THE GLOBAL JOURNAL OF ENERGY EQUIPMENT

International Turbomachinery

MAY/JUNE 2018 • VOL. 59 NO. 3 • $7.50

turbomachinerymag.com

UBM

TURBINE USERS GRAPPLE WITH RAPID CHANGE

Also in this issue:

Western Turbine Users Inc. Show Report • Air Filtration
Stress Corrosion Cracking • Steam Turbines • GT Market Trends
Gas Turbines • Supercritical CO_2 Turbomachinery

Service with passion.

Driving your performance

Marine Engines & Systems **Power Plants** **Turbomachinery** **After Sales**

As your worldwide service solution provider, we are able to drive your success through proactive, personal customer service and expertise, in a solution-oriented approach prioritizing ongoing innovation in first-rate technical support for your business. Harnessing the benefits of new technologies with an eye to the continuous optimization of the performance levels of your equipment, our digitalization solutions help address and resolve the issues you face in daily operations, keeping you one step ahead of the game. Find out more at: **primeserv.man.eu**

MAN | PrimeServ

MAN

Features

CONNECT WITH US:
www.turbomachinerymag.com
www.turbohandbook.com
Richard.Zanetti@UBM.com
Drew.Robb@UBM.com

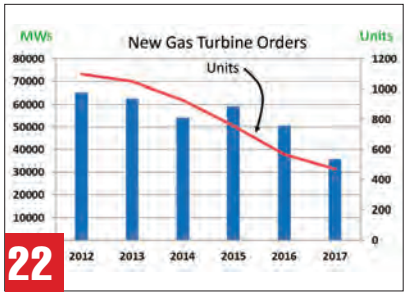
COVER STORY

14 TURBINE USERS ADDRESS RAPID CHANGE

Power producers and oil & gas operators are being impacted by tough market conditions. Gas turbines are being challenged to start faster and more often, operate with lower emissions, and have a lower power turndown and higher output, while staying reliable and being available.The oil & gas industry, meanwhile, is slowly emerging from a period of historic low prices per barrel. Operators are forced to deploy turbomachinery under severe economic restraints. However, an abundance of U.S. shale oil and gas resources, and the beginning of LNG exports from the Gulf Coast hold promise for the future.Companies such as GE, ANZGT, MTU Power, TCT, IHI Japan, SPS, Orange Grove Energy, Acuren Group, Nova Scotia Power and TICA addressed these issues at the annual Western Turbine Users Inc. conference.

Drew Robb

Cover photo: The Bin M'Cherga power plant in Tunis uses GE aeroderivative gas turbines



GAS TURBINES

22 TOUGH TIMES FOR TURBINES

Every year at the WTUI show, Mark Axford breaks down the GT marketplace. He begins with a review of last year's predictions. Often he gets it right, but not in 2017. He said that U.S. GT orders would be up 10% and worldwide orders would be down about 10%. The actual results were U.S. GT orders down 36% and worldwide down 28%. "We are witnessing the continuing collapse of the GT market," said Axford..

Drew Robb

STEAM TURBINES

26 STRESS CORROSION CRACKING

Steam turbines are used across the world as a source of power for many different industries.Even with the best maintenance procedures and preventative techniques, problems can arise. Older steam turbines are prone to stress corrosion cracking of the turbine blades for example. Understanding the causes of this condition can help minimize downtime and improve reliability.

Eesan Vamadevan

GAS TURBINES

28 AIR FILTERS

It is not uncommon for gas turbines in coastal areas to suffer from corrosion due to poor inlet air filtration. When outfitted with the wrong type of filters, salt gets inside and corrosion results.

Joshua Kohn

GAS TURBINES

30 MAKING CLEAN POWER POSSIBLE

An oxy-fired, trans-critical CO_2 Allam Cycle with a low-pressure-ratio turbine captures the CO_2 produced by the combustion of hydrocarbon fuels. It uses heating, cooling and compression to transform it into a supercritical state whereby it can be recuperated and recirculated. This has the potential to realize low cost and clean generation.

Q & A

33 THE EVOLUTION OF VIBRATION MONITORING

Randall Chitwood, Vice President OF BK Vibro America, discusses his history with Bently Nevada, and how vibration monitoring systems are evolving to meet the needs of modern equipment.

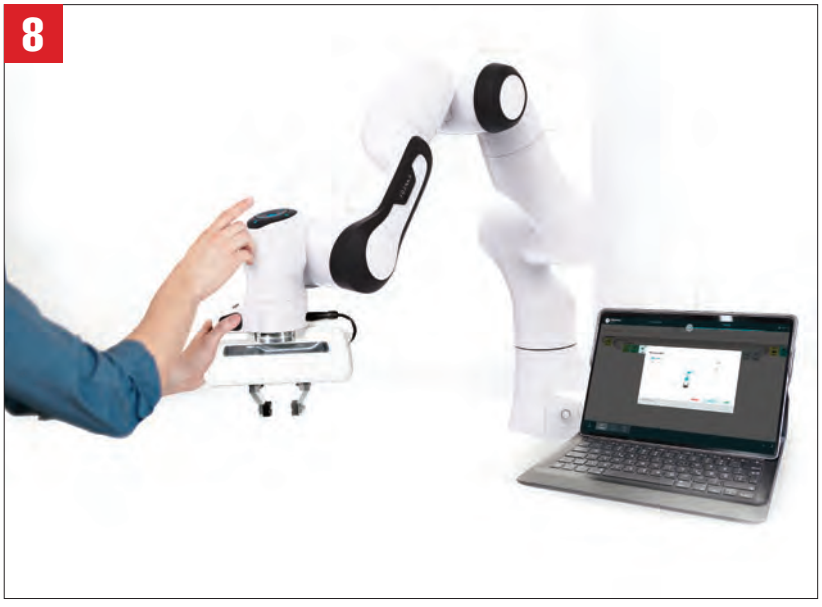
Departments

8 INDUSTRY NEWS

- **Lead story: Siemens digest**
- New plants
- Epic supplier
- Woodward acquisition
- Microgrids for LNG
- CHP plant with urea
- Biogas plants
- Furnances shipped
- Amazon collaboration
- SPX Iraqi center
- Artificial intelligence acquisition
- Condition monitoring
- GT auxiliaries
- MHPS digest
- Voith joint venture
- Georgia Power
- Energy storage
- GE digest
- ORC unit
- Floating solar
- Middle Eastern cybersecurity
- Utility digital problems
- Remote ABB
- BHGE-Statoil contract
- Steam condenser standard

34 NEW PRODUCTS

- **Lead story: Acoustic condition monitoring**
- Safety system
- Voith drive
- Marine LM2500
- Sealless pumps
- Bearing lube testing
- Wireless lubrication monitoring
- Cavity pumps
- 3D printed parts
- Grinding wheels
- Force testing
- Signal conditioner
- Laser scanner
- Hybrid ceramic bearing
- Gas bearings



COLUMNS

TURBO SPEAK

6 ADAPTING WITH THE TIMES

Despite difficult times within the industry, it is refreshing to hear many voices proposing solutions. These include more versatile turbines, adding value via ancillary services (spinning reserve and synchronous condensing), and tailoring turbomachinery to the needs of various industry segments.

