering the fire protection system and tripping the unit.

There are 48 of these components on each machine with AFS. At the site experiencing the failure, 40 of these components were replaced. At least two other plants have had AFS components replaced.

As later elaborated on by a site representative, the DLN 2.6+ combustion system on such units consists of a fuel flow path referred to as "axial fuel staging" (AFS). Fuel enters the GT compartment and passes into a ring manifold and is delivered to each combustion chamber via "pig tails." Fuel then is equally distributed to four ½-in. tubes attached on the outside of the "Unibody" (but internal to the combustor), and injected into the hot gas path through four nozzles.

The idea behind this flow path is to introduce fuel gas downstream of the flame zone and just upstream of the turbine first-stage nozzle. The fuel gas auto-ignites, increasing the energy available for the power turbine but with no increase in NO_x emissions. This also allows for extended turndown while maintaining emissions compliance.

At the site with the AFS tube failure (during normal operation), a flashback occurred causing complete disintegration of two fuel nozzles, damage to the Unibody assembly within the combustor, and some splatter impinging on the turbine first-stage nozzles and buckets within the quadrant of the failed combustor.

There was also a breach of the combustor wall. Hot gases entered the turbine compartment and triggered the fire-protection-system heat detectors, which also automatically initiated protective action of immediate unit trip. Data review revealed that approximately 45 minutes before unit trip there was an instant spike in NO_x, exhaust spreads, and low-band combustion dynamics.

The root cause of the AFS tube failure is unknown at this time pending completion of the analysis effort by the OEM.

Vibration

One site with around 3700 operating hours on its HA.02 machines reported that they had been plagued with cold-start transient vibration and start-to-start vibration issues associated with bearing No. 3, which the OEM had recently acknowledged were fleet-wide issues. The presenter said that half a dozen other machines were experiencing similar problems.

The vibration levels increase over time, and are associated with thermal changes in the unit. Low-load operation makes it worse. The vibration is supposed to be below 5 mils, but at times has been indicated as high as 12 mils, and routinely is around 7. Perhaps the most aggravating thing is there is no real pattern to the deviations, other than they tend to be "stable" at baseload.

Numerous foundation checks by the OEM didn't solve the problem, nor did attempting to correct the balance with strategically placed weights ("shots"). In fact, "placing the shots in the wrong places led to numerous fruitless iterations." An hypothesis of coupling misalignment also has not proven out.

Excessive vibration leads to secondary issues, such as oil leakage at the deflector plate from one of the generator rotor bearings, terminal strips coming loose, and failures of exhaust-thermocouple attachments. "We are replacing many exhaust thermocouples," one said. Another site experiencing similar vibration problems is testing a prototype thermocouple that may be more robust.

One site reported that they had changed out the seals on the leaking generator bearing, added a row of labyrinths, and made some other adjustments which appear to have corrected their problem.

Wolf Hollow offers early glimpse into H-machine performance

Two of the biggest, bad-ass gas turbines currently operating in the US are proceeding through their paces at Exelon Generation's 2 × 1 Wolf Hollow II facility, Granbury, Tex, southwest of Fort Worth. CCJ editors stopped in to visit with Plant Manager Jeff Klier last spring during a swing through the state.

The GE 7HA.02 machines, together with a D600 steam turbine/generator and two HRSGs (delivered under the new GE ownership of Alstom), anchor the 1160-MW powerplant. Wolf Hollow is the first-ever application of GE's D600 side-exhaust steam turbine—a design that translates to less complexity and lower construction costs.

The facility's most striking feature, according to Klier, is its cycling flexibility. The plant is expecting to turn down to 350 MW and to ramp up to 1160 at 80 MW per minute.

The site currently is working with the OEM to optimize performance around the facility's *typical* load points. Results of inspections to date, including removal of certain components at different intervals typical of early days with fleet-leader units, suggest critical parts will have the lifecycle durations anticipated.

After 6000 combined operating hours between the two gas turbines, Klier reported "no deal-breakers" on performance, which he says is impressive for fleet-leader machines. To date, equivalent forced outage rate (EFOR) issues tend to be exhibited in the ancillary systems, not the turbine itself and not the new-technology components.

Klier concluded the discussion by noting that "we're making history here, with respect to the evolution of advanced GT technology, and based on our early experience, this machine has a very bright future."

GE and Exelon are full partners at Wolf Hollow II. Exelon has a contractual services agreement for service and maintenance, and Exelon partnered with GE to apply the OEM's Predix monitoring, diagnostics, and knowledge-management platform.

7HA.02 backgrounder

The gas turbines installed at Wolf Hollow II are GE's largest and most-efficient 60-Hz engines. They were ordered in 2014 and began commercial operation in late 2016. Here are some bullet points from the OEM's 7HA.02 highlight reel:

- Fuel-flexible design accommodates the use of a wide range of gaseous and liquid fuels—including high-ethane (shale) gas and LNG.
- Simplified dual-fuel system uses less water, eliminates recirculation, and uses an enhanced liquid purge for improved reliability and dependability.
- Simpler configuration and modular design saved more than 10,000 installation hours compared to the 7F.03 gas turbine. Reasons include 40% fewer field connections and welds, and a 98% reduction in field-installed valves.
- Quick-removal turbine roof, field-replaceable airfoils, and full borescope inspection coverage of all airfoils streamlines maintenance.
- Four-stage air-cooled turbine with single-crystal airfoils protected by advanced thermal-barrier coatings.
- Advanced compressor has 14 stages (three with variable stator vanes) and field-replaceable super-finished blades.
- Fuel-gas pressure requirements are as low as 435 psig.
- DLN 2.6+ combustor with axial fuel staging is proven through tens of thousands of starts and more than 2 million hours of operation.
- Fast 10-min ramp-up from start command to full load; turndown to 25% of the baseload rating within emissions compliance.
- An air-cooled generator is available to simplify installation and maintenance.

Complex controls

Several attendees commented on the complexity of the H-class control system and the shortage of OEM control-system engineers familiar with the H machines. "Controls are really complicated," one said, "whenever we do a logic change, GE doesn't have enough controls engineers to support us." Another worried that "the digital intelligence is not 100% developed" for these systems. A site experiencing only one trip blamed it on a fieldbus error in the control system and subsequently requested that the GT controls be hard-wired.

A third presenter complained that the original GT/G controls had no redundant vibration configuration and cautioned attendees to "be aware of the primary-frequency response logic for performance tests." This site also had incorrect digital valve position (DVP) firmware settings resulting from miscommunication between the OEM and the sub-vendor. The presenter urged his colleagues to "be familiar with foundation Fieldbus and Profibus for controls as applicable to the Mark VIe GT control platform."

Punch-list items

Those in the queue for their machines, and those considering ordering an H-class unit, will want to consider the following punch list of items discussed at the meeting. These issues have not risen to fleet level issues, or at least not yet, and some may be peculiar to one or two sites, placed in the general category of "teething" issues common to all new facilities, and may have shared responsibility with the EPC contractor.

Digital valve positioners. The same site referenced above with about 3000 operating hours reported failures of digital valve positioners, an "instantaneous event" that leads to a GT trip, while another site reported that temperature-control issues with the DVP led to three trips.

Water intrusion. Fan/blowers in the GT housing reduce heat levels but also create a differential pressure which sucks water in when it rains. A site in an arid climate didn't experience this until the first time the area got a good soaking. These blowers are redundant and both need to be in service because they are critical to maintaining an internal temperature so that electrical and digital electronics don't "burn up." One plant lost a bearing in the motor of one of the fans and had to replace the entire motor.

Air-filter cleaning system. This system has 400 small valves. One plant experiencing leaking in a few of these valves decided to replace all of them. The communication-system bus which "talks" to all the individual valves failed.

Online washing. Several plants do this everyday and had to make modifications to "make sure the pump logic was properly integrated." One user cautioned that the drains are sized for "zero margin," and had to replace a few bad valves and fix loose flanges.

Water carryover. More than one plant has experienced water carryover from the evap cooler into the gas turbine.

Generator. One plant had a flashover event with the collector brushes. The original number of brushes was

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based on the nameplate rating, but the OEM recommended that they be reduced from 24 to 12. One user cautions that generator end windings have "required lots of money and work." The OEM calls it "normal wear and tear," according to one user, and that you have to be careful negotiating with the OEM because they will accuse you of "improper maintenance."

ST/G bearing leak. A site with a single-shaft combined cycle reported that the No. 1 bearing in the low-pressure steam turbine/generator had sprung a "major leak" and the plant had to "limp through the summer."

Miscellaneous heaters. The same site just above also reported "lots of workarounds" with the startup natural-gas auxiliary heat exchanger, the natural-gas performance heat exchanger, and the air inlet heating system (upstream of the inlet air filters), as well as "lots of issues with the air-cooled condenser."

Cap effusion plate. A site overseas reported minor cracks were detected in the combustor-cap effusion plate following a borescope inspection after around 8500 operating hours.

Igniters. One plant experienced packing leakage and overheated igniter wiring on two machines, discovered during the first inspection. The presenter noted that an igniter had liberated at another site he was familiar with.

Lift-oil pumps. One site experienced failures with the pumps, found a breaker off on one lift-oil pump and another that wouldn't start, and noted that "lube-oil skids are tightly designed, very compact." CCJ

TURBINE TIPS, No. 1 in a series

Limit output to maintain reliability of legacy engines

By Dave Lucier, PAL Turbine Services LLC
www.pondlucier.com

Turbine Tip No. 1, from the PAL O&M solutions library, applies to GE Frame 5 gas turbines—most specifically the MS5001D, K, L, and LA packaged powerplants manufactured between 1961 and 1970 and serving in peaking and emergency-power applications.

Some users operating these engines have found that reliability issues associated with equipment other than the gas turbine proper can be addressed by limiting power (megawatt) output to a percentage of the original rating. It should not be surprising that a 50-year-old machine would exhibit signs of ageing. Here are a few instances where limiting output might be a wise strategy:

- Generator experiences overheating at high loads, as sensed by RTDs in the stator.
- Reduction (load) gear vibrates excessively when operating at high power output.
- Turbine experiences vibration because of internal rubs attributed to casing distortion.

There are several "semi-permanent" ways to limit gas-turbine output, including the following:

1. Limit switches on the load set point. Motor-driven rheostat (70-R4) can be used to reduce power output (Fig 1). One limit switch usually is set for 40% of travel. It establishes the "called-for" speed (offline at 5100 rpm) for the subsequent startup.

Another cam and limit switch is used to stop the motor when the travel reaches the end stop (at 100%). This cam can be loosened and rotated to stop the motor—at say 80% travel—for the purpose of curtailing generator output.

2. Gag adjustment of Young & Franklin fuel regulator. Another way for temporarily limiting power output involves "gagging" of the fuel regulator (Fig 2, left). This can be done with the turbine at cranking speed. Here's how:

Start the turbine in the *crank* position and run up to 1000 rpm. Have one operator open the panel door and hold switch 43FS in the maximum VCO (variable control oil) position. Once the control-oil output presure rises to maximum (typical setting is 180 to 200 psig), use the gag adjustment to temporarily lower the VCO. Look at recorded data for the baseload setting (usually about 160 to 170 psig).

Using a 3/8-in. nut driver, looking downward, turn inward on the gag adjustment (located under the plug shown in Fig 2, right), carefully counting the number of turns. Two or three complete rotations usually is all that's necessary.

Next, restart the gas turbine and observe the new output limit with a lower VCO pressure than the previous baseload setting would allow. Example: 12-MW limit, when the original baseload setting might allow up to 15 MW.

3. Air signal into temperature bellows. A third semi-permanent way to limit power output is to insert a temporary air signal into the temperature bellows. A tee can be installed in the air-signal tubing coming from device 65EP (Fig 3).

To illustrate, let's say the temperature control will hold VCO pressure at 170 psig when on exhaust temperature control for the typical operating day, which is consistent with an output of 15 MW. For this condition the turbine exhaust temperature might be 930F and the air signal into the bellows approximately 22 psig from 65EP.

Install a tee in the tubing line to the bellows and raise the air pressure slightly. Example: 23 psig would limit the VCO to about 160 psig and exhaust temperature to 870F, reducing output to a nominal 13 MW.

Conclusion. Which method of output should you choose to help assure engine reliability? My preferred method is to stop 70-R4 short of its end travel (80%). Second choice would be VCO gag adjustment atop the fuel regulator. Increasing the air signal to the temperature bellows is third on my list and would get consideration only when a short-term solution is necessary. CCJ

1. Motor-driven set point 70-R4 is used for speed/load adjustment (left). Limit switches and associated cams for setting 70-R4 operating points are shown at right

2. A typical fuel regulator by Young & Franklin is at left, the plug providing access for gag adjustment is highlighted at right

3. Air signal to the temperature bellows is increased via the tubing highlighted

Latest GTs pose special challenges for NO_x, CO catalyst system design

By Dan Ott, Environex Inc

The state-of-the-art gas turbines (GTs), such as the H-class and J-class machines, are designed to maximize fuel-to-electricity efficiency, achieving and even exceeding 60% in combined-cycle mode. Already, there are an impressive number of these machines in the field; one supplier listed 80+ H-class GTs operating, in commissioning, being installed, or on order.

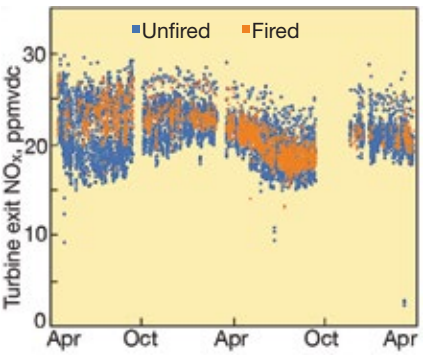
This achievement is accomplished through increased firing temperatures, upgraded combustion staging, and advanced metallurgy. The tradeoff to higher temperature, of course, is increased thermal-NO_x formation. The burden of turbine-exit NO_x emissions ends up on the SCR system, at least to achieve the same stack emissions as specified for F-class sites.

Additionally, these machines are being promoted for even faster starts, more frequent cycling, and operation at loads down to 20% compared to the 50%-to-baseload range historically required of earlier designs. Lower-load operation coupled with higher exhaust NO_x levels present a demanding set of design challenges for the post-combustion NO_x and CO catalyst systems.

Currently, gas-fired turbines often are required to achieve 2- to 2.5-ppmvdc stack NO_x, 2- to 5-ppm ammonia slip, and CO limits of 1 to 6 ppm. These limits became a de facto standard, at least in the US, after they were demonstrated based on F-class and aeroderivative engines with typical turbine-exit NO_x between 9 and 20 ppmvdc.

The new H-class machines exhibit 25 to 30 ppmvdc NO_x emissions (Fig 1) with some excursions above 35 ppmvdc. This is by no means a trivial increase.

The SCR system designs are going from 75% to 85% NO_x removal for F-class units to designs of 92% to 94% removal efficiency for the new advanced turbines. Higher conversion rates mean more catalyst, more frequent catalyst replacement, far more elaborate ammonia injection grids, and more frequent tuning.



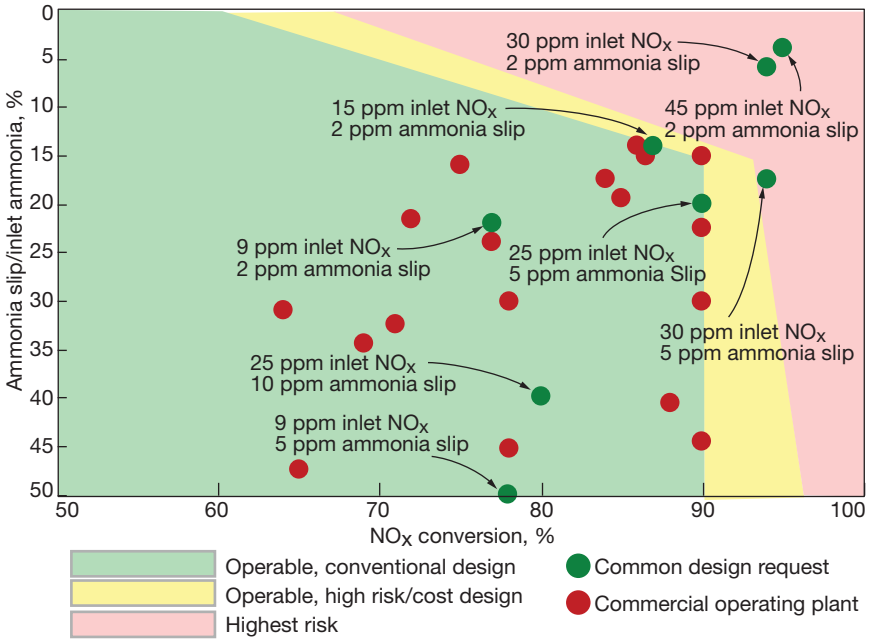
1. Higher exit NOx from H-class machines stresses the limits of current SCR design

Equally important to the SCR design is the impact from the ammonia-slip limit. A Frame 7F turbine with dry-low-NO_x technology and a turbine-exit NO_x level of 9 ppmvdc can rather easily meet a 2-ppm NO_x/2-ppm ammonia-slip limit with 78% NO_x removal and allowance for 22% excess ammonia (2-ppm stack/9-ppm inlet = 22%). When the turbine-exit NO_x increases to 30 ppm, a 2-ppm NO_x/2-ppm ammonia-slip limit requires 93% NO_x removal with only 7% excess ammonia.

The success of the SCR design is critically dependent on the amount of excess ammonia that can be injected. Systems should be designed for greater excess ammonia at higher NO_x removal requirements, but the regulations currently do not allow this.

Fig 2 compares designs with different NO_x-removal and excess-ammonia allowances, taking into account the complexity and operability of the designs. Note that most of the newest, higher-efficiency designs are in the "highest risk" zone where the risk of failure on commissioning is high and maintenance (catalyst replacement, catalyst cleaning, and ammonia tuning) is frequent and costly.

All turbines, including the newest designs, are now required operate at



2. Recent design requests land in the highest-risk part of the performance envelope

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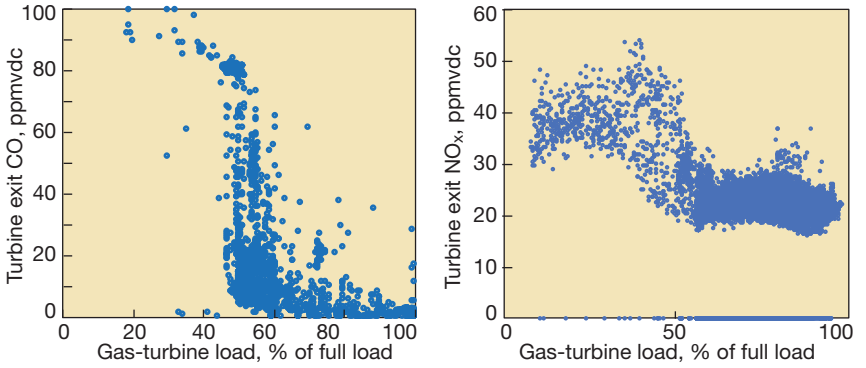

3, 4. H-class machines are at risk of exceeding CO (left) and NOx (right) permit levels at less than 50% of rated full-load output with current design capabilities

low and variable loads to respond to dynamic grid demands. This is in due in part to the growing impact of renewable power. Output down to 20% load is not uncommon.

Figs 3 and 4 show real-time operating data for NO_x and CO emissions versus load for an advanced-class turbine. Most low-NO_x/low-CO combustor technology is designed to function within guaranteed limits for NO_x and CO above 50% load. Below that, NO_x and CO increase rapidly because of suboptimal fuel/air mixing. These spikes in emissions at low load require the SCR and CO catalyst systems to achieve emissions reductions as high as 98%, far exceeding the capability of most designs.

Ott

We have reached the limit of current SCR and CO catalyst technology. We must increase awareness of these issues and look for broader solutions, including modified hardware and regulatory relief, to allow these new turbines to perform as required in an increasingly dynamic and unpredictable energy market. CCJ

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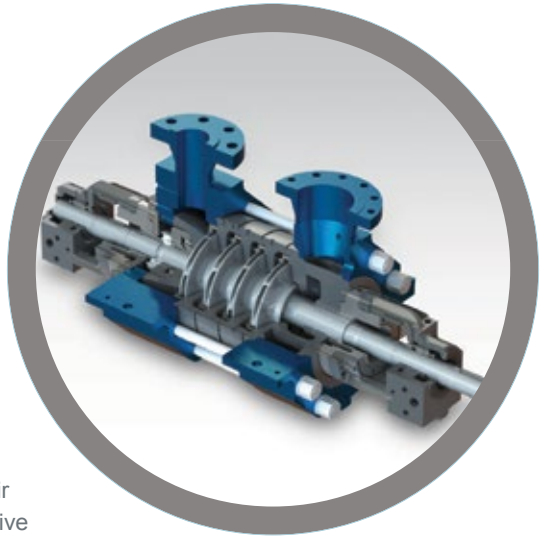

Multistage pumps are manufactured by a number of companies for high pressure medium flow applications and are critical to combined cycle plant operations.

These machines are critical but on occasion present challenges.

Hydro's study of this type of equipment and the issues encountered, has resulted in the development of engineering solutions and processes to ensure successful repair and installation of multistage pumps. Our engineers and technical staff have extensive experience with a broad range of pump equipment. This diverse engineering expertise, and use of the latest manufacturing and design technologies are why so many combined cycle plants rely on Hydro. We invite you to rely on us too.

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Attention to detail early in the lifecycle sets the tone for long-term reliable service

By Engineering Staff, HRST Inc

The first five years of HRSG commissioning and operation are critical to establishing unit reliability and a satisfactory service life. In these early years, control and organization of supplier documentation will help to improve current and future decision-making. Inspections and analysis can help ward off potentially damaging conditions or identify items to allow contract closure with suppliers.

As time goes on, analysis also can determine the effects of any current or impending changes to operations that were not planned when original specifications were prepared. Finally, there are commissioning and early operating practices and conditions that can harm the HRSG. There are many examples, several provided below.

Year 1

Gather, organize, protect documentation. Managing maintenance or operations is not an easy task without complete and comprehensive documentation. The first step is to gather and organize the documents, confirming that all suppliers have submitted complete design packages. A reconciled list of documents with the latest revisions and dates is very helpful. Obtaining copies of the ASME Manufacturer's Data Report forms can verify component design pressures and materials of construction, and aid in future repairs. Data reports can be purchased from the National Board of Boiler and Pressure Vessel Inspectors.

ASME B31.1 requires that every facility have an inspection program for covered piping systems (CPS). This primarily constitutes pipe 4 in. diam and greater between the HRSG and steam turbine or user. The program calls for a very comprehensive list of documents. A detailed list, as of the date of this publication, can be found in ASME B31.1, Article 141 under "Operation and Maintenance."

With everything organized, it is wise to confirm that the documents themselves are complete. Look for drawings that say *later* or *preliminary* and have them replaced with the final revision. If as-built drawings are a contract requirement, be sure to pursue completion, particularly with piping and pipe supports.

The second step is to protect the documentation, keeping complete sets in multiple locations. Hurricanes can wipe them out in hours (that happened), and information collectors can pillage them slowly over the years (almost guaranteed to happen). Whether documents exist in electronic format or as physical manuals, or both, one set should be available for ongoing use and one set should remain protected and secured.

Inspection, testing, analysis

A pre-fire inspection is similar to a standard inspection but, because of construction and commissioning sequences, may be extended over a longer period. Documenting the conditions with abundant photographs will help answer future questions. This inspection should focus on design details, correct materials, and proper installation.

Inspectors should go through the gas-side access and crawl spaces, paying close attention to the inlet duct and firing duct. Violent exhaust flow is known to take down components in the inlet duct if not installed properly. Note interferences from restrained thermal expansion of tube bundles and duct liner systems.

It is important to inspect each drum and pay close attention to the final (secondary) steam separator that covers the steam outlet to the superheater. It limits carryover of water droplets and impurities that can quench or plate out on downstream tube surfaces. Excessive carryover can lead to loss of superheat and elevated risk of tube damage from high temperatures.

1. Condensate trap on baffle-style (chevron) steam separator

2. Perforated plate incorrectly installed under the mesh pad (should be above pad)

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If enough water carries over, it can quench the tubes, causing fatigue damage at the header joints.

The final steam separator is typically an angled array of baffle plates or it may be a box filled with a mesh pad. For the baffle-plate style, a drain pipe should extend from the housing and either have a condensate trap or extend below the normal water level (Fig 1). This drain evacuates water from the casing while preventing steam from bypassing the baffles.

For separators that appear as a mesh pad in a box, the top and bottom typically have different mesh specifications. If installed upside down, the carryover will be higher than intended.

A more serious condition occurs when a perforated plate is placed on the bottom side of the mesh (Fig 2). The plate should be installed on the top of the mesh to boost the pressure drop through the separator, which evens out the steam flow through the mesh box, and lowers local velocities.

If installed on the bottom it does just the opposite. The orifice holes shoot high-velocity steam and water particles through the mesh, making

3. Reheater tubes stressed because of water leakage through desuperheater

4. Exfoliation is an indicator of excessive stress

5. Fin and tube wear at tube-tie support

6. T22 tube should have been T91 material

7. Ferritic and austenitic liner mix

it less effective and preventing any accumulated water from draining. The result is high carryover of water and impurities into the superheater.

All pipe and pipe supports external to the HRSG must be in the correct position and any hydro-stops removed before fired operation. This is a good time to document the hot and cold marks, before they fade or fall off. If low points in steam pipe cannot be drained, consult the OEM or contractor.

Some foundation base plates are intended to move as the duct expands. If so, the anchor bolt washers should be free to move if kicked.

Years 1 and 2

Post-fire inspection and testing. Near the end of the first year or just before expiration of warranty periods, post-fire inspection and testing will set excellent baselines for future inspections. By this time, hopefully, most operational kinks will have been worked out. Again, taking an ample number of photos allows comparison to pre-fire conditions, and provides clear references for future conditions.

Within the gas path, inspectors should look for signs of restrained expansion, interferences, and wear. Some cracks and twists can be expected and are often self-limiting. Others are signs of imminent or future trouble. Improper material selection or the occasional installation of the wrong material will often be revealed as a difference in oxide color or scale formation. If damage is found, this is the time to address the mechanisms that will cause future component failures.

Typical problems include the following:

Stressed tubes. Warped tubes are not necessarily a liability, but they are signs that the tube has been stressed and has yielded (Fig 3). Additional fatigue may cause failure. Cracking might be apparent in tube joints. Stress is common in the superheaters, reheaters, and economizers (Fig 4). Failures have been known to occur shortly after commissioning.

External tube wear. Tubes are susceptible to oscillation from forced vibration caused by exhaust flow. A tube-tie support lattice typically is installed at multiple points along the height of the tube bank to limit this oscillation. If the tube ties are spaced too far apart or if they are loose, tube vibration causes fin wear, and eventually wear on the tube wall. Fig 5 was taken during a first post-fire inspection. It is wise to inspect tubes for signs of wear on the upstream and downstream sides of the first tube bank (as a minimum inspection).

