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Combined Cycle Technology Trends

Outlook on Gas Turbine Development and Efficiency

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Features

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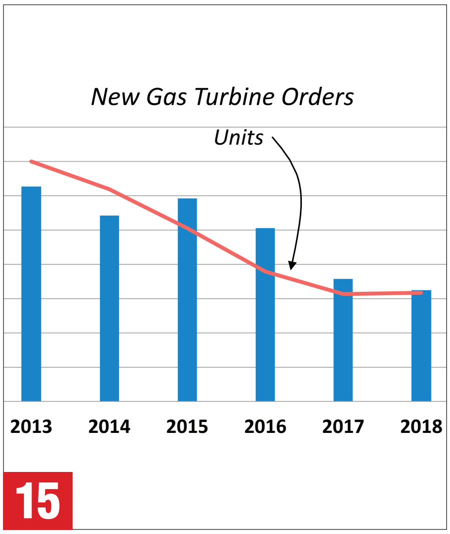
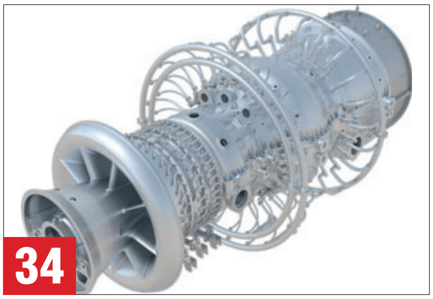


Cover images: The T-Point plant in Japan, top photo (courtesy of MHPS) and the Beni Suef plant in Egypt (courtesy of Siemens).

Departments



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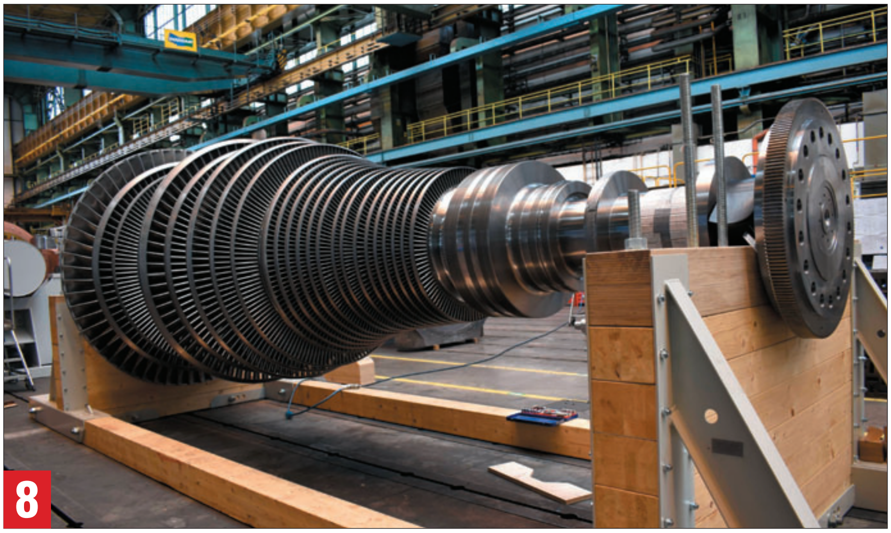

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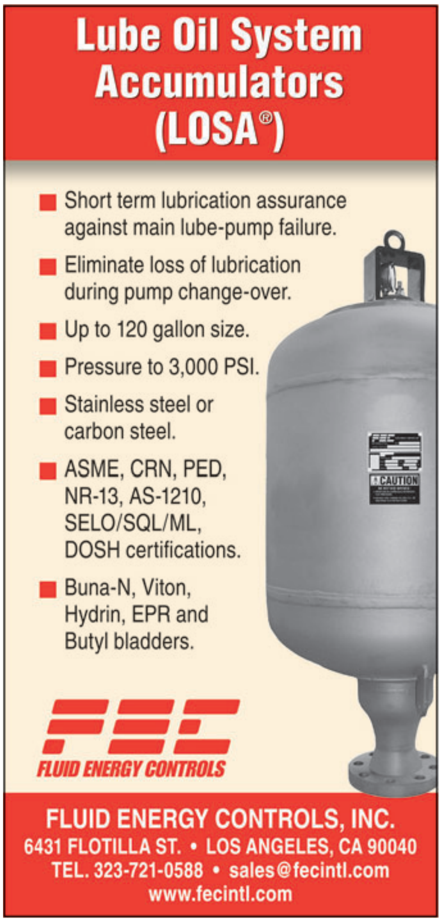

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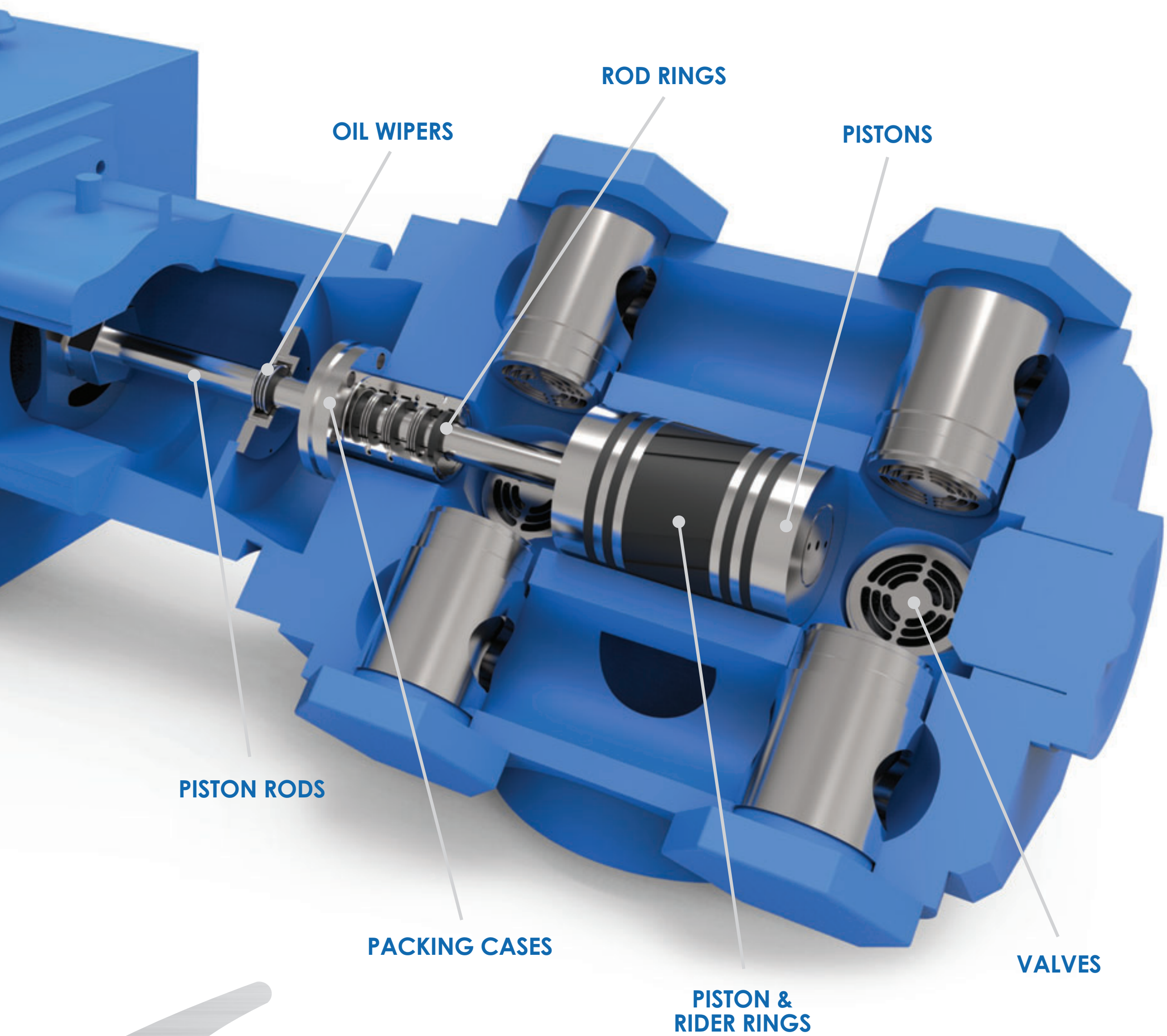

AFTERMARKET SERVICES

FIELD SERVICES

PROJECT ENGINEERING

Cook Compression offers custom-engineered components, repair and reconditioning services and technical support for reciprocating compressors around the world. Our solutions extend run times, increase efficiency, address emissions, reduce operating costs, eliminate unplanned downtime and resolve chronic problems—delivering quantifiable advances in performance.

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GOOD NEWS OR BAD NEWS?

If you prefer the bad news, go straight to page 15. If you prefer the good news, head for pages 18 and 36. The bad news is that gas turbine sales are down for five straight years. That trend is expected to continue for at least the next couple of years.

"Reeling From Renewables" doles out the many factors that are not only taking away orders for new power plants and gas turbines, they are also causing utilities and municipalities to cancel major upgrade projects. The prevailing sentiment in some quarters appears to be that energy storage, renewables and future technological advances can perhaps eliminate any need for GT power plants, so why upgrade them? The article ends on a more positive note, outlining areas of opportunity within a tough market. This includes LNG, oil & gas, various regions of the world and aeroderivative gas turbines.

> "There is so much oil & gas that it is driving new market opportunities.

Good news

Our show report by Mark Axford, "LNG Boom Dominates the CERA Conference," details the potential being unleashed on the U.S. Gulf Coast due to the build out of pipelines and LNG export facilities. Soaring production in the Permian Basis of West Texas is fueling this boom. There is so much oil & gas that it is driving new market opportunities.

There is also good news from our Myth Busters in this edition. They tackle the myth that oil & gas are dead. Their answer is a resounding "No." They also conclude that the gas turbine marketplace is far from dead either. Our Myth Busters even offer an alternate theory for the downward trend of gas turbine sales. It is not renewables, they say. Instead, they assert that low sales are due to the cyclic nature of the market, and a tendency to over-build plants at favorable times. This leads to an inevitable downturn.

Further good news is laid out in our cover story on combined cycle efficiency. The author notes that many areas of GT technology have advanced to such a degree that significant advances in efficiency will be far from easy. However, areas such as the hot gas path and the axial compressor show the most promise for improvement.

The reciprocating engine has expanded its capabilities over the past decade and can now provide combined cycle plants of 600 MW. You can read about it in, "Recip Engines Up Their Game."

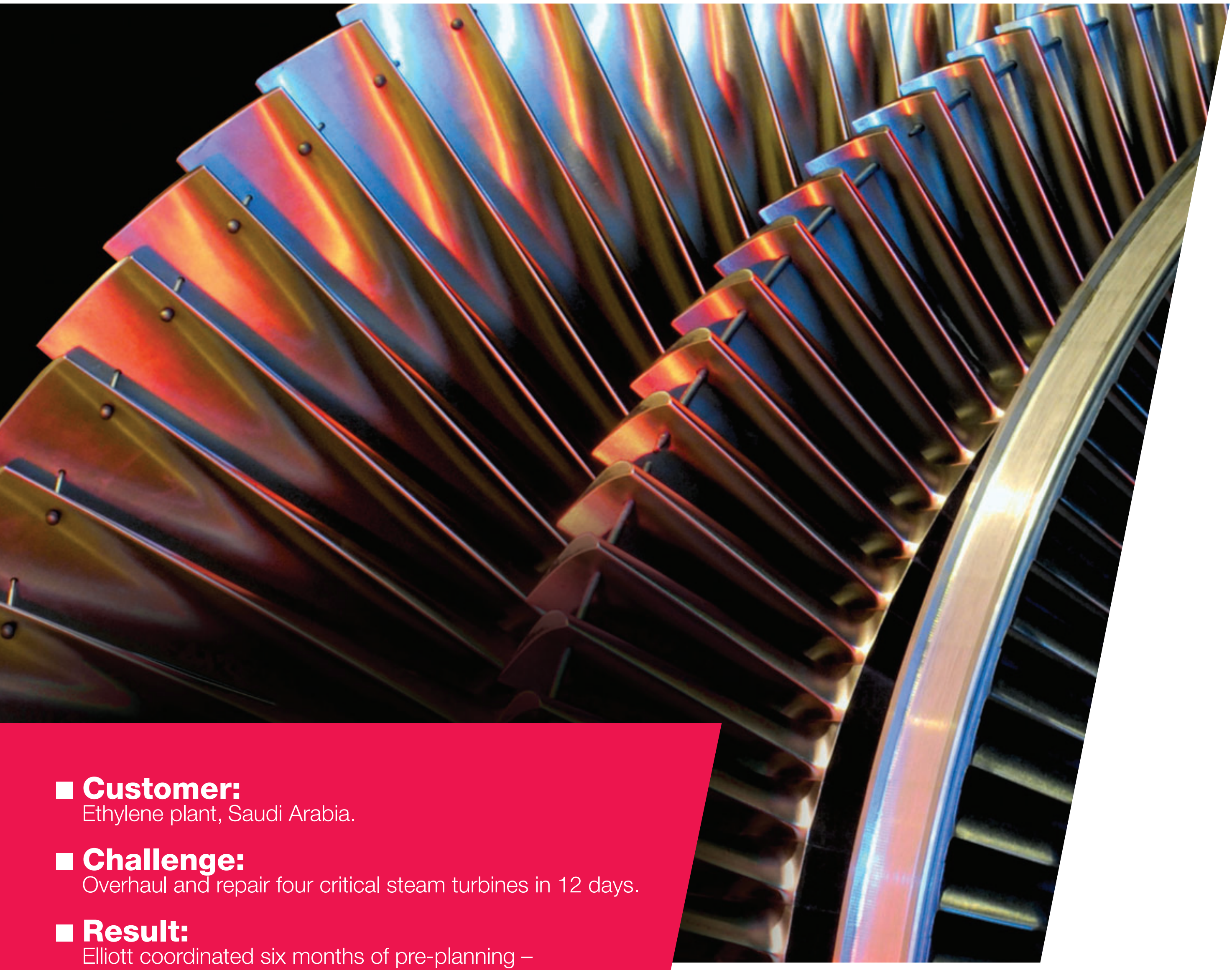
Beyond these topical matters, the issue is packed with varied content from a great many sources. We have stories about new water washing techniques, seismic monitoring, cybersecurity, HRSG maintenance, a user group show report and filter selection.

In conclusion, any stories about the death of the gas turbine industry can be considered as little more than propaganda. Yes, we may have a slower year or two, and there may be a few casualties. The industry will also need to adapt to changing needs and requirements. But for those who respond to this new reality, good times should lie ahead.

By the time you read this, we will be getting ready to head to Phoenix, Arizona for the annual Turbomachinery Expo show. We look forward to seeing many of you there. Let us know what you think about these trends and whether you think the turbomachinery glass is half empty or half full. ■

Drew Robb

DREW ROBB
Editor-in-Chief



Doosan Škoda steam turbine

Doosan delivery

A two-core steam turbine (ST) manufactured by Doosan Škoda will be installed in a new power plant on the banks of the Vistula River in Warsaw. The 155 MW turbine will become part of a new block for a combine cycle power plant (CCPP). Apart from the turbine, Doosan will supply the generator and related equipment. The new block, with a total output capacity of 490 MW, will increase current capacity by 80%. The project is expected to be completed in 2020.

MHPS digest

Mitsubishi Hitachi Power Systems (MHPS) has launched a startup known as Oriden, a play on the English word "origin" and the Japanese word "denki" meaning electricity. It aims to provide customized solutions for energy customers, including development and permitting, construction, financing, ownership, and asset management of renewable energy projects.

It will initially focus on distributed renewable solutions, with an emphasis on solar PV and energy storage. This will include community solar, behind-the-meter commercial & industrial customers, and distribution level front-of-the-meter projects.

MHI is entering the LNG liquefaction train market. ExxonMobil, Shell, Total and Bechtel have qualification studies on the 120 MW H-100 GT for use as the mechanical driver in conjunction with compressors from MHI Compressor Corp.

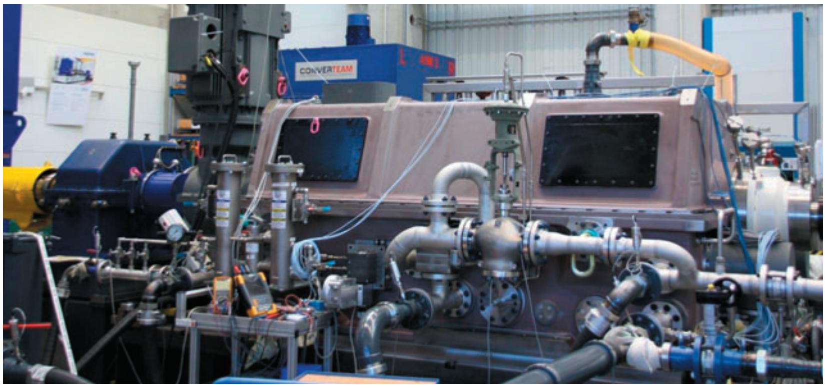
The H-100's two-shaft design provides a wide operating range and variable speed operation. It has the ability to re-start under full settle-out pressure without requiring a large external starter-helper motor.