Drew Robb

TURBO TIPS

13 GAS-TO-LIQUIDS TURBOMACHINERY

GTL is a refinery process to convert natural gas, flare gas or other gaseous hydrocarbons into longer-chain hydrocarbons, such as gasoline or diesel fuel. Methane-rich gases — natural gas or associated gases — are converted into liquid synthetic fuelpump design.

Amin Almasi

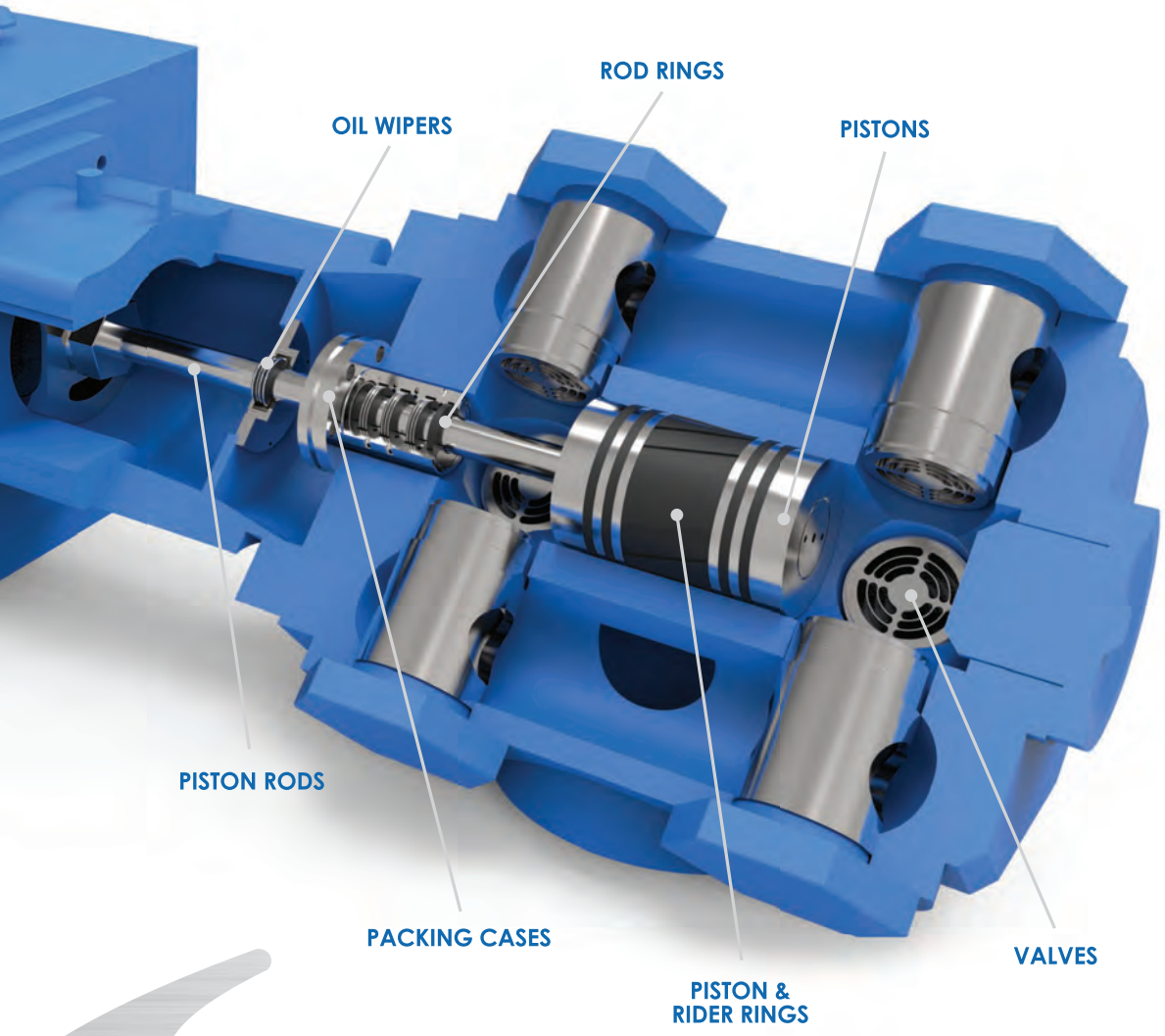
MYTH BUSTERS

36 TORSIONAL OSCILLATIONS ARE NO PROBLEM IN CENTRIFUGAL COMPRESSORS

Those of us who have used gas turbines as drivers for compressors have, for many years, thought that the problem of torsional train excitation was well understood and easy to deal with. Even long compressor trains with two or three multi-stage compressors, and possibly including a gearbox, were found to be manageable systems.

Rainer Kurz & Klaus Brun

ADVANCING PERFORMANCE | + RELIABILITY + EFFICIENCY



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.

COOK® COMPRESSION
A DOVER COMPANY

North America +1 877 266 5226
Europe +44 151 355 5937
Middle East +971 2 5575250
China +86 21 24112600

cookcompression.com

INTERNATIONAL
Turbomachinery
turbomachinerymag.com

ESTABLISHED IN 1959

Founders
G. Renfrew Brighton and R. Tom Sawyer

Publisher
Richard Zanetti, 203-523-7053
richard.zanetti@ubm.com

Editor-in-Chief
Drew Robb, 323-317-5255
drew.robb@ubm.com

Executive Editor - News/Blog
Kalyan Kalyanaraman, 203-526-7053
deerpark@gmail.com

Handbook Editor
Bob Maraczi, 203-523-7040
bob.maraczi@ubm.com.com

Executive Correspondents
Klaus Brun, Amin Almasi

Contributing Editors
Mark Axford

Art Directors
Steph Bentz, 218-740-6811

Production Manager
Anbarasan Mannar, +91 714-845-0257 Ext: 6055604

Circulation
Wendy Bong, 218-740-7244

EDITORIAL & BUSINESS OFFICES

UBM, PLC
Turbomachinery International
535 Connecticut Avenue, #300
Norwalk, Connecticut, U.S.A. 06854
Tel: 203-523-7053

Subscription Service
For subscription/circulation inquiries, 888-527-7008.
Outside the U.S. call 218-740-7273,
email to fulfill@hcl.com or send via mail to:
Turbomachinery International, UBM,
131 W 1st St, Duluth, MN 55802

ADVERTISING

WEST, MIDWEST, SOUTHEAST, SOUTHWEST U.S.A.
Gerry Mayer
5930 Royal Lane Ste E #201
Dallas, TX 75230
Tel: 972-816-3534 Fax: 972-767-4442
gm@mayeradvertising.com

NORTHEAST, MID ATLANTIC U.S.A. CANADA
Richard Zanetti
535 Connecticut Avenue, #300
Norwalk, Connecticut, U.S.A. 06854
Tel: 203-523-7053
richard.zanetti@ubm.com