Tubes should not be allowed to vibrate more than 0.125 in., assuming there are sufficient tube-tie restraints and that there is no sign of excessive or ongoing fin wear. Severe wear has been observed in early operations. Owners have contemplated removal and modification of tube panels to correct this issue or even purchased new panels if the wear exists on many tubes.

Overheated materials are those that have been subjected to a sufficiently high temperature for a length of time to cause changes in microstructure, or excessive scale formation (Fig 6). The materials are perhaps mismatched to the location in the HRSG.

In some cases, an entire group of components is mismatched, but more often, one or more individual pieces get mixed in with the correct materials. This is common almost exclusively to the inlet duct and firing duct (Fig 7). Inspectors may find one liner sheet, gas baffle, or tube that looks out of place. If not corrected, early failures can be expected.

Duct burners. Look for signs of flame impingement on the walls or downstream tubes (Fig 8). Long flames or excessive localized heat can be caused

8. Flame impingement on tubes

by failed burner nozzles, inadequate fuel distribution, inadequate exhaust distribution, or improper controls.

Failure of one threaded burner nozzle can shoot flames far into the downstream tube bank. There could be hundreds of nozzles, and tube damage only requires one nozzle to fail. (One owner/operator looks for this condition by monitoring stack exhaust for elevated CO emissions.)

Online inspections. With the unit in operation, several checks can confirm both healthy and unhealthy conditions for some equipment, controls, and operations.

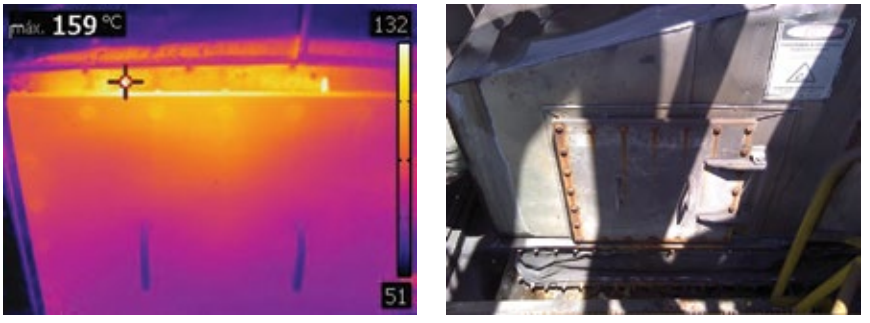
Infrared imaging inspections of the ducts can detect issues that could lead to excessive casing temperatures (Fig 9). Inspections should pay particular attention to the roof, doors, and pipe seals of the first three modules (HP evaporator and forward toward the combustion turbine).

The steam separators have been inspected, but their operation must be monitored. Testing of steam purity leaving the drums will ensure that downstream equipment is properly protected from carryover.

Examining flames through the burner viewports can verify that flame lengths are not excessive. OEM documentation will provide guidance, but a rule of thumb is that flames should be less than 10 ft long and not exceed two-thirds of the distance from the burner to the downstream tube face. Shorter is acceptable.

A review of operational instrument data can reveal troubling patterns with controls or equipment conditions. Excessive cycling of valves, valve leakage, excessive desuperheater spray water, and other harmful conditions can be determined from organization, trending, and examination of process and equipment data.

When piping is hot, movement may be more or less than calculated. If a pipe-support position indicator is significantly past the hot mark or short of the hot mark, stresses may be higher than anticipated. Support position



9. Infrared image of door at left; standard photo of same door at right

indicators that reach the maximum travel constraint are a serious concern.

Years 2 through 5

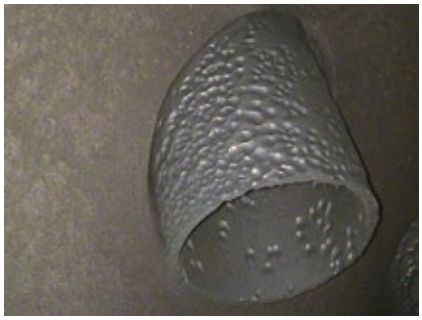
Regular inspections. Every year or two after the first post-fire inspection, a standard inspection is recommended to look for wear issues throughout the HRSG. As conditions develop, they can be identified and the underlying cause corrected before large-expense outlays are required. These inspections normally take 10 to 20 hours and focus on the gas path, header crawl spaces, steam drums, and exterior surfaces.

After four years' time, issues that tend to be more time-dependent get more focused attention–including corrosion, expansion-joint failures, pipe seal failures, and fatigue cracking of pressure parts and liner systems. Inspections can be enhanced with aerial drones, borescopes, thermal imaging, magnetic particle or dye penetrant NDE, and online assessments as needed.

Analysis for changes and vulnerabilities

FAC risk assessment. Flow-accelerated corrosion may be the most detrimental and expensive of tube and pipe failures (Fig 10). Localized damage from FAC often occurs in major components or all components of evaporators and economizers. An external release of water and steam from FAC damage can be fatal to personnel. Highly dependent on water chemistry, damage from FAC can develop rapidly with visual wear occurring in less than one year. Some HRSG designs are more susceptible than others, and OEMs typically do not consider the owner's water-chemistry programs.

The HRSG should be evaluated for risk of FAC before the third year of operation. A follow-on FAC inspection plan can then begin. However, your FAC mitigation program should begin earlier if there are telltale signs on FAC in the LP or IP drum in Year One.



10. FAC on tube but not alloy header

An FAC risk assessment will look at each component of the HRSG and feedwater systems that has potential for either single- or two-phase FAC. Many HRSGs are now constructed using FAC-resistant materials in high-risk areas and in those cases, the scope or frequency of inspection can perhaps be reduced but should never be neglected.

Operational changes. Several years into operation, the owner may need an operating profile different from that specified for the original design. This could include cycling frequency, low-load operation, or perhaps a gas-turbine modification.

Some changes may be out of the owner/operator's control. Power purchase agreements, changed market conditions, or new regulations could influence the number of starts, hours of operation, ramp rate, or combustion turbine output. Innovations in engine design may bring financial incentives to modify the gas turbine, and that invariably affects the HRSG and other equipment.

All should be evaluated for any new operating parameters contemplated. Examples include the following:

Cycling study. Many owner/operator specifications will require the HRSG be designed for a certain num-

ber of starts per year. Each start causes wear and tear on the unit. Inspectors generally find that HRSGs operated at base load look much better than those that cycle often.

A cycling study will look at those components vulnerable to thermal transients, high temperatures, and low flow rates that often accompany start-up and shutdown conditions. Cycles affect the allowable HP steam-drum ramp rate, so if startup time must be reduced or is in question, the cycling study will reveal the balance between cycle frequency and ramp rate.

Low-load operation. Operation of the gas turbine at low loads affects steam and water flow rates. This can lead to unstable flows in economizers and poor flow distribution in superheaters and reheaters, all affecting tube reliability. High exhaust temperatures from some turbines require excessive desuperheater spray that damages downstream pipes and tubes.

Gas turbine modifications. Turbine modifications primarily affect the HRSG through a change in exhaust mass flow and temperature. This changes the ratio of HP/IP/LP steam generation as well as overall heat recovery. Many components must be examined for suitable operation. Modifications with high exhaust temperatures may result in excessive desuperheater spray demand as well as superheater and reheater tube metal temperatures above the design temperature.

Avoid ongoing operations that damage the HRSG

Desuperheater leakage and excessive spray. The desuperheater is responsible for a significant share of damage to superheaters, reheaters, and steam pipes. In some cases, very few fatigue events are needed to initiate tube failures and cracks in the steam piping. There are two underlying causes:

11. Effects of water hammer on cold reheat line

First, there may not be enough energy in the steam to evaporate the spray water. This causes restrained thermal expansion and potentially high stresses in components that are quenched by the water droplets.

The steam temperature downstream of the spray nozzle should be more than 50 deg F above the saturation temperature. A review of operating data will reveal this potential problem. Installation of thermocouples on the exterior of the downstream pipe can reveal damaging conditions.

Second, damage to pipes and tubes often occurs when water flows through the spray nozzle without proper atomization. This is caused by a leaking block valve during periods of no spray water demand or from a broken spray nozzle. Water then can flow upstream or downstream through the steam pipe.

A drain pot with automatic detection and drainage is required on all new HRSGs with a desuperheater. In such cases it is important to verify that the drain pot will collect any leakage (sometimes it does not) and is functioning properly. Operators must be very careful if using manual operation of the pot drain valves or spray-water control and isolation valves.

Burner operation. Excessive heat can damage downstream tubes

and duct-wall liner systems. Burner failures result in high localized heat input while faulty control logic can cause a wall of flame pushing through the tube banks.

Burner system controls must be checked as well. Burner output should be controlled to the limitations of the HRSG, not to the burner design maximum. This is especially important when multiple HRSGs have burners controlled to provide a minimum steam generation rate in a common header. If one unit goes offline or if some of the burner elements are isolated, how is the additional heat distributed among remaining units? It is important to verify that controls distribute heat as intended. Burner management system permissives and fuel-skid set points must prevent excessive fuel flow to any one HRSG.

Piping and header drain control. It is critical to verify that low points in the steam pipe and tube circuits are properly drained and that there is no water leakage through steam conditioning systems.

Undrained pipe can lead to water hammer with damage to pipe supports (Fig 11). The cold reheat system has been particularly susceptible to such events.

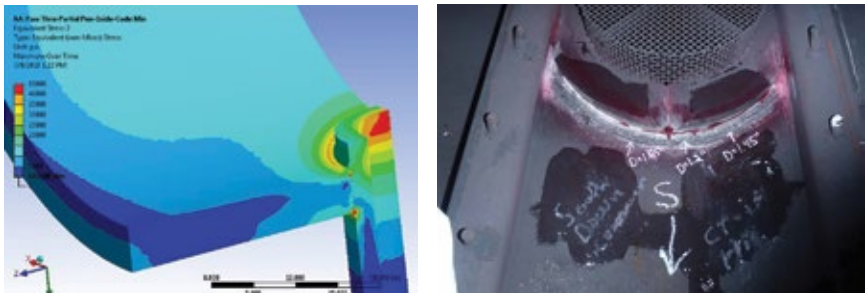
If water hammer does occur, it is important to inspect the damage and the position of the pipe. Water hammer could create a low point that did not previously exist. The reheat system can cause extremely expensive pressure-part damage if not maintained and operated properly (including sizing, location, and control).

After shutdown of the HRSG, steam will condense and flow to the lower headers of the HP superheater and the reheater. If this water is not removed prior to startup, steam can push water droplets up tubes or water can restrict steam flow. These conditions cause high stress resulting in tube failures.

HP-drum pressure ramp rate. HP steam drums in cycling service are susceptible to fatigue cracking of nozzles, particularly the downcomers. Inspections have revealed cracks that extend over half of the lower shell-to-head weld, and up to half the thickness of the weld. Exceeding the maximum ramp rate will increase the risk of such cracking.

A complete understanding of the basis for the ramp-rate calculation also is needed. If the purchase specifications required a specific ramp rate, it likely was based on a specified number of cycles. A future increase in the number of yearly cycles would yield lower recommended ramp rates. If the number of yearly cycles increases beyond what was specified, cycling analysis along with additional FEA analysis of the drum can produce new ramp curves (Fig 12).

Training. To tie in all that is learned from the inspections, industry practices, OEM design considerations, current operations and lessons learned, it is beneficial to bring the operators and stakeholders together in one place for operator training. Information can be shared among all to improve consistency in operation and to achieve common ground on those practices, concerns, and goals that are most important. CCJ



12. Stress analysis of steam-drum downcomer nozzle is at left; crack at downcomer is 1.65 in. deep in right photo

Would you like a little sea salt on that?

By Brian Hulse,
BDHulse Consulting Services LLC

Seems like a simple enough question. It gets asked thousands of times a day in restaurants around the world. But in generating plants powered by gas turbines, it takes on a whole different meaning. These engines are very sensitive to salt,and the are strict limits on its ingestion. Just a few parts-per-million can quickly lead to a multi-million-dollar repair bill.

That's all good to know, but the fact of the matter is that our plants get sited where they make functional and fiscal sense, not on the druthers of equipment manufacturers.

We have learned from work done in Hungary's Institute for Atmospheric Physics (by L Horvath, E Mfiszaros, and E Antal) and Central Institute for Meteorology (by A Simon), that marine air basically contains two kinds of aerosol particles: Those with radii larger than about 0.5 microns composed of sea salt (NaCl), and smaller particles of mostly sulfur species formed in the air by gas-to-particle conversion (excess sulfate). These particles are found in the atmosphere up to 11 miles from the seashore.

OEMs frown on sodium (Na) and sulfur (S) entering their engines, but just how much sodium are we really

talking about here? Sure, you can taste the salt in the air when you're at the beach, but how dense can it really be 11 miles inland?

So, let's take the mid-point—5.5 miles—from the shore for illustrative purposes. Assume the gas turbine at that location is an unfiltered LM2500 (base model with a single annular combustor). Based on the work of the Hungarian researchers and the amount of air the example engine swallows during an 8200-fired-hour baseloaded year, the GT would ingest a little more than 5 lb of salt.

Even if you don't add the sodium that enters the engine through other vectors (fuel, steam, water injection), you are way over the limit GE recommends for this machine.

Managing salts and sulfur in the non-air vectors can—and usually is—done through a combination of contractual obligations and plant processes. Managing the air is really down to one tool: filtration. The design, installation, operation, and maintenance of the combustion-air filtration system is the sole line of defense. What about them should we be concerned with if we find ourselves in a plant sited within 11 miles of a saltwater coastline? Well, here are a few thoughts:

Design. Some packagers only have one combustion-air filtration option, but others have multiple options that are designed for specific environments (desert, marine, etc). If options are available, ticking the appropriate box is a great first step. If options are not available, consider asking for a customized unit, or deleting the inappropriate unit and seeking options in the aftermarket (they *are* available).

Installation. When the construction team is assembling the combustion-air intake, some oversight/sign-off hold points are a good idea. Pay particular attention to the following:

- Make sure the structure's bolted flanges are made up tight, and that the gasketing is centered up on the bolt line as it should be.
- Check the structural alignment and grouting of the support legs to ensure that there isn't going to be any sagging or tweaking of the structures that could lead to cracking of welds or flange separations.
- Verify the proper alignment of any expansion joints or bellows in the ductwork; no binding allowed. And make sure there are no gaps or tears in these components that would allow air (and contaminants) to enter.
- Check the interior materials and coatings—especially downstream of the high-efficiency filter elements—to ensure they are in good condition and sufficiently robust to withstand the corrosive effects of a marine environment.
- Check the man-doors to be sure they are hung straight and square to promote good sealing.
- Inspect door gaskets for proper attachment; also, that latches are adjusted for firm closure. Same for inspection hatches—straight, square, and good tight gaskets.

Operations. Make regular checks on all possible ingress points during routine rounds. Monitor differential pressures (DPs) throughout the ductwork. Make sure all of the transmitters and gauges are in good working order. The DPs should be going progressively up as you get further into the duct—never down. The only time you should see a reduction is following a maintenance activity (filters replaced, etc).

Do not run the DPs past OEM-established alarm limits. When the unit is down and it is safe (an inlet entry protocol should be in place and adhered to at all times), go inside, close the door and look for light. If light can get in, air (and contaminants) can get in too. Make sure any deterioration noted is captured in work orders for the maintenance team to follow up on.

Maintenance. Obviously, keeping

all of the instrumentation working and calibrated is a must. Filters must be changed as needed. All surfaces must be preserved with appropriate prep work and coatings. Your packager will have coating specifications available. When spot-priming areas between coating refurbishments, make sure you don't use something that could harm the gas turbine (like a primer containing zinc).

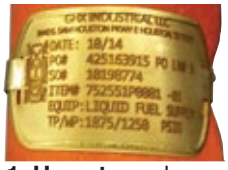
If the structure's bolted flanges start opening up, retighten the bolts and consider seal-welding the flanges at your next maintenance opportunity. As long as you're not a mobile installation, it is a good "final fix" tactic. As the equipment ages, it will become more and more needy in terms of maintenance. Make sure those needs are accounted for in your budgets and manpower planning.

Finally, there are a lot of resources out there in the aftermarket that can provide guidance in filter application, system modifications (such as adding demister pads or torturous-path particulate pre-filters, etc), and O&M advice on best practices. Take advantage of them. Listen closely, ask questions for clarification. Be data-driven and choose the path forward that is best for you and your plant. It's never a "one-size-fits-all" proposition, and if someone tells you it is, ask for the data.

Inspect, maintain hoses to prevent failures

If we know one thing about hoses, it's that they're *expensive*. So we always try to extract maximum value from them before they're replaced. The hoses used on most gas turbines are manufactured with no published shelf-life or working-life limitation.

Each hose on the unit is equipped with a tag at manufacture (Fig 1). It normally shows the maker, date of manufacture, order information, part number, intended service, test pressure, and intended working pressure. No limitation on lifespan (shelf or working) is given; the intent is that there are no set limitations.



1. Hose tags do not have lifespan information

That said, hose manufacturers (Aeroquip, Penflex, Omega Flex, etc), companies that use hose assemblies in their products (engine OEMs), specification organizations (ASME, ISO, SAE, etc), and regulatory bodies (FAA, Australian Civil Aviation Safety Authority, etc) have all written *extensively* on shelf life, working life, care, and custody of hose and hose assemblies. All of this information is available on the internet, and it makes great resource material.

There are several factors that can limit the life of a hose and, in fact, should be driving you to replacement—such as the following:

- Chaffing.
- Kinking.
- Prolonged exposure to UV.
- Mechanical abrasion.
- Lying in fluids (water, mud, fuel, oil).

If you have a GE engine, the OEM provides good information on these issues in the "general practices" foreword of the maintenance chapter in your O&M manuals. Other concerns driving replacement include these:

- Working temperature of the fluid carried.
- Cyclic pressure applications versus

2, 3. Used hose assembly (left) has oil-soaked Firebraid. If the hose was intact the Firebraid likely would be replaced. Otherwise, a new hose (right) would be installed

constant pressure.
- System criticality.
- Personnel exposure opportunity.
- Missing/damaged/illegible hose tags (unable to determine how old the hose is, or that it is working in its intended application).

Some hoses are equipped with an exterior (usually orange) protective sleeve—usually called "Firebraid" after the trademarked product. Firebraid Flame Shield is designed to protect hoses, wires, and cables from the hazards of high heat and occasional flame. The silicone coated glass fiber sleeve protects continuously to 500F and will withstand a molten splash at 2200F. Made of knitted fiberglass yarns in a flexible substrate, it is then coated with a high-grade silicone rubber.

If the Firebraid is torn, chaffed, oil-soaked, or otherwise unable to perform its intended task, the hose should be removed from service (Fig 2). Firebraid and banding systems are available commercially as separate pieces. If the damaged protective sleeve is removed and the hose is found in good condition, the Firebraid can be replaced and the hose returned to service. Alternatively, the hose can just be replaced (Fig 3).

So, as competent plant personnel, what approach should we take to ensure safe, reliable, and economical operation of equipment that uses these hose assemblies?

- Find them. Become familiar with where they are in your plant and what service they're in.
- Catalog them in your maintenance system so that visual inspections can be performed on a routine basis, and that none are missed.
- Develop a uniform visual inspection procedure that makes sense for your operation. Here's where all that resource information on the internet can come in handy. A lot of the work has been done—there's no sense reinventing the wheel. Use what's there to craft your inspection criteria. They have a lot of photographs that illustrate each failure mode, and information to go along with them. Better to use their examples of failures and disasters than to make your own.

Do your inspections and maintenance faithfully and you should not have an issue. Your team should see things being done correctly to gain the confidence needed to perform their jobs properly.

Don't be afraid to ask questions of your local suppliers if you have them. They may not know the answer off-hand, but almost all of them will have access to an applications engineer at the hose manufacturer, and they *will* know the answer or have access to it. **CCJ**

Repairs never-ending? Replace problematic exhaust systems

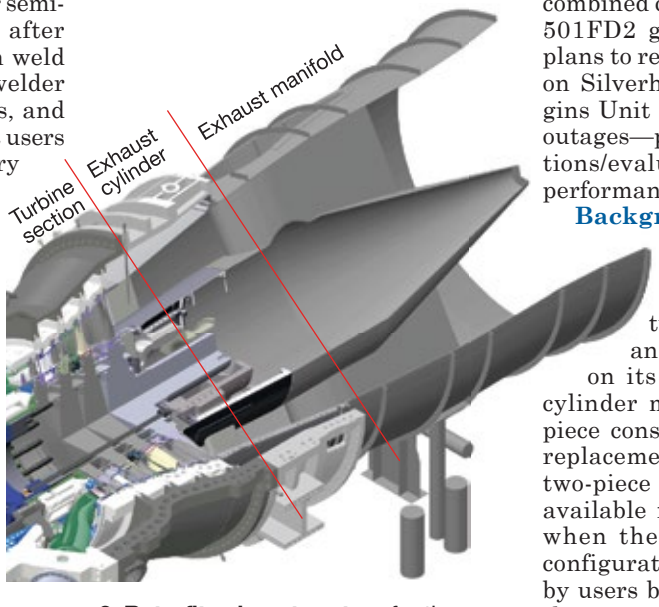
Exhaust systems are a presentation and/or discussion topic at most gas-turbine user-group meetings, particularly those supporting F-class and the more advanced frames. Cracking of components, broken struts, material distress, and leaks at joints are almost sure to occur in virtually any system handling a 1000 lb/sec or more of turbine exhaust at 1000F or higher and moving at near mach speed—especially so in starts-based engines with original equipment (Fig 1).

There was a period a few years back when the accepted "solution" was to have personnel standing by to make repairs during annual—or semi-annual—outages. In meeting after meeting, discussion focused on weld material, weld configuration, welder qualifications, expansion joints, and related topics. It came to be that users able to restrict repairs to every other outage were recognized for their acumen by peers.

The effects of hot gasses leaking from cracks into areas where they could cause accelerated wear and tear and/or personnel hazards provided owner/operators the incentive to press for root cause analyses and resolve the problems through better design and materials selection. There was a lot of finger-pointing to be sure, mostly directed at the gas-turbine OEMs. However, that might not have been entirely fair given the limited industry experience available to guide the design of early F-class units.

The OEMs of record—Siemens Energy Inc and Mitsubishi Hitachi Power Systems Americas Inc—upgraded the designs of their exhaust cylinders and manifolds for the 501F series of engines to eliminate the issues experienced. These have been retrofitted at several plants, as discussed in some CCJ articles published over the last several years. They can be accessed by using the search function on the magazine's home page at www.ccj-online.com.

1. Crack repair attempts on exhaust cylinders are largely unsuccessful



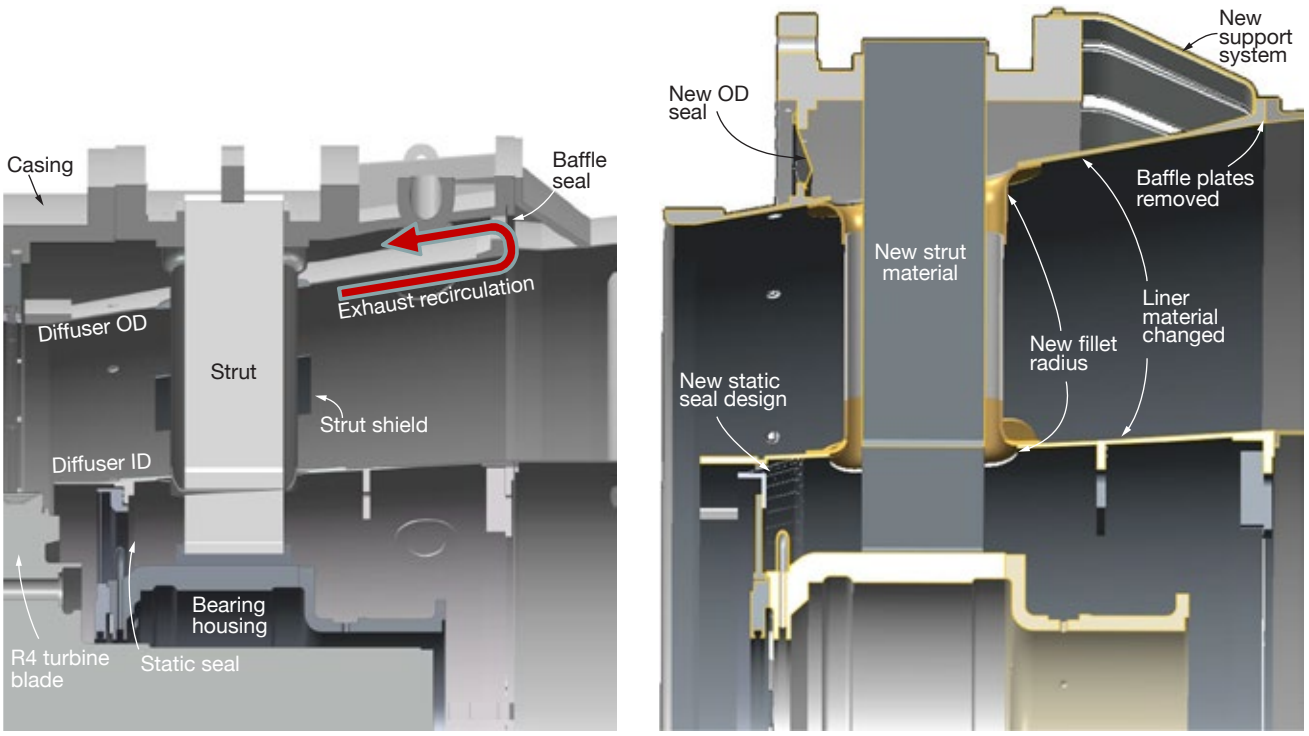
2. Retrofit exhaust system for the 501F from PSM is a "drop-in" replacement for the original. It is compatible with the existing support structure, bearing lube-oil supply lines, and expansion joint. The exhaust cylinder has six struts, protected by thermal shields, to support the aft rotor bearing. The manifold provides personnel access to the aft bearing; lube-oil piping passes through the two massive struts

More recently, Ansaldo Energia Group's PSM, headquartered in Jupiter, Fla, has expanded its 501F aftermarket product line to include exhaust systems. The first complete PSM exhaust systems were retrofitted in NV Energy's Silverhawk Generating Station (Unit B) and Walter M Higgins Generating Station (Unit 2) prior to the 2017 summer run.

Both plants, which began commercial operation in 2004, are 2 × 1 combined cycles powered by Siemens 501FD2 gas turbines. The utility plans to replace the exhaust systems on Silverhawk Unit A and on Higgins Unit 1 during their next major outages—provided upcoming inspections/evaluations confirm expected performance.

Background. The 501F exhaust system has two principal components: an *exhaust cylinder,* connected to the turbine case on its inlet side and to the *exhaust manifold* on its outlet side (Fig 2). The cylinder may be of single- or two-piece construction. PSM's "drop-in" replacement is a horizontally split two-piece cylinder, the only option available for pre-501FD3 machines when they were purchased. This configuration typically is preferred by users because they can maintain their current maintenance practices in future outages.