Voith order

Voith has received its first orders for the VoreconNX, a modular variable speed drive that combines a hydrodynamic power transmission with a planetary gear. A U.S. petroleum refiner will use two drives to transmit power at variable speeds to compressor units. A Canadian refiner will use the variable speed drive to operate an air blower.

The first VoreconNX drive was put through a five-hour testing sequence including a speed ramp, overspeed and four defined-load points. This initial test ended without any anomalies. It will be delivered later in 2019. The second unit will be commissioned in 2020.

Voith VoreconNX



GE digest

Russia's Inter RAO is forming a partnership with GE to produce gas turbines (GTs) in Russia. As the country does not produce mid- or high-power GTs, it needs to fulfill an ambitious government plant to modernize 41 GW of coal- and gas-based plants.

A plant jointly owned by Inter RAO, GE and Russian state conglomerate Rostec already produces 77 MW turbines in Russia's central region of Yaroslavl. Ongoing talks between the companies are for the local production of machines just under 200 MW.

A joint venture between Siemens and Russian firm, Power Machines, already produces turbines in Russia. Siemens owns 65% of the venture. Russian state-controlled firms, such as Rostec, Rosnano and Inter RAO, have been working to create their own GTs.

GE has signed an agreement to provide a 9E GT to the Iraq Ministry of Electricity's Al Qudus Power Plant. The company has also agreed to provide services for up to seven GE 9E GTs at the facility throughout this year, including maintenance, supply of parts and rehabilitation. The new turbine at the site and is expected to generate up to 125 MW of additional electricity.

GE Marine's LM2500 GTs now power two Littoral Combat Ships built by Austal USA that were recently commissioned by the U.S. Navy: USS Tulsa (LCS 16) and USS Charleston (LCS 18). The LM2500s are made at GE's Evendale, OH, manufacturing facility.

Commissioning has been completed for both surface combatants, which are high-speed, agile, shallow-draft and mission-focused vessels. They are designed for operations in coastal environments, yet fully capable of open-ocean operations.

Thermal measurement

Sensor Coating Systems has been awarded a grant to collaborate with the UK National Physical Laboratory. The funding was provided through the Government's modern industrial strategy by Innovate UK, part of UK Research and Innovation.

The aim is the development of a new standard light source to enhance thermal measurements based on temperature-memory materials. This will enable improved measurements on GT parts for power generation, jet engines or automotive parts.

Continues on page 10

Siemens digest

Siemens will install Remote Diagnostic Services (RDS) for GAIL India covering 29 GTs operating across the Hazira-Vijaipur-Jagdishpur (HVJ) pipeline and the Vijaipur C2/C3 plant. The scope includes the supply of RDS hardware, site installation and commissioning, including remote Operational Service Desk (OSD) and helpdesk services.

The OSD will be accessible 24/7, equipped with machine-learning tools and manned by experts to provide troubleshooting and guidance. GAIL is the largest state-owned gas transmission and distribution company in India.

Siemens has secured an order for the construction of a CCPP for the LNG-to-Power project GNA 1 of Gás Natural Açu in Brazil. Siemens signed a long-term service agreement and will operate and maintain the plant.

With a capacity of 1.3 GW, construction started in 2018. Slated for operation at the beginning of 2021, the project includes an LNG import and regasification terminal, a substation and a transmission line to the grid.

Siemens developed the project together with BP and Prumo and is building the plant in consortium with Andrade Gutierrez. It is delivering the complete power island with three H-class GTs, one ST, four generators and HRSGs and instrumentation and control systems.

Bayat Power has ordered an SGT-A45 mobile unit from Siemens. This trailer-mounted unit will soon provide electricity for the Jowzjan Province in Afghanistan. It uses an aeroderivative GT (formerly Industrial Trent 60), which can provide up to 41 MW. Installation on site takes less than two weeks.

Siemens and State Power Investment Corporation signed a partnership for heavy-duty GT development based in China. Both companies will collaborate in digitalization of power plants, hydrogen utilization projects and smart energy management for a decentralized energy system. They also agreed to cooperate in project execution and jointly develop Gas-to-Power projects worldwide.

Siemens Remote Diagnostic Services enables analysis of power plant conditions and recommendations for improvement.

Siemens has opened a MindSphere Application Center in India. The digitalized technology center is supported by Siemens' MindSphere, an open, cloud-based IoT operating system that connects machines and physical infrastructure to their thermodynamic digital twins. The MindSphere Application Center, opened in Gurgaon, is said to be the first in the world specifically aimed at digital solutions for coal and steam-based power plants.

It will offer Siemens digital technology solutions, such as remote desktop services, performance optimizer, remote maintenance, power plant management, digital whiteboard and virtual collaboration.

Emirates Global Aluminum (EGA) and Siemens announced the first power services agreement for an H-class GT in the United Arab Emirates. With the 20-year service agreement, Siemens will provide maintenance and repairs as well as onsite personnel support for the GT and its generator at the planned 600 MW CCPP project feeding EGA's Jebel Ali power plant in Dubai.

Braskem, the largest petrochemical company in Latin America, entered into an agreement with Siemens to modernize a cogeneration power and steam plant at its Petrochemical Complex in Sao Paulo, Brazil. Completion of the project is expected in early 2021.

Siemens will be responsible for implementation and the 15-year operation of an electric and steam cogeneration plant. It will implement two SGT-600 GTs, electricals, three reciprocating compressors and software for plant control.

The existing cogeneration plant provides steam and power to the petrochemical complex's cracking unit. The unit has an ethylene production capacity of 700,000 m.t. per year (kta). Braskem estimates the upgrade will reduce the cracking unit's water consumption by 11.4% and cut emissions.

Turboexpander shipment

L.A. Turbine (LAT) shipped an ARES Active Magnetic Bearing (AMB) Turboexpander-Compressor to a new processing plant located in the Bakken Shale Play of North Dakota. The plant will have a flow rate of 200MMSCFD. The machine will be used for natural gas liquid (NGL) processing. Installation and commissioning are scheduled for third quarter, 2019. LAT partners with Waukesha Magnetic Bearings on AMBs and associated controllers.

LA Turbine Ares turboexpander with AMB technology

Aker contract

Aker Solutions has been awarded a contract to support the delivery of a subsea compression system for the Chevron Australia-operated Jansz-Io field. The scope will cover an unmanned power and control floater, as well as field system engineering services. The field, part of the Gorgon Project, is 200 km offshore from the northwest coast of Western Australia at about 1,350 meters below the surface.

Pump testing

To test developments of pumps and systems under realistic conditions, Lewa developed a two-area container test bench for experiments with hot or explosive fluids.

In addition to an experimental area of explosion protection Zone 1, in which the test experiments take place, it also includes a safe control room without explosion hazard for housing the drive and control equipment.

Supercritical fluids such as gasoline, methanol, acetone or nitrocellulose thinner are used in the test chamber, whose interior can be viewed through gas-tight glass panes, at process temperatures of up to 80°C and a maximum quantity of 200 liters.

Hot experiments with rapeseed oil, glycerin or Fragoltherm, a heat-transfer fluid, can reach 200°C. A data recording system ensures that the proper function of the respective pump is monitored.

A Lewa Ecoflow LDG3 with an M9 pump head is used to test diaphragm clamps for micro-leakage. The test bench container has an area of explosion protection Zone 1 and a safe control room

Cybersecurity partnership

Schneider Electric has entered into a partnership with cybersecurity provider Vericlave to secure and protect critical systems from cyberattack. Schneider Electric will provide its customers with Vericlave's encryption technology, which shrinks the attack surface by more than 90%.

The Vericlave solution has been developed and tested by the U.S. Department of Defense, U.S. Intelligence Community and in the infrastructure, finance, healthcare and retail markets for more than 20 years. Vericlave technology will be combined with Schneider Electric's EcoStruxure platform to provide a multi-layered approach that includes cybersecurity solutions, services and expertise.

Monitoring system

Brüel & Kjær Vibro (B&K Vibro) received an order for the supply of VC-8000 Setpoint systems and services for monitoring a 250 MW steam turbine, generator and main boiler feed pump at the Huntly power station in New Zealand.

The B&K Vibro system provides protection and condition monitoring of the generating units. Huntly's generating units are mounted on steel frame foundations as a means of providing earthquake protection.

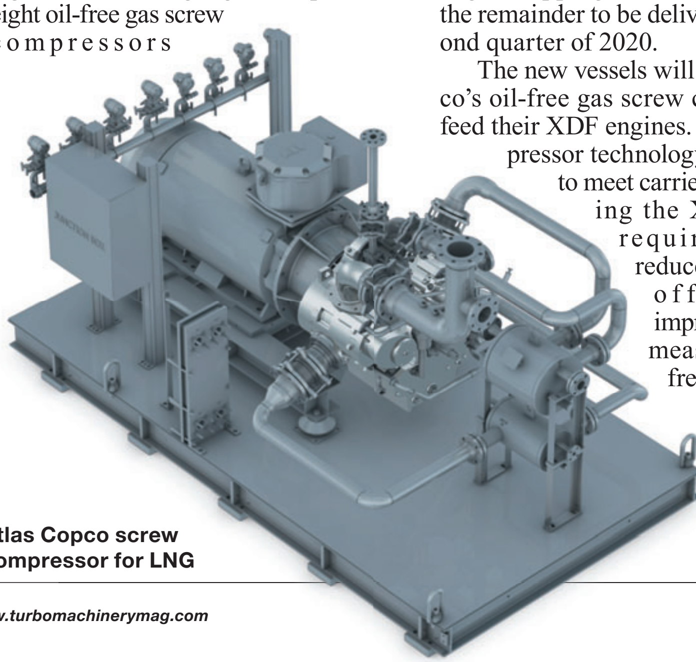
The VC-8000 system was customized to provide a speed-adaptive monitoring strategy for protection and condition monitoring of the units to deal with vibration resonances close to the operating speed.

Atlas compression

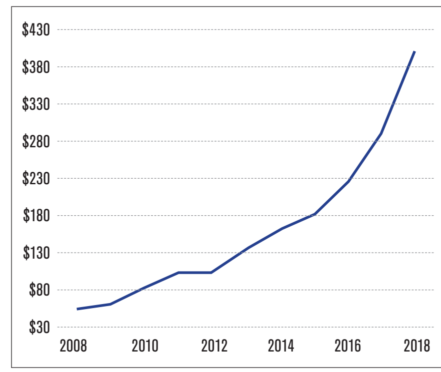
Atlas Copco Gas and Process Division has secured a compressor order from Samsung Heavy Industries in Korea for the carrier LNG market. The order is for eight HD centrifugal gas compressors, eight oil-free gas screw compressors along with the heaters and vaporizers.

The equipment will be used on four 180,000 m^3 vessels commissioned by Celsius Tankers. The first units will begin shipping in October 2019, with the remainder to be delivered in the second quarter of 2020.

The new vessels will use Atlas Copco's oil-free gas screw compressors to feed their XDF engines. This new compressor technology was designed to meet carrier needs, including the XDF pressure requirements and reduced flow of boil-off gas from improved insulation measures. The oil-free design allows for longer maintenance intervals.



Atlas Copco screw compressor for LNG



Sales of materials for 3D printing polymer powder bed fusion were at an all-time high in 2018. Figures are in millions of dollars.

3D printing upsurge

The Wohlers Report 2019 on additive manufacturing (AM) and 3D printing stated that the materials' segment of the industry saw record growth in 2018. Revenue from metals grew an estimated 41.9%, continuing a five-year streak of more than 40% growth each year. The forecast for 2020 is $15.8 billion for all AM products and services worldwide. Revenue should climb to $23.9 billion in 2022, and $35.6 billion in 2024, according to the report.

Siemens Oil & Gas CEO

Arja Talakar

Arja Talakar has been appointed CEO of Siemens Oil & Gas. He will be based in Houston, TX, global headquarters for Oil & Gas and its parent operating company, Siemens Gas and Power. Prior to taking this role, he was responsible for Siemens Saudi Arabia. Talakar has been with Siemens since 1996.

Continues on page 12

Ansaldo digest

Ansaldo Energia has been awarded a contract to supply an AE94.2K GT and syngas compressor train for the Bengang CCPP, located in Benxi in the northeast of China. The 180 MW facility burns low calorific fuel. The plant is owned by Benxi Steel Group, a large state-owned company.

Edison and Ansaldo Energia signed a contract for a CCPP. The Marghera Levante power island will be made up mainly of the GT36 GT. It will have a capacity of 780 MW and 63% efficiency. The plant will consist of a GT36 turbine, heat recovery steam generator (HRSG), a 250 MW ST and a catalytic system of nitrogen oxide reduction (SCR). It will replace two electricity generation units currently in operation.

Recip deal

Dresser-Rand reciprocating compressors

Siemens will supply 3 Dresser-Rand 5HHE-VL-3NL reciprocating compressors for what will become the largest hydrogen production unit in the U.S. The steam methane reformer being built for a large gas company in Texas will be completed in 2021.

It will increase hydrogen capacity to more than 1.5 billion cubic feet per day. The three 12.75-inch-stroke 5HHE-VL compressors will feature similar configurations to units that have been supplied to the customer in the past.

The design has a non-lubricated cylinder construction, which eliminates the need for an oil-removal system. Additional design features include integrated lube oil consoles, a cooling water console, purge panels, pulsation vessels, intercoolers, aftercooler, relief valves and process control valves. A slow-speed synchronous motor will drive the compressors.

Chinese emissions reduction

GE has completed a DLN1.0+ with Ultra Low NOx combustion upgrade on nine GE 9E GTs at five power generation facilities in China. This is part of the Chinese Blue Sky Air Quality and Public Health Improvement Plan.

The upgrade takes NOx from 25 ppm to 7.5 ppm at Shenzhen Nanshan Power, Shenzhen New Power, Shenzhen Datang Baochang Gas Power, Shenzhen Yuhu Power, and CNOOC Shenzhen Power in Shenzhen.

The Blue Sky campaign requires all gas-fired power plants in the city to lower emissions below 7.5 ppm. Power plants that fail to comply with these requirements will be taken offline.

GE's DLN 1.0+ with Ultra Low NOx upgrade is an improved combustion system for the DLN 1.0 that can reduce NOx down to 5 ppm.

This is achieved with:

- More robust materials and thermal barrier coatings to extend maintenance interval and parts life
- New fuel nozzles, liners and transition pieces to improve the mixing of air with fuel and enhancing the hot gas temperature profile
- Combustion dynamics monitoring system and improved controls system using real-time ambient humidity, ambient temperature, inlet and exhaust pressure loss data to adjust the fuel splits between the primary and secondary fuel circuit and maintain emissions below the target.

Chinese power plant upgrade

The upgrade allows the units to accept fuels with larger Wobbe index fluctuations, expanding gas source choices to operate flexibly. The upgrade can potentially extend combustion system maintenance intervals to 32,000 hours or 1,300 starts and stops.

LNG drives

Nidec has signed a contract for the supply of variable frequency drives systems (VFDS) and motors for the Arctic LNG 2 project, which will be used as part of the liquefaction plants located in the Yamal peninsula in Russia.

The motors make it possible to work continuously even at temperatures down to –52°C. Nidec has also been selected to provide three 37 MW Current Source VFDS and three synchronous motors for feed-gas-booster compressors, and three 20 MW Voltage Source PWM VFDS for starting six medium-voltage, fixed-speed induction motors for boil-off gas compressors.

The Arctic LNG 2 project developed by Novatek involves the construction of three plants for LNG via gravity-based structure platforms, each with a capacity of about 6.6 million tons/year, equivalent to 535,000 barrels/day. The liquefaction trains, installed on platforms in the waters of the Gulf of Ob, also include LNG storage facilities for a total of 687,000 cubic meters.

Hybrid engine

Wärtsilä has launched the Engine+ Hybrid Energy, pairing reciprocating engines with energy storage. It serves load instantly, addresses step changes and intermittencies, and provides spinning reserves. The GEMS control platform automatically dispatches available assets and accounts for any operational constraints.

Plants can be built ranging from 6 MW to 400 MW using standard Wärtsilä engines of various sizes. It can be powered by gas, liquid fuel or multi-fuel. Energy Storage is provided by GridSolv Li-Ion batteries, which can store 2 MW to 20 MW of capacity. That is enough to provide up to two hours of storage time. It can also be paired with a solar plant to account for solar variability.