GERMANY, AUSTRIA, SWITZERLAND
Sven Anacker
InterMediaPartners GmbH
Beyeroehde 14
Wuppertal, D-42389, Germany
Tel: 49-202-271-690 Fax: 49-202-271-6920
sanacker@intermediapartners.de

UK, BENELUX, SCANDINAVIA, ITALY, FRANCE
Ferruccio Silvera
Viale Monza 24
20127 Milano, Italy
Tel: 39-022846716 Fax: 39-022893849
ferruccio@silvera.it

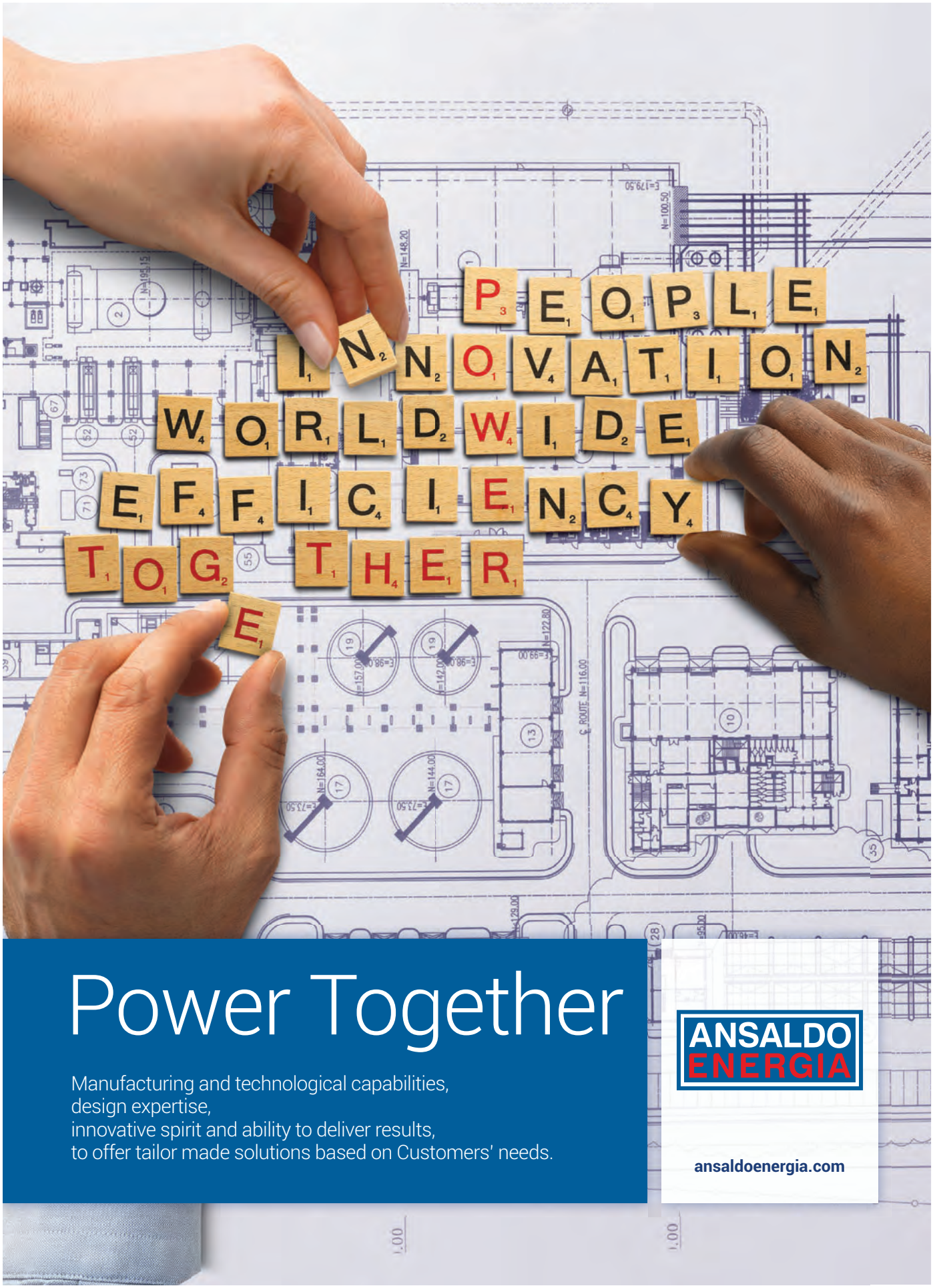
JAPAN
Yoshinori Ikeda
Pacific Business, Inc.
Kayabacho 2-chome Bldg., 2-4-5, Nihonbashi Kayaba-cho
Chuo-ku, Tokyo 103-0025, Japan
Tel: 81-3-3661-6138 Fax: 81-3-3661-6139
pbi2010@gol.com

INDIA, MIDDLE EAST
Faredoon Kuka
RMA media
Twin Arcade, C-308
Military Road, Marol
Andheri (E), Mumbai-400059, India
Tel: 91-22-6570-3081/82 Fax: 91-22-2925-3735
kuka@rmamedia.com

KOREA
Leithen Francis
Francis and Low (Pte) Ltd.
77 High Street, #08-01 High Street Plaza
Singapore 179443
Tel: 65-6337-0818
leithen@francisandlow.com

SOUTHEAST ASIA
Leithen Francis
Francis and Low (Pte) Ltd.
77 High Street, #08-01 High Street Plaza
Singapore 179443
Tel: 65-6337-0818
leithen@francisandlow.com

abm | BPA | UBM



Power Together

Manufacturing and technological capabilities,
design expertise,
innovative spirit and ability to deliver results,
to offer tailor made solutions based on Customers' needs.

ANSALDO ENERGIA

ansaldoenergia.com

ADAPTING WITH THE TIMES

Despite difficult times within the industry, it is refreshing to hear many voices proposing solutions. These include more versatile turbines, adding value via ancillary services (such as spinning reserve and synchronous condensing), and tailoring turbomachinery to the needs of various industry segments.

At the Western Turbine Users Inc. (WTUI) show in March, user group President Chuck Casey laid out the tough conditions his utility deals with due to renewable resources being given priority grid access. As a result, his nine peakers only run at about 3% capacity.

He laid out several ways to stay viable. He mentioned a hybrid power plant that combines gas turbines with batteries to support renewable variability. Casey also noted that GTs could add value by providing spinning reserve or grid support.

For example, turbine owners could receive payment for machines being on standby, ready to come online rapidly during periods when wind or solar resources suddenly fall off. This has been implemented in some parts of the country, but not in major renewable havens, such as California.

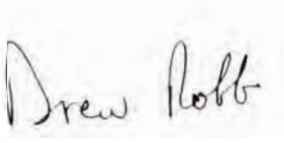
Similarly, adding a clutch to a gas turbine generator arrangement means reactive power can be supplied to support the grid. Instead of generating power, the turbine is disconnected from the generator via the clutch when reactive power is needed. If power is wanted, the clutch re-engages.