Depending on component dimensions, a spacer piece may be required downstream of the exhaust manifold to fit up with the heat-recovery steam generator. An expansion joint is located at the round-to-square transition between the manifold or spacer and the HRSG. In the case of a simple-cycle unit, there would be no



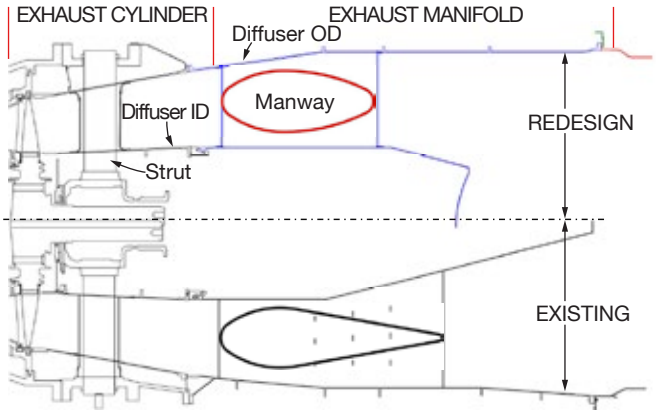
3, 4. Compare the original exhaust cylinder (left) to PSM's design (right). Operational concerns are highlighted on the former. The latter reflects elimination of baffle plates that allowed harmful exhaust gas recirculation and resultant casing creep when they failed; offers an improved static seal to prevent leakage of exhaust gas into the bearing tunnel which could overheat that confined space, making unnecessary activation of the fire suppression system a possibility; uses materials better suited for the actual operating conditions. Plus, PSM's design benefits from passive cooling; and the new support system is designed to control liner axial movement

HRSG and the manifold or spacer would connect via an expansion joint to the transition piece directing exhaust gas to the stack.

Scott Amos, a gas-turbine subject matter expert in NV Energy's central engineering group, and Fatima Bouzidi, maintenance manager at Silverhawk, walked the editors through the 501F exhaust-system challenges their company faced—including the following:

- Failure of static seals, allowing hot exhaust to contact bearing support struts, causing overheating and cracking which allowed the aft bearing and rotor to "drop." The rotor drop reduced critical compressor and turbine radial clearances to the point where metal-to-metal contact between the casing and rotating components became a concern. Experience of other users is that a crack can propagate quickly, extend through the entire strut, and force the unit into an outage with extensive damage.

  Thus timely strut repair and clearance correction are recommended to prevent the possibility of a wreck. Repairs and realignment are expensive undertakings, to be sure. Remember, too, that access to the aft bearing for inspection and the taking of measurements on legacy equipment is not a simple matter. In NV Energy's experience, it takes about a day and a half to cool an exhaust system with compromised seals before you can drop down through the manway and crawl forward to the bearing.
- No end to the cracking/repair cycle experienced with the exhaust cylinder. This was due, in part, to failure of the baffle plates illustrated in Fig 3, allowing recirculation of exhaust gas to the dead-air space. PSM's "fix" prevents recirculation and the casing creep issues attributed to it (Fig 4).



5. OEM's original exhaust system is shown below PSM's retrofit offering. Three takeaways from the illustration are the shortened tail cone of the redesigned manifold, the structural and aerodynamic enhancements of the new manway, and the dramatically different strut arrangements. Regarding the latter, note the thermal constraints associated with the original system: strut is welded to the casing, diffuser ID, and diffuser OD. In the PSM system, the diffuser is allowed to expand independently from the casing

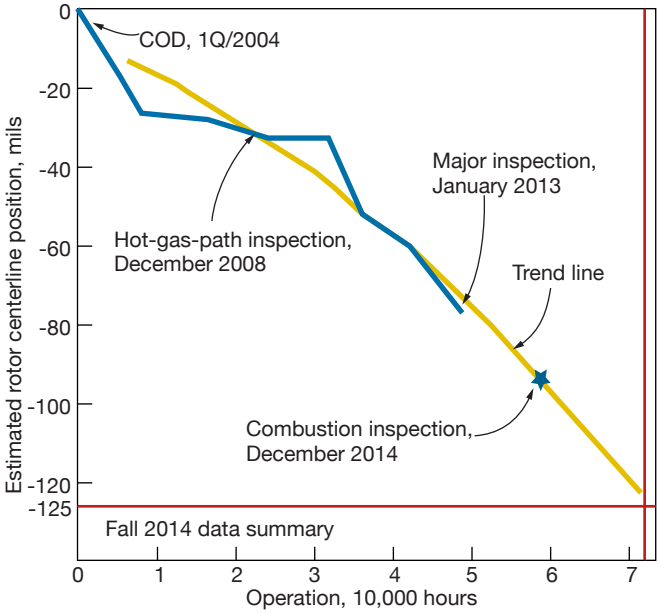
Exhaust gas also can overheat expansion joints, allowing them to leak and create safety and environmental issues. Repairs are time-consuming and expensive, and never "final."

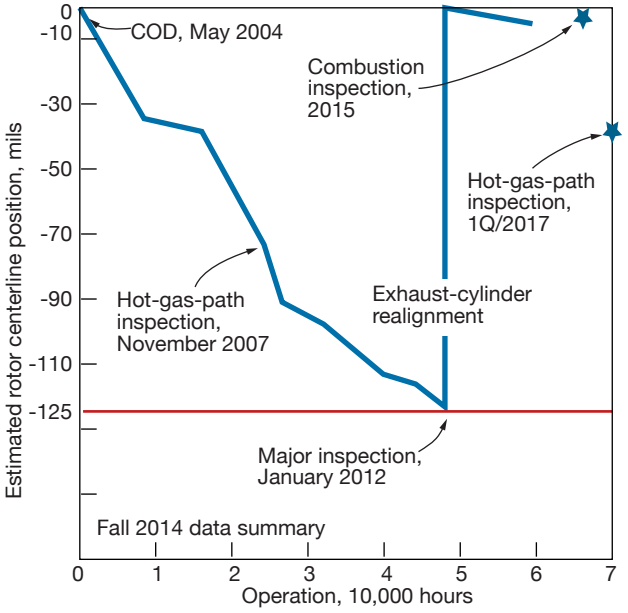
Another manifold concern: Cracking of the flat panel portion of the manway and the liberation of material. Primary causes were believed to be acoustic excitations and the impulse loading created by separation of the exhaust flow stream attributed to the manway's teardrop design. Fixes included weld repair of plate and the addition of stiffeners to address the excitation issue.

Designs of the PSM and original OEM exhaust manifolds are illustrated in Fig 5.

NV Energy's engineering team

had been following industry experience on 501F exhaust systems for years, while continually evaluating the condition of its Silverhawk and Higgins units, before deciding on a course of action for its assets. Amos said after receiving multiple alerts from the OEM and listening to owner/operator colleagues at forums such as





6, 7. Rotor position histories for Higgins Unit 2 (left) and Silverhawk Unit B (right) reflect downward trajectories over time. Engineers determined that a centerline drop of 125 mils was the point at which the exhaust cylinder had to be realigned.

Coupling misalignment on Higgins 2, discovered in January 2013, indicated the need for realignment of that unit. With the trend line predicting ongoing misalignment issues, good engineering practice suggested exhaust-cylinder realignment or replacement at the next available opportunity.

Exhaust-cylinder realignment in January 2012 "reset the clock" for Silverhawk B, but bearing drop was observed shortly thereafter. Although it was too soon to forecast the rate of rotor drop, engineers saw exhaust-system replacement on the horizon because another realignment was not possible

the 501F Users Group, it was obvious that repairs are temporary and the only long-term fix is replacement of the exhaust cylinder.

Bearing drops on the four 501Fs at Higgins and Silverhawk were monitored by PSM. Fig 6 reflects the relatively constant drop in rotor centerline position of Higgins 2 over time, averaging about 10 mils annually. Silverhawk B experienced a more severe drop: about 15 mils per year on average (Fig 7).

With the future easy to predict, NV Energy engineers conducted detailed design reviews of replacement exhaust systems offered by the two OEMs and PSM. The company focused on reliability improvements and reduced maintenance promised by the offerings. Its goals were the following:

- Eliminate exhaust-bearing drop.
- Improve the low-cycle fatigue life of the cylinder and its struts.
- Improve system durability in all modes of operation, with a focus on cycling.
- Reduce the thermal constraint on the strut shield.
- Improve the exhaust-cylinder/HRSG connection and protect the HRSG inlet expansion joint.
- Provide better access to areas that may require repairs.
- Assure compatibility with the existing structure, piping, and other connections.

Major design changes by PSM (from the original exhaust system) to achieve the goals bulleted above were these:

- Change exhaust-bearing support struts from Type-410 stainless steel to a nickel-based super alloy.
- Redesign exhaust cylinder and manifold support structure, and improve aerodynamics.
- Eliminate baffle seals by integrating a new manifold front flange into all PSM exhaust installations.
- Reduce thermal stress by making changes to material geometry.
- Change diffuser and strut shield to Type-347 stainless steel from Hastelloy®.
- Redesign exhaust-cylinder and -manifold gas-path seals.

Minor design changes by PSM are the following:

- Increase robustness of exhaust-cylinder inner and outer liners, and the manifold liner.
- Mating surfaces are scalloped to minimize thermal stresses; a thickness gradient also is used to achieve the same goal.
- Implement filleted radius.
- Improve the expansion-joint interface. CCJ

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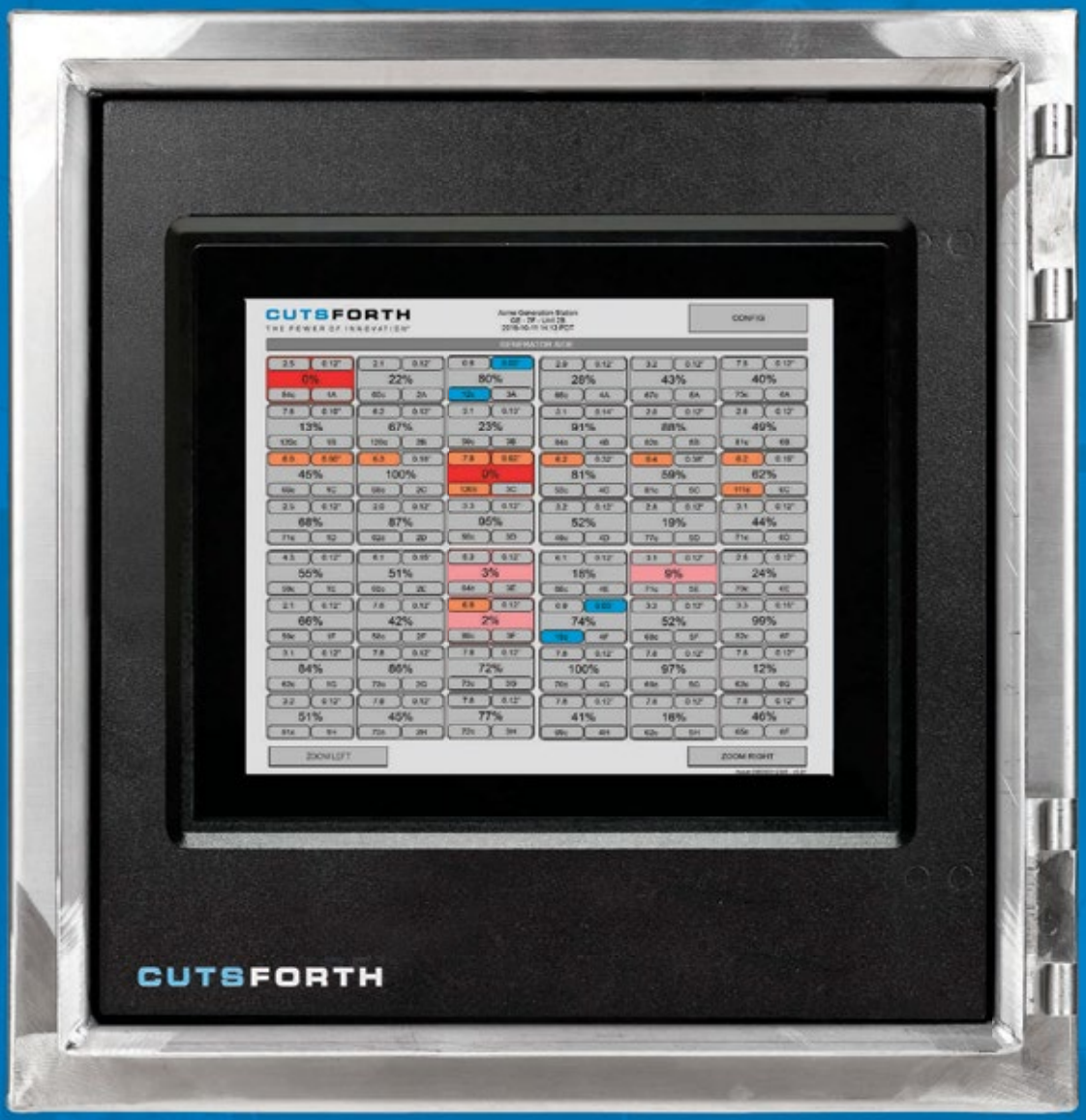

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Protect plant equipment through better training

Operator training is an ongoing theme in CCJ. Gone are the days when you could hire a capable mechanic off the street who could then learn what he needed to know about powerplant equipment on the job from an experienced technician or supervisor.

One reason might be that the experienced people have retired and there is no one left to learn from. Another: Staffing has been cut to the bone with remaining personnel assigned multiple responsibilities that management believes require only superficial knowledge rather than in-depth know-how.

At some point, this philosophy can bite hard and deep. In process plants, production is impacted; in institutions it might mean no hot water cool air, and heat. Risk can be mitigated by spared equipment, of course, but that's a rarity today, having been eliminated the sharp pencils of financially oriented executives who also cut staff.

If you are still pooh-poohing the value of formal training, consider the case history that follows and think about how much less expensive it would have been than the repairs required. This experience was shared with the editors by Bryan Grant, steam-turbine reliability manager for HRST Inc.

You're probably most familiar with HRST's inspection and design services for heat-recovery steam generators. However, the company has been supporting owner/operators since 2015 with steam-turbine inspection, failure-mode analysis, and repair management needs.

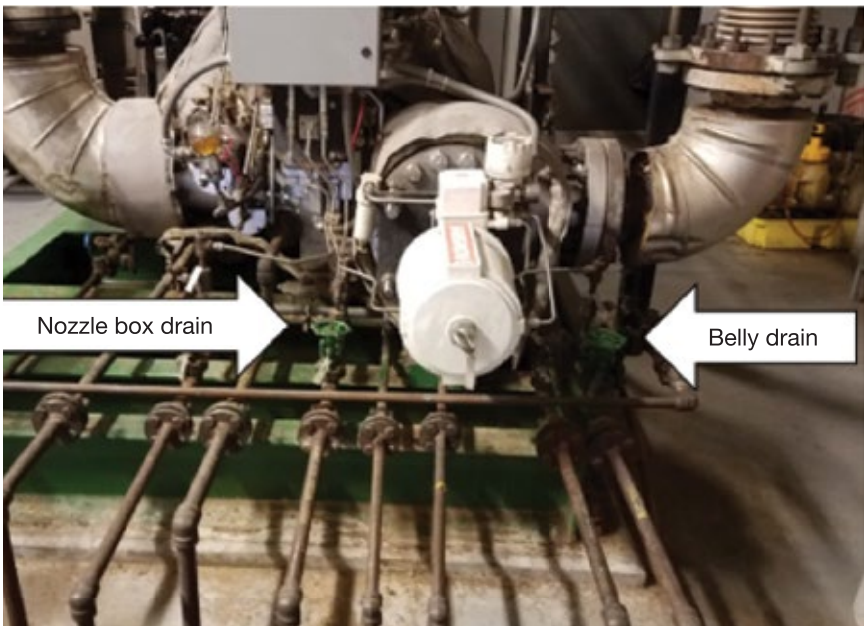
Grant began by reminding power professionals that the useful life of a steam turbine's steam path is determined primarily by two factors: steam quality and steam purity. Lose control of either parameter, he said, and the results can be devastating.

The focal point of Grant's lesson learned is a 1.5-MW, single-stage turbine supplied by 30,000 lb/hr of 400-psig saturated steam, the type of machine you might find driving a feedwater pump in larger plants. This facility was using the small turbine/generator to offset electrical demand while reducing steam pressure for process use.

Plant personnel had observed a steady decline in turbine performance throughout the machine's five-year service life. Management hired local labor to open the unit so stationary and rotating steam-path components could be inspected as a first step in determining why unit performance had declined.

Staff found significant erosion dam-

1-3. Erosion of critical steam-path parts caused by moisture and free water in steam affected the nozzle block (left), rotating blades (center), and reversing ring (right)



4. Opening the nozzle-block and belly drains prior to steam admission protects against erosion

5-7. New components restored the machine to its original condition. At the left is the nozzle block, in the center the reversing-ring segment, and at right the rotating blades

age to the nozzle-block nozzles (Fig 1), rotating blades (Fig 2), and second-stage reversing ring segments (Fig 3). Further investigation revealed the damage had been caused by moisture/water induction into the steam path.

Operator interviews, Grant continued, revealed that the standard operating procedure implemented during turbine commissioning had omitted use of the nozzle-block belly drain valve. The function of this valve is to remove condensate produced during cool down after it is removed from service. Operations personnel verified that the valve had not been opened prior to starting the turbine. Increasing the concern was that the turbine's operating profile dictated two or three starts weekly in support of process requirements.

The investigation concluded that the root cause of erosion was condensate induction at the nozzle block during startup. When the unit is shut down and cooled, condensate forms inside the casing at low points—specifically, the belly of the turbine casing and the belly of the nozzle box. Each low-point location has dedicated drain lines and valves to evacuate condensate prior to startup (Fig 4).

In this case, opening the nozzle-box drain valve before admitting steam to the turbine was not part of the standard operating procedure. Thus, the unit had been slugged with condensate hundreds of times since commissioning.

Management's bad: Capable operating personnel had never been trained properly. The oversight has since been corrected by updating operating procedures and by training. Finally, Grant said, the turbine was restored to as-new condition by refurbishing it with new steam-path components (Fig 5). CCJ

How best to replace an HP evaporator: Tubes only or entire harp?

Editor's note: Online forums hosted by independent users groups are an invaluable communications medium for sharing experiences among industry colleagues. Power Users (www.powerusers.org), which sponsors user-only discussion forums for the groups it manages—7F, Combined Cycle, Generator, Controls, and Steam Turbine—most recently launched an online HRSG forum.

It is moderated by former plant manager Bob Anderson. Today a consultant, Anderson is well respected industry-wide for his deep knowledge of heat-recovery steam generators. The HRSG Forum with Bob Anderson (www.hrsgforum.com), which he chairs, is the leading meeting for boiler users serving at combined-cycle and cogeneration plants powered by gas turbines.

One of the first posts to the new site was from an owner/operator seeking the experiences of colleagues who have replaced the HP evaporators in their HRSGs. What to do? Remove/replace tubes keeping the headers in place, or remove/replace the entire harp. The user said engineers assigned to this project were struggling to decide where the best location might be to draw a line in the HRSG between what should be replaced and what should be retained.

"As we dig deeper," he said, "we continue to find parts and pieces which could allow advantages to the OEM if we were to just cut the tubes and leave in the existing headers at the top and bottom of the HRSG."

Another approach, the engineer continued, is to expand the scope of replacement to allow for new headers with connection points defined as the bottom of the steam drum and the feedwater entry. The team's thinking was that this might provide a more apples-to-apples comparison as opposed to leaving potential proprietary design elements within the HRSG that other companies might not have rights to.

Anderson contributed to the dialog, sharing that he was aware of one module replacement in which the tubes were replaced while the original headers were retained in place. This was not an economic decision, but required because there was no access for cranes to remove/replace the modules. The logistics of the tube replacement were complex and challenging because of limited access and the need to support and maintain alignment of the lower headers.

Anderson figures the total job cost was higher than for a module exchange and certainly required a longer outage. If you replace tubes only, he added, you must either grind off the tube-to-header weld at each end to replace the entire tube (a very time-consuming process with risk of damaging the header), or cut the tubes and make a butt weld to the retained portion of the old tube. The $64 question: Can you know that there is no corrosion damage in the retained tube stubs?

Some HRSGs similar to the owner's Alstom unit, Anderson said, have a primary HP superheater section upstream of the HP evaporator (relative to gas flow). If so, welding in the new tubes only can be accomplished with the welder on the downstream side of the tube. This likely would require mirror welding—a skill becoming harder and harder to find. An alternative might be an orbital welder.

If there's no HPSH attached to the upstream side of the HP evaporator, a pair of welders could install the first (center) row of new tubes from both sides, but all other rows would require a welder on one side of the tube only. This "welding your way out" technique means that any leaks deeper than the row accessible from the maintenance bay will require removal/replacement of some good tubes—perhaps many—to access and repair the failure. Anderson estimated the HRSG under discussion has more than 1150 HP evaporator tubes. That's 2300 welds made from one side that must be perfect.

All other HP evaporator replacements Anderson is aware of relied on replacement harps or entire modules. They were removed/replaced during a much shorter outage than required for the tube-only replacement. Minimizing the number of field welds reduces outage duration and facilitates control over component fit-up, weld quality, NDE inspection, and hydro/repair—if needed. Plus all of these tasks remain outside the outage critical path.

Modules have been removed/replaced by lifting upward out of the HRSG the way they were originally installed (often requiring removal of the HP drum for access), or removal through the side of the HRSG to avoid disturbing the drum. The location of the HRSG side support columns will dictate if the new module can be removed/replaced in one piece or not.

Anderson continued, "If your unit has the two large-diameter fore and aft collection manifolds between the headers and the drum like other HRSGs from this OEM, you have a couple of choices on where to make the upper transition. The tradeoff will be the cost of material replaced versus the number of field welds required. The location of the HRSG's side support columns may dictate that the second option is possible only if the column permits removing the entire evaporator module intact.

Finally, Anderson recommended against the tube-only replacement option on this project. He suggested asking the bidders to identify and quote their preferred cut points top and bottom (save the collection manifolds and have more internal field welds, or replace the fore-aft manifolds and have no internal field welds and only a few external field welds), plus insist the bidders quote an option for the alternative cut-points they do not prefer. CCJ

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Factor European experience into O&M practices at US combined cycles

When we gather with colleagues, we listen closely for details and keep a notebook handy for those *Rules of Thumb* that transfer experience. We can also jot down a bulleted list of highlights, insights, and points of clarity. At a recent industry event in England, Consulting Editor Steve Stultz came away with a list of thought-provoking gems and a deeper sense of common global elements. They form the basis of his report, which follows.

Dr Ahmed Shibli, managing director, European Technology Development Ltd (ETD Consulting), organized and hosted a three-day International Conference on Power Plant Operation and Flexibility, preceded by two in-depth training courses. The July 2018 venue was the Institute of Materials, Minerals and Mining (IOM3) in central London.

The meeting covered recent developments in plant materials, operation, inspection, maintenance, and costs related to both baseload and cycling operation for different types of plants—including combined cycles, the focus here. Among the topics addressed in formal presentations and during discussion sessions were the following:

- Equipment design, materials, and corrosion.
- Operational constraints and optimization.
- Component replacement, maintenance, and operating costs.
- Strategies for optimizing inspection, maintenance, and cyclic operation.
- Workforce, management, and automation issues.

Plant owners/operators were joined by researchers, manufacturers, and inspection-agency professionals.

A partial list of gems:

- Europe is going through the same market changes as North America. Cycling is global.
- Some countries have more cycling and low-load experience than North America—such as those with geothermal and hydroelectric plants that cause varied operation of fuel-fired assets. This experience base has wide-ranging value.
- Europe and Japan are taking active roles in high-temperature materials development and testing.

Shibli's primary purpose was to help identify the basic causes of equipment problems in both baseload and cycling plants, and to clarify modifications, inspections, and procedures that will minimize costs.

The ETD conference

Key themes were engineering design, materials R&D, new inspection techniques, cost analysis, and plant management/maintenance. Optional pre-conference training courses centered on operation and maintenance (Day One) and both short- and long-term system preservation (Day Two).

The agenda was divided into two parts. The first half discussed plant flexibility including new developments in creep-fatigue interaction in high-temperature plant materials. The second half focused on new developments in plant preservation, maintenance, inspection, monitoring, repair, and life assessment.

Selected highlights from the seven sessions are given below.

"Who wins when plant components fail?"

This question launched a presentation by David Allen (Impact PowerTech Ltd, UK) a consultant to ETD, on the upgrading of materials and welds. His next question was equally pointed: "Why do we so often stick with last-century technology?"

Allen first captured attention with a philosophical discussion of *planned obsolescence*. He cited interesting examples from the automobile, white goods, and communications industries. Participants were captivated, and on alert for more.

Allen did not claim current evidence of planned obsolescence within the power industry, and in fact stated that a manufacturer with a unique design is careful to maintain its good reputation.

But he did note some dangers similar to those expressed by Eskom (South Africa) at last year's Air-Cooled Condenser Users Group meeting in Las Vegas (CCJ 4Q/2017, p 58).

We all experience the ongoing pressures for low bids, rapid investment payback, and increasingly stringent trading conditions. The potential menace is commonly applied standards that fail to ensure the most reliable long-term component operation.

In other words, once a supplier meets the standards or codes in the specification, further refinements or improvements can become less important (and more expensive) to the supplier. The same is true on qualifying bids for component supply. Providers' reputations are at less risk as long as they *meet the qualifications*.

Perhaps because "innovation brings risk," or because "regular repair and maintenance activities provide jobs," we could be letting ourselves down, suggested Allen. And in his words, "We are still building new plants with 40-year-old materials (P91, Alloy 617) and ignoring the newer, potentially better alternatives."

And how has market-driven flexible operation changed things? "Cycling makes it worse!"