Steam turbine report

The steam turbine market worldwide size is set to exceed $32 billion by 2024, according to the latest study by Global Market Insights. Resurgent economic growth in developing countries and overall build-out of large combined cycle plants is boosting demand for large capacity STs.

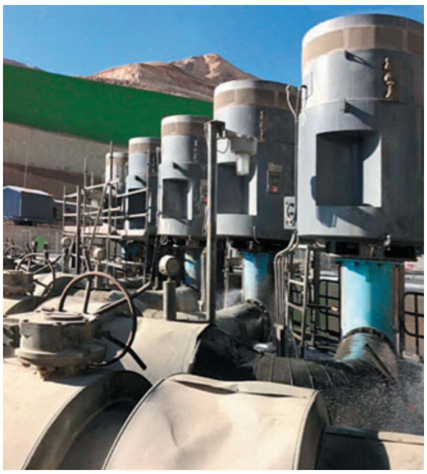
The market for small STs below 3 MW is expected to rise by 2% between now by 2024. The condensing turbine's ability to extract maximum energy from steam makes it suitable for power generation.

Continues on page 13

The condensing ST market is now worth close to $20 billion.

Biomass-based steam turbines account for more than $1 billion per year. Growing adoption of CHP is reinforcing demand for biomass-based capacity.

Regionally, the Indonesian market is anticipated to witness growth of over 12% by 2024. Similarly, the South Africa market has heated up due to favorable government policy. It is expected to become an area of high demand for steam turbines.



New two-stage pumps for solids handling

Vertical turbine pump

A copper mine in Chile had six 24-inch, two-stage 900 HP vertical turbine pump (VTP) units installed on intake structures in a process water application in its reclaimed pond system. As the concentrator plant's tonnage increased, the fluid began reaching the pond with a high concentration of solids, resulting in premature damage to the pump units and a shortened life of roughly 300 hours.

The pump failures were also causing operational disruptions as they required frequent maintenance and increased the customer's operating costs.

To increase pump life and decrease downtime, the mine installed Floway's Vertical Turbine Solids Handling Pump (VTSP). It pumps fluids with solids concentrations up to 10% by weight, with peaks as high as 20%.

The VTSP units were drop-in replacements for the standard VTP units, with no piping or foundation modifications required, and are driven by the original motors. The wear life on the pumps has increased from an average of 300 hours to over 1,000 hours.

Hydrogen research

Ansaldo Thomassen, Delft University of Technology, Opra Turbines, Vattenfall, Nouryon and EMMTEC have been awarded a subsidy by the Dutch Government for the High Hydrogen Gas Turbine Retrofit to Eliminate Carbon Emissions project.

The half-million-euro subsidy is part of a Dutch program for the development of carbon-free hydrogen value chains. A major objective is to develop a cost-effective, sub 9 ppm NOx and CO combustion system retrofit for existing GTs.

Fuel flexibility and stable operation from 100% natural gas to 100% hydrogen and any mixture is a requirement. Extreme changes in fuel reactivity switching from natural gas to hydrogen can result in shifting of heat release within the combustor, which can be physically destructive if not well controlled.

Ansaldo Thomassen's trapped vortex FlameSheet combustion technology platform is a core part of this program. It is operating commercially in multiple 60hz F-Class GT power plants with sub-9 ppm NOx emissions using a hydrogen- blended fuel mix. ■

PRACTICAL NOTES ON STEAM TURBINES

BY AMIN ALMASI

A steam turbine (ST) generates mechanical power from steam at high temperature and pressure. It can deliver constant or variable speed and is capable of close speed control.

Drive applications include pumps, compressors, electric generators and many more. Steam supplies power to about 20%–30% of all pumps and compressors that move fluids in plants and other facilities worldwide.

STs have been classified by mechanical arrangement as single-casing, cross-compound (more than one shaft side-by-side) or multi-casing (tandem-compound, which is two or more casings in a single train).

They have also been identified by steam flow. This tends to be axial direction for most, and radial for a few. In addition, STs can be categorized by steam cycle, whether condensing, non-condensing, automatic extraction or reheat.

In a steam turbine, the steam flows through directing devices and impinges on curved blades mounted along the periphery of the rotor. By exerting a force on the blades, the steam flow causes the turbine rotor to rotate. Unlike a reciprocating steam engine, an ST makes use of kinetic rather than the potential energy.

Steam turbines have evolved in the direction of multistage axial designs, in which the expansion of steam is performed in a row of sequentially arranged stages. Staging permits a considerable increase in power output, while preserving the speed required for direct coupling of driven equipment.

Steam cycle

The Rankine cycle closely describes the process by which a steam turbine generates power. The cycle consists of a heat source (boiler, heat recovery unit, and so on) that converts water to high-pressure steam.

Water is pumped to elevated pressure using boiler-feed water pumps (BFW pumps), which is medium- to high-pressure depending on the size of the unit and the temperature to which the steam is heated.

Steam is then heated to the boiling point corresponding to the pressure, boiled (heated from liquid to vapor). Most frequently, it is superheated above the temperature of boiling.

High yield strength combined with fracture toughness are important requirements in steam turbines.

The pressurized steam is expanded to lower pressure in a multistage ST, and exhausted either to a condenser at vacuum conditions (condensing) or into an intermediate-temperature steam distribution system (non-condensing) that delivers the steam to other applications. The condensate is returned to the BFW pumps for continuation of the cycle.

An ST usually consists of a stationary set of blades (called nozzles) and a moving set of adjacent blades (called buckets or rotor blades) installed within a casing. The two sets of blades work together, such that the steam turns the shaft of the turbine and the connected load.

The stationary nozzles accelerate the steam to high velocity by expanding it to lower pressure. A rotating bladed disc changes the direction of the steam flow, thereby creating a force on the blades that manifests as torque on the shaft on which the bladed wheel is mounted. The combination of torque and speed is the output power of the ST.

Material selection

The evolution of steam systems has been coupled to advances in high-strength steel alloys. Steam admission temperatures have continuously been improved. Traditional alloy steels were used up to 550°C. For 580°C and beyond, modern alloy steels are used. Super alloys are needed to keep creep deformation within acceptable limits.

In addition to temperatures, centrifugal forces put high stress on rotor and blade materials. High-yield strength combined with fracture toughness are important requirements. However, these are metallurgical contradicting properties. A challenge in recent decades has been stress corrosion cracks (SCC) in discs exposed to wet steam.

Many steam turbine rotor blades have shrouding at the top, which interlocks with that of adjacent blades to increase damping and reduce blade flutter. In large STs, the shrouding is often complemented (especially in the long blades of a low-pressure turbine) with lacing wires.

These wires pass through holes drilled in the blades at suitable distances from the blade root. They are usually brazed to the blades at the point where they pass through. Lacing wires reduce blade flutter in the central part of the blades. The introduction of lacing wires substantially reduces blade failure in low-pressure turbines. ■

Amin Almasi is a Chartered Professional Engineer in Australia and U.K. (M.Sc. and B.Sc. in mechanical engineering). He is a senior consultant specializing in rotating equipment, condition monitoring and reliability.

REELING FROM RENEWABLES

THE IMPACT ON GAS TURBINE SALES

DREW ROBB

Gas turbine orders have been down for five straight years. Most experts agree that 2019 will see that trend continue, although unit orders should level off in 2019 and 2020. The industry is clearly reeling from the influx of renewable generation onto the grid.

Energy storage is now the darling of legislators, utilities and renewable advocates, garnering heavy investment. Some see the influx of subsidized battery storage as the beginning of the end for gas turbines (GTs) used as standby peaking power.

We hear from the President of Western Turbine Users, GE Power, Dora Partners, Wood Mackenzie, the Energy Storage Assn., Invergy, Axford Consulting and Arizona Public Service on what is happening in the industry, where we might be heading and what can be done about it.

California dreaming

California is a microcosm of what is going on in the U.S. market, if not in the world as a whole. Chuck Casey, President of Western Turbine Users Inc. (WTUI) is in the midst of it. As the Utility Generation Manager for the City of Riverside Public Utilities, he has lived through vast changes over the past decade.

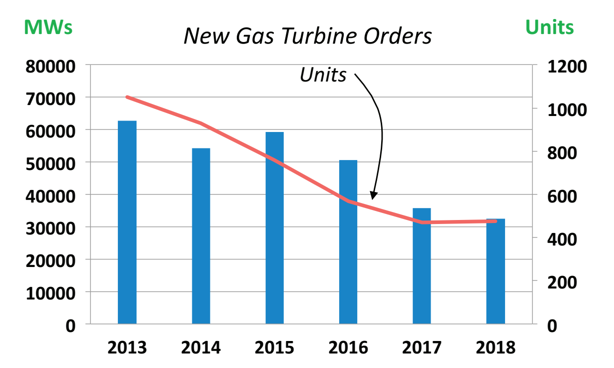
Casey has watched fossil fuel and nuclear plants shut down, and the Clean Power Plan mandate historic levels of renewable energy and energy storage. This has challenged GE LM turbine operators like him to start faster and more often, operate at lower emissions, at lower power turndowns and higher output while staying reliable and available and performing under budget. His aeroderivatives, therefore, have been operating fewer and fewer hours.

"To stay relevant, we need our aeroderivative engines to be more flexible, adaptable and versatile than ever before," said Casey. "We must challenge equipment suppliers, gas turbine engineers, owners and our operations staff to improve their products and operations, demand new capabilities and extend the life of our GTs and all facility support equipment."

Riverside Utility has been sending him to battery and solar conferences. Batteries are likely to be deployed on a five-acre lot adjacent to its 200 MW GT peaking plan in the near future. He believes that natural gas will soon become as much a target as coal is now.

"Natural gas will fill the gap till renewables and energy storage can feasibly be used 100% of the time," said Casey. "Be ready to adapt your turbines to bridge the gap."

His advice to turbine operators is to embrace change. Be willing to incorporate renewables and storage into your GT facilities, as it is coming in any case. "If your plant is not adapting, it will probably go away," he said.



Courtesy of Dora Partners & Co. and McCoy Power Reports

Energy storage grows

U.S. public consensus leans toward environmentally friendly solutions and greatly lowered emissions. That equates to the adoption of renewables and energy storage, and more fossil plant shutdowns.

Los Angeles, for example, has cancelled plans to spend $5 billion to upgrade three natural-gas generating plants on the California coast. This money was earmarked for the Haynes, Harbor and Scattergood gas plants to meet the requirements of a 2010 law outlawing once-through cooling. Instead, the Los Angeles Department of Water and Power (LADWP) intends to phase out these gas plants over the next decade and invest in renewable energy.

LADWP has already received presentations from Navigant and WorleyParsons exploring alternatives to replace the 1.66 GW of gas generating capacity in the city. This includes 1.8 GW of energy storage, as well as deploying more solar, wind, geothermal power and distributed energy resources. Scattergood is to be shuttered by 2024, and Haynes and Harbor by 2029.

Other utilities are gradually following suit. Pacific Gas & Electric in Northern California plans to add three storage projects amounting to 567.5 MW. The California Public Utilities Commission directed PG&E to purchase storage instead of approving upgrades for the three gas plants on the premise that batteries would be cheaper than continuing to operate the plants. Energy storage will include a 300 MW project from Vistra Energy and a 182.5 MW project from Tesla.

Arizona Public Services (APS) announced that it will install 850 MW of energy storage by the mid-2020s. Some 450 MW will come online by 2021 with an additional 400 MW slated for 2025.

This includes 200 MW of energy storage as retrofits to existing solar facilities, 150 MW of standalone batteries and a new 100 MW solar facility paired with a 100 MW battery system. The other 400 MW will comprise storage with three- or four-hour battery durations.

At the same time, APS signed a power purchase agreement for a 463 MW natural gas plant owned by Calpine. The seven-year contract is less than the typical 25-year term. The plan allows the utility to eventually convert to cleaner resources.

Florida Power and Light (FPL) is another utility getting in on the act. It recently announced the world's largest solar-powered battery storage system. The Manatee Energy Storage Center will be a 409 MW facility due to commence operation in late 2021.

The batteries will be placed beside an existing 74.5 MW solar plant. This is being done instead of upgrading two natural gas-fired units at the nearby 1,638 MW Manatee Power Plant. FPL also plans to add 15 GW of solar over the next few years.

Storage is thriving

The U.S. energy storage industry is thriving. It added 311 MW of battery storage in 2018, a record year. That number is predicted to double this year and triple in 2020.

Battery storage is gradually rising to utility scale, according to energy research firm Wood Mackenzie and the Energy Stor-

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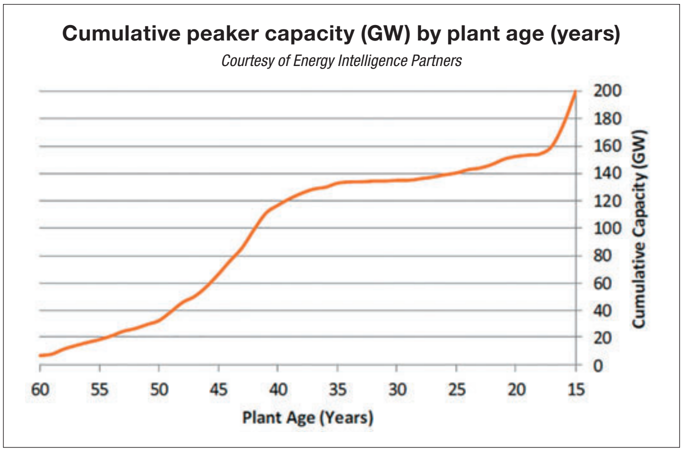
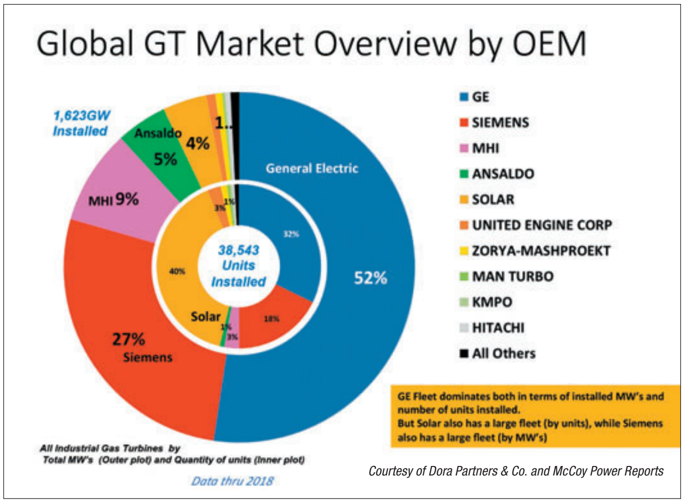
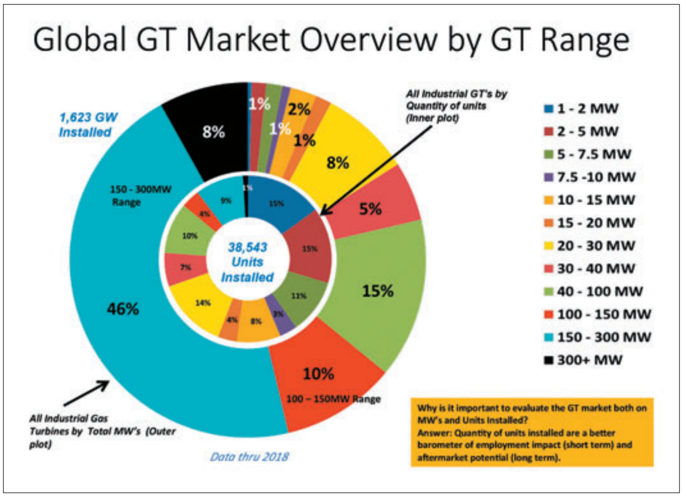
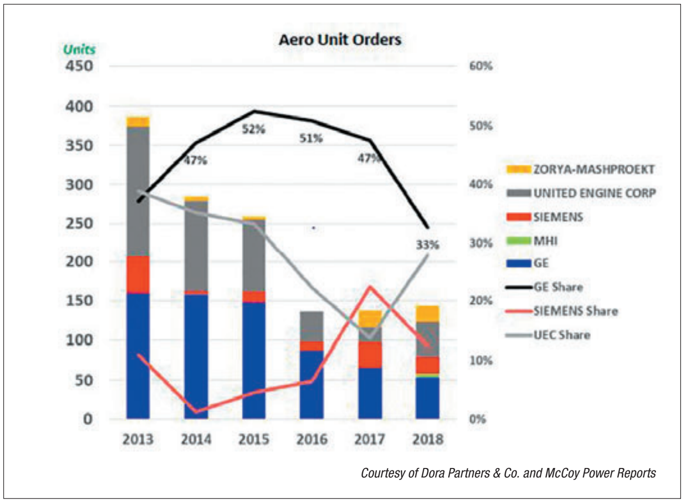




Courtesy of Dora Partners & Co. and McCoy Power Reports



The outer circle represents MW orders; the inner circle represents unit orders *Courtesy of Dora Partners & Co. and McCoy Power Reports*



Courtesy of Dora Partners & Co. and McCoy Power Reports

age Assn. These numbers are supported by Deloitte's 2019 renewable energy industry outlook which predicts 6X market growth over the next five years, and a storage market worth $4.7 billion per year by 2024.