For any of these approaches to work well, though, turbines have to be nimble, flexible and able to come online in short order. Faster ramp rates and the ability to cope with plenty of starts are two of the necessary features of such equipment.

Oil & gas is another area where turbomachinery opportunities are on the rise. Smaller GTs (less than 30 MW) are often utilized by different segments of that industry. Natural gas pipelines are being expanded. LNG projects are in the news. The price of crude oil is over $60 again. That adds up to more drilling, exploration, hydrocarbon processing, and orders for gas turbines and compressors. You can read more about how the GT market is adapting and the challenges being faced in our cover story (p.14) and gas turbine market report (p.22).

The issue contains further material on stress corrosion cracking, inlet air filtration, supercritical carbon dioxide turbomachinery and vibration monitoring. And our columnists tackle the topics of gas-to-liquids equipment, and torsional oscillations in centrifugal compressors.

Enjoy the issue. We hope to see many of you in June at the Electrify Europe Show in Vienna, Austria and at the ASME/IGTI Turbo Expo Show in Olso, Norway.



DREW ROBB
Editor-in-Chief

CHEMICAL ▪ PETROCHEMICAL ▪ OIL ▪ GAS ▪ PHARMACEUTICAL ▪ INDUSTRIAL

OUR COMPRESSORS ARE OVER-ENGINEERED FOR A REASON. THEY HAVE TO OPERATE IN HOSTILE ENVIRONMENTS FOR A LONG, LONG TIME.

Not all of our compressors operate in the most extreme environments, but many do. That's why we set such rigorous design and manufacturing standards throughout our entire product line.

Even in normal environments, our compressors have to run continuously and efficiently under very demanding conditions where breaking down or going offline isn't an option.

Our refrigeration and gas compression equipment... built tough, built strong, rock solid. Dependability proven daily in over 14,500 compressor installations worldwide.

Buy with confidence.
Specify York Process Systems.

Rock solid reliability™

YORK®
PROCESS SYSTEMS

www.johnsoncontrols.com/YPS

Johnson Controls

Siemens digest

Siemens has received an order from Inter Pipeline to provide long-term service for two SGT-800 GT generator sets in Canada. The units are scheduled for operation at the Central Utilities Block (CUB), part of the company's Heartland Petrochemical Complex currently under construction in Alberta's Industrial Heartland near Fort Saskatchewan.

Siemens SGT-800 gas turbine

The 25-year service and maintenance agreement includes scheduled maintenance for the two SGT-800s and associated auxiliaries. Siemens' remote diagnostics services, part of the company's "Digital Services for Energy" portfolio, are included. They are designed to predict and prevent issues before they impact turbine operations.

CUB is supplying power and steam to the propane dehydrogenation and polypropylene facilities within the Heartland Complex. This facility will use propane to produce polypropylene. Commercial operation of the CUB is expected in late 2021.

Siemens secured its first H-class gas turbine order in Mainland China. The company will supply two H-class GTs, two STs and four generators for a power plant project in Guangdong Province. The customer is Huadian Fuxin, a subsidiary of China Huadian Corporation.

The components will be installed at the CHD Guangzhou Zengcheng combined cooling, heat and power plant in Guangzhou City. Commercial operation is scheduled for the end of 2019.

China's Aero Engine Corp.

Siemens is working with Aero Engine Corp. of China (AECC) to supply SGT-700 GTs to a distributed energy station project run by Guangzhou Development Group (GDG) in Guangzhou. This project is expected to go into operation in the second half of 2019.

The gas-steam combined cycle unit uses natural gas. When it begins operation, it will meet the industrial park's electricity and heat demand and cut energy consumption and emissions.

Siemens has taken ownership of Agilion, a company based in Chemnitz, Germany. Agilion is a supplier of an industrial Real-Time Locating Systems (RTLS) focusing on applications in production, logistics and maintenance.

Agilion is a pioneer in the field of RTLS in the Ultra-Wide Band (UWB) frequency spectrum. This technology enables precise localization within a range of a few centimeters, tracking of different assets and commissioning. The localization of assets, such as tools or vehicles, will enable manufacturers to optimize their production and logistics processes.

Uses for RTLS include applications in complex environments. Used in a manufacturing scenario, for instance, it enables precise monitoring of the production process and a transparent material flow.

Real-time RTLS data about the location and status of assets forms the basis for networking involved players and logistical processes along the value chain. This allows users to continuously and automatically compare the position of every production asset with the 3D model of the product or production environment.

Mobile aeroderivatives

Siemens SGT-A45 mobile aeroderivatives will be used at the 52 MW Bayat-1 natural gas-fired power plant to be constructed in Sheberghan, Afghanistan, the first gas-fired power plant in this country. The plant's capacity will later be expanded to 200 MW.

Each unit can be pre-assembled at the manufacturing plant and transported to the site. The GTs can be restarted at any time and restored to full power due to the absence of hot lockout restrictions.

The SGT-A45 is based on Siemens' Industrial Trent 60 and Rolls-Royce aero technology. It can generate about 44 MW of power and capable of powering the grid in less than eight minutes.

Siemens Power and Gas, including its Dresser-Rand business, received an order for four SGT-A35 GT and two SGT-A35-driven Datum CO_2 compressor packages for Modec's Sépia floating production, storage, and offloading (FPSO) vessel.

Named FPSO Carioca MV30, it will be deployed at the Sépia field operated by Petrobras in the pre-salt region of the Santos Basin approximately 155 miles off the cost of Rio de Janeiro. In addition, Siemens will provide long-term expert service and maintenance for the supplied components.

The equipment is scheduled for delivery in late 2018. Once operating in 2021, the FPSO is expected to process 180,000 barrels per day of crude oil and have a storage capacity of 1,400,000 barrels of crude oil.

For power generation on the vessel, Siemens will supply four SGT-A35 GTs. The SGT-A35 aeroderivative GT (formerly the Industrial RB211), coupled with an MT30 2-pole synchronous power turbine from the marine Trent engine, has millions of operating hours.

In addition, two SGT-A35-driven Datum compressor trains will reinject CO_2 to more than 250 bar (3,626 psi) pressure. With the compressor's high-pressure and high-density technology, the footprint can be reduced when compared to a conventional compression and pumping module.

Siemens has developed its first 3D-printed metal ST replacement parts. This follows 3D-printed GT blades produced last year. The 3D-printed parts are two oil sealing rings used in keeping oil separated from steam inside the steam turbine using pressurized air.

The rings are being installed as replacement parts on the SST-300 ST operating at the JSW Steel plant in Salem, India. This follows an investment of €30 million in a 3D-printing factory in Worcester, UK.

Siemens signed an agreement with Shenergy Technology to implement a high-temperature subcritical upgrade for a 320 MW steam turbine unit at Xuzhou Power Plant, a subsidiary of China Resources Power Holdings (CR Power) in Jiangsu province.