Details have become clear, stressed Allen:

- Flexible operation only makes ser-

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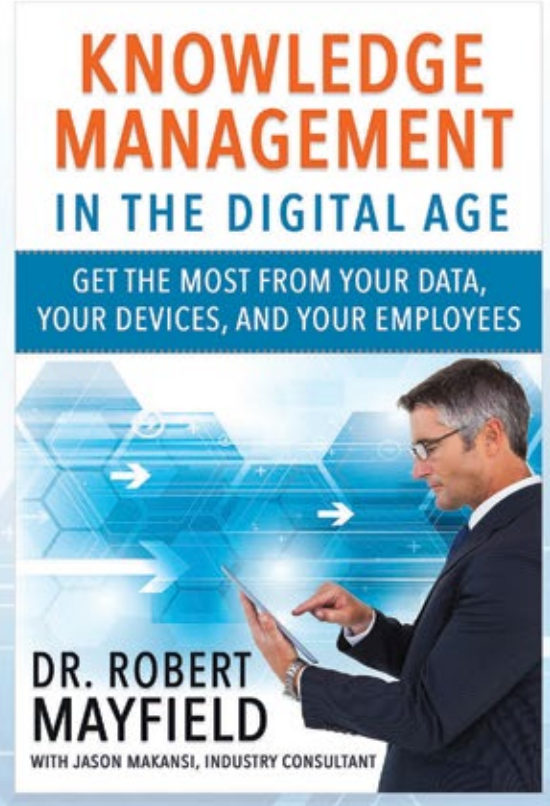

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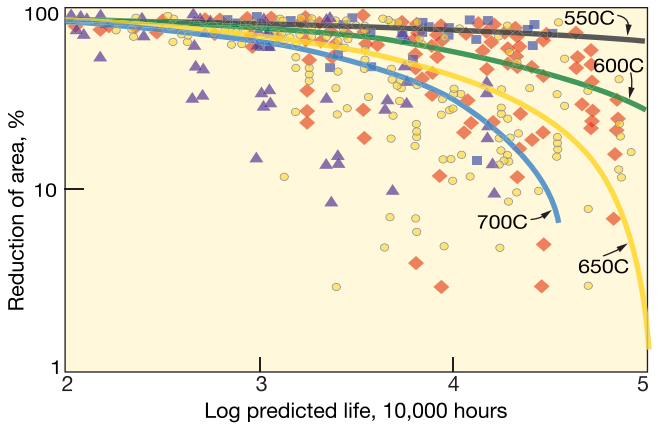
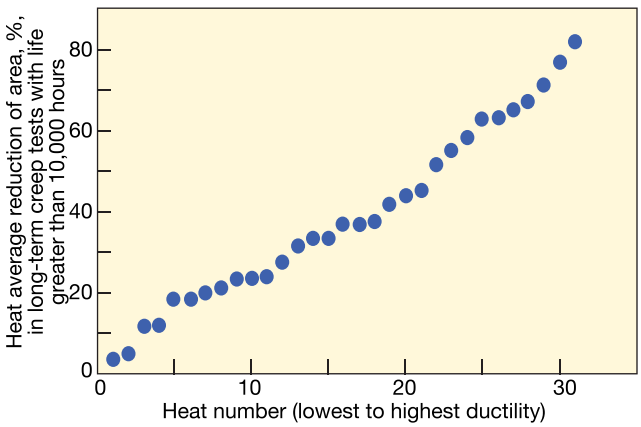


1. Long-term tests on P92 steel reveal creep-brittle behavior; data compiled by the European Creep Collaborative Committee show extensive scatter



2. ECCC data for P92 also show major differences among 31 different heats, with most showing high ductility

vice exposure more onerous.

- Thermomechanical transients cause additional cyclic loading:
  - Mechanical and thermal fatigue cracking.
  - Creep-fatigue cracking (with creep ductility exhaustion attributed to repeated transient creep strain).
  - Creep cracking (with creep life reduction caused by increased loading).
- Poor temperature control can severely shorten creep life.
- Creep issues do not go away; they get much worse.
- Fatigue brings additional challenges.
- Sticking with last-century technology increases risk!

So how do owners/operators minimize the potential costs? Allen outlined some thoughts:

1. Design out at-risk features" (thickness and materials mismatches, closely spaced header stubs, dissimilar-metal welds, etc).
2. Improve temperature control during startups and transients.
3. Make components thinner—perhaps.
   - Thinner components minimize thermal/mechanical mismatch loading and may therefore perform *better* when fatigue is a problem.
   - But thinner components will experience higher pressure stresses and may therefore perform *worse* when creep is a problem!

Allen reviewed typical owner/operator options. Some choose to continue operation until plant end-of-life, mind-

ful primarily of safety. Many take the financial hit and accept high inspection, repair, and replacement costs. The better strategy is to install upgraded retrofit components with stronger materials and welds at the same thickness (better for creep) or thinner (better for fatigue).

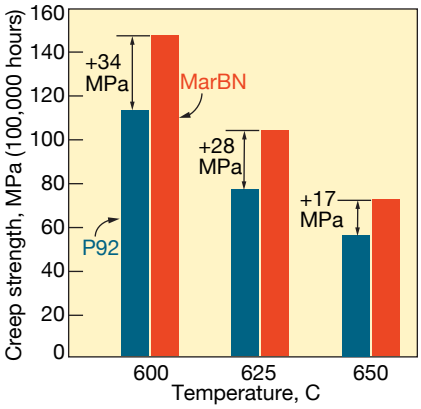
He then presented details and examples of current P92 materials (Fig 1) with good quality heat treatment, labeling this "a materials upgrade solution that is ready now." Following in-depth discussions of various manufacturing methods, heats, ductility and tensile strength, he asked participants to "Stop fearing P92!"

And he gave specifics from a recent review, showing a "strong correlation between heat treatment and ductility," as shown in Fig 2. He concluded that "normalizing is about twice as important as tempering. Under-normalizing is the main problem. Under-tempering makes the problem worse." And "notably, normalizing time is more important than temperature."

- The four most creep-brittle casts, with long-term average area reduction (Ra) in creep test values in the range of 3% to 12%, all had normalizing times in the range of 0.2 to 0.6 hours.
- The seven next most creep-brittle casts, all with Ra values in the range of 18% to 24%, had normalizing times of 0.2 to 1.0 hours.
- No cast with a normalizing equivalent to 2 hours at 1050C or 1 hour at 1070C had a long-term Ra value lower than 28%.

Summary: This indicates that simple controls on allowable heat treatment can resolve the Grade 92 creep brittleness concern. Further work is ongoing to assess very long-term ductility out to 100,000 hours, and beyond.

Allen next looked at "near-future



3. Projected creep strength of MarBN versus P92 illustrates a benefit of the new material

MarBN, a novel high-alloy steel for powerplants." This material, being studied primarily in Japan and the UK, is martensite plus boron and nitrogen. The process involves "careful microalloying with boron and limited nitrogen for high creep strength." Allen listed temperature capability of P92 as about 20 deg C better than P91 and "expects temperature capability of MarBN to be at least 25 deg C better than P92."

But the microalloying process is extremely sensitive.

Following discussions on welding processes, he ended with the summary:

"Today we can replace P91 with P92.

Tomorrow we could use MarBN for even greater security."

MarBN alloy

Zhuyao Zhang, Lincoln Electric Europe, followed with MarBN filler-metal development work from Impel and Impulse, two collaborative power-industry research programs in the UK. Intended applications include castings and forgings for steam-turbine components and steam piping (up to 650C). One slide included creep strength predictions (Fig 3).

His summary:

- The development of matching filler

metal for MarBN alloy, Chromet 933 SMAW electrode has achieved encouraging progress.
- The weld-metal chemical composition is optimized.
- Satisfactory ambient tensile strength, ductility, and impact toughness have been achieved.
- Satisfactory high-temperature (550C to 700C) tensile strength and ductility have been achieved.
- Results of initial short-term stress rupture tests showed considerable increase in creep strength compared with P92 weld metal at the same conditions.
- Work continues.

Aberrant P91 life predictions

Shibli and David Robertson of ETD tag-teamed an in-depth presentation on life-prediction concerns for aberrant P91 components, often found in powerplants worldwide. They are usually the product of not understanding the precise heat-treatment requirements, by the component producers and fabricators, for high-Cr martensitic steels.

They issued a stark warning: "Traditional NDE techniques do not show damage in P91/P92 until late in life (70% or later), making current detection and component integrity management difficult." New techniques are needed.

"A problem with 9Cr martensitic steels," they said, "is that the creep cavity size for the first 70% of life can be on the nanometer or few-microns level only. Thus cavity detection and quantification by traditional means, such as replication or UT inspection, can be difficult."

At the same time, "for aberrant microstructures powerplants often assume the safe life is equal to P22 or P91. But the industry could be underestimating life, thus condemning these components too early and thereby losing revenue. We currently do not have long-term rupture strength data for such abnormal microstructures to predict their safe operating life accurately."

The two presenters gave examples of potentially abnormal materials:
- Material over-tempered or tempered high in the ASME range.
- Material under-tempered at the bottom of the new ASME range (730C) or old range (704C).
- Cooling too slowly from austenitizing.
- Soft spots and soft bands found in some piping materials.

Welding issues include:
- Various repairs and weld-repair configurations/geometries.
- Repeat weld repairs.

Shibli outlined a six-year joint industry project that began in 2014 "aimed at producing 15 aberrant microstructures in P91 (both base and weld metals) and conducting stress rupture tests to 30,000 hours, which can then be extrapolated to 100,000 hours and beyond to estimate the safe operating life."

Initial industry sponsors, coordinated by ETD, are various European and Japanese utilities, although new partners/sponsors are welcome at any stage to contribute towards the testing of one more of these aberrant microstructures. This project also involves detailed metallography, including use of transmission electron microscopes (TEM), to categorize the microstructures and their behaviors.

"To make matters worse and life assessment more difficult," he continued, "it is now fairly well established that the creep failure stages for high-Cr martensitic steels (P91/P92) are reduced to creep cavity initiation, cavity growth, and failure with little warning."

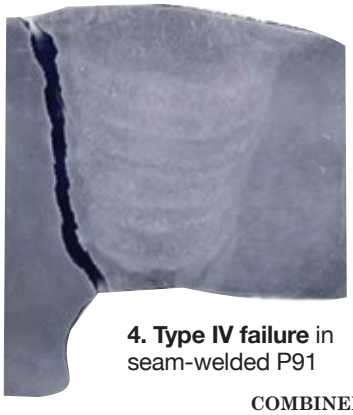
Specific visual examples were given for all points made in the presentation. Featured in the examples was Type IV damage in seam-welded components (Fig 4).

"The 9Cr martensitic steels have been very useful in raising powerplant temperatures and pressures (and making HRSGs more compact), improving plant output and efficiency," Shibli stated. "However, more and more of these components are now showing cracking at the Type IV position associated with the weldments."

And their conclusion: "Even components that can be identified to be at risk are creating issues for the plant owners and integrity assessors in view of the unknown long-term rupture strength of the aberrant steels, hence the need for the long-term stress rupture data to ensure their safe operation."

More on materials

Other materials-related presentations included the cyclic loading and cyclic oxide conditions (Federal Institute of Materials Research & Testing, Germany), assessment of welds under creep, fatigue, and creep-fatigue loadings (University of Stuttgart, Germany), dissimilar metal welds in ultra-supercritical powerplants (Belgian Welding Institute), stress corrosion cracking in T24 material (VGB PowerTech Service GmbH, Germany), and microstructural evolution of P91 in high temperature conditions (INAIL, Italy).



4. Type IV failure in seam-welded P91

HRSG revamp for GT upgrade

Pascal Fontaine, CMI Heat Recovery Systems (Seraing, Belgium), discussed example HRSG modifications to match a gas-turbine upgrade.

King's Lynn Power Station in the UK is a high-efficiency, baseload combined cycle commissioned in 1996, designed for peak firing up to 370 MW. The plant is of Siemens single-shaft design with a 120-MW steam turbine and CMI vertical, triple-pressure, unfired HRSG.

The operating difficulty became inflexibility to market conditions. Thus, the unit was mothballed in 2012, but significant residual life remained in the plant infrastructure.

In 2016, owners signed contracts to revamp the plant and targeted more than 300 starts per year. The gas turbine and generator would be replaced, and the HRSG upgraded to match the new conditions, including new steam piping and attemperation systems. One street would be added to the air-cooled condenser.

Final superheater/reheater modules are now being replaced by two Euro Norm modules with additional heating surface.

Fontaine's presentation walked systematically through the dismantling/replacement processes, including details of pipe-to-header welding and inlet duct restoration.

King's Lynn will return to commercial operation in 2019.

Cyclic-tolerant options

In a later conference session, Fontaine returned to discuss developments toward more cyclic-tolerant HRSGs—both horizontal and vertical designs.

A key part of this was the question: "What are the root causes of fatigue damage?"
- Heat exchanger construction (stiffness between tubes).
- Superheater drainage.
- Tube/header connections (thin wall to thick wall).
- Economizer steaming.
- Cyclic stress fatigue of drums, specifically HP.
- Desuperheater design and risks of water quenching.

He also discussed the benefits of internal accessibility for inspection and maintenance, offering examples for both horizontal and vertical designs.

Fontaine ended with a discussion of superheater startup vents applied for multiple HRSGs on one steam turbine.

Thermal transient impacts

Richard Walton, SSE (formerly Scottish and Southern Energy Plc), addressed the group on thermal transients and their impacts throughout the SSE fleet, suggesting more targeted inspections, monthly monitoring and reporting, trending and investigating, and the need for improved industry guidance.

Details of his presentation outlined what he called "up-shock" and "down-shock" events and impacts on the HP and IP systems (superheater and reheater).

The benefits became recurring conference themes:

- Better inspection scope forecasting.
- Reduced risk of on-load failure.
- Reduced risk of forced outage.
- Issue identification and reduced costs of both maintenance and inspection.
- A managed approach to life extension.

Change the inspection philosophy

James MacArthur, senior engineer, pressure systems, was also present from SSE and discussed the effect of UK grid demand on HRSG damage mechanisms. Running plants on demand is "arduous," he stated, but one tactic is to "change the inspection philosophy."

His example was a 735-MW plant with two HRSGs, recently converted from baseload to two shifting, commissioned in the mid-1990s, and experiencing 900 starts in the past three years.

He reviewed fatigue-related damage locations: reheater tube stubs, reheater outlet and inlet headers, and superheater headers.

For the inlet header, a combination of system stresses and poor attemperation led to corrosion fatigue failure (a common topic). He also reviewed pipework stress analysis, indicating that "even with all supports operating correctly, stresses in the header stubs are high."

Problems in his example case were caused by "anomalous and excessive axial stress during operation." Stress analysis showed inadequate supporting and restraint arrangement on the outlet manifolds (Fig 5). "Even with all supports operating correctly," he stated, "stresses in the header stubs were high."

5. Excessive stresses in reheater outlet-header stubs are a direct result of cycling. Photos reveal cracked outlet branches and cracked and bent trunnions

He then turned to both single- and two-phase FAC (flow-accelerated corrosion), pointing out locations, mechanisms, detection, and consequences. "In a combined-cycle plant," he summarized, "FAC typically occurs in the LP and IP evaporator circuits, HP economizers, and feed pipework." He pointed out that typical locations in conventional plants are the feedwater heaters and systems, and for all plants in air-cooled condensers.

This leads to the need (common theme again) of reassessing the inspection strategy as well as the impact of expected future operation (cycling).

Benchmarking, cycling analysis

Feroza Akther (ETD) reminded participants of the common impacts of cycling, including a note that owner/operators should also be aware of "higher fuel consumption during startups and shutdowns because of inefficient heat transfer and non-optimal heat rate."

Therefore, owner/operators need to know the technical and financial impacts of converting base-load units to cycling, as well as the operating costs for current cycling units. Her presentation described both benchmarking and analysis for a large group of conventional and combined-cycle units.

The plant database included 30 conventional and 65 combined cycle units from Europe, US, and Asia, all with at least seven years of O&M data, ages from 1 to 35 years operation, and net generation from 50 to 500 MW. Analysis included data for:

- Modifications.
- Damages attributed to operating conditions.
- Maintenance activities.
- Inspections.
- Availability and reliability factors.

Akther outlined ETD methodology of data analysis, statistical analysis and normalization (to share best practices), plant condition analysis to assess relevant O&M events, and how to determine O&M costs for equivalent hot starts. This included performance indicators (equivalent forced and planned outages, availability, and reliability) and annualized non-fuel costs.

"The performance assessment of the plants operating in cycling mode has been performed," she said, "by demonstrating the evolution of forced and planned outage factors during the plant life cycle—that is, starting from commissioning until the end of plant life." She labeled the phases as commissioning (one to six years), useful life (six to 20 years), and wear-out (more than 20 years).

Hot start is defined in this study as an overnight shutdown of less than eight hours, with turbine metal temperatures above 750F. Warm start reflects weekend shutdown of up to 60 hours (390F). Cold start is anything greater than 60 hours (below 390F).

Based on analysis of these units, "it appears that the strongest indicator of combined-cycle annual O&M costs is the number of equivalent hot starts (EHS) that the unit has performed."

"To minimize economic impacts of cycling," Akther explained, "it is crucial to create a well-balanced maintenance plan including proactive, predictive, and preventive programs." This led to a discussion of advanced tools currently promoted including risk-based maintenance (RBM), condition-based maintenance (CBM), and reliability-centered maintenance (RCM).

Such programs are commonly discussed at these sessions. "If not already implemented," stated Akther, "it will be extremely beneficial for the plants to consider these tools to achieve a well-balanced maintenance program." Not surprising, perhaps, but reinforced.

Participant discussions were active and included a suggestion of adding the cost of lost generation to this study. An interesting follow-on discussion centered around the pros and cons of vertical versus horizontal HRSG designs.

Gen 3

ETD's Nadeem Ahmed continued this theme with a look at a "Gen 3 RCM-based maintenance and reliability program."

He began with a review of common programs and philosophies, listing

6. Piping-system surveys become more critical when cycling

the range of acronyms widespread throughout the industry.

"Gen 3," he stated, "combines reliability and scheduled maintenance programs." It focuses on reliability-centered maintenance, and "seeks the optimal mix of condition-based, time-based, and run-to-failure strategies." He called it "a risk-based process for determining the least-cost maintenance and surveillance actions needed to meet operating performance targets."

He then outlined implementation phases, including integration into plant operating and monitoring software.

Flexible operation studies

Uniper Energy Services' Scott Lockyer discussed the company's long-term flexible operation journey and offered thoughts on economic improvement from the operational view. Within this discussion was a process that seemed adaptable to various targeted component and system concerns.

The challenge was to minimize damage caused by cycling. The solution discussed:

- Appraisal of plant-specific risk areas.
- Fitting of additional instrumentation and performance of flexible operation trials.
- Analysis and understanding of the thermal transients.
- Repeated trials to confirm understanding.
- Detailed stress analysis of at-risk components to help plan future strategies—maintenance, for example.

The outcome: Implement modifications to operating procedures and/or design to address the identified issues.

Uniper has followed this process throughout its fleet for various at-risk areas including:

- Progressive drainage techniques.
- Optimized firing patterns and firing rates.
- Use of excess air.
- More precise temperature matching.
- Faster ramp rates.
- Improved use of attemperator sprays.

More on inspection

Other inspection topics included a boiler-tube inspection program for Southeast Asia's first ultra-supercritical boiler (TNB, Malaysia), modeling of creep deformation and rupture criteria (Huddersfield Univ, UK), life assessment under creep-fatigue conditions (Univ of Stuttgart, Germany), high-temperature strain mapping in steel weldments using digital image correlation (Univ of Cape Town, South Africa), and DC/AC potential-drop technique for creep damage monitoring in piping systems (Metalect, UK).

Don't forget the piping

Rob Wang, Engineering Analysis Services Ltd (UK), discussed outage planning and life extension of load cycling plants. He highlighted both piping system health management (Fig 6) and analytical techniques for component life assessment.

Piping system details are, perhaps, too often overlooked. Wang reminded participants of cyclic thermal movements, large stresses at nozzles, and incremental plastic collapse damage to constant-load hangers.

For system health issues, stated Wang, "long piping systems are subject to cyclic thermal movements that generate peak stress/strain at the nozzles and hangers." Constant-load hangers (and variable-load spring supports) are used for balanced piping systems, allowing movement within clearly specified limits and maintaining stresses within code.

But operators must be aware of cycling's impact, as well as the more common degradation forces of corrosion, loosening of bolted connections, and misalignments (among others). He therefore encouraged piping stress analysis and assessments, and periodic hanger surveys and full piping system reviews.

For the latter, he offered clear specifics:

Set up a live database from the design and installation records to include:

- Hanger ID and setting positions in both cold and hot conditions.
- Hanger travel limits.
- Movement between cold and hot conditions.
- Dates for installation, effort adjustment/reset and replacement/resetting.

Conduct the following three surveys for every maintenance period:

- Pre-outage survey in hot condition.
- Survey during outage in cold condition.
- Post-outage survey in hot condition.

For each survey, generate a technical report on findings, system health, and maintenance recommendations. He then gave details for each survey:

Pre-outage hot survey

- Survey hangers/supports to obtain hanger position readings.
- Review current readings against as-built benchmark and historical data.
- Identify out-of-range hot positions and predict possible out-of-range cold positions.
- Make outage-team maintenance recommendations for hanger effort adjustments or hanger replacement.

Outage cold survey

- Survey hangers/supports to obtain position readings.
- Review current readings against as-built and historical data.
- Confirm/verify out-of-range cold positions predicted during the pre-outage hot survey.
- Make hanger support effort adjustments based on pre-outage hot recommendations and the current out-of-range findings.
- Record adjustment details and revised hanger readings.
- Predict out-of-range hot hanger positions.

Post-outage hot survey

- Survey hangers/supports to obtain position readings.
- Review current readings against as-built and historical data.
- Check that adjusted hangers are within range.

- Record adjustment details and revised hanger readings.
- Note any potential out-of-range indications.

Wang stressed his recommendation to repeat these surveys for every maintenance cycle. He reminded participants to also inspect for any degradation by rust, lost or loose nuts, obstruction, misalignment, unintended deformation or configuration change, and to finish each survey process by informing outage planning of all findings.

Such information assists the entire plant in life-extension work, and provides early warnings on risk issues.

In the editor's opinion, such level of detail is a hands-on and practical benefit to attending and participating in these sessions. The details reflect experience.

Drones expanded

Capitalizing on a development reported by Xcel Energy at previous *HRSG Forums with Bob Anderson,* Ahmed Shibli and William Moore issued an extensive report on ETD's Group Sponsored Project on drones and robots for powerplant inspection.

The exploratory phase (just completed) of this project was directed at determining suitability of drones and robots for visual and UT inspection, as well as a review of R&D activities. The upcoming phase is the design and development of the most suitable and economic automated devices in three types:

- Drones for visual inspection and data analysis of remote, out-of-view and at-height components.
- Robots for polishing and UT inspection of components including crack sizing.
- Small or mini-robotic devices for polishing and UT inspection requiring access through narrow spaces—such as between HRSG tubes.
- Various organizations and experts are involved and more are invited to participate.

Drones. One development point is the oil and gas industry, currently using drones for UT inspection by attaching them to pipes. However, drones are not yet stable enough for complete UT inspection.

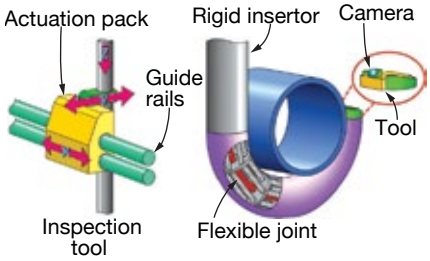
Some significant points were made:

- Photos taken by modern commercial surveillance drones can be enlarged on a computer screen by factors greater than 20× before pixilation creeps in.
- Such detail can help diagnose the cause of failures. In the case of a burst evaporator tube, for example, a thick edge can indicate impure feed or boiler water; a thin edge can indicate overheating, fireside wastage, etc.
- This valuable information is available as soon as the boiler has cooled sufficiently for access.

In emergency shutdowns, a drone is a frontrunner for immediate access to the failure location. Quick access is especially beneficial if there is a need to procure materials or services. It also enhances the placing of scaffolding in the correct, precise location. Plus, drones can check surrounding areas before a chain of failures occurs and capture a permanent record.

For thermal surveys, drones are particularly adept at carrying thermal imaging cameras and reaching correct positions. This can identify the areas of heat leak or damage to insulation.

Powering the drones carries two options: internal combustion engines, or electrical power. Electric became the choice with lithium batteries, but carrying loads for long time periods is difficult. The group sponsored project is investigating this further.



7. Flexible robotic arms offer potential for visual inspection, surface polishing, and other remote tasks

8. Portable scanning force microscope is in use on a vertical pipe

Robots. For this project, a robot is defined as "a surface crawler that carries out visual/NDE inspection and sends inspection data to a remote-control unit."

Robots can reach inaccessible areas, or those where scaffolding is required. There is a range of proven technologies for robots, robotic machines, and intelligent flexible arms, but further development is needed for the powerplant environment—for example, polishing heads and UT probes for wall-thickness measurements.

Current development recognizes the challenges. Robots are not suitable for climbing tubes with thick deposits. Closely-spaced wall tubes can limit access, and plants have wide variations in tube diameters and tube-to-tube gaps.

A look ahead. Robotic arm development, especially for access through narrow spaces, shows promise (Fig 7).

Stated Shibli, "a highly flexible and long robotic arm of about 0.4 in. diameter is needed that can pass between tubes in an HRSG, has multiple axes of rotation, and can carry out visual examination, surface polishing, initial inspection, and assessment."

The next phase of this ongoing group sponsored project is development of "a novel drone-robot hybrid device."

Other inspection techniques discussed included Obikou, a pipe strengthening mechanism for creep damage and/or steam welded pipes (ETD); a portable scanning force microscope (Fig 8) for early stage creep and fatigue damage detection and life assessment (ETD); electrical discharge sampling equipment for removal of samples from pressure vessels and turbine rotors for quality checks and life/crack assessment (ETD/SGS, UK); portable magnetic measurement equipment for onsite creep damage detection (Univ of Manchester, UK); and shop welding interruptions of P91 components (PPC, Greece).

Related topics

Related topics discussed at this comprehensive event included gas turbines coupled with upcoming battery technology (Engie Laborelec, Belgium); condenser failure modes and powerplant chemical cleaning (Bill Moore, consultant, UK), and fracture mechanics assessment for boiling-water-reactor circulating-pump bowls (TUV SUD Industrie Service GmbH, Germany).

The host

ETD's various capabilities are described at www.etd-consulting.com. Emphasis is on high-temperature plant inspections and materials (P91 and others), component safety and durability, performance of in-service welds, and probabilistic life and crack assessment.

A conference similar to the one described in this article was organized by ETD Consulting and held in Charlotte, NC, in November 2012. Upcoming conferences will be announced in CCJ.

User group to publish tube-cleaning guidelines

The Air-Cooled Condenser Users Group, established by NV Energy in 2009, will soon publish its second technical guidance document, ACC.02, "Guidelines for Finned-Tube Cleaning." This document includes fundamental principles, operational factors that can limit efficiency, types of tube fouling, debris removal methods and examples, cleaning frequency, as well as safety and environmental concerns. Following is a preview.

1. Heat-transfer tubes for ACCs normally are oval or rectangular and equipped with closely spaced aluminum fins

Heat-transfer surface and fans

Air-cooled condensers use specialized heat-transfer tubing; the tube design most commonly employed today is aluminum-clad carbon steel tubes with exterior aluminum fins (to increase air-side surface area). Tubes are normally oval or rectangular with approximately 0.059 in. wall thickness and closely spaced fins (Fig 1). Over time, these fins become fouled with debris.

In most cases, air flow around the tubes is provided by large fans (Fig 2) positioned below the tube bundles, directing cooling air upward in a forced-draft configuration.

During plant operation, steam from the low-pressure steam turbine is directed via large ducts to the top of the heat-exchange tube panels. Moving down the approximate 36-ft tube length, steam is condensed by releasing its latent heat of vaporization, and the water returns (as condensate) to the steam generation process.

Because air is a relatively inefficient heat-transfer medium, ACCs are large elevated structures with considerable surface area. Efficient optimization in both design and operation are critical to viable plant operation.

Operational factors limiting efficiency

Inefficient ACC operation can result in higher system backpressure, less efficient plant operation, and possible turbine trips. As efficiency declines, more steam (and fuel) is required to maintain megawatt output.