California and the Mid-Atlantic Region dominate U.S. cumulative installed storage capacity. But Hawaii, Texas, Minnesota and Colorado also have added battery projects. Hawaii intends to add over 1,000 MW of battery storage and 260 MW of solar.

State-level policy updates in Massachusetts, New York and New Hampshire should see the northeast introduce large-scale battery storage initiatives. Meanwhile, Puerto Rico has mandated up to 900 MW of energy storage within four years.

Further, a new policy tool known as the Clean Peak Standard (CPS) has emerged. Its goal is to increase the share of renewable energy resources used to meet peak demand. With most U.S. peaking capacity aged between 20 and 40 years, it is possible that a good portion of that will eventually be retired, perhaps as much as 152 GW.

Massachusetts has already enacted a CPS. Arizona, California and North Carolina have proposed one. The idea is that a portion of power delivered during peak periods must be supplied by a renewable energy generator and energy storage. North Carolina's scheme applies to its three major electricity retailers. It proposes 5% of peak load be covered by the CPS by 2025 and 10% by 2028.

"Energy storage mandates and subsidies in California and other states will probably kill the GT peaking market," said Mark Axford, Principal at Axford Turbine Consulting.

The Deloitte study noted that utilities have demonstrated strong "voluntary demand," as opposed to demand driven by policy mandates seen in the past, said the report. Corporations, too, are demanding renewable generation and energy storage. Some are installing it at their headquarters and other facilities.

Last year, for example, corporations signed Power Purchase Agreements (PPA) for renewable energy in excess of 13 GW. Apple purchased enough renewable energy to power all of its facilities across 43 countries last year. Facebook purchased 2.6 GW globally. Google sourced 100% renewable electricity for its global facilities. And Exxon purchased 575 MW of solar and wind via a Texas PPA.

Mark Axford

GT market impact

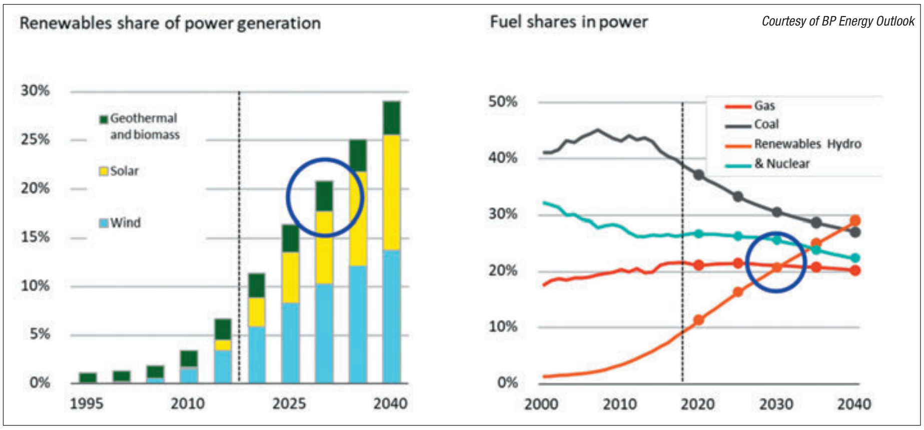
There is no doubt that the rise of renewables and the financial incentives being given to energy storage are impacting GT sales. Tony Brough, an analyst at Dora Partners, laid out the harsh reality.

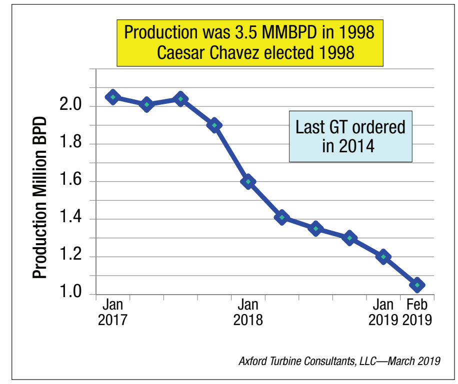
Since 2012, MW orders for GTs are down 50% and unit orders are down 57%. In 2018, MW orders fell 9.1%, though unit orders were 1.5% up due to a large order for a Russian/Ukrainian pipeline.

By far the largest segment of the market lies between 150 MW and 300 MW. This represents almost half of all capacity in the field. However, that only accounts for 9% of worldwide unit orders. Meanwhile, even larger GTs are experiencing growth.

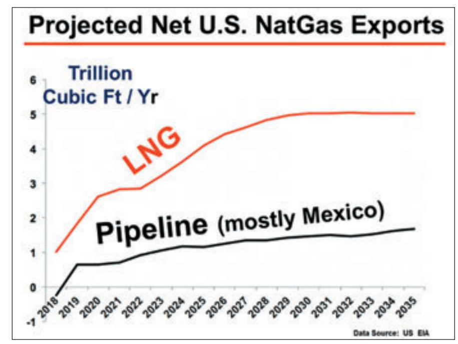
Tony Brough

"The range above 300 MW may only represent 8% of MW orders, but it is growing fast, primarily in response to





Venezuelan oil production in steep decline



coal plant retirement," said Brough.

On the vendor side, GE controls 52% of all GTs in MWs and 32% in units. MHI, said Brough, may only be at 9% of MW installed, but is reaping the benefits of hot section and cooling investments. This has enabled the company to grow robustly.

Half or all installed units worldwide are in oil & gas, which is the fastest growing sector. Solar Turbines dominates here. As the leader in smaller units, it supplied 40% of all GTs worldwide.

"Oil & gas is a huge opportunity for service," said Brough. "Africa, too, is a region that could well explode in the next five to 10 years."

In the aeroderivative market, GE continues to rule via its LM2500 and LM6000 machines. Its five-year share amounts to 66%, with Siemens/Rolls-Royce at 10%, PWPS at 4.5% and United Engine Corp of Russia at 19.3%.

The LM2500 and its variants gained more than 50% of all aero orders over the past five years, with the LM6000 taking up another 12%. The LMS100 managed 2.8%. PWPS picked up six FT4000 orders last year.

The overhaul and repair potential for aeroderivatives is worth almost $2 billion per year globally, said Brough. Two thirds of gas turbine sales over the next 10 years will include Dry Low Emissions (DLE) technology.

In the U.S., aero unit orders were up 150% and MW orders up 87% in 2018. Globally, aero unit orders were up 15% and MW orders up 2.6%.

Brough predicts a doubling of the renewable share of power generation worldwide by 2030, reaching 20% of the market. That would bring it on a par with natural gas. By 2040, renewables should surpass coal as the biggest source of energy worldwide. Natural gas use will remain relatively flat through 2040.

What is to be done?

Those cited earlier offered a few tips on how to respond to the changing gas turbine marketplace:

- Adapt existing GTs to grid demands and the heavy presence of renewables
- Challenge equipment suppliers to improve their products, add new capabilities and add value
- Target oil & gas, a big opportunity for aftermarket service
- Consider Africa, a burgeoning market within a decade
- Sell and maintain aeroderivatives, likely to perform better than heavy-frame machines
- Focus on the overhaul and repair of aeroderivatives
- Follow the U.S, China and other regions expanding pipeline infrastructures
- Embrace LNG, a booming market.

Within the general oil & gas sector, opportunities will vary regionally and within various market niches. Axford called attention to the oil production statistics for Venezuela. In 1998, that nation produced 3.5 million barrels per day. Today production is down one million barrels. Venezuela has more oil than Saudi Arabia, but it is not as easy to produce. The last GT ordered by the country was in 2014.

"If the country stabilizes, there could be heavy demand to fix its turbomachinery as it seeks to ramp up production," said Axford.

In parallel with the decline of Venezuela, the U.S. has emerged as a major oil exporter. "The U.S. has become the peaking plant for world oil. When the price goes up, they turn the wells on," said Axford.

LNG boom

LNG is another bright spot and good news for aeroderivative GTs, in particular. Brough noted that there will be another 11% jump in LNG trading in 2019, with that sector doubling over the next 15 to 20 years.

"Import (and especially export) terminals are likely to benefit aeroderivative growth," said Brough. "Operators prefer aeroderivatives over heavy frame turbines as they can shut a smaller engine down and still keep their LNG trains going."

U.S. LNG export capacity has been steadily expanding. Cheniere 1 in Louisiana has a capacity of 27 MMTPY. The Dominion facility in Maryland has a capacity of 5 MMTPY. Three other facilities are coming online over the next year or so, adding 40 MMTPY.

"Oil and gas for export is a strong driver for GTs around 20 MW, especially in trailer-mounted format, as well as mechanical drive for pipelines and gas separation," said Brough.

If you can't beat them...

The old phrase, "if you can't beat them, join them," could be applicable to gas turbine OEMs, suppliers and the aftermarket. If wind farms, solar plants and battery storage are the wave of the future, it is up to the industry to find ways to fit turbomachinery into the equation.

Case in point: Wellhead Electric's innovative approach in Norwalk, California. It has paired a GE LM6000 with 10 MW of battery storage for what is called the GE LM6000 Hybrid-EGT.

Two units are now in service in California, and Southern California Edison has ordered two more. It offers quick-start, fast-ramping capabilities. The GTs can provide 50 MW of spinning reserve, flexible capacity, or peaking power, as well as reactive voltage support and primary frequency response when not online.

The turbine can operate in standby mode powered by the batteries instead of consuming fuel. The control system blends output between the battery and the GT. ■

LNG BOOM DOMINATES THE CERA CONFERENCE

SOARING PRODUCTION IN THE PERMIAN BASIN OF WEST TEXAS IS DRIVING DEMAND FOR TURBOMACHINERY, PIPELINES AND LNG EXPORT TERMINALS

BY MARK AXFORD

The annual CERAweek (Cambridge Energy Research Associates) conference by IHS Markit in Houston during March drew attention to soaring oil and gas production in the Permian Basin of West Texas. This boom, now in full swing, has been heralded as the "Second Wave" of the shale revolution in North America.

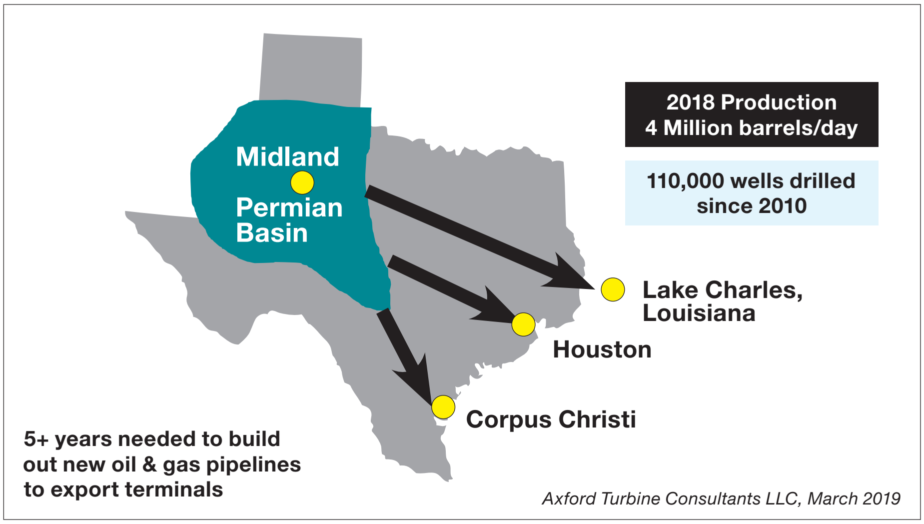
New fracking and drilling techniques are further reducing the time and cost to complete a well and produce a barrel of oil. The volume of associated natural gas is enormous, far beyond the U.S. domestic needs. LNG export terminals never imagined only 10 years ago are sprouting up on the Gulf Coast of Texas and Louisiana.

In the first quarter of 2019, Permian production of light crude oil exceeded four million barrels per day (MBPD) for the first time. More than 110,000 wells have been drilled there since 2010. As a result, the U.S. surpassed Russia and Saudi Arabia to become the world's top oil producer.

But current pipeline capacity cannot transport all the oil and gas to where it needs to go. Massive infrastructure investment is needed to support the bonanza. When critical pipeline projects are completed over the next couple of years, Permian oil production is predicted to climb from 4 MBPD to 6 MBPD.

A great many gas turbines and centrifugal compressors are being ordered and built to support oil and gas in this region:

- Midstream facilities to process the associated gas and capture the valuable propane, butane and ethane fractions used for plastics production
- Trailer-mounter gas turbine gensets as a source of power at fracking sites
- Pipelines and compressor stations to deliver methane gas to customers
- LNG terminals with huge compressors to liquefy methane gas for export



Export terminals

Cheniere Energy revolutionized the U.S. natural gas business. It foresaw a vast surplus of natural gas being created by fracking and made a bold decision: change its existing LNG import terminal at Sabine Pass, LA into an export terminal.

In February 2016, the first tanker of LNG to be exported from the U.S. was shipped from the Sabine Pass terminal. To date, more than 500 cargoes have been delivered to customers around the world. Sabine Pass has an export capacity of 27 million metric tons per annum (MMTPA).

In late 2018, Cheniere began shipments from its second LNG export terminal (13 MMTPA) at Corpus Christi, Texas. The Dominion LNG export terminal in Maryland has also opened (5 MMTPA). The Freeport, (15 MMTPA), Cameron (12 MMTPA), Magnolia (8 MMTPA) and Elba Island (2.5 MMTPA) projects are under construction. More export terminals are in the advanced planning or early construction stages.

GE has succeeded in having its gas turbines specified for most of the Gulf Coast LNG refrigeration compressor trains. The GE Frame 7EA gas turbine was selected for the largest trains, and GE also earned big LM2500+ and LM6000 aeroderivative orders for medium-sized LNG trains.

Solar Mars units were selected for Kinder Morgan's Elba Island terminal. Siemens has received an order for four SGT-750 compressor sets for the Magnolia LNG plant. Outside of the U.S., GE has been selected to supply LMS 100 gas turbine compressor sets for Canada's first major LNG export terminal, now in construction in British Columbia.

Mitsubishi Hitachi Power Systems (MHPS) is a recent entrant into the LNG game. Its two-shaft H-100 gas turbine, rated at 120 MW, has been qualified by ExxonMobil, Shell, Total and Bechtel for mechanical drive.

The H-100 has been selected by ExxonMobil for a multi-train LNG liquefaction plant in Mozambique. It will drive centrifugal refrigeration compressors manufactured by Mitsubishi Compressor Corp. The Mozambique project is awaiting a final investment decision by ExxonMobil. ■

Mark Axford is President of Axford Turbine Consulting, which offers services to customers including selling, sourcing, appraisal, valuation, forecasting and market analysis. For more information, visit axfordconsulting.com

WESTERN TURBINE USERS CONFERENCE

AERODERIVATIVE MAINTENANCE AND REPAIR, SERVICING HEAT RECOVERY STEAM GENERATORS, AND RAISING FLEET RELIABILITY WERE AMONG THE MANY TOPICS PRESENTED

BY DREW ROBB

The Western Turbine Users Inc. (WTUI) conference in Las Vegas in March detailed the operation & maintenance of GE aeroderivative gas turbines (GTs). This drew over 1,100 users to hear from their peers, as well as from O&M experts, such as Calpine, MTU Power, TransCanada Turbines, IHI Japan, Air New Zealand Gas Turbines and GE Power.

GE, HRST, and Petrobras discussed cybersecurity, the role of natural gas in the energy mix, heat recovery steam generator maintenance, and fleet management reliability and maintainability.

Chuck Casey

Chuck Casey, President of WTUI delivered a keynote that warned about cybersecurity (*Turbomachinery International*, March/April 2019). Terrorists are focusing efforts on disrupting the electric grid overseas, he said. U.S. plants, therefore, have to be more vigilant.

"Physical security and cybersecurity intertwine so there is no blaming it on IT anymore," said Casey. "SCADA, plant controls, and other systems must be hardened in a tight network."

He cautioned users not to pick up stray USBs and plug them into their systems. Contractors should be monitored, he said, as materials and software brought into facilities may be infected with a virus, especially overseas component suppliers.

GE view

Martin O'Neil, GM Aero Product Line, GE Power, said the use of GTs in grid firming and balancing of renewables was not happening at the rate expected.