It is estimated that the upgrade will enhance the unit's power output efficiency up to 42.9%, reduce emissions by more than 10% and extend its overhaul interval from 6 to 12 years. The project is expected to be concluded in mid-2019.

Advanced blade designs

The project will include advanced blade designs, such as 3DS and 3DV blades, and additional steam extraction for the A0 high-pressure pre-heater. This will help CR Power lower coal consumption of the subcritical unit by more than 10% to 287g/kWh, which is close to the ultra-supercritical level. The project will also help reduce performance degradation.

Siemens was selected to supply an SGT-700 mechanical drive compression train for the Camisea gas-condensate asset located in Peru. The equipment, identical to what Siemens supplied in 2011, is essential to the continuing exploration and production of hydrocarbons in Block 88, operated by Pluspetrol Peru.

Due to the natural gas pressure decline of the reservoirs, the Camisea production plan includes a centralized wellhead compression system for all fields. The scope of supply includes an SGT-700 mechanical drive GT, driving two STC-SV centrifugal compressors, including associated equipment such as gas coolers, scrubbers, instrumentation, valves and spare parts. Equipment commissioning is scheduled for mid-2020.

Epic supplier

Epic International is now a full supplier of parts, repairs, field service and technical support for Atlas Copco HP, ZH, ZT and ZR rotary screw compressors. Coupled with Epic's recent acquisition of Air Relief, and the opening of a new Milan, Italy compressor service center, it is expanding in the air compressor market.

Woodward acquisition

Woodward has agreed to acquire L'Orange and all its operations located in Germany, the U.S. and China. The transaction is expected to close in early June 2018, pending regulatory approvals.

L'Orange is a wholly owned subsidiary of Rolls Royce Power Systems. It supplies high-pressure fuel injection technologies for diesel, heavy fuel oil and dual-fuel engines applied in marine power and propulsion systems, special-application vehicles, locomotives, oil and gas processing, and power generation. L'Orange will be renamed Woodward L'Orange and will be integrated into Woodward's Industrial Segment.

Crowley is developing Microgrids for LNG

Microgrids for LNG

Crowley Fuels and PowerSecure, a Southern Company subsidiary, have formed an alliance to develop and deploy microgrids incorporating liquefied natural gas (LNG), renewables and storage. This is aimed at providing greater reliability and resiliency to customers and economies throughout the Caribbean and Central America. The immediate focus of the alliance is to improve the resiliency of power sources for industrial and commercial power users and municipalities in hurricane damaged Puerto Rico.

Since 2014, Crowley has safely transported and delivered LNG in ISO containers from Jacksonville, FL, to industrial and commercial customers throughout Puerto Rico. Crowley has more than 32 MW of LNG supply contracts in Puerto Rico and more than 98 million gallons of LNG storage available near Crowley's terminal in Jacksonville. PowerSecure has installed 2.5 GW of fossil fuel, solar, fuel cell and energy storage microgrids.

ETW SCR units at a plant in Germany

CHP plant with urea

The German Combined Heat and Power (CHP) specialist ETW Energietechnik has delivered natural gas CHP units with selective catalytic reduction (SCR) technology and urea injection (Adblue) to Stadtwerke Duisburg in Germany, the first user of Adblue technology. The units will be used in three plants with MWM engines of the type TCG 2020V12, each with an

(Continued on p. 10)

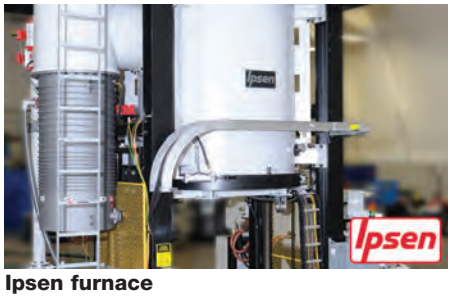
electrical output of 999 kilowatts and an efficiency of 94%.

Two of the three ETW plants have been in operation since the end of 2017. The third plant will be commissioned in 2019. All plants comply with the exhaust emission limits:

NOx: < 100 mg/Nm³ (exhaust gas dry at 5% O_2)

CO: < 100 mg/Nm³ (exhaust gas dry at 5% O_2)

Formaldehyde: < 20 mg/Nm³ (dry flue gas at 5% O_2).



Ipsen furnace

Furnaces shipped

Ipsen has shipped ten furnaces to companies in California, Georgia, Ohio, Washington and Wisconsin, as well as one in Asia. This equipment will be used to process parts for companies in the aerospace, commercial heat treating and medical industries.

The shipments included:

- Two Titan furnaces — one Titan H2 12-bar with a 18" × 24" × 18" work zone and one vertical Titan 2-bar furnace. Both are equipped with PdMetrics software for predictive maintenance
- Two MetalMaster furnaces — one vertical 6-bar with a 96" D × 96" work zone and 10,000 lb. load capacity, and one horizontal 10-bar with a 96" × 84" × 96" work zone
- One VFS horizontal internal quench 10-bar vacuum heat-treating and brazing furnace
- Several custom-built atmosphere furnaces that will process parts for aerospace.

Amazon collaboration

OSIsoft is in collaboration with Amazon Web Services (AWS) to make it easier to analyze OSIsoft PI System data on Amazon platforms. A growing number of users want to mine data on cloud platforms to extend their value at the local and plant levels with PI. This ties into a new PI Integrator for Business Analytics that makes it easier to stream data to cloud platforms. One piece of software will stream to multiple clouds, such as AWS or Microsoft Azure.

Additionally, Kansai Electric Power is developing efficiency and consulting services based on a PI System that Kansai will sell to other utilities. At one 2 GW plant, Kansai saved $3 million in operating costs by tweaking parameters.

The PI System from OSIsoft captures the data streams from sensors, machinery and other devices and transforms them into real-time insights to reduce costs, improve performance or develop connected products.

The PI System can be found inside wind farms, national labs, rail networks, pharmaceutical manufacturing centers, data centers, stadiums, over 1,000 utilities and over 90% of the world's oil and gas companies.

Biogas plants

German biogas specialist Weltec Biopower is building three anaerobic digestion plants in Northern Ireland. All three 500 kW plants will go live in the summer of 2018. Two of them are being set up in County Antrim in northern Ireland. Another plant is being built in Benburb in County Tyrone.

They will largely be charged with slurry and pig, cattle and poultry manure as well as a small amount of renewable raw materials.

SPX Iraq center

The SPX Flow service center in Southern Iraq, a joint venture between SPX and WTE Wajdi Group, services all rotating and static equipment for oil and gas, industrial and power customers in Iraq. Located in Basrah Provence, it is now fully operating. It has offices in Dubai and local operations and a subsidiary based in North Rumalia Oil Field.

Using WTE's presence in the area and knowledge of the Iraqi market, the facility will serve an installed base of equipment from the SPX Flow ClydeUnion Pumps, Bran & Luebbe, Plenty & Lightnin Mixer and Copes and M&J Valve Brands.