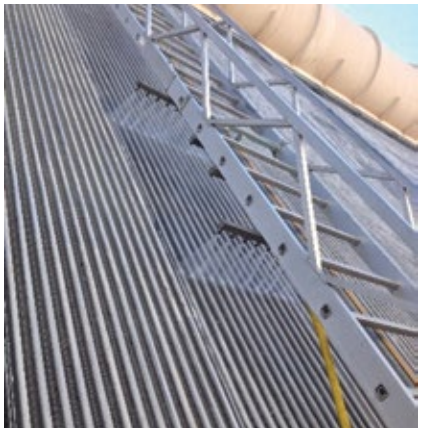
The cooling fans moving high volumes of air through the narrowly spaced fins will inevitably result in the accumulation of airborne debris on the fan side of the tubes. Blockage of air passageways prevents optimal heat transfer, reducing steam condensing efficiency (Fig 3). Debris is often site-specific, and may include vegetation (cottonwood seeds, leaves), trash, animal sources (birds or bats, feathers, flying insects), and local sources such as industrial byproducts (cement factory or coal dust, etc). One common and particularly troublesome foulant is oil from fan gearboxes.

Ambient temperature is a major factor in ACC operation, and any detail that improves heat transfer, such as maintaining clean tubes, should be optimized.

2. Air flow around the tubes usually is provided by large fans positioned below the tube bundles

3. Blockage of air passageways prevents optimal heat transfer, reducing thermal efficiency

4. Pressurized water applied from outside the tube bundle typically is used for cleaning



5. Cleaning is performed most often by a semi-automatic spray system traveling on a track

6. Safety and environmental concerns factor into maintenance and housekeeping

Cleaning/removal

The most common foulant removal method is pressurized water, applied from the exterior (top side) of the unit (Fig 4). This is typically performed by a semi-automatic system that moves multiple spray nozzles vertically on a track that can also be manually moved in the horizontal direction (Fig 5). Water quality and direction of spray are important to avoid fin damage and risk of tube corrosion.

Cleaning system and medium options are discussed in the document.

Frequency

The need for cleaning should be evident by observing deterioration in condenser performance as described in the document. Visual inspections are also important.

It is common for operators to report significant improvement in overall plant performance following cleaning. Finned tubes typically require cleaning annually, but site conditions may require more- or less-frequent action. Ambient temperature and humidity factors are also important and are discussed.

Implementation

Full implementation details are reviewed including safety and environmental concerns. Factors include equipment and water supply, personnel requirements, site planning, and the effect on other equipment and systems during cleaning (neighboring fans, water protection for electrical equipment, etc—Fig 6). Seasonal, temperature and safety recommendations are included.

Other ACCUG reports

This document, in final review, will be issued early 2019, and made available on the organization's website. Technical guidance document ACC.01, "Guidelines for Internal Inspection," was issued in May 2015 and is available at http://acc-usersgroup.org/reports/.

ACCUG's charter is to foster collaboration among owner/operators of powerplants with air-cooled condensers, enabling chemists, engineers, and O&M personnel to grow professionally and maintain their plants at peak performance while reducing expenses. Group participants include water chemists and operational personnel at steam plants, combined-cycle facilities, and other types of generating stations that rely on dry cooling technology.

The Group's 10th annual conference was held Oct 8-11, 2018, in Colorado Springs, and will be reviewed in CCJ.

Best Practices Awards

501F/G users share their best practices with colleagues

The 501F fleet was recognized by peers with five Best Practices Awards in the 2018 judging; the 501G fleet received one. The annual program, sponsored by CCJ, has as its primary objective recognition of the valuable contributions made by owner/operator personnel to improve the safety and performance of generating facilities powered by gas turbines.

In this section, 501F and 501G fleets share their methods and procedures for continual improvement in the areas of safety, predictive analytics, O&M, and water management. These best practices, of course, pertain to engines in other fleets as well.

If you've fallen behind in your reading, note that the 2018 best practices for aeroderivative plants were presented in CCJ No. 56 (1Q/2018). The Best of the Best award recipients—Effingham County Power, Green Country Energy, Hermiston Generating Plant, Minnesota River Station, Ontelaunee Energy Facility, River Road Generating Plant, Terry Bundy Generating Station, and Tuxpan II and V—were saluted in CCJ No. 57 (2Q/2018).

Looking ahead, you might want to begin considering what success stories to share with colleagues via CCJ's 2019 Best Practices Awards program. Due date is Jan 31, 2019. To prime your thought processes, know that subjects of greatest interest generally are fast starts, new skills/workforce development, water management, performance improvements, plant safety, outage management, operation and maintenance, and predictive analytics. Get the details at www.ccj-online.com/best-practices.

State Line

How wet cooling tower operates in extreme cold without freeze-up

Challenge. Operating wet cooling towers can be problematic in extremely cold weather, when the minimum amount of cold-air cooling exceeds heat-transfer requirements and starts to affect the plant cycle. Compounding this problem, ice can form on the outside of the tower and, if left unchecked, accumulate, possibly causing structural damage, safety hazards, and perhaps even a plant shutdown.

Solution. To prevent ice-related issues, State Line personnel came up with a simple but effective solution. Perhaps the best analogy is the cover semi drivers put on the front of their rigs in extreme cold. These "winter fronts" reduce the amount of cold air entering the engine compartment to maintain the optimum operating temperature.

This same principle was adopted for the plant's cooling tower. Pipes were installed longitudinally down both sides of the tower, along horizontal fiberglass members. When temperatures are very low, warm water is run through these lines at circulating-water pressure, providing an additional curtain of warm water to mitigate ice formation.

State Line Combined Cycle

Owned by Empire District, a Liberty Utilities company, and Westar Generating Inc

Operated by Empire District

500-MW, gas-fired, 2 × 1 combined cycle located in Joplin, Mo

Plant manager: Brian Berkstresser

Results. While warm curtain water is required only infrequently, it has enabled the plant to continue running during severe weather when power prices were high and customers needed the electricity to stay warm. Since implementation, the plant has not experienced an outage caused by cooling-tower icing.

Project participants: The entire staff—especially Terry Krause, Phillip (Scott) Boatright, and Ken Case.

Pipes extending down both sides of the cooling tower provide an additional curtain of warm water during extremely cold weather to mitigate ice formation

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AMP Fremont

Transparent wall, curtain protect staff from chemical hazards

Challenge. Cramped quarters in the water-treatment building at this 501F-powered combined cycle, home to the demin plant and its associated chemical injection skid, created an unintended safety hazard because of the caustic and acid required for regeneration of the mixed-bed resin. While the high-pressure chemical injection systems were equipped with flange shields, an unsuspecting person entering that space could, in the event of a leak, be sprayed with caustic or acid.

More specifically, when you enter the demin plant through the main door, the chemical injection skid is immediately to your right. To your left is a tank that presents an egress concern. Essentially, when you cross the threshold, you pass between dangerous chemicals and a tank that obstructs your escape routes.

Solution. Among the proposed solutions not recommended by the safety committee were signage and relocation of the chemical skids. The use of heavy protective curtains also was evaluated, but personnel thought they could create another hazard: In the event of a leak, the curtains might prevent operators from seeing the spray in time to avoid walking into it.

Fremont's maintenance team proposed the solution selected: see-through chemical-safe curtains for the entryway and an enclosure of transparent Plexiglas® panels to provide an unimpeded view of the skids (photos). Perhaps the best part of the approved plan was that personnel protection was assured for only about $2000 in labor and materials.

Results. With the new protection barriers, plant personnel can walk across the threshold into the demin plant with complete confidence that, if there were a leak, it would be contained. While the issue of egress is still there, you can turn around easily and exit the main access door without concern of being sprayed by acid or caustic.

Personnel protection was the plant's top priority, but cost necessarily factored into the solution selection process. While engineering controls always should be the first choice for ensuring plant safety, followed by change of procedures and then PPE, plant management knew relocating the chemical skids would be expensive and not viewed favorably.

Project participants: Craig S Bonesteel, Josh James, Josh Barker, and Rick Moyer.

AMP Fremont Energy Center

Owned by American Municipal Power Inc

Operated by NAES Corp

703-MW, gas-fired, 2 × 1 combined cycle located in Fremont, Ohio

Plant manager: Craig Bonesteel

Protective barrier of transparent Plexiglas® is supported by Unistrut® frame (left); entry curtain of chemical-safe plastic is at right

Dogwood

Safety underpins plant's approach to predictive motor maintenance

A challenge facing the empowered staff at this 2 × 1 501F combined cycle was how perform predictive maintenance (PdM) on low- and medium-voltage motors while reducing—with a goal of eliminating to the degree possible—personnel exposure to electrical hazards and improving the accuracy and repeatability of data collected.

Historically, a contractor has performed the testing necessary to capture the LV and MV online and offline data required at Dogwood. To do this, the vendor would open the motor feeder cubicle to connect test leads and then leave that cubicle open while the motor was started to permit data collection.

The contractor was required to follow NFPA 70E requirements, but even when wearing arc-flash protective clothing, he could not safely connect the leads necessary for online testing to the medium-voltage bus. The voltage was monitored at the cubicle being tested using a test cart and multiple cables strung throughout the area. Because of the electrical hazards, the contractor had to wear NFPA 70E gear while collecting data on a laptop (Fig 1).

Solution. To address the challenge, Dogwood implemented PdMA Corp's MTAP technology for testing LV and MV equipment. It uses current transformers (CT) and potential (voltage) transformers (PT) to reduce hazardous currents and voltages to levels that meet OSHA and NFPA 70E requirements.

The safety system was installed on each MV motor covered by the plant's six-month predictive maintenance plan—one MTAP to monitor current (Fig 2), another to monitor bus voltage (Fig 3). This upgrade protected contractor personnel from electrical hazards. Each MTAP was mounted to the cubicle door, allowing data collection by simply plugging the test lead into the receptacle as shown in the photos.

In the past, test accuracy relied on the CT being set to the proper setting and oriented in the correct way, requiring a test re-run if it was not set up correctly. The MTAP removes the setup from the equation as all internal connections already have been made and tested. Accurate and repeatable test results are assured, regardless of who perform the test.

Results. Installation of the MTAPs allows the simultaneous collection of data from multiple devices at multiple locations without requiring equipment isolation. This saves money by reducing the number of contractor visits required because of plant conditions. Plus, nuisance traps have been reduced because cubicle doors remain closed during the procedure.

More benefits attributed to MTAP technology: (1) Data can be collected by one person and in only five or six hours compared to a full day previously. (2) Having specific test points with the CTs and PTs permanently mounted assures data are reliable and repeatable.

Dogwood Energy Facility

Owned by Dogwood Energy, City of Independence, Missouri Joint Municipal Electric Utility Commission, Kansas City Board of Public Utilities, and the Kansas Power Pool

Operated by NAES Corp

650-MW, gas-fired, 2 x 1 combined cycle located in Pleasant Hill, Mo

Plant manager: Steve Hilger

Project participants:
Mike O'Reilly, IC&E technician
Glenn Brons, project oversight

1. Testing of a medium-voltage motor is in process

2. MTAP is at a MV motor cubicle monitoring current

3. MTAP installed at switchgear compartment is monitoring voltage

Reducing turbine lube-oil varnish potential extends fluid's useful life

Challenge. Lea Power Partners' (a/k/a Hobbs Generating Station) combined cycle is equipped with two M501F gas turbines and a D11 steam turbine. The GTs have 5000-gal lube-oil reservoirs, the steamer a 3600-gal tank. After eight years of service, the varnish potential of GT lube oil, based on the Membrane Patch Colorimetric Test (MPC) results, ranged from 46 to 50, the ST fluid was more than 20.

Plant's goal was to reduce the varnish potential and safely extend the life potential of these reservoirs, thereby deferring the cost of replacement oil to coincide with a future planned outage.

Solution. Working with Hilliard Corp's HILCO Div, plant personnel and lube-oil experts developed a plan to recover the reservoirs to acceptable varnish-potential levels as quickly as possible to prevent further oil degradation and not disrupt Lea's operations. The solution was to treat the reservoirs by using a temporary, portable oil-conditioning unit with a remediation dosage of dry-resin ion-exchange media in a kidney-loop arrangement.

Concurrently, Lea's staff repurposed HILCO oil conditioners no longer required by a sister plant to maintain low varnish-potential levels going forward with a much smaller amount of ion-exchange media once the higher-capacity conditioning unit had removed the bulk of the varnish.

Plan was to run the bulk treatment unit on each reservoir for four weeks and then commission a permanent maintenance unit to run continually. The portable unit then would be moved to the next reservoir for bulk treatment.

Results were immediate and impressive. After only 24 hours of operation of the bulk treatment conditioner on GT1, a substantial improvement in the appearance of the oil samples was observed (photo). Varnish potential was reduced from 50.5 to 28.3 MPC. Similarly, after GT2 had one of the 3.5-gpm repurposed oil conditioners hooked up for 24 hours, samples showed a reduction in varnish potential from 46.1 to 34.9 MPC.

Clean up of GT1 oil using the portable bulk treatment conditioner took less time than expected, allowing staff to switch to the permanent smaller conditioner in only three weeks. The bulk treatment conditioner then was moved to GT2.

Long-term results: During the eight-week monitoring period, the varnish potential on GT1 turbine lube oil was reduced from 50.5 to 3.7 MPC, on GT2 from 46.1 to 3.8 MPC, and on the steam turbine from 21 to 2.7 MPC (figure).

The reduction in varnish potential allowed the plant time to arrange for lube-oil replacement consistent with a future planned outage, thereby deferring the purchase of new oil until the expense could be budgeted. Note, too, Lea saved $15,000 by recommissioning conditioning equipment no longer needed at a sister facility.

Lea Power Partners LLC

Owned byWestern Generation Partners

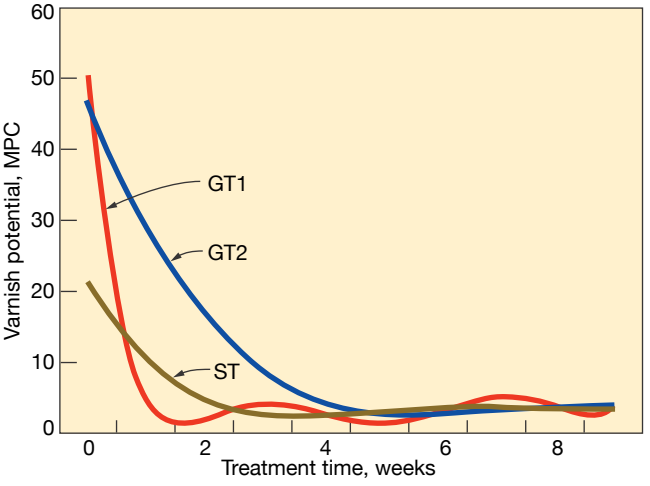
Operated by Consolidated Asset Management Services (CAMS)

604-MW, gas-fired, 2 × 1 combined cycle located in Hobbs, NM

Plant manager: Roger Schnabel

Project participants:

Richard Shaw, O&M supervisor
Carlos Sanchez, engineering manager
Tyler McCoy, Guadalupe Garay, and Kelvin Mendenhall, I&E technicians
Cesar Garcia, senior operations technician
Roger Schnabel, plant manager



Eight-week test results for each of the three lube-oil reservoirs illustrate the dramatic reduction in MPC achieved by the conditioning equipment

Varnish removal from GT1 oil was quick and dramatic using a portable bulk treatment conditioner. Note the color change after the first day when MPC was reduced from 50.5 to 28.3

High Desert

Chlorine dioxide bests bleach for organics control in cooling water

Challenge. High Desert Power Project uses a zero-liquid discharge system to process cooling-tower blowdown for recycle. The ZLD system incorporates microfiltration, softening, two stages of reverse-osmosis concentration, forced-circulation crystallization, and a centrifuge for crystallizer solids removal. The plant's desert location dictates the use of multiple makeup water sources of varying quality, making microbiological and organics control challenging.

The facility historically used bleach to control organics in the cooling-water system, but the existing bleach feed system was unreliable, with pumps losing prime at the worst possible time, pump failures, loss of bleach feed, cracked and leaking tubing, ORP probe failures, etc.

Erratic oxidant feed impacted ZLD-system performance and caused disturbances in the cooling-tower blowdown system, wasting time and money. Excessive chlorides from the bleach application affected ZLD cycles.

To achieve good results, free-chlorine concentrations often exceeded 1 ppm. Performance was mixed using bleach: Plate counts were acceptable, but sessile populations were high, indicating the presence of a highly insulating biofilm.

Solution. Extensive research convinced plant personnel to replace bleach with chlorine dioxide. A six-month pilot test was conducted in 2017 and it confirmed that conclusion. The biocide supply system selected, a turnkey solution from Nalco, uses sulfuric acid and the chemical company's Purate™ to make chlorine dioxide (photo). Note that the acid tank required was not included in the turnkey solution.

High Desert's biocide, chlorine dioxide, is made onsite

Use of chlorine dioxide reduced RO membrane cleanings, improved cooling-tower appearance, improved reliability in biocide application, helped optimize manpower requirements, reduced chlorides, reduced corrosion potential in the condenser, and lowered the total cost of operation.

Results. The new system runs reliably (Nalco was contracted for maintenance) and the proper concentration of oxidant is applied consistently. Chloride loading on the ZLD plant was reduced by at least 15% and microbial monitoring shows good control of both planktonic and sessile bacterial populations. The cooling tower is consistently cleaner. Plus, RO and microfilter membrane cleanings have been halved. Finally, the use of chlorine dioxide is less expensive than bleach in terms of total operating cost.

High Desert Power Project

Owned by Avenue Capital

Operated by NAES Corp

830-MW, gas-fired, 3 × 1 combined cycle located in Victorville, Calif

Plant manager: Claude Couvillion (former), Victor Barron (current)

Project participants:

Ross Walden, O&M manager
Victor Barron, assistant plant manager

Athens

ST shaft temperature predictor reduces risk of permit violations

Athens Power Plant

Owned by Talen Energy

Operated by NAES Corp

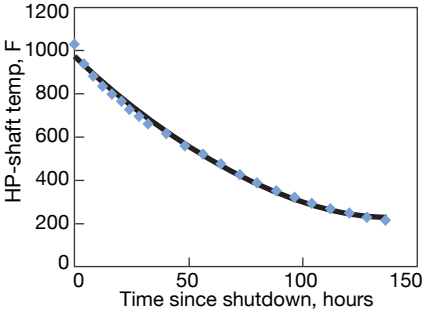
1080-MW, gas-fired, three-unit, 1 × 1 combined cycle located in Athens, NY

Plant manager: Hank Tripp

Challenge. In July 2016, Athens' Title V air permit was modified to include startup and shutdown limits. The former included emissions as well as startup time limits: three hours for a hot start; six hours for a warm start; and eight hours for a cold start. These were determined by the shaft temperature of the HP steam turbine.

A hot start translates to shaft temperatures of 800F or greater; a warm start, temperatures over 300F but less than 800F; cold start, shaft temperatures up to 300F. The type of start determines how many hours the plant is allowed to operate at less than 75%. Athens must shut down and restart if it is going to exceed the permitted startup hours.

The units at Athens do not run baseload. They can run for several days at a time and then shut down for several days. This results in steam turbine temperatures that can vary widely. The type of startup—hot, warm, or cold—is included as part of the plant's air permit but it is also considered critical information by the marketing team. Because the marketers must purchase the necessary gas and submit the ramp bids to the ISO before the unit can be dispatched, the plant must let them know as early as four days out whether the start will be hot, warm, or cold.



1. Historical data were used to develop the equation for this curve, which, in turn, is used by the DCS to predict HP-shaft temperature based on the number of hours from shutdown

To accomplish this, the operations team was using a rule-of-thumb approach based on the number of hours since shutdown: less than 12 hours, a hot start; 12 to 100 hours, a warm start; more than 100 hours, a cold start. This approach worked well until the July 2016 Title V modification. Under the new requirements, it became critical that the marketing team submit the correct startup profile bid to ISO, or Athens would be at risk of running a startup beyond its permitted hours limit.

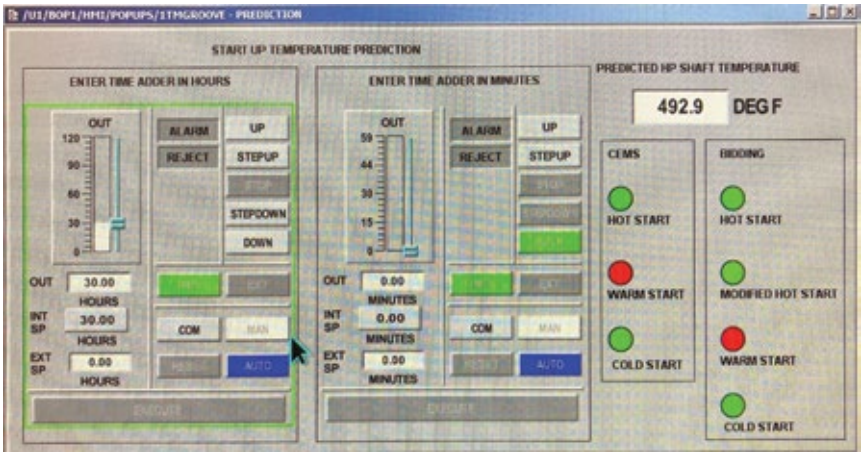
This could have occurred if marketing believed a start was going to be cold when the shaft temperature at the startup was actually 301F. Thus, staff needed a way to determine exactly what the shaft temperature was going to be at the time of startup—down to the degree.

Solution. To calculate an accurate baseline, plant personnel pulled HP-shaft temperatures from shutdowns over the past couple of years. They sorted the data, then plotted it with "time since shutdown" on the X axis and "HP-shaft temperature" on the Y axis (Fig 1).

An equation was developed from this plot that allowed plant persoonel to accurately predict HP-shaft temperature as a function of the number of hours from shutdown. The equation and plot were a useful tool, but our goal was to incorporate this curve into the distributed control system (DCS) so the operators could easily determine the shaft temperature at startup.

Results. The I&C staff built the faceplate shown in Fig 2 which appears on the steam turbine warmup page. If a unit is going to be dispatched, the control room operator (CRO) will total up the hours from the current time to the anticipated dispatch time, then input this number into the "hours" block on the left-hand side of the faceplate. Using the curve developed in Fig 1, the DCS will then output a predicted HP-shaft temperature.

This tool has been used many times over the past year and has been accurate down to ±1 to 2 deg F even several days in advance of a startup. This probably has saved the plant several costly Title V permit violations.



2. Faceplate on the steam-turbine warmup page takes operator inputted time-to-dispatch (left-hand side) and provides predicted HP-shaft temperature by DCS calculation

Project participants:
Colleen Dolan, compliance manager
Ken Cardona, operations coordinator
Bob Robinson, I&C technician

Learn from colleagues, rub elbows with 100 vendors in Scottsdale, Feb 17 – 22

It's time to decide which conferences you will attend in the first quarter of 2019 (schedule of events, p 3), assuming you haven't already done so. If you're involved in the specification, installation, operation, and/or maintenance of 501F gas turbines made by Siemens Energy Inc and/or Mitsubishi Hitachi Power Systems (MHPS), participation in the upcoming 501F Users Group annual meeting (see box at right) is particularly important.

The players in the service business are changing and their product/services offerings are evolving—oftentimes faster than you might think. It's virtually impossible to do the job company management expects unless you keep up with that the suppliers are doing—especially the OEMs and their third-party competitors.

The all-volunteer 501F steering committee, headed by Cleco Power LLC's Russ Snyder, has posted the agenda on the group's website. This year's program has the same compelling elements as the information-rich 2018 conference which ran four days and included the following:

- User presentations on issues identified in the fleet and solutions implemented, as well as on experience with upgrades to improve unit performance.
- User-only sessions promoting open discussions and short presentations by owner/operators on safety; compressor, combustion, hot-gas, inlet, and exhaust sections; rotors; auxiliaries; and generator.
- Special closed sessions by the major products/services providers serving this frame.
- Vendorama progam, comprising three-dozen half-hour technical

2019 Conference and Vendor Fair

February 17-22

DoubleTree Resort by Hilton Paradise Valley (Scottsdale), Ariz

For the latest program information, visit http://501f.users-groups.com

Refer questions on the vendor fair, sponsorships, etc, to Tammy Faust, tammy@somp.co, or Jacki Bennis, jacki@somp.co, 843-856-5150

presentations by third-party services providers, brings attendees up to date on offerings of primary interest to the 501F community.
- Vendor fair, following the Vendorama program on the first day of the meeting, gives users the opportunity to peruse the offerings of nearly a hundred manufacturers and services firms.

If you have never attended a 501F Users Group meeting, make the 2019 conference your first. You will learn things vital to your plant's future success that's not available in one place anywhere else. Chairman Snyder stressed, "Owners of 501F equipment certainly will leave the conference with a better understanding of their options in the marketplace for maintaining their equipment."

Special closed sessions

There were four special closed sessions of either two or four hours each at the 2018 meeting to provide details on 501F performance-improvement solutions offered by industry heavyweights GE, MHPS, PSM, and Siemens.

Officers, directors of the 501F Users Group

President/Chairman of the Board
Russ Snyder, *general manager, Southern Gas Fleet, Cleco Power LLC*
Vice Chairman/Secretary
Carey Frost, *program manager, Duke Energy*
Board members:
Blaine Gartner, *outage supervisor and technical support, Xcel Energy*
John Burke, *O&M manager, Cottage Grove Power Plant (NAES Corp)*
Brian Berkstresser, *plant manager, State Line Plant (Liberty Utilities)*
Dave Gundry, *staff engineer, Xcel Energy*
Dennis Winn, *managing director, Klamath Energy LLC (Avangrid Renewables)*
Ivan Kush, *principal CT and Controls Engineer, Cogentrix Energy Power Management*

These sessions were sandwiched between user presentations and discussion sessions on Tuesday, Wednesday, and Thursday to maximize participation. The special sessions all were well attended by owner/operators who asked insightful questions and actively participated in discussion opportunities. Presentations by PSM, GE, and MHPS can be accessed by registered users on the group's website. Siemens posted its presentations on the company's private Customer Extranet Portal. Unregistered owner/operators of Siemens power generation equipment can request access at https://siemens.force.com/cep.

General Electric

Recall that GE was a new entry on the agenda of the 501F Users Group annual meeting in 2017, having acquired that engine technology as part of its purchase of Alstom in late 2015. At the 2018 conference, engineers in the company's cross-fleet solutions business unit updated attendees on their successes and upgrade products.

Key points that resonated throughout the presentations included the following:
- GE is a full-service provider for the 501F fleet and offers long-term service agreements as evidence of its commitment.
- Initial development activities focused on improvements and refurbishment. Today, the company is offering more advanced upgrades, ones based on GE F technology and its proven validation processes.

Colorless varnish?

Sponsored by C C Jensen Inc

Recently, some C C Jensen customers have suffered turbine trips and typical varnish-related issues—without seeing any obvious signs of varnish.

Example: If it were only for the standard MPC test, one user could have concluded his plant's turbine oil was varnish-free based on the excellent rating of 4 from a Membrane Patch Colorimetric Test (Fig 1). However, two more analyses gave far different results and a truer picture of oil condition:
- An Ultra Centrifuge score of 7, which is associated with a "critical" level of varnish (Fig 2). Recall that the UC scale runs from 1 to 8, with the high score the worst possible.
- A significant difference in the results from the two particle-count methods—optical, which counts both soft and hard particles, 25/24/13; and pore block, which counts only hard particles, 15/14/10. Note that particle counts above the high teens typically reflect a significant concentration of soft particles.