Still, natural gas will play a vital role in the future of the power market, he said. Planetwide, electrical demand is growing at 2% per year and will continue to do so for foreseeable future. The highest growth is in developing economies.

But with 700 GW of coal and nuclear retirements due in the next 20 years, gas facilities are going to be needed.

"Aeroderivative GTs are the best complement for renewables," said O'Neil.

Power density is the big strength of GT plants. They use 50-to-100 times less space per MHW compared to renewables with energy storage.

"Wind and solar will struggle to provide the power needed for mega-cities with tens of millions of people," said O'Neil. "GE will be investing in the gas turbine marketplace, and aeroderivatives are going to be a primary focus."

Continues on page 20

LM6000 track

Andrew Gundershaug, Plant General Manager at Calpine Corp., introduced representatives from GE-authorized service shops to discuss various LM6000 issues.

The LM6000 PD high-pressure turbine's leading-edge Stage 1 nozzle has experienced a few instances of burn through. Inspection revealed a missing leaf seal and the combustor liner lip with wear steps. Missing leaf seals had caused cooling air leakage that resulted in less cooling of the nozzle airfoil.

Service Bulletin SB306 provides an improvement plan to address leaf-seal issues. GE recommends the addition of brazed doublers to both the inner and outer seal, as well as replacement of current coil spring material with INCO X-750.

In addition, adding a lug on the inner band will limit leaf-seal deflection. Combustor liner lip wear is repairable with a T800 anti-wear coating.

"If the leaf seal is gone, you may need to buy a new combustor," said Ken Ueda, Manager of the Customer Support Group at IHI Japan. "Fixing it could save you a lot of money."

Hydraulic starter carbon seal oil leakage was also discussed. Carbon seals are used in three locations within the LM6000: the liquid fuel pump pad, the starter pad seals and the VG pump pad.

The seals used as part of the starter assemblies had the most leakage. Several were found to be damaged before reaching 8,000 hours. Indicators of a problem included high oil consumption.

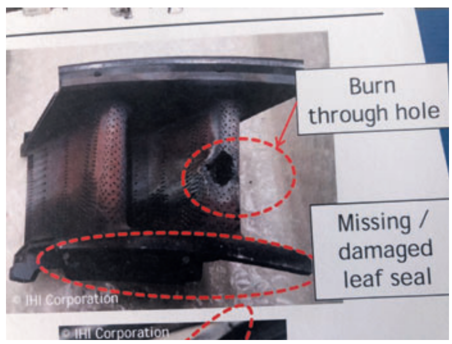
Users should check each drain line to look for signs of leakage. Further recommendations: replace carbon seals annually to prevent unscheduled repair; annual cleaning is recommended for starter carbon seals; and separating the drain lines corresponding to each system would simplify the oil-leak troubleshooting process.

Coupling nuts on the gas-supply hose were found to have loosened in some cases. Users were advised to tighten them in strict accordance with the engine manual. To avoid leakage on fuel, oil and hydraulic hoses and tubes due to loose connections, a good tip is to drill safety wire holes in all coupling nuts. You can add locking holes and have them safety wired.

Ralph Reichert, Gas Turbines Engineer at MTU Power, covered corrosion protection. Some users had observed excessive corrosion at the Variable Inlet Guide Vane (VIGV) inner and outer case. Corrosion on the forward surface of the bolt holes was heaviest. Corrosion pits were also found on the low-pressure compressor case, disks and shafts.

"Corrosion is common in these areas but varies from site to site and per operat-

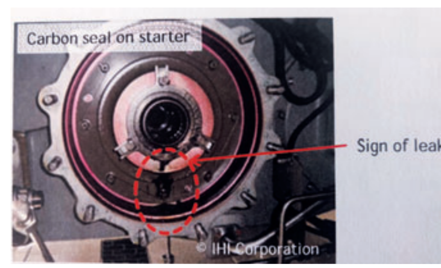
Users from around the world packed the LM6000 track



Burn through hole in the leading edge of the HPT Stage 1 nozzle

ing cycles in terms of degree of damage," said Reichert. "These areas were all exposed to inlet air, and moisture accelerates corrosion."

The recommendation is to keep GTs dry where possible and implement the relevant GE service bulletins on humidity control of

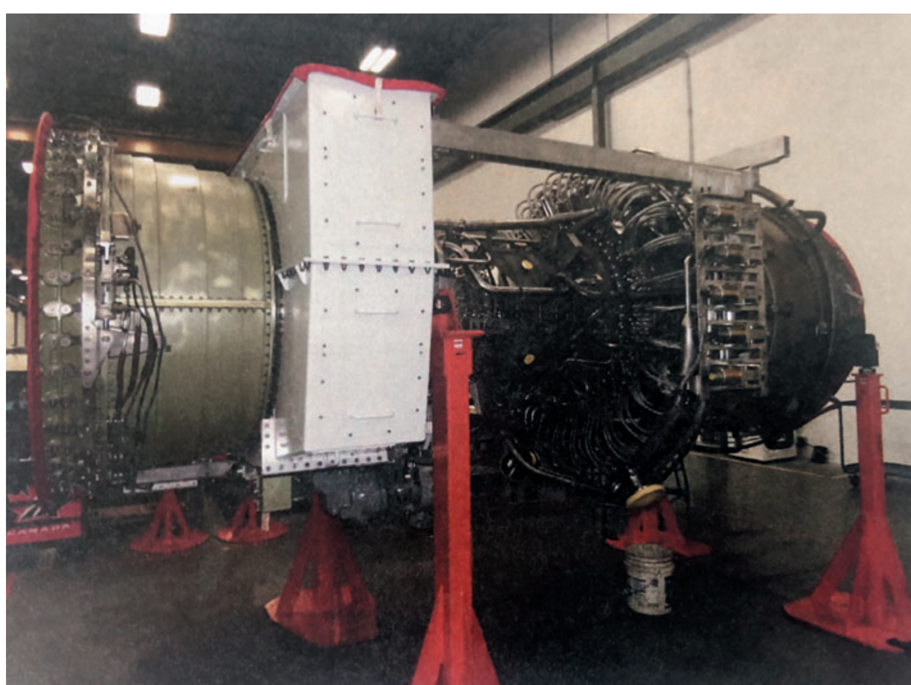


Leakage from carbon seals was observed in some LM6000s

LM packages. An epoxy repair is also available as an option for aluminum cases.

Low-pressure turbine (LPT) static pressure balance seal movement was the next topic to be addressed. One user reported a stall. Investigation found the cause to be static seal and rotating high-pressure system contact.

When the unit tripped, excessive pressure difference pushed the seal forward



LM6000 PD gas turbine. *Courtesy of TransCanada Turbines* and damaged the LPT static pressure balance seal and the HPT Disk Stage 2. One HPT Disk had to be scrapped and a complete disassembly in a depot was necessary for the repair. The lip of the pressure balance seal was machined in the shop to the minimum acceptable length.

Another user talked about an outage that led to the LPT module being sent to a service depot for an unscheduled repair. Disassembly showed severe damage in State 1 and 2 blades, including cracks, dents and loss of material.

On the surface of the nozzle segments, splashed material was found. Analysis discovered a probe to be the origin of this material. Users were advised to conduct semi-annual inspections of single thermocouple probes.

Reichert moved on to two test runs that failed due to erratic LPT vibrations. Trim balancing was unsuccessful. Inspection of the LPT found that nearly a third of the connection bolts of Stage 3 and 4 LPT Disks were sticking hard in their bolt holes and their nuts were insufficiently torqued.

A diameter check of the affected bolts did not show deviation to the manual's limits, but all bolt holes were too small. Thermal growth and improper bolting caused looseness, which resulted in disk misalignment and the rotor spinning out of axis. This eccentricity created erratic vibrations.

"Each flange bolt hole should be checked to ensure it is the correct diameter during reassembly to avoid similar problems," said Reichert.

Robert Smans, Senior Engineer at TransCanada Turbines (TCT), discussed engine preservation. He defined short-term preservation as less than 30 days and long-term as anything longer.

If an engine is going to sit idle for more than 15 days, operators should oil any wet bearings using Brayco 599 or equivalent. They should also cover the inlet, exhaust and VBV. If the turbine is in a container, lubricate it, install a desiccant, seal it and store in a shaded area.

"If the desiccant indicator remains blue, no action is required," said Smans "If the indicator is pink, replace the desiccant and oil the wet bearings within 14 days."

HRSG maintenance

An afternoon session delved into steam drum inspection and maintenance priorities for aging heat recovery steam generators (HRSG). Ned Congdon, Systems Engineer at HRST, noted that many HRSGs were built in the late nineties and early 2000s. With a typical life of 30 years, some are getting to the end of their term, and many others need serious attention.

He mentioned service and tools from HRST that could help. For example, a steam drum manway door kit includes spring washers to maintain tension and gasket compression during hot and cold cycles.

This eliminates the need to perform "hot-retorquing" of manway nuts, an inherently hazardous operational procedure. Other products include the HRST Shock-Master Economizer to address tube leaks caused by excessive differential temperatures between adjacent tubes, and pipe penetration seals made of fabric.

More attention is paid to HRSGs steam drums when those maintaining them have a better understanding of their components and inner workings. Downcomers take water from the drum to the feeders.

These feeders distribute water into tube panels. Evaporator panels convert some of the water into steam. The risers flow the steam and water mixture back up to the drum where steam and water separation takes place. A steam outlet channels steam to the superheater. Remaining water flows back to the downcomer.

"A water molecule can travel through the downcomer 15 times before reaching

Continues on page 22

the superheater," said Congdon.

As well as performing steam separation, the steam drum provides surge capacity and retention time for the HRSG. In the case of a failure, this offers two to three minutes more time before a trip.

Steam drums are also a good place to inject chemicals, and they provide a stable waterline that is used to control feedwater flow. Most steam drums concentrate dissolved solids in drum water and those drums offer the ability to control the solids level via continuous blowdown taken from the drum.

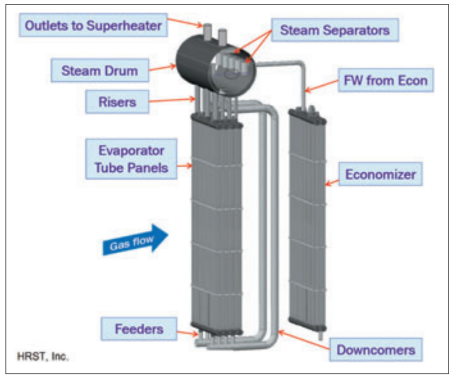
Within the steam drum are primary and secondary separators, as well as level measurement piping, nozzles, welds and manway openings.

Congdon called attention to steam purity degradation that can take place over time. Typically, steam drum purity is tested only during commissioning. He recommended regular testing to ensure impurities and solids are not entering the superheater tubes.

Fouling and degradation can happen gradually in steam separators. Fouling constricts the flow path, increases steam velocity and results in reduced moisture separation.

When agglomerators become about 25% fouled, they should be cleaned. Fouling can also build up in chevron final separators. If fouling is only on the surface, it is easy to brush off. But if the fouling goes deeper, it can cause serious separation problems.

The session covered several other areas of HRSG maintenance. If instruments show a high drum level, this could be due to problems with level transmitter calibration, or compensation calculations could be incorrect. Congdon advised users to continuously monitor saturated steam and to sample different nozzles if multiple parallel pipes are carrying the steam flow.



How HRSG components relate to the steam drum

Spring washers are recommended to maintain tension and compression

Corrosion found under insulation blankets covering condensate pots

Insulation blankets inhibit corrosion by preventing water ingress

Drum-level piping is critical for reliable drum-level indication, he said. Sensing lines, for example, can plug with debris, which creates errors. Corrosion of small diameter external piping can cause a forced outage.

"Inspect drum level piping for corrosion," said Congdon. "Inspect under the insulation blankets and use blankets that shed rainwater."

For HRSGs being cycled on and off regularly, a higher incidence of weld cracks

The WTUI exhibit featured hundreds of vendors

is likely due to the temperature differential. The saturation temperature increases most rapidly at low pressure, so a cold start has much more potential to cause drum shell damage than a hot start.

"A thick cold drum plus a fast pressure ramp rate generates stress at the large nozzles, which are often attached to the drum wall with partial penetration welds," said Congdon. "Users should demand full penetration welds, not partial penetration welds."

To inspect the welds in a steam drum, the basic steps are:

- Gather the various drum drawings and design documents. This should include nozzle weld details for the high-pressure drum, if possible
- Calculate the minimum wall thickness, as well as the shell and head material thickness
- Select and prepare the HRSG inspection team members (NDE contractor and plant personnel)
- Plan which drum internals need to be removed to permit weld inspection access
- Develop weld repair procedures prior to the outage
- Develop "scan plan" before performing phased array UT
- Be ready to perform a quick "Fitness for Service" evaluation to help decide whether weld repairs are needed now or can wait until a future outage.

A thorough visual inspection should be done with the drum drained so you can see everything. Do not leave any puddles as this can obscure cracks. Magnetic particle testing and dye penetrant testing are also recommended.

Fleet management

Davi D'Elia Miranda, Turbomachinery Consultant at Petrobras, lectured on how to improve the reliability and maintainability of GTs as part of fleet management. He used a risk-based maintenance policy with two key features:

- Balance between condition-based campaign extension and the risk of unavailability of spare engines
- Maintain corrective maintenance services at the operator-owned workshop for a subset of failure modes.

Considering independent failure modes and a probability distribution for each GT, he developed an overall gas turbine reliability metric as the product of all probability distributions for the entire Petrobras GT fleet in Brazil.

"Fleet management may be improved through the computation of such probability distributions to achieve a maximum likelihood estimate for fleets whose workshop maintenance history is fully known," said Miranda.

Fleet management may be improved in various ways:

- Simulation-based-optimization of the number of spare engines. This should account for factors, such as spare engines acquisition cost, maintenance cost over time, average net present value of the investment, and degree of organizational risk
- Calculating the probability of occurrence of failure modes
- Suitable sizing of spare parts inventories
- Suitable budget allocation based on the expected number of overhauls at third-party workshops
- Forecasting periods of high probability of spare engine unavailability allowing early reactions
- Preventive replacement scheduling.

"Petrobras has 44 LM2500 engines in service, including 18 spares," said Miranda. "Some engines are fixed at our workshop, and some are sent to third party workshop."

The WTUI show will be held in Long Beach, California from March 29th until April 1st of 2020. For more information, visit wtui.com ■

GT AIR FILTRATION

THREE MAJOR PROPERTIES DIFFER FROM ONE FILTER TO ANOTHER. THE TECHNOLOGY USED IMPACTS UPTIME AND OPERATING COSTS

BY MIKE ROESNER

At an outdoor gas turbine (GT) plant, inlet air must be clean and dry as it mixes with fuel to produce power. Airborne dirt and contaminants can hamper power output, drive up fuel costs and potentially damage critical components. According to the U.S. Environmental Protection Agency, around 1,300 pounds of particulate could still enter a GT housing and inlet air filter in a year of operation.

Each facility has different filtration needs based on variables such as:

Local environment: Is the plant in a humid or ocean-front location, a desert, agricultural, or arctic environment and is it subject to severe weather events?

Operating demands: Is the facility a peaking plant or does it operate continuously, or power a mechanical drive?

Inlet design: Does the system automatically pulse-clean the filters with compressed air during operation or does it operate as a static system?

There are also three primary filter characteristics that contribute to optimal GT operation for pulse filter housings: efficiency, water-tightness and pulse recovery rate. Since filter media are engineered for specific conditions, variations exist that make certain filters more suited to given environments.

Inlet guide vanes (left) after 1,200 hours of low-efficiency filtration and the same components (right) after 5,000 hours of high-efficiency filtration

Plants in some geographies demand all three characteristics; some, just one or two. Those charged with filter selection, therefore, can use these characteristics to only pay for the filtration characteristics that are required.

Efficiency

Efficiency refers to the proportion of inlet air particulates the filter removes, measured by particle concentration upstream and downstream of the filter. This is the most widely recognized filter trait, and until recently, the only one with consistent testing standards.

The cleaner air produced by higher filtration efficiency produces better combustion, sustained power output and longer lasting turbine blades. A low-efficiency filter used for 1,500 hours, for example, allows significantly more fouling than a high-efficiency filter used for 8,000 hours.