The joint venture provides field service, site survey, workshop overhaul & maintenance services for all types of rotating equipment including centrifugal, reciprocating, and metering pumps, mixers, as

MHPS digest

Mitsubishi Hitachi Power Systems (MHPS) has received an order to provide an ST power generation system for a pulp and paper mill in Sumatra, Indonesia. With an output of 97 MW, the system will be used as an in-house power source, while steam will be used in pulp and paper production. It is scheduled to begin operation in year-end 2019.

The power generation system will consist of the back-pressure turbine, a boiler and a generator. MHPS will supply the core components, such as steam turbine and generator, an oil unit, and instrumentation control devices.

MHPS will also dispatch engineering staff to support equipment installation and test operations. The steam turbine will be designed in-house at MHPS and manufactured by Qingdao Jieneng Steam Turbine Group in China. Quality control will be managed by both MHPS and Mitsubishi Hitachi Power Systems Jieneng (Qingdao) Steam Turbine, a Chinese joint venture of MHPS and QJST.

MHPS Americas has created a Power & Energy Solutions business focused on delivering solutions in digital power, energy storage, and low-carbon power generation. MHPS Vice President Tom Cornell leads this business. The new business unit will deliver services including expanded digital offerings from MHPS-Tomoni, which uses artificial intelligence and autonomous operation to improve energy efficiency, increase operational flexibility, and predict equipment failures before they happen.

MHPS has announced the integration of PWPS within MHPS Americas. This broadens the MHPS product portfolio and allows synergies between various manufacturing and service centers in the U.S. MHPS also gains turnkey power plant capabilities as well as industrial GT parts and repair. This ends the period when PWPS functioned as a stand-alone MHPS subsidiary.

PW Power Systems, formerly Pratt & Whitney Power Systems, was acquired by Mitsubishi Heavy Industries, in May 2013 and changed its name to PW Power Systems, (PWPS).

Transitioned to MHPS in August 2017, PWPS has future development rights to Pratt & Whitney aero-engines, as well as ongoing engineering and aero-engine production.

PWPS has over 2,000 GTs installed worldwide, which have accumulated over 19 million operating hours. The PWPS product line includes aero-derivative gas turbines from 30 MW to 140 MW as well as the FT8 MobilePac and FT4000 SwiftPac configurations.

MHPS Americas also has integrated the PWPS Industrial Gas Turbine (IGT) division with Mechanical Dynamics and Analysis (MD&A). MD&A has provided service, parts, repairs and upgrades for a variety of GTs, STs, and generators. It now adds PWPS experience in the hot gas path component and repair space.

GE digest

GE's Power Services business has signed an agreement to service power generation equipment in 11 power plants owned by Petrobras, Brazil's majority state-owned oil company. The fleet under the contract represents some 80% of the Petrobras total installed fleet and generates 4.3 GW of energy. GE's Fleet 360 platform of plant services will help Petrobras ensure reliable, long-term execution of the scheduled outages of plants throughout the country.

The four-year agreement includes inspections, parts and repairs for twenty of GE's heavy-duty GTs (four 6FAs, six 7FAs, ten GT11N2s), twenty-three LM6000 aeroderivative GTs, three STs and thirteen generators, which Petrobras has been operating since 2001.

GE is also working with CELSE (Centrais Elétricas de Sergipe) on a Brazilian combined-cycle power plant (CCPP) being built in Barra dos Coqueiros in the state of Sergipe. The project will include three of GE 7HA GTs, as well as ST, heat recovery steam generator and transmission technology. GE also will provide operations, maintenance, repairs and digital solutions for the 1.516 MW CCPP.

A GE LM6000 GT at the CCPP in Maputo, Mozambique, had its first fire March, 2018. With a capacity of 106 MW, a second turbine is expected to start operating in about a month. By June the entire plant is expected to be operational.

LM2500 aeroderivative gas turbine

well as static equipment service (valves, filters and quick-release closures).

Artificial intelligence acquisition

Industrial artificial intelligence (AI) software provider Uptake has acquired Albuquerque-based Asset Performance Technologies (APT) for an undisclosed amount. The acquisition provides Uptake with a library of equipment failure modes used for preventive and conditions-based maintenance optimization in power generation, petrochemical, oil and gas and steel industries.

APT's Preventance APM has failure mode information for nearly 800 equipment types. The software adjusts to changing operating conditions, plant requirements and economic market conditions. Uptake will leverage the library to build digital twins that are self-learning.

An IVC technician performing condition monitoring

Condition monitoring

Pruftechnik and IVC Technologies have joined forces to provide a comprehensive condition monitoring solution for clients throughout North America. Pruftechnik Condition Monitoring Services, powered by IVC Technologies, combines a suite of alignment and condition monitoring tools, with IVC's 30+ years of condition monitoring services.

GT auxiliaries

International emissions and noise control vendor Innova Global has won multiple orders for gas turbine auxiliaries across North America, Europe and Africa. This expansion follows a merger with Braden last year. About 50% of the merger's new sales have been generated in Europe.

Innova Braden comprises Innova Global's divisions of Environmental Solutions (formerly Higgott-Kane and Braden Manufacturing), the Retrofit Solutions (formerly Braden Manufacturing) in Tulsa, OK and Consolidated Fabricators in Auburn, MA, as well as a subsidiary Innova Braden Europe (formerly Braden Europe) located in Heerlen, the Netherlands.

Voith Robotics

Voith joint venture

Voith and the Munich-based robotics company Franka Emika have entered into a partnership. Voith Robotics, the joint venture, will offer self-teaching lightweight robots made by Franka Emika. It will also offer associated software solutions, apps, services and process consulting. Voith will contribute its process and industry know-how, and sales and service network.

Georgia Power

Georgia Power has placed the nuclear reactor vessel inside Unit 4 containment at the Vogtle nuclear expansion project near Waynesboro, GA. Standing 35 feet tall, the reactor vessel functions as a heat source from the nuclear fission process to produce steam that will generate electricity.

The 306-ton reactor vessel was fabricated by Doosan Heavy Industries in South Korea, shipped through the Port of Savannah and arrived at the construction site via train on a specialized rail car. Earlier this year, Georgia Power announced the placement of 2,400 cubic yards of concrete for the Unit 4 turbine tabletop. The plan is to achieve the target in-service dates of November 2021 (Unit 3) and November 2022 (Unit 4).

Energy storage

EDF Group, a French electric utility company, plans to develop 10 GW of additional storage around the world by 2035, on top of the 5 GW it already operates. EDF's research investment in storage for the power system will double, reaching €70 million for the 2018-2020 period.

ORC unit

Turboden, a group company of Mitsubishi Heavy Industries (MHI), signed an order with AGT, a Turkish wood industry company, for a 5.5 MW Organic Rankine Cycle (ORC) power-only unit. The ORC unit is in a new biomass plant at Antalya in Southern Turkey.will turn wood waste into power. The unit is equipped with an air-cooled condenser to save about 250,000 tons of water per year. Start-up is scheduled for the third quarter of 2019.