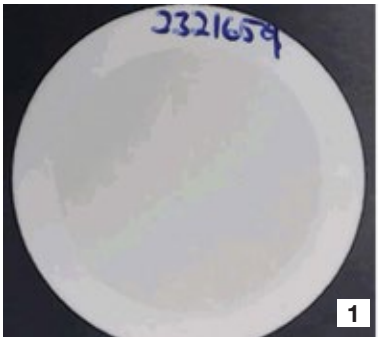
A conclusion drawn from the foregoing results: There are countless soft contaminants that can act like varnish, and no matter where they come from, must be dealt with.

For turbines running baseload or cycling where high oil temperatures are the norm, the only two options for oil conditioning/varnish removal are: filtration with selective chemical bead/resins and VRU technology, which physically removes all soft contaminants from solution and captures them in fairly inexpensive, high-absorption capacity filters (Fig 3).

Both methods work very well. While it sometimes a takes a few trials to identify the right chemical/resin to achieve the results expected, the VRU method works with any and all soft contaminants without any adjustments necessary.

As a general rule, the larger the discrepancy between a low MPC and high UC, the more soft contaminants you will have to remove. In a typical 6000-gal lube- and control-oil reservoir with varnish issues you can have less than 10 lb of varnish. In extreme cases, more than 100 lb of varnish may be removed from the oil.

Finally, feel free to share your oil analysis with Axel Wegner (axel@ccjensen.com) if you are in doubt or just want a second opinion.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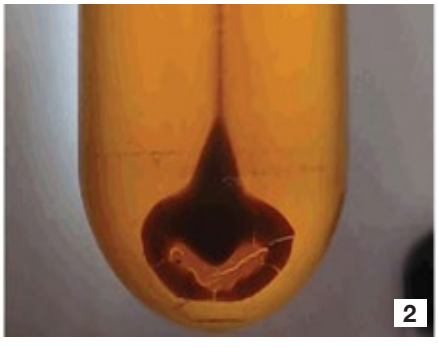
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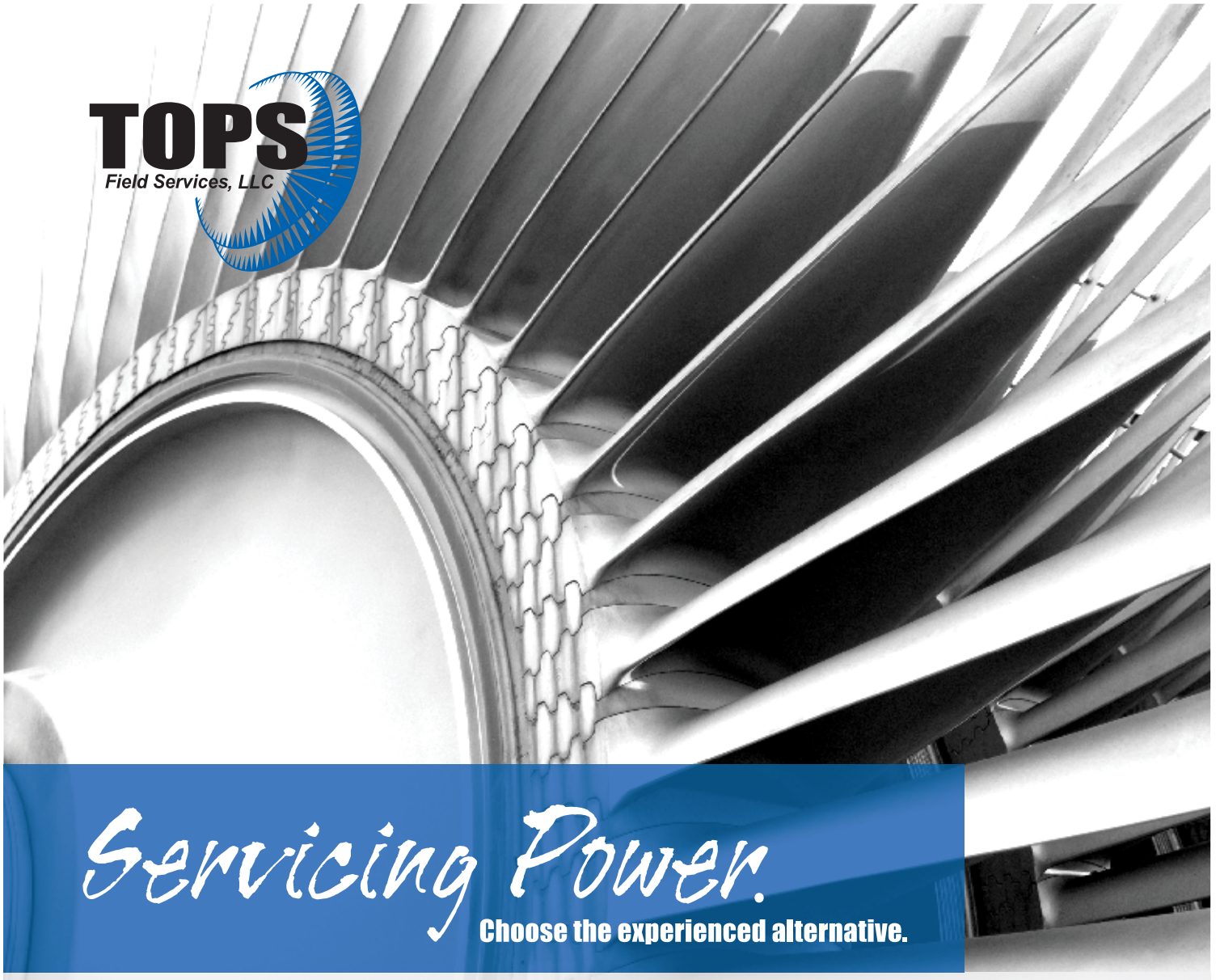

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10 YEARS
2008-2018
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Users convert to single-layer SCR catalyst to reduce pressure drop, ammonia use

Sponsored by Groome Industrial Service Group

Jeff Bause, who heads up Groome's HRSG Maintenance Division, well known for its cleaning and catalyst services to support reliable and efficient operation of heat-recovery steam generators, brought owner/operators attending the 501F Users Group meeting in Orlando, February 2018, up to date on industry challenges and trends.

At the top of Bause's list were user goals of reducing pressure drop plus ammonia consumption, which were the focus of the case histories he presented. He also discussed current concerns regarding the sulfur content of natural gas and ammonia quality, catalyst end-of-life predictions, experience with combined SCR/CO catalysts, and the impacts of low-load operation on SCR performance.

The first two case histories Bause presented involved 2 × 1 501G-powered combined cycles with double-layer catalyst designs; both used 29% aqueous ammonia. Work scopes: The two plants opted to convert to a single-layer catalyst system and specified cleaning and tuning of their ammonia injection grids (tuning performed by Environex Inc). One plant added installation of a permanent sampling grid on its "to-do" list.

Results of the upgrades to both systems were excellent. At the first plant, NO_x emissions were reduced from 3.86 ppm at the stack before conversion to 3.76 after—with a reduction in ammonia consumption from 488 to 380 lb/hr. Tuning reduced ammonia use by another 20 lb/hr. Pressure drop through the catalyst was decreased by 4.5 in. water—from 24 in. to 19.5.

Regular inspection and maintenance can help prevent performance-robbing deterioration—such as the spent catalyst at the left and damaged ammonia injection lance at right

Before/after SCR catalyst cleaning left/right

At the second plant, stack NO_x dropped from 5 to 3.5 ppm following conversion to a single-layer catalyst and ammonia slip decreased from 10 to 4 ppm. Ammonia consumption went from 72 to 52 gal/hr (including tuning). Pressure drop through the catalyst bed decreased by 2.9 in. water after the upgrade (from about 4.5 to 1.6 in.).

A third case history presented by Bause involved an LM6000 with a double-layer catalyst system using 19% aqueous ammonia. In this case, the pathway to better performance involved SCR catalyst cleaning, replacement of CO catalyst, and modifications to the ammonia injection grid. Last included new nozzles, mixing plates, and valve for the AIG, and tuning. Engineering for the AIG upgrade was provided by Environex, which also did the tuning.

Results: Required NO_x conversion was achieved with less ammonia (22 gal/hr before the upgrade, 12.8 gal/hr after) and ammonia slip was returned to the compliance level.

Bause closed his presentation by saying his company's services have been vetted and approved by catalyst manufacturers and OEMs alike. The Maintenance Division has serviced catalyst for more than 600 HRSGs and simple-cycle gas turbines. Contact Bause at jbause@groomeindustrial.com.

Crane picks section of catalyst (left) and moves it to ground (above) for cleaning

- Full engine spares are available.
- Dedicated engineering and service teams serve each frame in GE's cross-fleet portfolio.

The status summary presented noted that GE has full upgrade capability in place for the 501F and that multiple outages have been completed. Plus, significant performance enhancements were said to have been implemented prior to the 2018 meeting.

A second phase of upgrades, planned for deployment in 2019/2020, and applicable for W501FA through FD3 models as well as the M501F, include a DLN combustor with additional fuel staging, full GE Advanced Gas Path (AGP) capability, and enhanced turndown with single-digit NO_x.

A presentation on outage experience focused on the details of a W501FD3 combustion inspection that included integration of a wet-compression system.

In the generator portion of the program, the first example of GE's capabilities was a generator in-situ robotic inspection incorporating a visual air-gap inspection and ElCID test. That outage window was only 48 hours. A second generator outage, this one for an AeroPac I commissioned in 2003, involved replacing the original pole-to-pole connector onsite to assure long-term reliability.

A fast stator rewind (22 days) was conducted on yet another AeroPac I—done during a turbine major inspection. This machine suffered misalignment of magnetic core segments leading to increased partial-discharge activity; the stator revealed significant indications of slot discharge. The owner opted for the rewind to avoid the increased risk of a three-month outage that would be required for stator/core repair should a failure occur.

The project included new stator bars incorporating the latest MICAREX insulation technology. Plus, lateral wedging with round packing to address misalignment of core plates and assure high-quality contact between insulation and the core.

Interesting to note is GE's extensive experience in cross-fleet generator service, which pre-dates the Alstom acquisition by more than two decades. The company reports having completed nearly 500 jobs on generators made by 20 OEMs. Included are nearly 200 inspections and overhauls, more than 120 condition assessments, more than 75 rewinds (stator plus rotor, partial and full), etc.

Repairs. Focus of the first presentation in the repairs session showcased the company's flexibility in dealing with "surprises." The example given: Technicians were prepared to make repairs on IN738 first- and second-stage turbine blades, which turned out to be made of the nickel-based superalloy CM247 (VGP in Siemens speak) when they arrived at the shop. The configuration of these airfoils also differed from the design expected and they incorporated shaped diffuser cooling holes.

While unexpected, no "biggie." Materials engineers and technicians implemented a process to characterize, inspect, and analyze the hardware received to develop the necessary repair solutions, which involved the development of coating, welding, and machining techniques. Photographs illustrated the work—including model creation, examination of the internal geometry, and metallurgical examination.

Inspection of the airfoils upon receipt at the shop revealed trailing-edge, platform, and weld cracking. Personnel likened the distress modes to those experienced with IN738 and GE F-class first-stage buckets.

The speaker explained the process developed for tip repair. Cracking extending below the tip cap was typical on these airfoils. In GE's experience, CM247 is prone to cracking and it was important to develop a repair process that leveraged the OEM's 7FA.04/FB experience.

A DVC (dense vertically cracked) coating system was developed and applied to the repaired turbine blades. Anyone under the mistaken impression that coatings and their application is akin to spray painting got a wake-up call at this point. The speaker explained how coating thickness is tailored to maintain the throat area, how air-masking is used to maintain cooling-hole diameter and shape, etc. GE believes the coating developed, and its application, will maintain past performance while improving durability.

The discussion moved to first-stage vanes, which had about 550 cooling holes. Challenges included (1) not

Turnkey outage support for HRSGs, including complete valve services

Sponsored by SVI INDUSTRIAL

HRSG outage planning can be a difficult task, particularly when the outage scopes have varying levels of support required—including inspection, analysis, engineering, labor, equipment, and project management. SVI is positioned to support turnkey work including anything from liner repairs and upgrades to specialty welding and turnkey valve services. ASME and valve-repair certifications allow SVI to support the broad range of outage services required for HRSG maintenance and upgrades.

Design and Engineering

If exhaust flow would just go where it is supposed to go! Liner systems in HRSGs are not overly complicated, but when problems develop it can be a downhill battle if not fixed or upgraded correctly. With extensive experience from GT exhaust systems (simple-cycle peakers) over the years, SVI applies various liner designs and fixes to leave the gas path as exactly that, a place to reliably channel exhaust flow without leaks and failed liners that can lead to anything from a hot spot to a safety issue.

For systems that are more degraded and have developed cracks and stack wall thinning, SVI can support the structural engineering to fix areas of major concern. Systems experiencing potential structural issues because of failing casings or stacks should be inspected and repaired accordingly at the earliest opportunity.

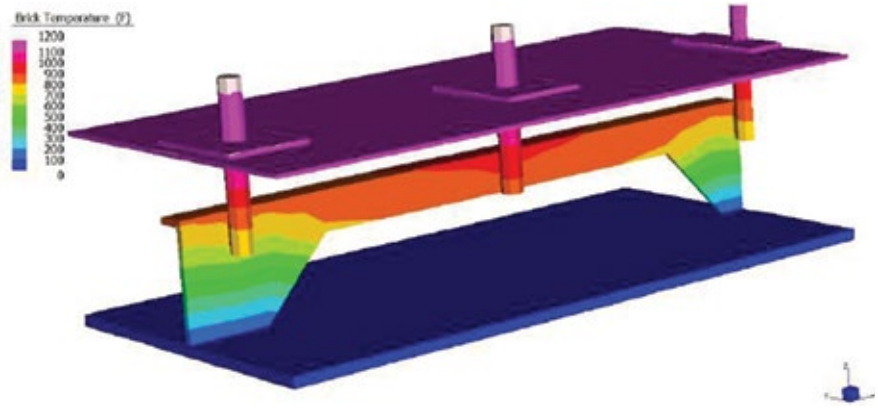
SVI can help keep your flow in line, don't let gas-path liner issues lead to significant failures.

Equipment Supply

With ASME code certifications, SVI is flexible for equipment supply of pressure and non-pressure parts from its own fabrication shop in Pineville (NC), or using its network of contact fabricators. This allows SVI to be a sole source to obtain high-quality equipment when it is needed.

Field Work

There are many mechanical contractors that specialize in boiler field work but not all have the depth of support that SVI has developed to ensure a one-stop shop to meet all outage requirements. By incorporating all the resources needed to support the complete project lifecycle, SVI streamlines the execution and eliminates finger pointing and costly surprises for outage work. We strive to make safety the top priority and avoid any shortcuts that may compromise safe project execution.



Project Management

A dedicated project engineer is the sole point of contact to handle all things related to your project. We understand that many times plant resources are limited so we act as an extension of your organization to ensure all project goals are met.

SVI INDUSTRIAL is headquartered in Pineville (NC), with operating locations around the US. SVI DYNAMICS is a division of SVI INDUSTRIAL providing additional synergies to support engineered noise control and gas-path solutions.

To learn more about how SVI can help support your next outage, email Scott Schreeg at sschreeg@svidynamics.com. Or call Scott at 219-380-9267.

having access to the OEM's component flow targets and (2) relatively small cooling holes (nominal 30-mil diameter) drilled without coating collectors (counterbore). The GE team had to characterize incoming flow and establish final flow targets. A chart of airflow results for the first set of first-stage vanes repaired showed data points tightly clustered and within standard new-make tolerances.

Basket repairs also have required a significant investment to improve their durability with no adverse impact to part performance. The challenge here was that the 501F is a highly fragmented fleet with two OEMs participating, each having designs that have evolved over the years. The result: Several basket variants exist.

One example given was uncoated resonators that are prone to cracking. Another: An OEM coating configuration and system that offers little room for operational improvements. To extend component durability, GE conducted a program to analyze and test the original resonator configuration and make changes to accommodate coating application.

Parts and performance. The last segment of the GE session focused on improvements to second-stage blades and vanes, plus combustion testing in a high-pressure rig to support a combustor redesign and upgrade. Second-stage blades were said to suffer high fallout during repairs as well as early mortality.

Post-cast changes implemented by the GE shop included redistribution of cooling-air flow, additional platform cooling, and use of the company's DVC thermal barrier coating. For replacement parts, GE touted the superior performance of its DS GTD141-1 material, a redesigned airfoil, and re-engineered root fillet and core.

GE's second-stage vane also was designed to provide better performance than the OEM's original airfoil. The benefits: a 1% increase in power output and a heat-rate reduction of 0.3%—based on the FD3 configuration. In addition, the promise of three 32k intervals. Key to the improvements, the speaker said, was improved airflow distribution by conversion to a single cavity. The new vane is interchangeable/compatible with OEM hardware on a row-wise basis.

Combustor. Phase 1 combustor work included an upgrade to a Co-Cr-based wear coating and GE proprietary TBC; fuel staging (four fuel circuits and no transition-piece bypass; and more-forgiving weld geometry. The benefit of this effort: Combustors directly retrofittable in Siemens and Mitsubishi machines capable of 32k hours/1250 starts intervals to eliminate CIs.

Work underway on the Phase 2 flex combustor has the following goals: single-digit NO_x, up to 20% additional turndown, and greater fuel flexibility, among other benefits. It will incorporate the same life-extension approaches as the Phase 1 combustor, enhanced fuel staging (late axial staging with fuel and air injected into the transition piece), and improved premixing by use of GE's F/H-class integrated swirler/fuel injector.

MHPS

Team Mitsubishi's program began with presentations on the company's product portfolio, facility capabilities, key initiatives, and safety performance—as most OEM sessions do. The meat of the program for CCJ's subscribers focused on rotor and exhaust-system issues and proven solutions offered by MHPS, plus the OEM's engine performance and durability upgrades.

Presenters for this segment of the session were led by Scott Cloyd, recently promoted to chief engineer, gas-turbine service engineering, who opened the program with a primer on the inspection and care of W501FD2 rotors of value to both experienced attendees and first-timers (more than a third of the audience).

Cloyd shared the company's experience gained during more than 200 comprehensive rotor inspections (CRI), stressing MHPS's growing experience

Getting to the bottom of bearing damage

Sponsored by Bearings Plus Inc

As one of the most critical components of high-performing rotating equipment, fluid-film bearings are designed to provide long, reliable service. When a bearing does suffer damage, the root cause is often external to the bearing. Damage can be the result of inadequate lubricant, overloading, misalignment, or a number of other issues.

While immediate bearing repair or a direct replacement may be the most expedient way to get machinery back up and running, performing a bearing damage analysis can, in the long run, improve overall availability and reliability. If equipment is experiencing recurring issues, a direct replacement can provide an interim solution while an analysis is performed and an upgrade made ready for the next outage.

Since bearing damage is frequently an effect, rather than the cause, identifying the root of a problem can be difficult. For example, among the most common types of bearing damage is wiping, characterized by a rubbing, melting, or smearing of the bearing's babbitt material. The cause of wiping may be any number of issues: excessive load at startup or shutdown, insufficient lubricant, operational overload, inadequate or loss of clearance, excessive vibration, or misalignment. The common factor is that contact occurs between the bearing and rotor.

To properly identify the root cause of wiping, it is necessary to look at the characteristics of the wiped bearing surface and for other damage on the bearing. Wiping that occurs during startup and shutdown may exhibit as successive thin layers of wiped bearing material.

Misalignment, on journal bearings, may cause a parabolic-shaped wiping or a wear pattern angled across the bearing surface. On thrust bearings, it may result in a group of pads on one side of the bearing being wiped.

Inadequate clearance may be indicated by an evenness of the wiping on all of the pads or lobes in a journal bearing. However, high dynamic loads may also cause wiping on all of the journal pads and resemble the effect of a loss of clearance.

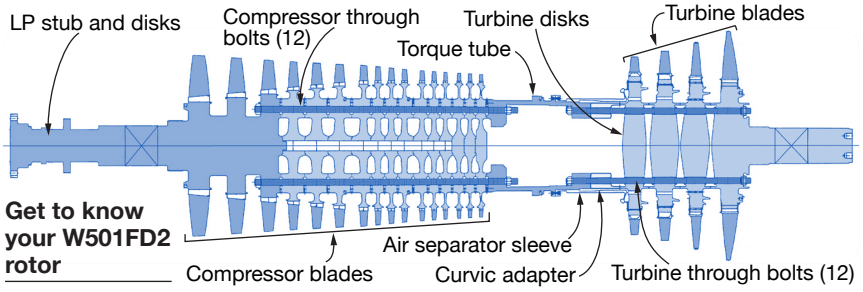
Additional types of damage may provide clues to the root cause: On tilt pads, wiping caused by excessive load typically is seen together with significant pivot deformation. Wiping accompanied by oil varnish may indicate insufficient oil flow to support the bearing load or to cool the bearing. Yet, diagnosing bearing damage is frequently complicated by the fact that one type of damage may progress from—and hide—other types, or may lead to further damage.

Analysis of the bearing damage alone may not be enough to identify the root cause. As much information as possible regarding the equipment startup and operating conditions should be provided. For example, in the case of a journal bearing that exhibits even wear on all pads, knowing whether the equipment experienced high dynamic vibrations or whether there was a sharp increase in pad temperature during startup would be of significant value.

A gas-turbine journal-bearing pad exhibits a combination of wiping and varnish from frequent starts/stops and misalignment. Visit www.bearingsplus.com for a Bearing Damage Index

Data provided as part of a diagnosis should include the frequency of starts/stops, startup loads, operating loads, dynamic loads, bearing clearances, oil supply, operating temperatures, and steady-state position and vibration data.

In addition to helping to identify the root cause, bearing specialists can advise on the appropriate steps to address damage, be it repairs to the existing bearing, a replacement bearing, or an upgrade that will better handle the machine's unique conditions.



Get to know your W501FD2 rotor

in its Savannah and Houston repair facilities. One of his primary objectives was to raise user awareness regarding CRI planning, common wear mechanisms, and torque-tube cracking and service support.

Before digging into CRI planning, Cloyd reviewed the operating history of peak, intermediate, and baseload engines. It was obvious from the data plot shared with the group that operating beyond MHPS's recommended CRI intervals of 100,000 actual service hours or 12 years was akin to inviting problems. More than half of the engines in service are operating outside recommended inspection intervals.

He noted that corrosion was of particular concern to low-hours units, saying that some machines may go 12 or more years before their first hot-gas-path (HGP) inspection. Corrosion occurs primarily because of condensation in a cold rotor cycling in and out of service while subjected to ambient-temperature and humidity changes.

The condition is exacerbated when wear from blade rock reduces the contact area between the blade and disc fir-tree serrations. This concentrates stress at the top-most serrations; defects in the serrations below can amplify stress in the already highly stressed locations.

Cloyd said CRI results should be able to answer this question for the engine owner/operator: Can rotor components operate until the next scheduled interval? A pre-CRI assessment will help determine inspection scope and assist in parts planning and availability. It is intended to identify rotor component concerns, determine the state of material degradation, and characterize the wear of turbine-disc root serrations.

Historian data are important to the accuracy of any rotor assessment. Trending of rotor ageing characteristics improve component life predictions. This analysis should begin at the turbine inspection (TI) prior to the CRI and provide a continual stream of information to planners. Depending on the results of the pre-CRI rotor assessment, the engine owner might want to have a spare rotor on standby for a possible swap-out to minimize outage duration.

Cloyd suggested the following inspections be performed at the TI before the CRI to trend rotor health:

- Visual and dimensional checks.
- Corrosion-pitting inspections to measure size and depth.
- Hardness measurements.

- Blade shroud gap and platform gap checks.
- Grain-structure replication and anslysis.
- Turbine-blade root serration wear.

In your pre-CRI investigations, remember that dental molds are valuable for characterizing blade groove wear (high turning-gear hours can result in uneven wear and loading) and serve as a historical reference point for future evaluations. Molds of the turbine-disc root serrations are excellent for evaluating the severity of corrosion pitting.

Cloyd next outlined key aspects of a CRI recommended by Mitsubishi. Below is a list the components that should be checked, what should be investigated, and the inspections typically called upon to assure an accurate assessment. The rotor cross section provided may prove useful if you have limited first-hand knowledge of the W501FD2.

- Spindle bolts can suffer fatigue or fretting wear. NDE of bolts, lands, and threads can point to possible problems.
- Turbine-disc cooling-air passages can become clogged. Find visually and clean.
- Turbine-disc blade serrations can suffer corrosion, wear, and fatigue. First step is surface cleaning and scale removal. Then NDE contact surfaces, measure blade rock, and evaluate pitting. Blend as needed.
- Curvic clutch may experience wear, which can be found by visual inspection plus checking metal-to-metal contact.
- Compressor and turbine discs are susceptible to corrosion, cracking, pitting, creep, and/or hardness changes. Conduct visual inspection and NDE all contact surfaces, perform hardness checks, and take replicas.
- Journals are susceptible to wear, scoring, and/or cracking. Dimensional and runout checks point to certain problems; visual checks can identify scoring and pitting. NDE is relied on as well. Machining corrections are made as needed.

Cloyd had users' eyes glued to the screen with his photos of turbine-disc corrosion, wear and tear attributed to blade rock, etc.

He then reviewed typical CRI findings and repairs, including:

- Peening and machining of compressor-disc spigots to remove fretting and restore proper interference.
- Root end-face cutbacks on compressor blades to reduce the potential for diaphragm rubs caused by locking-groove wear.
- Shot-peening of compressor-blade grooves to remove scale which otherwise would accelerate wear of the root coating.
- Removal of debris from air-baffle grooves to mitigate baffle-plate wear.
- Blending-out of indications and signs of wear.

Before moving on to torque-tube cracking, Cloyd addressed air-separator health. He said fretting often is observed on the air-separator contact face and that restoration of this surface is critical to reduce the risk of crack propagation. Cloyd also reminded the group that a shim can be used at the torque tube-to-air separator flange to restore pre-load.

Torque-tube cracking. Recall that the torque tube on 501F engines joins the compressor and turbine sections of the rotor. Cloyd said three W501Fs were reported to MHPS as having experienced forced outages attributed to vibration events caused by through cracks in the torque tube. The cracks were concealed by the air separator (figure provides clarity). He added that no M501Fs have had this problem.

One failure was described by a second speaker directly involved in the analysis. Deck-plates personnel closely monitored increasing vibration levels

PAG favored over petroleum-based lubricants by an increasing number of turbine users

Sponsored by American Chemical Technologies Inc

Polyalkylene glycols (PAG) are no longer the "new guy on the block" in the power generation industry. American Chemical Technologies' (ACT) EcoSafe® line has remained unchanged, using PAG base stocks in its formulations since the early 1990s. PAG chemistry has provided lubricant solutions in many different turbine applications for over a decade.