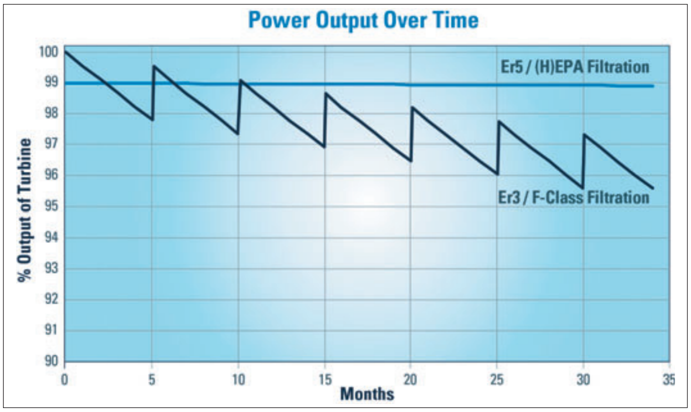
Of course, there are cost trade-offs to consider. Lower-efficiency filters have a low initial price tag. However, they can sometimes require on- and off-line water washings to periodically regain some of the power output loss due to fouling.

High-efficiency particulate air (HEPA) filters cost more initially but stabilize power output due to increased compressor health. Due to being more restrictive, though, the turbine will put out slightly less initial power than a comparable lower-efficiency filter that offers a lower initial pressure drop.

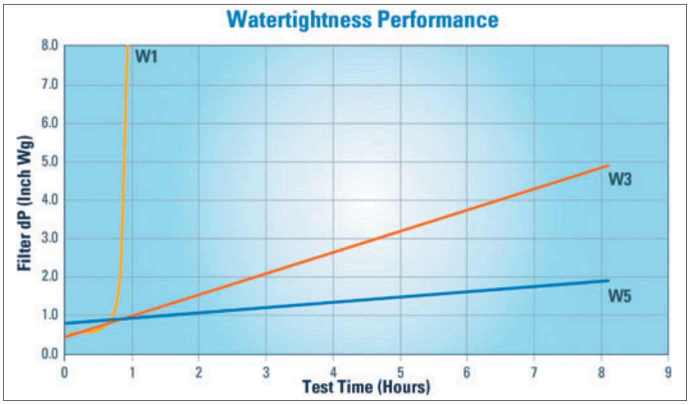
It is a case of balancing these factors to determine the right choice, i.e., does the stabilized power output of HEPA filtration offset the decrease in output due to efficiency loss in lower-efficiency elements.

Water-tightness

How well a filter stops water or how it performs in a wet condition may outrank efficiency as a priority for some operators. In



With a lower-efficiency F-Class filter, multiple compressor washes may be required over time to recover efficiency and power output. A HEPA filter maintains steady performance.



Higher levels of water-tightness indicate the ability to prevent water ingress and provide stable pressure drop when challenged with water. Filter testing indicates how pressure drop increase is reduced with higher-rated filters.

humid or ocean-front locations, salts and other dissolved solids carried by water can be highly corrosive, often even more detrimental than airborne contaminants.

GT manufacturers usually recommend that less than 0.01 parts per million (ppm) of salt enter the system. In coastal environments, airborne salt can easily range from 0.05 to 0.5 ppm on a typical day. This is more than 10 times the chloride concentrations of inland areas.

A good way to test water-tightness is to direct a 60-liter-per-hour water spray at the filter over an eight-hour period. The filter pressure drop and volume of water passing through the filter are recorded. The best-performing filters survive the test with at least 99.5% water stoppage and no more than a 2-inch water-gauge (WG) increase in pressure drop across the filter during this test.

Pulse recovery rate

When dust builds up on filters, the resulting drop in airflow compromises power output. As an option, some inlet housings have a self-cleaning mechanism incorporated into their design. In these systems, compressed air pulses dislodge dust while the system operates.

Pulse recovery rate measures how cleanable air filters are in such systems, i.e., how often they can be pulsed and how quickly they return to a like-new condition. A filter with a high pulse recovery rate sheds dust more easily and restores optimal airflow faster.

Fast pulse recovery is a high priority in deserts, high-dirt load or Arctic environments where there is continual exposure to dust, snow, ice or the potential for sudden episodes of heavy loading, such as sandstorms. Some operators turn on their pulsing systems prior to severe weather events to prevent fouling.

As with efficiency and water-tightness, pulse recovery can be rated using laboratory test data. After exposing filters to simulated high-dust conditions for a long duration, pressure-drop and efficiency can be measured.

The construction of filter media determines cleanability. Surface-loading filters trap particles on the top media layer where they form a slight dust cake that is easily pulse-cleaned. Depth-loading filters, by contrast, have media layers that trap progressively smaller particles and thus cannot be readily cleaned.

For those with a static system, it is advisable to specify filters with good dust-holding capacity. Back this up by monitoring pressure drop and turbine performance. Change the filters when pressure loss exceeds an acceptable limit, as there is no way to recover a static element.

Knowledge of these three properties can help operators periodically evaluate plant filtration needs. It may become necessary to convert to a more optimal filter if the environment or operating conditions change.

If a rock quarry re-opens near a GT plant and creates dirtier air, for example, a plant with a pulsing system might consider converting to filters with better pulse recovery. Alternatively, if a coastal peaking plant switches to base-load operation, the owner may want to upgrade to filters with higher efficiency and better water-tightness. ■

Mike Roesner is Aftermarket Manager of the Gas Turbine Systems division of Donaldson Company. All photos courtesy of Donaldson. For more information, go to go.donaldson.com/gas-turbine-systems/ or call 800-431-0555.

COMBINED CYCLE TECHNOLOGY TRENDS

A REVISED OUTLOOK ON THE FUTURE PROSPECTS FOR GAS TURBINE DEVELOPMENT AND EFFICIENCY

BY S. C. GÜLEN

In an earlier article published in *Turbomachinery International* 2016 Handbook (P. 24), the author provided a brief glimpse at future prospects for gas turbine (GT) combined cycle technology based on its historical evolution (Figure 1).

Since then, major OEMs have announced "world records" and published performance ratings as high as 64% (net lower heating value at ISO base load). However, there are thermodynamic limits imposed on GT simple and combined cycle performance.

Where can further efficiency improvements be realized? In many areas of gas turbine technology, only nominal advances are possible. The most promising developments for further gains in efficiency are probably to be found in the hot gas path and the axial compressor. However, the gains anticipated in these and other areas of technological upgrade are not expected to boost efficiency by a large margin.

Thermodynamic limitations

The GT is an internal combustion engine. As such, it is a member of the larger family of heat engines. The starting point of any heat engine is the thermodynamic cycle that describes its basic operation. For the GT, it is the Brayton cycle.

Like all heat engine cycles, the Brayton cycle is a poor approximation of the thermodynamic ideal quantified by the hypothetical Carnot cycle. The cycle hierarchy is illustrated graphically on the temperature-entropy (T-s) diagram (Figure 2).

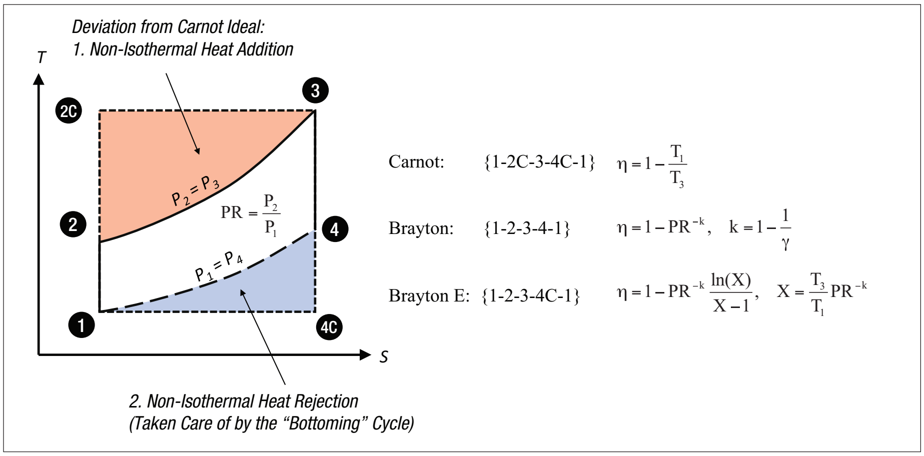


Figure 2: Gas turbine cycle hierarchy (Brayton E is the Enhanced Brayton cycle, which is the ideal proxy for the combined cycle)

- Carnot cycle is the theoretical maximum imposed by heat source and sink temperatures, T_3 and T_1, respectively
- Next comes the air-standard, ideal Brayton cycle, whose performance is controlled solely by the cycle pressure ratio, PR
- At the bottom lies the real cycle beset by hardware imperfections, which, strictly speaking, cannot be depicted on a T-s diagram.

The deviation of the ideal, air-standard Brayton cycle from the Carnot cycle can be quantified by the two, roughly triangular areas in the T-s diagram of Figure 2: heat addition imperfection quantified by the area {2-2C-3-2}; and heat rejection imperfection quantified by the area {1-4-4C-1}.

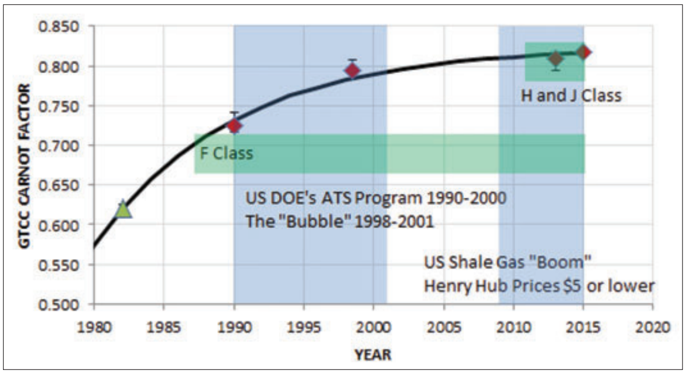


Figure 1: Historical improvements in GT technology.

The second imperfection can be rectified to a great extent by a second thermodynamic cycle via waste heat recovery. The waste heat in question is the energy content of the GT exhaust (state-point 4).

This is the thermodynamic driver behind the Brayton-Rankine combined cycle, wherein the ST Rankine bottoming cycle makes use of the GT exhaust heat to generate additional power. The ideal combined cycle is essentially an enhanced Brayton cycle represented by the area {1-2-3-4C-1}.

It is a function of heat source and sink temperatures, T_3 and T_1 and the cycle pressure ratio, PR. Since T_1 is dictated by the site ambient conditions, there are only two parameters left to the design engineer for cycle optimization, T_3 and PR. It can be shown that:

- The optimum (not the maximum) combined cycle efficiency is obtained when GT specific output is maximum
- Brayton cycle PR corresponding to maximum specific output is a unique function of T_3.

The counterpart of T_3 in the actual GT is the turbine inlet temperature (TIT). This is the hot gas temperature at the exit of the combustor and at the inlet of turbine stage one nozzle guide vanes.

It is not to be confused with the firing temperature, which is the hot gas temperature at the inlet of turbine stage 1 rotor blades. Firing temperature is about 200°F lower than TIT primarily due to dilution with upstream (nonchargeable) cooling air.

In essence, turbine inlet temperature is the primary combined cycle design parameter. TIT is also the determinant of the heavy duty industrial GT class hierarchy. Based on their introductory ratings, advanced class gas turbines are classified as follows (only air-cooled and non-reheat machines are considered):

F class (TIT = 1,400°C)
H Class (TIT = 1,500°C)
J Class (TIT = 1,600°C).

The current iteration of the machines in each class have TITs up to about 50°C higher than the introductory values. The next generation of gas turbines is likely to be a 1,700°C TIT machine.

Basic thermodynamics tells us the theoretical upper limit of combined cycle efficiency for a given TIT (the enhanced Brayton cycle efficiency in Figure 2). State-of-the-art technology can only achieve a fraction of that upper limit.

That fraction is known as the technology factor (TF). In the 2016 TMI Handbook article (Figure 1), TF for H and J class GT combined cycles was around 0.82. This is a testament to the engineers designing these power plants and the equipment therein.

The high value of TF and its asymptotic trend (a line that approaches a curve but never touches) are indicative of the cost and difficulty involved in achieving further gains.

Combined cycle efficiency estimates (ISO base load ratings) projected for three different TITs are summarized in the Table. Cycle pressure ratios are approximate optimum values (to maximize the GT-specific output).

Estimates are provided for two TF predictions. Today's state-of-the-art, based on published field-measured performances (discounting hyperbole), supports the lower value. It remains to be seen if an aggressive technology push for the higher TF will bear fruit.

Table: Projected combined cycle efficiencies

TIT, C	1,500	1,600	1,700
TIT, F	2,732	2,912	3,092
PR	18	22	25
T3/T1	6.15	6.50	6.84
X (see Figure 1)	2.69	2.69	2.73
Carnot	83.7%	84.6%	85.4%
Brayton	56.2%	58.7%	60.1%
Brayton "Enhanced"	74.4%	75.8%	76.8%
Combined Cycle, TF=0.825	61.4%	62.5%	63.4%
Combined Cycle, TF=0.85	63.2%	64.4%	65.3%

Opportunities for improvement

In order to investigate where the opportunities for improvement lie, a sample calculation is done. An advanced class gas turbine with 1,600°C (2,912°F) TIT and cycle pressure ratio of 22:1 (simple cycle efficiency of 41.4%) is taken as the starting point.

For PR = 22, the theoretical efficiency entitlement is 58.7% (with zero losses, isentropic components and no turbine cooling). Going through the elimination of loss mechanisms in an orderly fashion, one ends up with the stairstep chart in Figure 3. The hot gas path provides the largest opportunity for improvement.

The improvements in Figure 3 add up to about 12%. Thus, the maximum possible efficiency is 53.4%. The difference between 53.44% and 58.7% is due to the exergy destruction (irreversibility) in the combustor. There is nothing that can be done to alleviate this fundamental loss.

Efforts to minimize the hot gas path losses include:

• Reduction of cooling flows materials (superalloys, ceramic matrix composites), casting techniques (directionally solidified,

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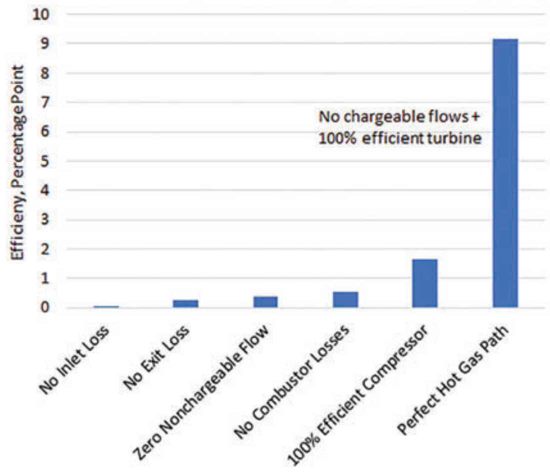
Figure 3: Gas turbine Brayton cycle entitlement stairsteps



The most promising developments for further gains are probably to be found in the hot gas path and the axial compressor, but this is not expected to boost efficiency by a large margin.

single crystal), film and effusion cooling, thermal barrier coatings

- Brush and honeycomb seals, and reduced clearances
- 3D CFD for airfoil profiles and vane/blade geometries.

Technologies that can help in this endeavor are additive manufacturing, faster computer processing, data analytics and adaptive controls.

The goal of combustor improvements is to achieve stable, premixed combustion for low NOx at 1,700°C. The enabling technology is axial fuel staging.

The concept can be thought of as reheat or sequential combustion without a turbine stage between the combustors. The technology also enables the turndown of the GT to low loads while staying emissions-compliant.

Modern axial compressors are also quite close to entitlement with polytropic efficiencies of 93% or higher. Similar to the combustor, the focus of the designer is on stable operation without surge or stall across the entire operating regime (ambient and load conditions).

The enabling technologies are 3D aero design codes and multiple stages of variable stator vanes with model-based (adaptive) controls. As the GTs become bigger and hotter, it is imperative to optimize component size (lower stage numbers and flow-path profiles). One OEM's next generation machine has a 12-stage axial compressor with a pressure ratio of 24:1.

In addition, OEMs have originated various initiatives and technologies to improve performance. This includes sequential (reheat) combustion, rotor and hot gas path cooling air, steam cooling of hot gas path components, welded rotors, hydraulic clearance optimization, serrated (Hirth) or Curvic coupling of disks and fuel moisturization.

For the bottoming cycle, the status of the technology maturity is such that it allows only incremental improvement at best. As turbine inlet and exhaust gas temperatures creep up, the key thermodynamic design principle is to match source (exhaust gas) and sink (steam) temperatures.

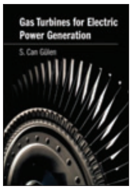
This is primarily a material-and-cost issue. The state-of-the-art is 600°C (1,112°F) in main and hot reheat steam temperatures. At existing steam cycle pressures (as high as 180 bar or 2,600 psi for high-pressure steam), alloy tubes (in the heat recovery boiler) and pipes are required.

This adds significantly to construction costs. Even higher steam temperatures are requisite for an optimal match with exhaust temperatures pushing 650°C or higher.

Rating performances are typically quoted with minimal auxiliary equipment loads and once-through water cooled condenser (lowest possible steam turbine back-pressure with minimum parasitic loss).