Floating solar

Kyocera TCL Solar has started operation of Japan's 13.7 MW floating solar plant. Located on the Yamakura Dam reservoir in Ichihara, Chiba Prefecture, the plant was constructed over the surface of the reservoir. With over 44 acres of surface area, 50,904 Kyocera solar modules were installed to generate an estimated 16,170 MWh per year. Power is sold to TEPCO Energy.

(Continued on p. 12)

Storage disrupting the market

Each March, CERAWeek by IHS Markit gathers in Houston with high profile speakers from around the world to discuss the markets for coal, oil, natural gas, and electricity.

Of particular note was an emerging technology that threatens to destroy the market for peaking gas turbines: Battery storage.

Tesla brought beauty and chic to electric cars; customers got excited. Other automobile manufactures feared being left behind. They responded with announcements of new electric vehicle (EV) models. European governments are providing strong EV development support to the likes of BMW and Volkswagen in the name of reduced CO_2 emissions. China even announced a strategic initiative to electrify its automotive fleet to reduce urban smog and dependence on foreign oil.

But there are issues to resolve. The most expensive part of an EV is the battery pack. Customers want a driving range of 200 miles to 300 miles per charge. This necessitates an even larger battery pack and therefore, a higher price for the car. As the volume of lithium ion battery production has ramped up worldwide, the price of a battery pack has been falling by more than 20% per year. The price at the end of 2017 was $209 per MWh. For EV sales to compete effectively with conventional gasoline engines, however, the price of the battery pack must fall into a range of $ 50 to $100 per MWh.

The question remains: Will battery prices continue such a steep fall as the manufacturing volume ramps up yet again? Or will the curve flatten out due to cost increases for lithium and cobalt? The answers to these questions are of vital importance to the GT business. At $100 per MWh, a large battery pack may have a better value proposition than a peaking gas turbine generator.

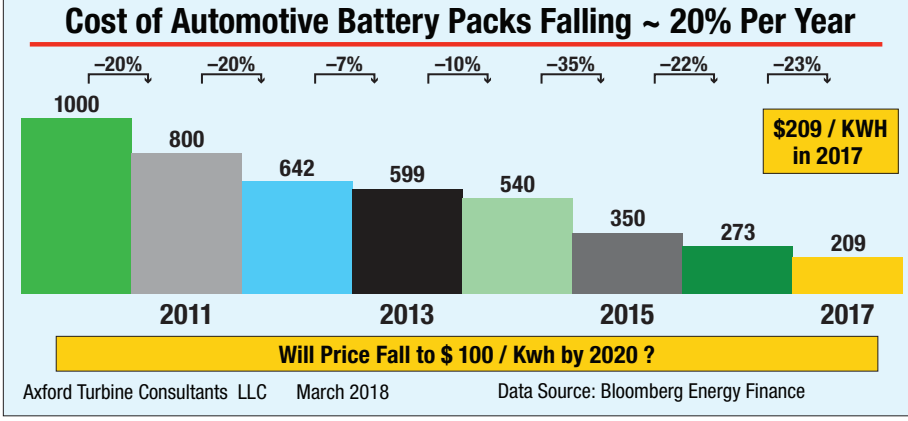
A battery peaker at that price per MWh would have many advantages:

- Ramp rates would be virtually instantaneous
- Reliability would theoretically be higher as there are no moving parts
- There would be no deration for high ambient temperature or elevation
- Fast permitting; no air permit would be required
- Arbitrage: It would be possible to buy electricity at a low price (sometimes even a negative price) and then discharge it onto the grid or load point at on-peak prices
- Subsidies exist for battery storage in many areas, which can tip the balance further towards storage.

This does not mean the end of the GT peaker market. However, it is going to become more common for any utility planning a peaking project to invite bidders offering battery storage as well as gas turbine technology. This could also shift traditional energy infrastructure patterns. It probably makes more sense to locate battery storage at industrial sites to directly serve load instead of at a utility generating station or substation.

Bottom line: Battery storage technology could cause heavy disruption in the power business as end users expand their toolbox for demand response when electricity prices are very low or very high. If the lithium ion battery pack continues its steep price decline, a corresponding drop in the price for peaking gas turbines will be needed to stay competitive.

Report by Mark Axford



Middle Eastern cybersecurity

Cyber security breaches in the Middle East are widespread and frequently undetected, according to a new study by Siemens and Ponemon Institute of the region's oil and gas sector. Until recently, cyber-attacks generally targeted Information Technology (IT) environments, such as PCs and workstations. With the acceleration of digitalization and the convergence of IT and operational technology (OT), the region is now seeing 30% of attacks targeting OT.

The report found some 60% of respondents believe the cyber risk to OT to be greater than IT. In 75% of cases, those questioned had experienced at least one security compromise resulting in confidential information loss or operational disruption in the OT environment in the last 12 months.

Utility digital problems

According to the J.D. Power's 2018 Utility Digital Experience Study, utilities are among the lowest-performing industry groups when it comes to delivering distinct digital customer experiences. One area that remains a challenge is cross-channel communication. Poor scores are due to major gaps in social media, email, messaging and customer service capabilities.

The study evaluates customer perceptions of the websites, mobile apps, social, chat, email and text functions of the 67 largest electric, natural gas, and water utilities in the U.S. Alabama Power ranks highest in overall satisfaction. Arizona Utilities' Salt River Project ranks second and MidAmerican Energy ranks third.

Remote ABB

ABB continues to expand its remote service centers for variable speed drives with its latest facilities inaugurated in Dubai, United Arab Emirates. The new facilities complement service centers operating already in China, India and Finland.

BHGE-Statoil contract

BHGE (formerly GE Oil & Gas) will supply Statoil's Floating Production Storage and Offloading (FPSO) facility in the Johan Castberg field in the Barents Sea with two GE LM2500+ G4 turbines. Both come with dry low emission combustion and dual-fuel capability. They are direct coupled with two-pole electric generators. Each unit will have a waste heat recovery unit with an extended scope that includes Balance of Plant (BOP). The units will be assembled onsite into a total of three industrial modules.

Steam condenser standard

The Heat Exchange Institute (HEI) has released the 12th edition of *Standards for Steam Surface Condensers*. It may be purchased in electronic or hardcopy format (www.techstreet.com/hei).

The new edition offers revisions and insights on FM hard-to-ignite tube material, gauge correction factors, pressure design equations, nuclear applications, condenser hotwells, atmosphere relief devices, vacuum-breaker valves, condenser tube cleaning, steam inlet expansion joints, waterbox coatings, lay-up procedure, and frequently asked questions. ■

GAS-TO-LIQUIDS TURBOMACHINERY

AMIN ALMASI

Gas to liquids (GTL) is a refinery process to convert natural gas, flare gas or other gaseous hydrocarbons into longer-chain hydrocarbons, such as gasoline or diesel fuel. Methane-rich gases — natural gas or associated gases — are converted into liquid synthetic fuels in different processes, such as FT (Fischer–Tropsch) and others. In this column, we discuss turbomachinery for GTL with a focus on the emerging market of offshore GTL.