These synthetics are a paradigm shift away from all the obstacles contended when using petroleum-based lubricants—including varnish, electrostatic discharge, failed demulsibility, and hydrolytic instability. The challenges with varnish and solids are here to stay, and might heighten because of the changes forced upon the petroleum industry by OSHA and the EPA.

With more and more turbine users suffering varnish-related issues, the power industry has turned to the non-varnishing PAG to rid their operations of unfavorable variables. In chemistry "likes dissolve likes."

Petroleum products are non-polar with only hydrogen and carbon in their make-up. As petroleum products oxidize, they produce polar decomposition products that will not solubilize in the base stock. By contrast, PAGs have 28% oxygen, and as they oxidize, produce low-molecular-weight polar byproducts that will always remain soluble in the base stock.

ACT offers the following synthetic non-varnishing PAG formulations in the EcoSafe line for power generators:

- EcoSafe EHC, a Factory Mutual-approved, fire-retardant hydraulic fluid, was developed for use in servo-operated electrohydraulic control systems. This product, in use since 2004, is now protecting over 220 units, including nine 501F gas turbines.
- Full-synthetic EcoSafe TF-25 was developed for lube-oil systems. The first user of this fluid just surpassed 11 years of non-varnishing performance with no lubrication-related trips, failed starts, or servo-valve failures. With an anti-oxidant loss of around 2.5% annually, the fluid in the oldest system is tracking to provide an approximate 30-year fluid service life. Today, more than 110 turbine lube systems rely on PAG chemistry.

Oftentimes an end-user plagued by varnish/solids doesn't have a budget for an oil change, or an outage planned to conduct the work. Some of the newer turbine-oil formulations are yielding reduced service life, with varnish potential lurking after only a few years of service.

Powerplants are having to proactively investigate alternatives to remove the soluble and insoluble varnish. To provide a chemical solution to the chemical varnish problem, ACT developed and patented an oil-soluble PAG base-oil modifier—EcoSafe Revive—that when added to a varnished petroleum product (patent calls for 2% to 20% treatments), shifts the polarity of the co-mingled lubricant, and solubilizes varnish/solids keeping the system liquid. All varnish in the system is "dissolved" back into solution with no need to remove it by way of mechanical filtration. EcoSafe Revive has provided varnish solutions in over 170 units, including 18 501F turbines.

Now with over a decade of use and data under its belt in the power generation industry, EcoSafe is one of the oldest formulations on the market. PAGs have proven that no matter the situation, they are a true solution to varnish.

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recorded on a W501FD3 over a 14-hr period. As the vibration approached alarm limits, the engine was shut down for investigation. Polar plots indicated there was a change in rotor stiffness, which could have been caused by a cracked air separator, cracked torque tube, or turbine or compressor bolt failure. The highest vibration level was recorded at the exhaust bearing.

A diagnostic strategy was defined to identify the cause of the vibration-trend change with the goal of minimizing outage duration. A borescope inspection revealed no irregularities and a cover lift showed the air separator to be in good condition. But ultrasonic inspection of the torque tube identified a large crack; the indication traveled 60 deg around the torque tube. More accurate shop measurement recorded a crack 24 in. long and 90 deg around the torque tube.

The field work associated with this project was challenging and timing was critical given the forced-outage situation. Previous work on the unit included modification from FD2 to an FD3 with a single-piece exhaust to address cracking issues with the original exhaust system. Work-arounds for MHPS field-service personnel included limited overhead crane travel and the lack of special tooling to handle the SPEX.

Mitsubishi provided tooling for rotor support and bearing removal, as well as skids for removal of the exhaust spacer, manifold, and cylinder to enable a conventional rotor lift. Rotor extraction was facilitated by removal of all compressor blades which were inspected and blended as necessary. At the time of the meeting the rotor was in the Savannah shop for a CRI, torque-tube replacement and a root-cause analysis of the torque-tube crack.

What the speaker revealed based on rotor disassembly and early shop work was that there were actually two cracks—the 24-in. crack and another one of about 4.5 in. in length. The second crack formed after the first had propagated. A review of cracking of a torque tube of similar geometry on a W701F suggested the root cause might be corrosion-assisted low-cycle fatigue with propagation by high-cycle fatigue (rotor bending from gravity). Be sure to attend the upcoming meeting to learn more.

Based on this and previous work, the speaker suggested a cover lift as part of the pre-CRI and phased-array inspection of the torque tube to detect the presence of a crack before a forced outage occurs.

MHPS presented its solution for the torque-tube and air-separator failures facing some owner/operators, including the company's 501F3-style torque tube and bolted air separator for the W501F machine. The first such arrangement sold is installed, having met all quality requirements on its balance run.

Other upgrades recommended by the speaker included root springs to reduce disc wear from blade rock during long periods of turning-gear operation; plus coating of compressor rotor discs to protect against particulate matter in the flow path, as well as corrosion.

Ramy Massoud followed Cloyd with an overview of MHPS technology flow-down for gas-turbine durability enhancement and improved engine performance. Massoud shared that at the time of his presentation these upgrades had logged more than 6.8-million hours of operation and 60k starts on Mitsubishi machines.

Pictures of both hours- and starts-based fleet-leading W501F hot components in excellent condition were shown on the big screen at the front of the meeting room. None required more than light repairs—including the Row 1 vanes and blades. There was zero fallout. A user in attendance confirmed these results. MHPS validation methodology supported an interval extension for all turbine components to 32k hours/1200 starts.

Massoud then provided an update on MHPS's latest F-class turbine upgrade, which was derived from M501J technology with optimized cooling, advanced and thicker TBS, as well as an optimized wall thickness. An F-class case history confirmed both output and heat-rate expectations were exceeded and that the 32k-interval goal was achieved.

Pictures showed hot parts in very good condition, with no visible coating chipping or cracks. MHPS is confident that the reliability of these high-performance parts will be at least equivalent to the company's standard turbine components.

Massoud's portion of the program concluded with an overview of the OEM's TOMONI© solutions and a digital analytics road map. The company's strategy is to work with key software partners having deep experience in critical areas while leveraging MHPS's value-added experience working with big data and powerplant operations knowledge.

Matt Grysko wrapped up the session with an overview of the MHPS exhaust cylinder and manifold. Design features and operating experiences were shared. No abnormalities were evident in the photos taken at up to 83k EOH.

Grysko pointed to aspects of the MHPS design that addressed each of the W501F failure modes experienced in the fleet. These included improved/aligned materials, optimized mechanical loading, and more strategic cooling. The upgrades allowed for the relief of stresses and reduction of temperatures conducive to the cracking identified with the existing design. Photos of an installation in progress confirmed the availability of a drop-in solution that did not require changes to auxiliary piping or the foundation.

PSM

PSM's four-hour session incorporated presentations on the vendor's product line, combustion options, airfoils and upgrades, exhaust system, and the 501F rotor, as well as other topics. Global Product Manager Brian Micklos got the ball rolling with a review of 2017 accomplishments—including the following:

- PSM's first two exhaust-system installations. Details are provided in a separate article on p 46, "Repairs never-ending? Replace problematic exhaust systems."
- Replacement in-kind of targeted rotor components as of part of refurbishment—including some discs.
- Rotor component procurement.
- Achieved 33k equivalent baseload hours (EBH) without repair on transition pieces and baskets.
- Demonstrated turndown to less than 40% of rated engine capability, with inlet bleed heat.

Next, Micklos discussed the interchangeability of PSM parts—both standard and upgraded—with original equipment stating that all of the company's hardware is set-wise compatible for applicable frames. A few of the examples he presented included these:

- Compressor. Replacements for all FD components.
- Combustor. Full drop-in system or component replacement, gas only and dual fuel. FlameSheet™ for both W501F and M501F featuring sub-9-ppm NO_x operation.
- Turbine. All major components for the W501FC-FD2 and M501F3 models, plus the first three stages for the W501FD3 (fourth stage in process).
- Exhaust. W501FC-FD2 drop-in cylinder (includes new manifold front flange); FC-FD2 drop-in manifold (but only available with PSM exhaust cylinder).

While most users were generally familiar with the company's W501FC-FD2 and M501F3 hardware, and to some degree with its W501FD3 components, several were surprised to learn that it also offered some W501F4/F5 hardware

Case for third-party outage solutions strengthens

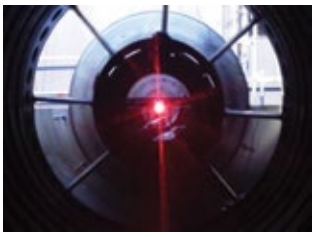
Sponsored by TOPS Field Services LLC

A visit by CCJ editors to the TOPS shop during an editorial swing through Houston revealed how capable third-party companies are evolving as turbine OEMs try to corner the market for total plant outage solutions.

Among the growing concerns of the end-user community, very loudly voiced at most industry user groups this year, is the ability of OEMs to perform acceptable outages on-time and near budget. According to this chatter, many OEM field engineers are retiring (or going elsewhere) and the replacement rate is not on pace, exacerbating the experience deficit.

After a couple of hours at TOPS, you can see why and how this OEM-alternative services provider is not just weathering the storm but gaining on the competition, according to its order book:

- People.
- Growth.
- Expertise.
- Strategic partnerships.



People. TOPS leadership includes two industry veterans in its president, Toby Wooster, and Engineering Director Jim Beckett. In past lives, Wooster ran the GE Wallisville 7FA rotor shop; Beckett is a former GE field engineer and plant manager at 7FA, 501F, 501G, and 501D5 sites. Wooster's sons, Luke, Josh, and Adam, head up operations, safety/logistics, and business affairs, respectively. This kind of generalship and family values have created a culture of hard work and people who care, as evidenced by its high retention rate, safety record, and job success. During the peak season, TOPS employs nearly 300 millwrights with over one-million hours of power-generation experience.

Growth. Now in its 10th year operating as a third-party field-services company, TOPS has performed over 900 maintenance-related activities on gas and steam turbines. More than half of these jobs have been performed on Siemens (including Westinghouse) engines with the vast majority on the 501F.

TOPS has worked extensively in one of the nation's largest fleets where it performed its first major outage on a W501D5 in 2009 with a successful turbine/generator rotor pull. From there, jobs came in for the 501F and 7F, along with steam turbines. Fast forward to today, at the time of printing, TOPS is at eight sites across the USA performing four majors (including generators), two HGPs, a generator field removal, a generator FTI, an iron-cross gas-leak repair, and a general-health borescope inspection.

For the 501F, TOPS has developed both inspection-specific and outage-specific toolkits to suit customer needs. Wooster touted the company's sustained growth in this market as TOPS added a major outage toolkit for six consecutive years. These resources are located strategically around the country (Nevada, Texas, and North Carolina) for rapid deployment coast-to-coast. Services for the 501F fleet now include:

- Borescope inspections.
- Basket changeouts.
- Blade blending.
- Four-way-joint leak repair.
- Engineering.
- Balancing.
- Exhaust-cylinder removal and replacement.
- Combustion inspections.
- Hot-gas-path outages.
- Major outages.

Expertise. With experience comes expertise and the TOPS culture stresses improving safety and efficiency for better customer outcomes. Several process-improvement initiatives and capital investments have brought about effective solutions for all units, including:

- New system to pull generator fields.
- A significant investment in the latest hydraulic tensioning equipment.
- Mobile machine shop.
- Innovative flange-spreading tooling.

Productivity and safety initiatives developed specifically for the 501F fleet are:

- Blade-ring stands.
- Dummy blade rings.
- Top-hat bolting tools.
- Roof stands.
- Fuel-nozzle stands.

Strategic partnerships. So, how does a relatively small company compete with behemoths like GE, Siemens, and MHPS? Simply put, TOPS is positioned for rapid deployment of its field-services expertise by working closely with capital parts and generator experts to offer turnkey outages. The goal: Provide maximum value for end users through improved quality of work and lower cost than the OEMs.

Maintaining reliability in 501F generators

Sponsored by National Electric Coil

Howard Moudy, director of operations for NEC, rarely misses a user-group meeting or an opportunity to speak about the practical aspects of electric generator operation, inspection, maintenance, and problem-solving. At the 2018 meeting of the 501F Users Group, he presented on the top issues affecting generator reliability in this fleet, including: stator spark erosion (SE), stator partial discharge (PD), stator endwinding looseness and resonance, and rotor pole-to-pole failures.

SE occurs when there is intermittent loss of contact between one or more stator bars and core iron. Because bar vibration is at fault, this deterioration mechanism sometimes is called vibration sparking. Moudy said SE is unique to manufacturers that do not use side ripple springs to maintain side pressure on the coil. He added that even if flat side filler is installed properly, insulation shrinkage over time creates additional gaps allowing SE to occur.

A borescope inspection is, perhaps, the best way to see first-hand if there's any damage and to trend damage over time. Inspection frequency, Moudy said, depends on how the machine is operated and its condition. Access to the back of the core for borescoping is through panels (photo 1); core vents are accessible from the back of the core (2). Level 3 SE deterioration—slag/rough surface appearance over the vent duct opening is shown in (3).

Possible corrective actions: flat filler replacement with ripple springs, epoxy injection, or stator rewind with the latest preventive measures.

Partial discharge exists on virtually stator windings and is a good telltale for several common deterioration modes—including SE. With good PD sensors and monitors useful data can be captured. However, interpreting the significance of those data can be challenging. The method selected for PD repairs, Moudy said, depends on the location and extent of damage. Repairs are likely an ongoing effort. A rewind with a coil of better design and a superior insulation system should be considered.

Endwinding looseness, which can be identified by dusting, greasing, and broken ties, is a common aliment in the 501F fleet. Damage inflicted by endwinding vibration can be severe. Replace or repair loose or compromised components promptly.

Moudy noted that resonant conditions have been found in many of the endwinding components of generators coupled to 501F engines. Windings should be tuned to maintain their natural frequency below 110 Hz or above 135 Hz by changing mass or stiffness with additional ties or spacers, extra blocking, etc. Use a bump test to verify results.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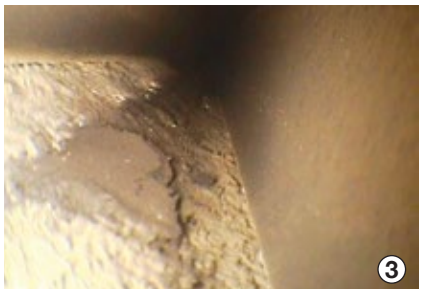
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as well—including transitions and fuel nozzles, Gen4 baskets, FlameSheet, and Stage 4 turbine blades.

Discussion of interval and life expectations for PSM hardware had attendees focused on the speaker. Here's what he said:

- Concerning the rotor and compressor, no maintenance is expected until the second major outage from installation.
- Concerning the combustor, maintenance intervals are 25k hours/900 starts, with a four-interval lifetime for all parts. Components incorporated into the company's GTOP6 (Gas Turbine Optimization Program) upgrade—roughly the equivalent of a Siemens FD3 upgrade for performance, but executed in a smaller scope—can have a maintenance interval of up to 32k/900.

  Regarding GTOP6, note that the 25k version of this upgrade allows a 15-MW simple-cycle increase in output and a heat-rate reduction of 3.5% compared to that for the standard W501FD2 combustion system. Opting for 32k hours reduces the output gain to 7 MW and the simple-cycle heat-rate benefit to 1.5%.

  GTOP7, planned for release in 2019, is expected to boost the performance improvement for the 25k interval to 20 MW of simple-cycle output and plus a 3.8% reduction in heat rate. For the 32k interval, the benefits are 8 MW more output and 2.1% lower heat rate.
- Concerning the turbine, first-stage parts are designed for two intervals of 25k/900, second stage for three intervals of 25k/900, third and fourth stages for two intervals of 50k/1800. GTOP6 extends those intervals to 32k/900 and 64k/1800.

Hardware experience was a perfect sequel to the interval discussion. Component durability is confirmed by fallout rates of 0% for all critical hot-gas-path (HGP) parts—except for PSM's Gen 2 and Gen 3 baskets and Gen 3R1 blades, which suffer about 10% fallout. Fleet leaders for transition pieces and pilot nozzles are now in their third intervals of 25k EBH.

Combustor products and experience was the next topic. PSM has three basic offerings here: (1) Standard drop-in 501F combustor; (2) Drop-in combustor plus inlet bleed heat (IBH) plus AutoTune for automatically keeping emissions and combustion dynamics within specified limits under varying ambient conditions; and (3) FlameSheet.

The first two maintain NO_x and CO emissions to less than 25 ppm between the lower operating limit and 100% of the full-load rating when burning liquids-free gas; FlameSheet restricts emissions of both pollutants to less than 9 ppm on liquids-free gas. All three can meet 42 ppm NO_x (wet) on liquid fuel. Turndown capability of the standard combustor extends to 55% to 65% of rated load, with enhancements (Option 2) to 45% to 55%, with a FlameSheet drop-in to 30% to 40% using the standard firing curve.

A big benefit of FlameSheet, in addition to extended turndown capability, is greater fuel flexibility compared to traditional OEM offerings. This is particularly beneficial both to plants burning shale gas and LNG, which may have a wide range of varying constituents, and to those with access to off-gases from industrial processes.

For the first two combustor offerings

The pressure-drop dilemma with self-cleaning filter houses

Sponsored by Pneumafil/Nederman

It doesn't have to be a balance between efficiency and operating flow resistance.

Starving incoming air flow to a gas turbine forces it to consume more fuel and potentially de-rate, or force a shutdown of the turbine. Ingestion of submicron contaminants fouls turbine blades causing compressor degradation. Many owner/operators used to think they had to choose between acceptable operating pressure drop, and high particle capture efficiency. Not anymore.

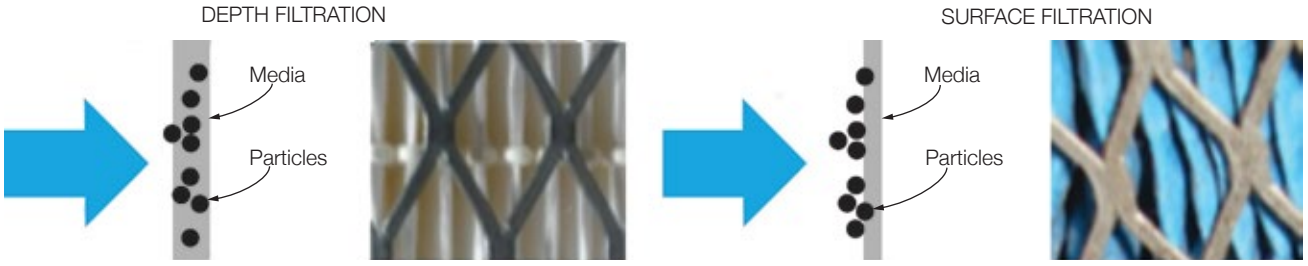
Self-cleaning filter houses, when applied in atmospheric conditions with low ambient dust concentrations and small particulate sizes, struggled when operating "online" to remove fine particulates.

Depth-loaded static filter technology was originally developed for the HVAC marketplace, where media technology focused on dealing with the lower dust concentrations and very small dust sizes. Depth filtration typically uses a thicker layer of media, or multiple layers (also known as composites), to separate the fine particles by creating a torturous flow path. Larger particles would be captured on the surface or on pre-filter stages with progressively finer particles separated through the thickness of layers.

The higher-porosity media structure of depth-loading media combined with improved fiber and mechanical element design has an inherently lower resistance when compared to surface-loaded wet-laid pulse media. The highly engineered fibers used in composite-media structures now offer users the ability to eliminate compressed-air pulse systems. Similarly, operators save money on maintenance of the cooler skids for compressor take offs or on plant air to supply the self-cleaning systems.

If your operating conditions include low ambient dust concentrations and you haven't seen significant reductions in DP by using pulse cleaning, you may gain a few benefits by discontinuing the use of the self-cleaning pulse system. Consider the potential advantages of how depth-loaded synthetic media can be applied to the cartridge design you use.

Although wet-laid micro-glass fibers are a proven filtration medium, synthetic fibers are more robust and durable. The combination of continuous strands and staple lengths provide loftier and more porous structure. They have better performance during humidity and moisture and recover more quickly to upset conditions. Significant reduction in fine particle ingestion to the turbine with no pressure drop penalty may provide the next step in your continuous-improvement efforts.



above, PSM specifies a minimum of 85% methane, no hydrogen, and a maximum of C2+ constituents; plus, it restricts the variation in Modified Wobbe Index to 5%. Compare this to the specs for FlameSheet: a minimum of 40% methane and up to 40% hydrogen, 40% C2, 20% C3, 10% C4 to C6, and 30% inerts.

Results from the first two installs of FlameSheet in 2015 (Eastman Chemical Co, Longview, Tex) were reviewed to confirm stated performance. The data: Turndown confirmed to 40% of rated load with NO_x emissions below 5 ppm at 40% and less than 7 ppm at 100%. CO was less than 9 ppm at 40% load and about 1 ppm at 100%. Part-load efficiency was measured at less than 127% of the full-load number; goal was 130%. Startup visual emissions were eliminated, reducing exceedance reporting by 200 reports annually.

Important: FlameSheet enables Eastman to keep its units operating year-round because of their increased turndown. Also, it gives the company the potential to burn waste fuel streams rich in hydrogen.

Drop-in combustion-system experience, a/k/a market penetration, was summarized in one slide. About 70 sets of pilot nozzles had been sold as of January 2018, the speaker said, with fleet leaders above 60k fired hours and 1250 fired starts. Total fleet experience was closing in on 2-million EBH.

For transition pieces, the numbers were about 95 sets sold, fleet leaders at more than 60k fired hours and 1250 fired starts, and fleet experience at 2.2 million EBH. Extended-turndown combustion baskets have been installed in more than 30 engines, with fleet leaders at 33k fired hours and more than 550 fired starts. The numbers for support housings: About 20 sets sold with fleet leaders at 31k fired hours and more than 450 fired starts.

Session focus migrates to the rotor. PSM reported that, at the time of the 2018 meeting, it had completed two rotor lifetime evaluations and another was in progress. The company also had completed rotor lifetime evaluations for two Frame 6B engines and one 7F.

Experts explained how rotor lifetime evaluations were conducted. They began by listing the inspections required: MPI/FPI, eddy current, and ultrasonic; plus, a metallurgical evaluation. Using these techniques in a set of overlapping inspections the following key failure modes can be identified and all defects found:

- Surface defects.
- Forging/volume defects.
- Compressor-bolt inspections.
- Torque-tube nut groove.
- Air separator goose neck.
- Turbine-disc scallops and small radaii.

PSM's portable lab permits onsite hardness and microstructure review in a single shift using two technicians. Grinding and polishing prepare the metal for imaging using a Keyence microscope. Hardness testing is done in locations near where microstructural reviews are conducted; multiple tests are conducted at a given location and the results are averaged.

Eddy-current inspections are conducted in bolt holes, bores, and critical locations. No defects are allowed. All components—disk bores, webs, slots, attachments, posts—are fully inspected using a combination of conventional and phased-array ultrasonic methods.

The speaker stressed that a 501F rotor assembly contains more than 200 parts and all must be flawless.

Siemens

The Siemens session began with a presentation highlighting some of the successful

Proactive approach to mitigate torque-tube and air-separator risks

Sponsored by Doosan

The issue of greatest concern among owner/operators at the 2018 501F Users Group conference was the rotor. Specifically, the more than a half-dozen forced outages across the fleet caused by vibration events traced to through-cracks in their torque tubes, which were concealed by the air separator. Recall that the torque tube joins the compressor and turbine sections of the 501F rotor.

There is no identifiable operational footprint as to the cause of these cracks yet: some units in baseload service, others cycling, another with high turning-gear hours. The wide dispersion of hours and starts for the affected units is a major factor as to why it caused such a stir.

What is known is that the propagation of such cracks is slow followed by rapidly progressing high-cycle fatigue and failure. Early crack detection would allow for outage planning and parts acquisition before a vibration event. Inspection, however, requires de-stack (Fig 1) to access the affected zone, which is usually under the air sleeve. As of yet, there is no tried-and-true way to thoroughly inspect for cracks in-situ.

With options limited for predictive and preventive maintenance and the risk of revenue loss from a forced outage, one baseload W501FC plant decided to take a proactive approach and replace both the torque tube and air separator during a major maintenance interval. The fear of a 12-month or more lead time in an emergent situation facilitated this decision.

With a tight schedule and a long list of action items in hand, the plant realized it needed a vendor with the expertise and resources to pull it off. Doosan Turbomachinery Services (DTS), La Porte, Tex, was selected to undertake this challenging assignment.

The scope of work included:

- In-kind replacement of torque tube and air separator.
- Class 3 rotor lifetime extension inspection.
- Refurbishment and replacement of components.

Component manufacturing. Immediately after de-stack at the DTS shop, reverse engineering began because component manufacturing was time-critical for delivery. White-light 3D scanning and metallurgical analysis of the existing torque tube and air separator started the process.

Doosan Heavy Industries, the parent company of DTS, had a turbine forging in Korea that matched the material composition; the forging properties were confirmed and rough machining commenced shortly after receipt of the rotor. A team of DHI engineers was sent to Houston to assist in the completion of the reverse engineering and characterization.

1. Rotor is prepared for a de-stack at Doosan's LaPorte (Tex) shop

2. New air separator and torque tube are coupled to the compressor section

3. Project complete, rotor awaits shipment to the plant

In the final stages of the project, DTS sent the 16th-stage compressor disk and the curvic adapter to DHI in Korea. The disk was properly matched to the torque-tube pins, the curvic adapter was mated, and the components were returned to La Porte for reassembly (Fig 2). Despite the added logistics, the project remained on schedule with enhanced repair integrity.

Lifetime extension. The 501FC rotor had 115k hours of run time when it entered the shop. A few years before this outage, the site had decided to forego the recommended Class 2B rotor inspection at 96k hours. Thus, this was the first major for the unit.

The Class 3 rotor lifetime extension was performed in conjunction with a well-known major industry partner, and inspection scope consisted of eddy-current and ultrasonic testing in critical areas and components. Luckily there were no significant findings and it was determined based on the inspection results that there were no known limiting factors that would be cause for concern with an additional two major run intervals.

Also, during the rotor's 69 days in the shop, DTS reverse engineered and manufactured three full rows of compressor blades for replacement, along with combustion hardware and diaphragms (Fig 3).

The components at the core of the project, namely the original torque tube and air separator, were found to have no damage. These parts were refurbished and returned to the customer as emergency spares for its fleet. Total outage duration was 100 days.

programs the company has in place to promote awareness of, and bring attention to, safety. Siemens' safety record validated the success of its efforts.

A comprehensive presentation on technical solutions and improvements followed. Siemens speakers discussed technical issues experienced by the F fleet over the last several years and then provided details on the improvements implemented to address them.

Next came presentations on repair technology development and technology innovations. They covered some of the many tools Siemens is investing in and developing to pave the way for the future in repair-process improvement, cost-reduction initiatives, additive manufacturing, materials development, coatings, inspections, measurement accuracy, etc.

An update on current developments in Siemens' robust digital portfolio of energy services—including cybersecurity offerings—followed. The solutions presented (access the list on the Customer Extranet Portal) can be tailored to each customer's unique needs and operating conditions.