In many places in the world, water scarcity and environmental regulations make this impractical. Another site-specific limit is the stack gas temperature from a plume abatement perspective.

On paper, it is possible to design a heat recovery boiler and steam cycle to bring the stack temperature to very low levels. However, even when cost is ignored, it could only be built in a few places in the world. ■



S. C. Gülen is a Bechtel Fellow and Senior Principal Engineer at Bechtel Infrastructure and Power. For more detailed coverage of the concepts discussed herein, see his recent book Gas Turbines for Electric Power Generation (Cambridge University Press, 2019). For more information, the author will make a presentation at Turbo Expo 2019.

RECIP ENGINES UP THEIR GAME

MODERN RECIPS ARE SEIZING MARKET SHARE IN THE SMALL- AND MID-SIZED POWER PLANT SECTOR

Reciprocating engines are no longer relegated to small power projects or emergency generation. Today's engines can function up to plant sizes of 600 MW and run on multiple fuels.

They can be used in baseload or for peaking power. They can also operate in combined cycle mode and as part of a combined heat & power (CHP) plant.

The world's largest internal combustion engine power plant, for example, is near Amman, Jordan. It is powered by 38 Wärtsilä 50DF multi-fuel engines with a capacity of 573 MW.

Amman Asia Electric Power Company (AAEPC) owns the plant, which is known as IPP3. Its purpose is to deal with sharp daily peaks of electricity demand in Jordan.

"By starting one engine at a time, the plant can follow the demand precisely," said Taemin Kim, Administration Manager of AAEPC.

A 250 MW sister plant known as IPP4 is also in commercial operation. Since the two engine plants now cover most of the peak demand, the gas turbine (GT) power plants provide steady baseload power. These Wärtsilä plants can run on fuel oil and natural gas.

The Jordan plants are far from the only examples of large-scale reciprocating engines facilities. Another under construction and owned by Energía del Pacífico in Acajutla, El Salvador, will run on LNG-based natural gas. The 378 MW facility will incorporate 19 Wärtsilä 50SG engines and a steam turbine (ST). It uses a closed-loop cooling system that requires zero water consumption.

Simple cycle efficiencies of recip engines lie in the 46%-to-49% range. Exhaust gases from reciprocating internal combustion engines are around 360ºC. As a result, Heat Recovery Steam Generators (HRSGs) designed for reciprocating engine plants are simple in design. They provide steam at one pressure level—about 15 bar.

Since late 2014, IPP3 (537 MW) and its sister reciprocating engine plant IPP4 (250 MW) have captured the daily peaks in electricity demand in Jordan.

Courtesy of Wärtsilä

One engine can be used to preheat all the HRSG exhaust gas boilers with steam to keep the HRSGs hot and enable fast starting. The ST can be run with 25% of the engines at full load, or 50% of the engines at half load. For a 12-engine power plant of around 200 MW, only three engines need to be operating to produce enough steam to run the steam turbine.

Reciprocating engines can burn a variety of fuels, including natural gas, light fuel oil, heavy fuel oil, biodiesel, biofuels and crude oil. Engine sizes from 4-to-30 MW. Lean-burn technology means that units can reach full load in two minutes under hot start conditions: Cooling water is preheated and maintained above 70°C, engine bearings are continuously pre-lubricated, a jack-up pump supplies pre-lubrication to the generator bearings, and the engine is slow turning.

As a result of being online in a couple of minutes, the power plant can quickly adjust load by bringing additional engine sets online to meet changes in electric demand.

These plants also have a wide range for emissions-compliant turndown. As load is decreased, individual units are shut down to reduce output. The engines that remain operating can generate at full load. The output of a 300 MW plant can be turned down to 18 MW.

Combustion engines are less sensitive to temperature and humidity, retaining their rated efficiency and power output over a broader range of ambient conditions. At an ambient temperature of 40°C, combined cycle efficiency decreases by 3.5% compared to ISO conditions. In a Wärtsilä Flexicycle plant, efficiency drops by 1.1%.

Electric power represents one of the largest consumers of water globally, about 15% of the world's water withdrawals. In the U.S., over 40% of freshwater withdrawals are for thermoelectric power. A combined cycle gas turbine power plant with a recirculating system will consume approximately 780 liters/MWh. In combined cycle, a Flexicycle plant with a cooling tower will consume 409 liters/MWh.

In addition, water-stressed regions can deploy Dry Flexicycle plants. They use air-cooled condensers (dry cooling) to reduce water use to near zero. The cooling system uses a radiator closed-loop circuit and fans to help dissipate heat. ■

STEAM TURBINE WATER WASHING

HOW TO SAFELY REMOVE WATER-SOLUBLE MINERAL DEPOSITS UNDER NORMAL OPERATING CONDITIONS

BY DAVID STASENKO & JOSEPH REDOVAN

Water washing of steam turbines has long been done at reduced loads, flows and speeds using special equipment in the steam inlet piping. More recently, however, conservative application limits have been developed to implement water washing within normal operating conditions, including for some of the generally dry stages of the condensing section of a steam turbine.

This procedure allows water washing to be carried out within the normal operating range of speeds and steam flows.

Water injected into an operating steam turbine can remove contaminant mineral compounds that have plated onto the airfoil surfaces (Figure 1). The controlled injection of water increases the moisture content of the wet stages and moves the moisture transition point further upstream.

Water-soluble deposits might then be washed from those normally dry stages. However, adequate monitoring and careful control of the water washing process are required to prevent damage to the steam turbine during the washing process.

Before water washing, the end user must complete performance trend monitoring of key operating parameters, including speed, power, section flows and internal pressures. This helps to determine the degree of degradation of the turbine.

Figure 1. Turbine rotor with mineral deposits.

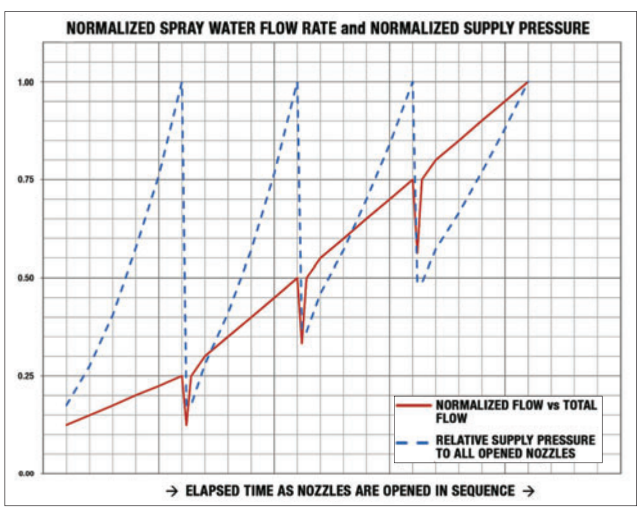


Figure 2. Schematic example of ramping water wash flow with four nozzles.

Gradual long-term increases in flow or turbine steam path pressures at the same nominal operating conditions provide a good indication that mineral deposits are partially obstructing the steam path.

An engineering study was done to verify that steam turbine internal parts could withstand the effects of the thermal transient caused by injecting relatively cold water into the hot casing and valve lifting bar.

After careful review of both the transient thermal analysis as well as a low cycle fatigue analysis, the conclusion is that there is no risk of the valve lift bar failing within the conditions analyzed.

The basic procedure for water washing does not change with speed or load. However, the risk of damage to the turbine steam path does increase compared to washing at reduced speeds and loads.

During water washing, the water injection flow should be increased and decreased at a limited rate to minimize the risk of axial rubs from unequal cooling or heating of the steam turbine rotor and casing. Although the water flow rate can be gradually moved up or down, this change is usually intermittent or in steps in a multi-nozzle system (Figure 2).

There are several reasons for this. The minimum water pressure for atomization should be approximately 30 psi greater than the injection location. This leads to a non-zero flow at the start of washing.

Additionally, when bringing spray nozzles online one at a time, the supply pressure to the opened nozzles should be quickly decreased before the next nozzle is opened. The pressure should then be increased to all open nozzles to approximate an overall ramping flow rate. This helps maintain a smoother overall temperature ramp rate.

Finally, as each nozzle is opened, it should have a low flow of "tempering" water initially introduced to minimize thermal shock. The supply pressure should then be quickly increased to the pressure required to obtain the flow fraction that provides a smooth increase in water flow.

Water washing can remove water-soluble mineral deposits from the internal surfaces of a steam turbine within the normal operating range of speeds and steam flows. This water washing procedure can be performed on a straight-condensing machine or the condensing (low pressure or LP) section of a turbine with a controlled extraction. ■

David Stasenko is a Senior Aerodynamic Engineer at Elliott Group, USA. Elliott developed the water washing procedure discussed in this article.

Joseph Redovan is a Stress Analysis Engineer at Elliott. For more information, visit www.elliott-turbo.com

USING COATINGS TO EXTEND LIFE

COATINGS PROVIDE A BARRIER AGAINST EROSION, CORROSION AND HEAT IN THE FIGHT AGAINST WEAR AND TEAR

BY MATTHEW WATSON

If you operate turbomachinery, the best way to extend the service life is a barrier against erosion, corrosion and heat. Getting the right barrier, or coating, can extend the time between scheduled maintenance and reduce the number of unscheduled events. It can also improve fuel consumption by up to 1.7%.

Hard-chrome plating has been used for many power generation applications, including gas turbine shafts. However, heat and abrasives can dull the surface of turbine shafts over time. It is not uncommon for a low-amplitude, high-frequency application to wear through chrome plating. Similarly, impurities deposit on steam turbine surfaces and cause erosion.

Hard-chrome plating ranges in hardness from 700HV to 1,000HV (Vickers Pyramid Number). A chemical nickel coating on a component can achieve about 600HV. A better option is a carbide coating, such as tungsten carbide (1,200HV) or chrome carbide (900HV).

OEMs and machine shops apply carbide coatings using a high velocity oxygen fuel (HVOF) spray process. An HVOF gun or torch takes feedstock and heats it to a semi-molten state, then applies the coating to a machine component using kinetic energy from a hot-gas stream. The process makes for a coating that is dense, has low porosity, and resistance to wear and abrasion. A tungsten carbide coating on a turbine shaft or fan blade can improve lifespan by as much as 45%.

Another option is abradable coatings (e.g., aluminum silicon, nickel graphite) applied via a plasma- or thermal-spray gun. Abradable coatings are softer than steel, titanium and nickel alloys. Applying an abradable coating to an engine shroud makes it possible to reduce the clearance between the blade tips and casing. They also work well on steam turbine shaft seals and help to reduce leakage.

Nickel graphite is a good coating to apply to compressor shrouds and labyrinth seals. It can withstand operating temperatures of 900°F. Cobalt-based abradables are better choice for components with service temperatures of up to 1,300°F. Zirconia-based ceramic abradables can protect components against thermal shock when operating at more than 2,000°F.

An employee at HFW Industries finish-grinds a shaft for a power industry customer

A high velocity oxygen fuel (HVOF) torch applies tungsten carbide to a turbine shaft.

Precision finishing

Once an OEM or machine shop applies a coating, it takes one of three steps to achieve the desired finish: Leave the coating as applied; machine the coating; and grind the coating with a diamond-wheel grinder to a specified finish, measured in roughness average (Ra).

Power generation applications generally require machining or grinding to achieve finishes ranging from 8 to 16 Ra or finer. Grinding HVOF-applied metal compounds to the appropriate tolerances is a skilled activity.

Cobalt- or zirconia-based abradables can require machining too, but not grinding, to attain the desired finish. During the spraying process, OEMs and coating facilities scrutinize the process parameters of the spray torch to obtain the correct hardness or porosity. This is best done by metallurgical analysis in a materials lab on the premises.

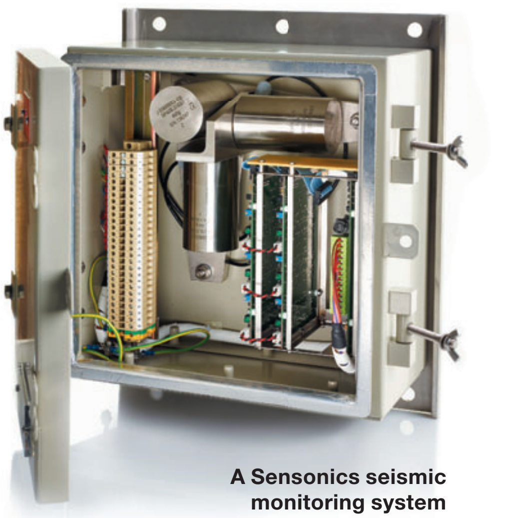
Projects often require machine shops to undertake pre- and post-machining to prepare components. Operators must carefully monitor the speeds and feeds of machining or grinding tools when finishing coatings, otherwise they can de-bond or tear the coating. Done right, however, abradable coatings enable turbomachinery users to reach higher operating temperatures and increased efficiency and reliability. ■

Matthew Watson, Vice President of Operations for HFW Industries, a Buffalo, N.Y.-based machine shop serving industries such as power generation and chemicals. For more information, visit hfwindustries.com

SEISMIC MONITORING

INFRASTRUCTURE MUST BE PROTECTED AGAINST DISASTER

BY RUSSELL KING



A Sensonics seismic monitoring system

Following the Fukushima incident in 2011, the power and energy industries renewed their focus on risk mitigation from extraordinary events caused by nature. Regulatory bodies around the world revisited the plant's design and risk analysis, as well as its accident-management strategy and the periodic safety review policy related to the facility's location.

Many nuclear power stations, oil and gas terminals and power plants are located on the coast where there is higher risk of flooding from seismic events and severe weather. The operational monitoring of seismic vibration for structures and equipment plays an important role in providing automatic shutdown protection and the recording of seismic events for post analysis.

No two facilities are the same in terms of their approach to seismic monitoring and protection. Some sites use data from the national network of geophysical instruments, while others implement independent monitoring and shutdown on each critical plant item.

The structural effects to be expected from an earthquake result from the vibration induced by the event, classified in terms of seismic response spectra. This defines the ground acceleration magnitude versus frequency, typically over a range of 0.1Hz to 100Hz.

Two such types of spectra are specified, the Operational Basis Earthquake (OBE) and the Design Basis Earthquake (DBE), based on a predicted worst-case seismic event within a specified period (for example, OBE may be specified within 100 years).

Secondary response spectra are derived from ground accelerations through modelling to predict the response of each structure and each level within that structure.

Typically, a plant allocates several seismic categories for specifying design requirements according to the safety class. The highest category demands the equipment or process be tested to the DBE level plus a margin (+40% is recommended in IEEE- 344, Standard for Seismic Qualification of Equipment for Nuclear power generating Stations).

Any earthquake above the OBE level may result in a plant shutdown until post analysis and inspection determine that the plant can safely operate.

The challenge is to design and construct cost-effectively to meet the seismic categorization and provide sufficient margin. It may not be possible for all equipment or processes to fully meet its categorization.

This is where seismic monitoring systems can provide detection of the OBE event and bring the process to a safe state. Not only must these monitoring systems be robust, they also need to exhibit high levels of availability beyond the DBE magnitude event to maintain a valid alarm function.

Various safety standards are applied to obtain a stated availability, with EN IEC 61508 being the most common approach. Adherence to such a standard provides a stated system reliability and availability while providing an understanding of the systematic failures and ensuring compliance with the 61508 Lifecycle Model.

Sensor differences

The starting point with any seismic monitoring design is the sensor. There is a clear technical difference between the types of sensors used for seismic protection and those used for geophysical earthquake monitoring.

Geophysical seismic monitors use broadband magnet and moving coil (electrodynamic) sensor arrangements capable of measuring micro g acceleration events with sinusoidal periods of over 100 seconds.

Strong motion sensors for seismic protection applications only need to provide a resolution down to 1 mg and a response to 10 seconds. While electrodynamic sensors have been used historically, piezoelectric-based accelerometers are preferred. They match the technical requirement and provide higher reliability as they have no moving parts.

A trend in vibration monitoring is the adoption of Micro Electro Mechanical Systems (MEMS) devices for sensing applications. They offer low-frequency response and exhibit the required dynamic range for strong motion seismic monitoring.

The relatively low cost and small size of MEMS devices suit applications where many measurement points are required on structures for a limited time. However, adoption has been slow for the seismic-protection market where reliability and maintainability are key.

Significant earthquake events are few and far between. Therefore, it is necessary to verify an installed strong motion sensor is working correctly. It is common to have a secondary coil arrangement which can be excited and stimulate movement of the mass to verify calibration without physical shaking. This self-test feature is a critical requirement.

It is common to use redundant sensor configurations in the overall monitoring system concept. Three physical locations are monitored with triaxial sensors capable of measuring acceleration in the three orthogonal axes.

The acceleration of each sensor is processed by a trip amplifier with the overall triaxial unit performing a one-out-of-three (1oo3) logic operation to derive the OBE alarm. Alarms from each location are fed to the control panel which determines the final trip result.

The avoidance of SMART devices within the protection loop eases the analysis burden to meet safety requirements. It is the solution preferred by most users. Separating the protection and event recording functions enables the latest technologies and features for seismic waveform recording without impacting protection safety. ■

Russell King is Management Director at Sensonics, a UK-based company specializing in vibration, displacement and speed monitoring. For more information, visit sensonics.co.uk

RAISING MAINTENANCE EFFICIENCY TO MINIMIZE DOWNTIME

Gregor Stoecker, MTU Power's Director of Sales and Marketing for Industrial Gas Turbines, discusses the aeroderivative market, aftermarket services, brush seals and expansion plans.

What is MTU Power?

MTU Power is the MTU Aero Engines brand for all services relating to gas turbines. Our expertise ranges from developing, engineering and manufacturing parts and modules for original equipment manufacturers (OEMs) to aftermarket care for LM series aeroderivative gas turbines.

As part of the MTU Aero Engines Group, we are at home in the aviation world, where the highest technological and quality standards are the norm. The company operates a global service network with locations in the Americas, Europe and Asia-Pacific. More than 10,000 employees from over 60 nationalities serve MTU's customers.

What differentiates you from competitors?

Our biggest differentiator is the experience, dedication and creativity of our people. This helps our customers to solve all manner of problems, keep their costs down and increase turbine reliability.

What aeroderivative services do you offer?

MTU Power is a maintenance, repair and overhaul provider for GE LM2500 and LM6000 engines. We are committed to reducing operational cost and maximizing performance and reliability. Our services are flexible and customized. Of all licensed depots, MTU Power has the widest range of GE LM subsystems in its portfolio. We provide engineering support for any turbine or maintenance event.

Our maintenance line tears down, inspects, repairs and builds up GE LM2500 and LM6000 gas turbines. Our goal is to have turbines smartly moving through the shop, so operators can cycle them back into revenue service with minimum impact on operations.

Our global network of experienced professionals work out of MTU's level II service centers around the globe:

- MTU Maintenance Service Center Ayutthaya, Thailand
- IGT Service Center Mongstad, Norway
- MTU Maintenance IGT Service do Brasil, Brazil
- MTU Maintenance Service Centre Australia
- MTU Maintenance Dallas, Texas, USA

This service center network ensures minimum reaction times in case of emergency, as manpower and tooling are in close proximity to the customer. MTU Power offers long-term agreements in which we assume responsibility for all maintenance of contracted gas turbines, including on-site visits wherever necessary.

For which equipment do you provide brush seals?

Brush seals can be found in airplane engines, gas and steam turbines, compressors and other mechanical engineering applications. The technology was developed in the 1980s, initially for military and aero engine applications, before making an entry into the power industry in the 1990s.

The move into the energy industry came after years of development, improvement and refinement according to lessons learned in the aerospace industry. Reducing leakage in engines and turbines was the primary motivator in this product development.

Brush seals are made up of thousands of thin bristles fixed together using core wire and a clamping tube to form a flexible seal. Incoming gases press this wire pack against a supporting ring, compressing it further.

The seal continuously adapts to the moving surface being sealed and eliminates up to 90% of leakage. Brush seals are used, for instance, in the bearing chamber, shaft, interstage, balance piston, impeller and static seals of turbines and compressors.

How much work should be done on site?

We perform as much as possible on site to reduce cost and downtime. This can be dry ice cleaning, LPC and HPC blade and vane, washer bushing and CRF oil-in manifold replacements, exchange of hot section modules or combustors.

What trends have you observed in aeroderivative operation?

We are noticing an increase in lease engines and rotables being used to avoid downtime when a customer's turbine is with us for maintenance, repair and overhaul. Take the U.S. market, where a lot of LMs are used as peakers to cope with spikes in power demand.

These machines see multiple starts and shutdowns, leading to more material fatigue. If I'm a peaker operator and my hot section fails, I need a replacement fast, so I can be back up and running when the grid needs me. Electricity demand isn't going to wait for anyone.

As a result, we introduced a dedicated asset manager in Berlin who takes care of all customer lease and rotable needs. We have also allocated LM6000 lease engine and rotable hot section modules to our service center in Dallas.

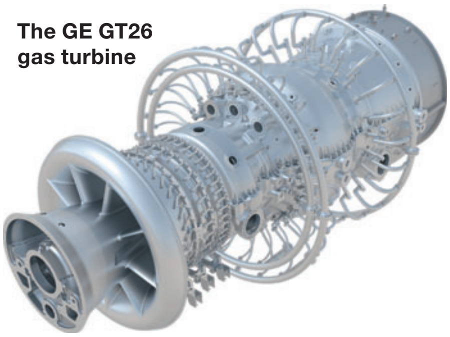
What trends have you observed in aeroderivative maintenance?

In the past couple of years, we have seen strong growth in maintenance requirements from the industrial and aviation sectors. This has led to situations where parts demand has been higher than expected by the OEMs with subsequent shortages on new material availability.

We suggest that scheduled maintenance be planned well ahead of time to allow proper planning of parts requirements as this will reduce downtime during an outage.

What's new?

We are expanding our facility in Berlin-Brandenburg, adding a logistics center by mid-2019. This will free up shop floor space, which is being reorganized to increase overall capacity. Furthermore, we are expanding our global network and looking to create new service centers in Indonesia and Africa, as well as relocating our service center in Australia. ■



The GE GT26 gas turbine

GT26 upgrade

GE has upgraded its GT26 HE (high efficiency) gas turbine (GT) for Uniper's Enfield Power Station in London, the first plant to install this new technology. The upgrade takes technologies and from GE's F- and H-class fleets to create a solution for GT26 power plant operators.

It blends GE and Alstom technology across all major components. The upgrade is said to boost full-load combined cycle efficiency by 2% and part-load efficiency by up to 1%. Output is boosted by around 15 MW. Inspection intervals are extended up to 32,000 hours.

Features include:

- A low-pressure turbine used in GE's H-class technology
- High-pressure turbine improvements to increase efficiency, using F-class technology
- Combustor engineering to reduce cooling requirements by 15% and lower emissions
- A 3D aero-profile compressor configuration to improve base-load and part-load performance.

GE.com

Mobile turbines

Dynamis Power Solutions offers portable power ranging from 3 MW to 35 MW. It packages the GE LM2500+G4, LM2500 and NovaLT5 turbines in containers for rapid transportation to the field. Its packages, that serve shale oil and gas operators with temporary power, are available in one or two trailer configurations. No crane is required for mobilization. All auxiliaries are integrated into the structure of the main trailer. An electric turbine starter is used to eliminate hydraulic motors, reservoirs, cooling and oil.

Dynamisps.com

Remote Diagnostic Services

Siemens Remote Diagnostic Services (RDS) are now available for reciprocating products, including gas engines. RDS is designed to help operators minimize the risk of forced outages by providing advanced notice of equipment issues.

This is achieved by a dedicated Siemens RDS engineer daily monitoring and analyzing various equipment operating statistics. In conjunction with RDS, Siemens offers the web-based application myHealth, which enables users to check their machine's health status and access notifications and reports anywhere, anytime. myHealth provides an overview of important operational KPIs over a variety of time periods, displays sensor and event data, and gives an overview of notifications and reports.

Siemens.com

Camseal ball valve

New valve

Conval, a provider of valves for heat recovery steam generator (HRSG) applications, upgraded its Camseal metal-seated, forged ball valves with a new stem-position-indicator disk for on-site identification and inspection of open-close status.

These severe service valves are available in ½" through 4" sizes with socket weld, butt weld and flanged ends, in pressure classes from ASME 900 through 4500.

Camseal valves are in-line renewable within 30 minutes in the event of process application abuse. The cartridge is removed for on-site parts replacement, reassembly and re-installation. No welding is required. They feature zero-body, seat and stem leakage on stand-alone and actuated valves.

Conval.com

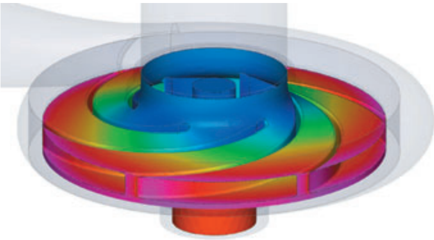
Kelvion K°Bond heat exchanger

Heat exchanger

Up to six times smaller than conventional shell & tube heat exchangers, the K°Bond is good for operations with space restrictions. It can work in pressures up to 1,000 bar and temperatures from –200°C to 600°C. In addition, it provides a high heat transfer rate thanks to the proximity of the fluids.

It is composed of a series of stainless steel plates integrally welded together at high temperature (diffusion bonding). Each plate is chemically etched with microchannels appropriate to the specific application. The bonding process creates a solid core of metal. As required, multiple cores can be welded together. Diffusion bonding ensures the highest levels of safety, free from the risk of leakage, and high resistance to cyclic services.

Kelvion.com



Radial pump design via CFturbo

CFturbo update

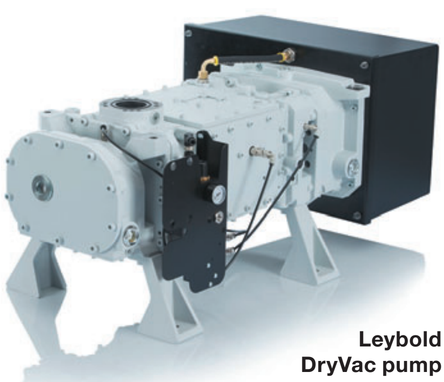
CFturbo 10.4 can be used to design axial, radial and mixed-flow pumps, fans, blowers, compressors and turbines, as well as for diffusers, stators, return channels and volutes including secondary flow path modeling. New features include a bi-directional, parametric integration into Ansys Workbench, elliptical cross-section shapes for volutes, export interfaces to Parasolid and hyperMill, a direct path to the Coolprop library for real gas behavior, easier access to parametric batch mode optimization, and numerous other enhancements.

cfturbo.com

New pump

Leybold has released the DryVac DV 200 and DV 300 dry vacuum pumps. They complement the already existing product range of DryVac 450, 650 & 1200. This series of dry compressing screw-type vacuum pumps is engineered for smart manufacturing. Low constant power consumption and designed for the harshest conditions, it offers a long lifespan, despite demanding parameters, such as vapors, dust and particles.

leybold.com



Leybold DryVac pump

Actuator monitor

Rotork has launched the latest generation monitoring and control system for valve actuators and plant equipment. The Rotork Master Station can operate up to 240 actuators across three separate field networks.

It supports the Modbus RTU protocol with third-party device integration and Pakscan Classic, Rotork's standard two-wire loop system. It can manage assets connected to it, condition-based monitoring and predictive maintenance. A touch screen interface and web pages share the same menu.
Rotork.com

Dry gas seal

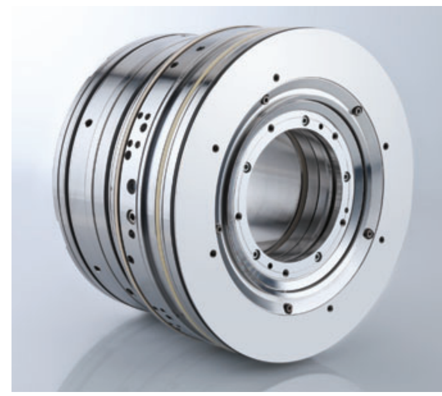
The RoTechSeal dry gas seal from EagleBurgmann is known for its extended operating periods, even when supplied with contaminated gas. It is configured to seal the shaft and increase the operational safety of compressors, even under harsh operating conditions.

A change in the composition of the process gas, clogged filters, unsuitable filter systems or operating errors can lead to contamination of the supply gas through liquid or dirt particles. The seal can deal with such problems.

The integrated Smart Labyrinth gas cleaning system ensures that liquids and particles bypass the sealing surfaces. 3D gas grooves generate a self-cleaning effect and prevent deposits on the sliding faces.

Torque transmission protects the sliding faces from damage due to contamination of high torques. For applications with demanding requirements and extreme conditions, the sliding faces are usually coated with the microcrystalline DiamondFace, which prevents damage from dirt particles.
eagleburgmann.com ■

The new Rotork Master Station can monitor and operate up to 240 valve actuators across three field networks and supports third party device integration.



The RoTechSeal dry gas seal is a ready-to-fit unit available in single, double and tandem configurations.

AD INDEX

MYTH: OIL & GAS ARE DEAD

There is a famous scene in the "Monty Python and the Holy Grail" movie where a dead body collector repeatedly tries to carry off someone who continues to insist that he "is not dead yet." After several such exchanges, the collector clubs him and carries the now-dead man off. This is analogous to the repeated proclamations about the imminent demise of the oil & gas industry.

Every couple of years, since at least the early seventies, people have been predicting the death of oil & gas. The justifications given for this view are many: fear of running out of oil (peak oil), multiple wars in the Middle East driving up energy prices, country oil embargoes, and more recently, concerns about the impact of carbon dioxide and its relation to global warming.

Yet another wave of imminent-death predictions is currently being made due to the advances in alternative energy technology and the fast build-out of wind and solar power plants.

Accompanying this, we have witnessed a marked decline in orders for fossil-based power plants (primarily gas turbines combined cycles) and hand-wringing politicians accusing power industry leaders over their supposed incompetent misguidance of future energy resources.

This rhetoric stands in sharp contrast to the real numbers. They show that world oil & gas production has increased by more than 30% over the last 20 years. It is predicted to increase by at least another 15% over the next 10 years.

There is near consensus in virtually all serious forecasts about the continued growth of oil, and particularly gas demand, usually at the cost of coal demand.

Growth in oil & gas production is primarily driven by the urgent energy needs of developing country populations experiencing a rapid increase in living standards. Adding to that is the dramatic industrialization of China and India over the last 30 years.

The total increase of oil & gas produced over the last 20 years is three to four times higher than the world's entire installed capacity of alternative energy plants combined. Alternative energy sources have certainly encroached on fossil fuel power plants, but the recent decline in power plant orders has little to do with market pressure from alternative energy sources.

Oil and gas are not dead, and neither are gas turbine power plants.

It is a market response to cyclic overbuild of fossil fuel power plants caused by the availability of low interest rate financing over the last 15 years. We have seen this cycle before. Historically, gas turbine orders do not follow smooth sine waves. They experience rapid upward and downward swings.

Power plants are just one user of fossil fuel. Transportation (automobiles, airplanes, truck freight and shipping) require fuels with a high energy density. Besides use as a transportation fuel, oil and gas are key ingredients for another rapidly growing use: the non-combusted oil and gas feedstock for conversion to petrochemicals and lubricants. This is a use that cannot easily be replaced by renewables.

For the distribution of energy, electricity and batteries provide a limited alternative. But the massive electric infrastructure required to distribute and store energy is not currently available. This is also a far less efficient way to bring energy to consumers and power plants when compared to simple hydrocarbon pipeline transport and distribution.

Further, technical and commercially viable solutions to handle the intermittent supply nature of renewable energy-sourced power have yet to be developed. That said, there is always the risk that a politician may try to club the oil & gas industry over the head to hasten its demise.

For the foreseeable future, though, combined cycle power plants will continue to be built at GW rates easily exceeding those of alternative energy plants. Should we expect to see changes in the market? Yes. There is and will continue to be an ongoing adaption to renewables. But the sheer amount of energy the world requires is daunting.

Bottom line: Oil and gas are not dead, and neither are gas turbine power plants. ■

Klaus Brun is the Director of R&D at Elliott Group. He is also the past Chair of the Board of Directors of the ASME International Gas Turbine Institute and the IGTI Oil & Gas applications committee.

Rainer Kurz is the Manager for Systems Analysis at Solar Turbines Incorporated in San Diego, CA. He is an ASME Fellow since 2003 and the chair of the IGTI Oil and Gas Applications Committee.

Any views or opinions presented in this article are solely those of the authors and do not necessarily represent those of Solar Turbines Incorporated, Elliott Group, or any of their affiliates.

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Atlas Copco
Handle the Pressure
We know you're no stranger to pressure, especially when it comes to the time and performance pressures that regularly affect the gas processing market.
Atlas Copco Gas and Process offers the ECOTS™ line of standardized expanders that reduces equipment delivery times by up to 40%, while including customized aerodynamics to ensure a perfect fit for your process needs. Available in five frame sizes, and in oil or magnetic bearing options, we offer the flexibility to handle a wide range of plant outputs.
With 45+ years of expander experience, Atlas Copco Gas and Process can help you design an expander solution that helps you handle the pressure in your gas processing facility.
Learn more about our expanders at www.atlascopco-gap.com
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