Siemens concluded the session with a comprehensive overview of its product portfolio for F technology. In some combination, the available products are designed to offer safety, power, efficiency, operating and starting reliability, availability, emissions improvement, flexibility, maintenance ease, and interval extension—depending on the particular needs of an owner/operator, plant, or site. Statistics on implementation and experience with the upgrades were included and speakers encouraged users to contact their platform teams for further discussion. **CCJ**

IAPWS working group reports progress on four new documents

The Power Cycle Chemistry (PCC) working group of the International Association for the Properties of Water and Steam gathered at the parent organization's annual meeting in Prague, Czech Republic, Sept 2-7, 2018, to advance the development of several new Technical Guidance Documents (TGDs).

The annual IAPWS (pronounced eye-apps) conference was conducted concurrently with the International Conference on the Properties of Water and Steam (ICPWS), which is held every four or five years. The 2018 edition of the ICPWS was the seventeenth; the first was held in London in 1929.

The joint meeting attracted more than 100 papers from 140 scientists and engineers representing 27 countries. Purpose of the conference is to connect scientists with the engineers who use their information. Both groups of professionals benefit: The researchers/scientists learn about problems seeking resolution while the engineers gain access to the latest research results. The information exchange included experience with film-forming substances (FFS), which are of increasing interest to combined-cycle owner/operators.

IAPWS Executive Secretary Dr R Barry Dooley of Structural Integrity Associates Inc, well known to the global power-generation community, contacted CCJ's editorial offices to say that four TGDs are in final draft form with planned release dates in 2019:

- Guidance on air in-leakage.
- Guidance on the use of FFS in industrial plants.
- Guidance on generator-cooling-system chemistry.
- Guidance for ensuring the integrity and reliability of demineralized makeup water supply.

Additionally, the PCC working group is preparing several white papers likely to be developed into TGDs at a later time. These include "Corrosion Products in Flexible (cycling, two-shifting) Plants" and "Guidance for HRSG Condensate Polishing Plants."

Dooley reminded that there are eight TGDs currently available free-of-charge on the organization's website at www.iapws.org. They offer a wealth of practical information on topics such as steam purity for turbine operation, phosphate and sodium hydroxide treatments for steam/water circuits of drum-type boilers, instrumentation for monitoring cycle chemistry, how to measure carryover of boiler water into steam, etc.

The next IAPWS meeting will be held in Banff, Canada, Sept 29-October 4, 2019.

Ring eight bells for Frank Berté, 77

News of Dr Frank Berté's passing on July 4, 2018 reached us only recently. He was the co-founder of Tetra Engineering Group Inc, perhaps known best by readers of CCJ for its solutions to problems associated with heat-recovery steam generators and high-energy piping systems.

Berté was a frequent participant at user group vendor fairs and an occasional presenter. He was easily distinguishable among the many exhibitors because of his calm, quiet nature in a sea of salespeople. Plus, he never arranged his table display without his funky air-powered simulated flame. You could spot him "a mile away."

Peter S Jackson, PE, who succeeded Berté as president of Tetra, remembers Frank as an excellent engineer, inspiring leader, and genuinely friendly man. Everyone who knew Frank or worked with him, Jackson said, enjoyed his enthusiasm for work and love of life.

Berté's career in the electric power industry spanned nearly five decades; it began in the mechanical engineering group at Commonwealth Edison Co's Dresden Generating Station. Next step was a management position in the reactor design department at Combustion Engineering Inc. Berté founded Tetra with two other engineers in 1989.

Later he started Innovative Marine Technology to pursue, in his *spare* time, the design of sailboats and other things related to the sea. Accomplishments included the first ever Tridactyl sailboat, which he patented. Also, TankerProa, a modular sailing vessel using Tridactyl technology to help power transoceanic tankers.

Berté was a restless doer who kept his hands and mind moving non-stop—always receptive to professional challenges and to sharing his knowledge with industry colleagues. One example of the latter was an article he penned for the first issue of CCJ, "Assessing the true cost of cycling operation is a challenging assignment." Things haven't changed much on this topic in the 15 years since its publication.

Born in Brooklyn, Frank moved to the Bronx with his family before continuing his migration north to West Hartford, Conn, and later to Westford, Mass. He earned a Master's Degree in Mechanical Engineering from The City College of New York and a PhD in Nuclear Engineering from the Massachusetts Institute of Technology.

Registration opens for three 2019 user meetings

By mid-November, registration had opened for three high-profile 2019 conferences dedicated to the information needs of owner/operators: 501F Users Group, Western Turbine Users Inc, and *HRSG Forum with Bob Anderson.* If you haven't registered already, sign up now and make good use of your 2018 budget surplus.

501F Users Group

Dates: February 17 – 22
Location: Paradise Valley (Scottsdale), Ariz
Venue: DoubleTree Resort by Hilton

The compelling program for this meeting is posted online at http://501f.users-groups.com. It has many of the same elements as the information-rich 2018 conference, which ran four days and included the following:

- User presentations on issues identified in the fleet and solutions implemented, as well as on experience with upgrades to improve unit performance.
- User-only sessions promoting open discussions and short presentations by owner/operators on safety; compressor, combustion, hot-gas, inlet, and exhaust sections; rotors; auxiliaries; and generator.
- Special closed sessions, ranging from two to four hours each, by the major products/services providers serving this frame: Siemens, Mitsubishi, Ansaldo Energia's PSM, and GE.
- Vendorama progam. At the meeting last February, 33 companies made 35 half-hour technical presentations to bring attendees up to date on products/services of interest to the 501F community.
- Vendor fair, following the Vendorama program on the first day of the meeting, gives users the opportunity to peruse the offerings of nearly a hundred manufacturers

and services firms.

If you have never attended a 501F Users Group meeting, make the 2019 conference your first. You will learn things vital to your plant's future success that's not available in one place anywhere else.

Western Turbine Users Inc

Dates: March 17 – 20

Location: Las Vegas, Nev

Venue: South Point Hotel & Spa

GE aero (LM2500, LM5000, LM6000, and LMS100) owner/operators from around the world will share experiences, both good and bad, at the 29th annual meeting of the Western Turbine Users. Get all the details at the group's well organized, easy-to-navigate website at www.wtui.com—social events, agenda, special tours, exhibit hall, breakout sessions, etc. Then register and book your hotel room at the same website for the electric-power industry's largest independent user group meeting.

HRSG Forum with Bob Anderson

Dates: July 22 – July 25

Location: Orlando, Fla

Venue: Hilton Orlando

With two solid events under its belt, the *HRSG Forum with Bob Anderson* introduces an expanded program for the organization's third annual conference and exhibition (diagram), making it the undisputed king of content in the world of heat-recovery steam generators. HRSG Week 2019 begins with a Make-up Water Workshop (July 22) the day before the traditional two-day HRSG Forum and concludes with the morning session of EPRI Technology Transfer Day (July 25).

You can register for the entire program now at www.hrsgforum.com for only $650; or $475 for the two-day forum plus the EPRI session on Thursday morning. The user-driven program features technical presentations by HRSG experts, with significant time for group discussions and networking with peers. Plus, registrants will receive complete meeting minutes, copies of presentation slides, and up to 24 hours of continuing education units (forum + workshop + technology day).

Visit the website for program details as they become available.

HRSG O&M Tip No. 1:

Operate drain valves on different HP superheater harps simultaneously, not in sequence, prior to and during hot, pressurized startups.

Most operators know it's important to drain the HPSH during startup before steam flow is initiated to prevent accumulated water at the bottom of the harps from migrating up some tubes—quenching them and upper headers/piping. But opening drain valves individually causes a pressure drop in the harp being drained that will pull water over the top from other harps, causing the water migration you were trying to avoid.

IPG´s Dodero contributes to decarbonization solutions

Ing Giorgio Dodero, president, IPG Industrial Project Group Srl, Milan, Italy, and CCJ's electric-power consultant on European matters, recently reviewed the proceedings of a two-day, closed-door meeting in the Vatican organized by American Catholic Uni-

versity to bring together the heads of major energy corporations and Pope Francis and those in the Holy See dealing with the environment.

The intent of the meeting, "Energy Transition and Care of Our Common Home," was to encourage business leaders and governments to invest in renewable energies and decarbonization technologies as a source of employment and well-being.

In late August, the Italian Catholic-inspired newspaper *Avveniere* interviewed Dodero for his thoughts on the meeting's content and impact. The consultant, a former senior manager of ENEL, reflected on several aspects of the subject matter discussed, chief among them decarbonization, a focus of IPG's consulting work. Here is a snippet from the interview on that topic:

"Decarbonization is a complex subject that deserves in-depth research. In addition to defining new strategies for integrating renewable sources into the production mix, we are developing alternative processes, taking into account that industrial ones were designed decades ago, when the environmental issue was less urgent.

"In particular, the need for new steel, nickel, aluminum, and cement production systems is required. Advanced studies are in progress for green energy and for the energy-storage sector—fundamental for the future management of the grid.

"The future is bright. The British government has allocated 246-million pounds for studies on decarbonization involving research centers, universities, construction contractors, and technical experts. The European Commission is budgeting 10-million euros for research in the same field."

Industry briefs

Emerson has agreed to acquire Intelligent Platforms, a division of GE focused on leveraging automation technologies to drive digital transformation in their end markets. The acquisition expands Emerson's opportunities in machine control and in discrete applications across targeted markets.

GE Power completed its acquisition of Doosan Engineering & Construction's heat-recovery steam generator business in mid-August (2018). Doosan has a long history as a licensee of Alstom which GE purchased in November 2015.

Egyptian Electricity Holding Co selects Siemens to provide comprehensive O&M services for the Beni Suef, New Capital, and Burullus powerplants for the next eight years. Each of the three 4.5-GW facilities is considered the largest gas-fired combined-cycle plant ever built. The agreement covers all onsite equipment—including 24 H-class gas turbines, 12 steam turbines, 36 electric generators, 24 heat-recovery steam generators, and three 500-kV gas-insulated switchgear systems.

Mitsubishi Hitachi Power Systems announced that the Grand River Dam Authority's combined cycle in Oklahoma had surpassed 8000 hours of commercial operation in mid-September 2018, making its J-series gas turbine the 25th such engine to do so. GRDA is the fleet leader in the US; the global fleet leader has operated for more than 40,000 hours. There are 33 turbines operating in the J fleet.

Siemens Corp and Chromalloy Gas Turbine Corp celebrated the grand opening of their new joint venture, Advanced Airfoil Components, Tampa, the last week of October 2018. The Advanced Components casting facility is 210,000 ft² and will enable production of the entire range of blades and vanes for the Siemens gas-turbine fleet—including those for the latest frame, the 9000HL. Equipment buildout will continue for the next four years.

Anniversary news. Where were you 40 years ago, when on Nov 9, 1978, the Public Utility Regulatory Policies Act passed as part of the National Energy Act? Its purpose: Promote both energy conservation (reduce demand) and greater use of domestic energy and renewable energy (increase supply). November 9 also was the 53rd anniversary of the Great Northeast Blackout.

KnechtionRepair (www.knechtionrepair.com) continues to expand its product line. Tap and die kits for repairing both the internal and external threads of industrial standard two-ferrule-type compression tube fittings, popular among CCJ subscribers, now come in six sizes: ¼, ⅜, ½, ⅝, ¾, and 1 in. Plus, AN/MS (aviation) and JIC (hydraulic) tap and die kits are available in #4, #6, #8, and #12 sizes with #5 and #12 ready by year-end.

Multiple tests to verify the effectiveness of KnechtionRepair have been conducted on samples of stainless-steel tubing with a wall thickness of 35 mils. No leakage was observed at the tube fittings, indicating a leak-proof connection—even with up to three threads removed from the fitting nuts. All test samples failed by rupture of the tubing wall at pressures in the neighborhood of 15,000 psig—far above the allowable design pressure.

PROFESSIONAL SERVICES

International Association for the Properties of Water and Steam

IAWPS is a global non-profit association involving 25 countries in all aspects of the formulations of water and steam and seawater, as well as in power-plant cycle chemistry. It provides internationally accepted cycle-chemistry guidance for power generation facilities in Technical Guidance Documents freely downloadable from the organization's website at www.IAPWS.org. Specific TGDs for combined-cycle/HRSG plants include the following:

- Procedures for the measurement of carryover of boiler water into steam.
- Instrumentation for monitoring and control of cycle chemistry.
- Volatile treatments for the steam-water circuits of power plants.
- Phosphate and NaOH treatments for the steam-water circuits of drum boilers.
- Steam purity for turbine operation.
- Corrosion-product sampling and analysis.
- HRSG high-pressure evaporator sampling for internal deposit identification and determining the need to chemical clean.
- Application of film-forming amines in power plants.

COMBINED CYCLE Journal 3Q/2018

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Has delivered unbiased fleet experience and superior customer service for more than a decade. Company provides users high-resolution borescope inspections, cutting edge ultrasonic and eddy-current inspections, and magnetic-particle and liquid dye-penetrant inspections in accordance with OEM Technical Information Letters and Service Bulletins.

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AGTSI offers a full range of aeroderivative gas-turbine, off-engine, and package parts from the most basic to the most critical. An expansive inventory of spares and replacement parts is maintained at our warehouse for all models of GE LM2500, LM5000, LM6000, and LMS100, as well as P&W GG4/FT4.

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Provider of repairs and custom technology upgrades for turbomachinery. Designs and manufactures an integrated solution to meet specific

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requirements for every operating environment, applying the latest fluid film bearing and high-performing seal technology to legacy equipment to optimize performance.

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Full-service industrial maintenance contractor since 1976. Company experience in combined-cycle projects includes header, tube, and complete panel/harp replacements. We also have significant experience in liner repairs/upgrades, duct-burner repairs, penetration seals, and stack-damper installations.

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The world's leading developer, manufacturer, and supplier of catalysts for selective catalytic reduction (SCR) systems to control emissions of nitrogen oxides from stationary sources. Cormetech SCR catalysts are highly efficient and cost-effective where systems must be capable of reducing NO_x by more than 90%.

COVERFLEX Manufacturing

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CPS is a group of engineering companies in the power generation and energy utilization sector. Its mission is to provide advanced, efficient, and customized technology solutions to clients ranging from OEMs to plant operators and energy consumers.

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Our experience and innovative designs have brought best-in-class brush holders, collector rings, shaft grounding, and onsite field services for generators and exciters to some of the world's largest power companies.

DEKOMTE de Temple

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Ovation™ control system offers fully coordinated boiler and turbine control, integrated generator exciter control, automated startup and shutdown sequencing, fault tolerance for failsafe operation, extensive cyber security features, and embedded advanced control applications that can dramatically improve plant reliability and efficiency.

EthosEnergy

This JV between Wood Group and Siemens is a leading independent service provider of rotating equipment services and solutions. Globally, these services include EPC; facility O&M; design, manufacture, and application of engineered components, upgrades, and re-rates; repair, overhaul, and optimization of gas and steam turbines, generators, pumps, compressors, and other high-speed rotating equipment.

Evapco-BLCT Dry Cooling Inc

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EvapTech Inc

Full service provider of new towers and aftermarket services for field erected cooling towers. World leader in evaporative and hybrid cooling technologies specializing in design, component manufacturing, construction services, parts, upgrades, and consultation.

Falcon Crest Aviation

Distributor of ZOK27 and ZOKmx gas-turbine compressor cleaning detergents. ZOK27 is a single cleaner and inhibitor in one that cleans and protects the engine—and also inhibits corrosion. ZOKmx is a power cleaner formulated to replace solvents providing exceptional cleaning without the health and environmental risks associated with solvents.

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Distributor of seamless HRSG high-energy pipe and power piping. Scheduled and heavier than scheduled walls in stock for headers, steam lines, etc. SA106 B/C and SA335 P11/P22/P91. Fittings to complement all pipe. Offering cut-to-length, custom fittings, specialty end preparation, supplemental testing, and emergency same-day shipments.

Frenzelit North America

Specializes in providing long-term expansion-joint solutions for gas-turbine exhaust applications. In addition to manufacturing superior quality expansion joints, Frenzelit also makes HRSG penetration seals, insulating materials, and acoustic pillows for silencers.

Gas Turbine Controls

World's largest stock of GE Speedtronic circuit boards and components for the OEM's gas and steam turbines. GTC stocks thousands of genuine GE-manufactured cards for the MKI, MKII, MKIII, MKIV, MKV, MKVI, and LCI controls, as well as EX2000, Alterrex and Generrex excitation.

Groome Industrial Service Group

Offers a variety of SCR and CO catalyst cleaning and maintenance services nationwide and has formed strategic alliances with industry experts and catalyst manufacturers to ensure that Groome offers the most widely supported, comprehensive, turnkey service available.

GTC Services

Field engineering company offers gas-turbine owners and operators worldwide "Total Speedtronic Support." Engineers have decades of experience servicing and troubleshooting all GE Speedtronic systems.

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The HILCO® Division cost-effectively brings fluid-contamination problems under control and engineers a full-range of filters, cartridges, vessels, vent mist eliminators, transfer valves, reclaimers, coolant recyclers and systems, and membrane filtration systems.

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Specializes in technical services and product designs for HRSGs, waste heat boilers, and smaller gas or oil fired power boilers globally. Experience on over 200 boilers annually and able to provide quality inspections, analysis work, design upgrades, professional training, and more.

Hydro

Engineered solutions enable combined-cycle plants to achieve pump reliability and reduced O&M costs. As the largest independent pump rebuilder, Hydro works hand-in-hand with pump users to optimize the performance and reliability of their pumping systems.

Hy-Pro Filtration

Provides innovative products, support, and solutions to solve hydraulic, lubrication, and diesel contamination problems. Company's global distribution and technical-support networks enable customers to get the most out of their diesel, hydraulic, and lube-oil assets. ISO 9001 certified.

JASC

Engineers and manufactures actuators and fluid-control components for power generation, aerospace, defense, and research applications to improve operational capability and performance.

KnechtionRepair Tools

Manufactures tools designed to make thread repairs to both the female and male ends of cross-threaded compression fittings. In most cases, the repair will be accomplished without removing the tube from the system. This saves the O&M tech time and avoids additional downtime.

Kobelco Compressors America

Provides robust, high-efficiency fuel-gas compressors for use with all major types of gas turbines—including GE, Mitsubishi, Alstom, Siemens, Rolls-Royce, and Solar. Over 300 of the company's screw-type compressors have been supplied for gas turbines.

Liburdi Turbine Services

Advanced repairs employ the latest technologies and are proven to extend the life of components for all engine types. Company specializes in high-reliability component repairs and upgrades for blades, vanes, nozzles, shrouds, combustors, and transitions.

M & M Engineering

Provides failure analyses and related services to industrial and insurance-company clients. M&M's expertise includes corrosion in boilers, steam turbines, generators, combustion turbines, deaerators, feedwater heaters, and water and steam piping.

Mechanical Dynamics & Analysis

One of the largest turbine/generator engineering and outage-services companies in the US. MD&A provides complete project management, overhaul, and reconditioning of heavy rotating equipment worldwide.

Membrana, a 3M company

Market-leading producer of microporous membranes and membrane devices used in healthcare and industrial degassing applications. The Industrial & Specialty Filtration Group manufactures Liqui-Flux® ultrafiltration and microfiltration modules as well as Liqui-Cel® membrane contactors.

Mitten Manufacturing

Leading fluid system packager for numerous OEMs, EPC firms, utilities, and plant operators all over the world offering a number of value-added designs, spare parts management, and field services.

Multifab Inc (MFI)

Over 40 years of experience in design and manufacturing of products used for high-temp equipment along with air and flue gas applications. Offers a wide variety of services for all types of expansion joints, dampers, and high-temp products including installation, removal, repair, and splicing.

NAES

One of the world's largest independent providers of operations, construction, and maintenance services, provided through a tightly integrated family of subsidiaries and operating divisions. NAES services include O&M; construction, retrofit, and maintenance under dedicated long-term maintenance or individual project contracts; and customized services designed to improve plant and personnel effectiveness.

National Breaker Services

Industry leader in switchgear life optimization, life extension, and system upgrades. Manufactures new, highly customized low- and medium-voltage switchgear and provides on-site troubleshooting, maintenance, and testing of existing systems.

National Electric Coil

Leading independent manufacturer of high-voltage generator stator windings with expertise in design and manufacturing of stator windings for any size, make, or type of generator. This includes diamond coils, Roebel bars—including direct cooled, inner-gas, and inner-liquid cooled bars—and wave windings.

Parker Balston

Develops and manufactures nitrogen generators for all your power generation needs including boiler layup, gas seals, purging gas lines prior to service, blanketing demin water tanks, and LNG terminals.

Parker Hannifin

Reduce costs and optimize performance with the world's leading diversified OEM of motion, flow, process control, filtration, and sealing technologies, providing precision engineered solutions for the power generation market.

Parker Hannifin Gas Turbine Filtration

With over 50 years of experience delivering innovative solutions for GT inlet filtration and monitoring fleet-wide performance data, our industry and applications experts will select the appropriate filter for your site designed to meet specific operating goals.

Power Service Consultants

Boutique consulting group focusing on LTSA contract negotiation support for owner/operators of gas turbines, steam turbines, and generators. With over 30 years of experience in power systems service, our focus is to drive down avoidable maintenance costs.

Praxair Surface Technologies

Leading global supplier of surface-enhancing processes and materials, as well as an innovator in thermal spray, composite electroplating, diffusion, and high-performance slurry coatings processes. Company produces and applies metallic and ceramic coatings that protect critical metal components such as in gas turbines.

Precision Iceblast

World leader in HRSG tube cleaning. PIC cleans more HRSGs than any other ice blasting company in the world. It ensures that HRSGs operate efficiently by providing the cleanest boiler tubes possible.

PSM

Full-service provider to gas-turbine equipped generating plants, offering technologically advanced aftermarket turbine components and performance upgrades, parts reconditioning, field services, and flexible Long Term Agreements (LTAs) to the worldwide power generation industry.

PW Power Systems

Provides competitive, efficient, and flexible gas-turbine packages rated from 25 to 120 MW. PWPS offers a full range of maintenance, overhaul, repair and spare parts for other manufacturers' GTs with specific concentration on the high-temperature F-class industrial machines.

Rentech Boiler Systems

International provider of high-quality, engineered industrial boiler systems. Rentech is a market leader in providing HRSGs for cogeneration and CHP plants. It is in its second decade of designing and manufacturing high-quality custom boilers—including HRSGs, waste-heat boilers, fired packaged boilers, specialty boilers, and emissions control systems.

Sargent & Lundy

Provides complete engineering and design, project services, and energy business consulting for power projects and system-wide planning. The firm has been dedicated exclusively to serving electric power and energy-intensive clients for more than 120 years.

Siemens Energy

A leading global supplier for the generation, transmission, and distribution of power and for the extraction, conversion, and transport of oil and gas. Leadership in the increasingly complex energy business makes it a first-choice supplier for global customers. Known for innovation, excellence and responsibility, company has the answers to the sustainability, flexibility, reliability, and cost challenges facing customers today.

SNC Lavalin

Global engineering, construction, and project management company, and a major player in the ownership of infrastructure. Our passion for solving complex problems has allowed us to excel across many industrial sectors. We are a market leader in thermal power, having designed and constructed more than 50 GW of power capacity in over 200 locations.

SSS Clutch Company

Clutches enable operators to disconnect generators from simple-cycle turbines for synchronous-condenser service. Clutches also find application in CHP plants and in single-shaft combined-cycle facilities where operating flexibility is beneficial.

Strategic Power Systems

Provides products and services focused on capturing power-plant operational and maintenance data to develop reliability metrics and benchmarks for end users—including some of the most recognized organizations in the global energy market.

Sulzer

Provides cutting-edge maintenance and service solutions for rotating equipment dedicated to improving customers' processes and business performances. When pumps, turbines, compressors, generators, and motors are essential to operations, Sulzer offers technically advanced and innovative solutions.

TEC-The Energy Corp

Our skills and experience assist GT owners with front-end engineering, procurement of major equipment, and management of engineering, construction, and commissioning of new facilities. From due diligence to detailed design, TEC covers all phases of complex power projects.

TEi Services

Offers a full range of heat-transfer products and services and fully trained, certified maintenance personnel. Provides world-class emergency repair services, underpinned by a 75-yr history in the design and manufacture of condensers, feedwater heaters, and heat exchangers.

TesTex Inc

World leader in electromagnetic non-destructive testing (NDT). We continually define the state-of-the-art for the testing of ferrous and non-ferrous materials and structures through applied research and development.

Trinity Turbine Technology LP

Provides innovative, cost-effective and reliable gas and steam turbine maintenance solutions to industrial operators worldwide. We provide high quality and reliable turn-key outage support and component repairs with unmatched responsiveness and dependability.

ValvTechnologies

Global leader in the design and manufacturing of zero-leakage metal-seated ball valve solutions for severe service applications. Committed, dependable partner providing the best isolation solutions to ensure customer satisfaction, safety and reliability, and improved process and performance.

Vogt Power International

Supplies custom-designed HRSGs for GTs from 25 to 375 MW and has extensive experience in supplementary-fired units. Scope of supply includes SCR and CO systems, stack dampers, silencers, shrouds, and exhaust bypass systems.

World of Controls

Worldwide, low-cost provider of DCS circuit boards offering an array of ancillary services which include testing/repair of circuit boards, parts, DCS troubleshooting, Dos support, HMI upgrades/backup and field-based mechanical and controls training.

Young & Franklin

Premier fuel control supplier for combustion turbines for both long-term hydraulic solutions and, more recently, innovative all-electric controls solutions. Product scope supports natural gas, liquid, syngas, and alternative fuels as well as providing air controls to provide proper fuel to air mixtures.

Zokman Products

Distributor of ZOK27 and ZOKmx gas-turbine compressor cleaning detergents. ZOK27 is a single cleaner and inhibitor in one that cleans and protects the engine—and also inhibits corrosion. ZOKmx is a power cleaner formulated to replace solvents providing exceptional cleaning without the health and environmental risks associated with solvents.

EATON
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Aeroderivative, Industrial
&
Commercial marine engine components and services.

AGTSI Teams with Eaton on Global Product Distribution for Aeroderivative Market.
In a new agreement with power management company Eaton, Aeroderivative Gas Turbine Support, Inc. (AGTSI) of Boca Raton, Florida, has been selected as Eaton's official global distributor for aeroderivative, industrial and commercial marine engine components and services.
Eaton's products include dynamic and static seals, hoses and fittings, as well as specialty lube system sensors and components. Eaton's product reliability is proven across all gas turbine applications including aerospace, ground based industrial, power-generation and marine propulsion.
"AGTSI is well positioned to serve this highly specialized market and maintains a vast inventory of complex products and components manufactured by Eaton. AGTSI also provides operators and repair facilities that specialize in Eaton's marine gas turbines."

Aeroderivative Gas Turbine Support, Inc. (AGTSI) was established in 2004 and is a global stocking distributor of parts and assemblies for industrial and commercial marine gas turbines.
The company maintains an extensive inventory at its headquarters in Boca Raton, Florida in order to fulfill customers' "just in time" requirements.
AGTSI also facilitates component overhauls and maintains rotable exchanges for many of the parts.
For more information, please direct any request for quotes or information to quotes@agtsi.com (or sales@agtsi.com) or visit www.agtsi.com

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