The FT process starts with partial oxidation of methane to carbon dioxide, carbon monoxide, hydrogen and water (steam). The ratio of carbon monoxide to hydrogen is adjusted using the water-gas shift reaction, while excess carbon dioxide is removed by a dedicated process.

Removing the water yields synthesis gas (syngas), which is chemically reacted over a catalyst to produce liquid hydrocarbons and other byproducts. Oxygen is usually provided from a cryogenic air separation unit.

An alternative methanol-to-gasoline (MTG) process converts natural gas to syngas, and then methanol. The methanol is usually polymerized over a catalyst to form alkanes.

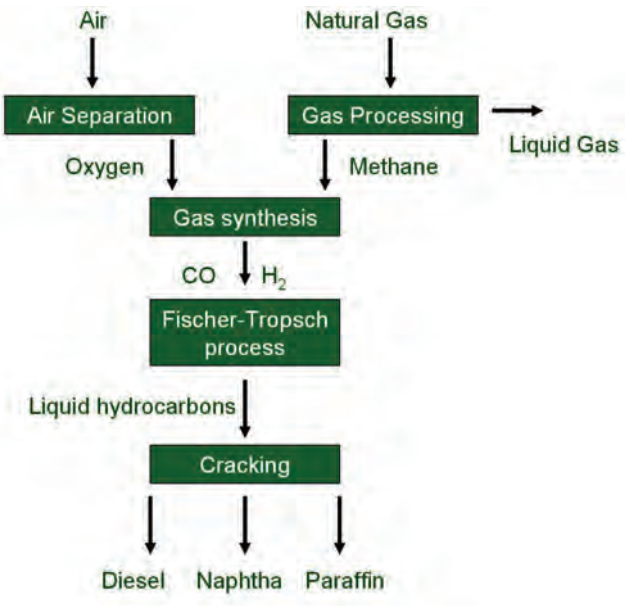
A third GTL process builds on the MTG technology by converting natural gas-derived syngas directly into drop-in gasoline and jet fuel via a thermo-chemical, single-loop process. This is usually known as the syngas to gasoline plus (STG+) process.

STG+ generally follows four principal steps in one continuous process loop. It often consists of reactors in which syngas is converted to synthetic fuels. Most often, four fixed bed reactors in series are used. Alternative equipment can also be employed.

GTL turbomachinery

The GTL process begins with the air compression system. It feeds the syngas unit directly, or through an air separation unit (ASU) if production of oxygen is required as part of the process. A compact, lightweight and efficient air compressor package is important for any FT-GTL unit.

An axial air compressor is one option for a large FT-GTL unit. Another solution is a hybrid compressor, which contains initial axial stages and final centrifugal stages. This combination benefits both technologies.



Turbocompressors are required for various services in a FT-GTL, such as recycle applications, syngas compression units and others throughout the entire GTL process. They are usually compact barrel-type centrifugal compressors, like those used in methanol and ammonia synthesis trains.

Since various GTL process steps are exothermic, steam turbines could be a good option for drivers. Steam is usually generated as part of the process. The large volume of low-caloric tail gas in air-based processes can also be used to generate steam using a compact steam generation unit (compact boiler or similar).

Steam turbines use high enthalpy steam, which is at high pressure and temperature in an expansion process. Steam enthalpy is converted into mechanical energy as it passes through a turbine stage.

Each stage consists of nozzles and rotor blades. In the nozzles, the steam is accelerated and transformed into kinetic energy with a reduction in potential energy. The flow is directed onto the rotor blades, which convert kinetic energy to mechanical energy.

Steam turbines for offshore applications are usually compact and relatively light. They often use impulse blading for high reliability and efficiency and require low maintenance.

Steam turbines are proven in offshore and marine applications. Those driving compressors or other machinery used in GTL usually require large outputs. The flow at low pressure sections might be greater than typical offshore applications.

To meet these requirements, advanced blade cascades should be used for variable speeds, high loads, and low pressures. Steam turbines require less space and are lighter than variable-speed drives (VSD), such as variable-speed gas turbines or VSD-driven electric motors. ■

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.

TURBOMACHINERY USERS GRAPPLE WITH RAPID CHANGE

OPERATORS ARE IMPACTED BY PRESSURE FROM RENEWABLES, REGULATIONS AND DISTRIBUTED ENERGY RESOURCES

BY DREW ROBB

Power producers and oil & gas operators are being impacted by tough market conditions. Gas turbines (GTs) are being challenged to start faster and more often, operate with lower emissions, and have a lower power turndown and higher output, while staying reliable and being available.

The oil & gas industry, meanwhile, is slowly emerging from a period of historic low prices per barrel. Operators are forced to deploy turbomachinery under severe economic restraints. However, an abundance of U.S. shale oil and gas resources, and the beginning of LNG exports from the Gulf Coast hold some promise for the future.

Companies such as GE, Air New Zealand Gas Turbine, MTU Power, TransCanada Turbine, IHI Japan, Strategic Power Systems, Orange Grove Energy, Acuren Group, Nova Scotia Power and the Turbine Inlet Cooling Association addressed these issues at the annual Western Turbine Users Inc. (WTUI) conference. It was held in March of 2018 in Palm Springs, California.

As the largest aeroderivative GT user group gathering in the world, about 1,100 people gained insight into how to deal with rapid change, as well as best practices for turbomachinery maintenance.

The keynote session of the Western Turbine show

Keynote

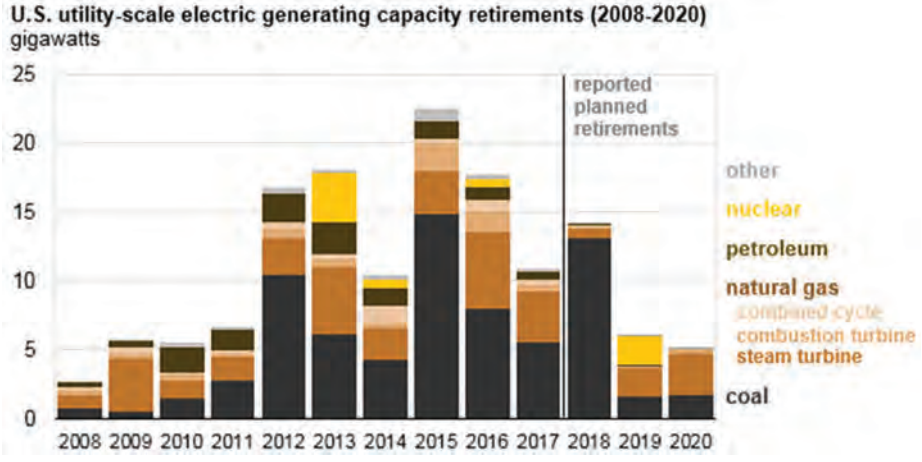
Chuck Casey, President of WTUI and the operator of a City of Riverside gas turbine plant in California, operates nine peakers—four are GE LM6000s. His plant has a combined cycle unit that also operates as a peaker due to shifts in the generation mix. His units only run at about 3% capacity.

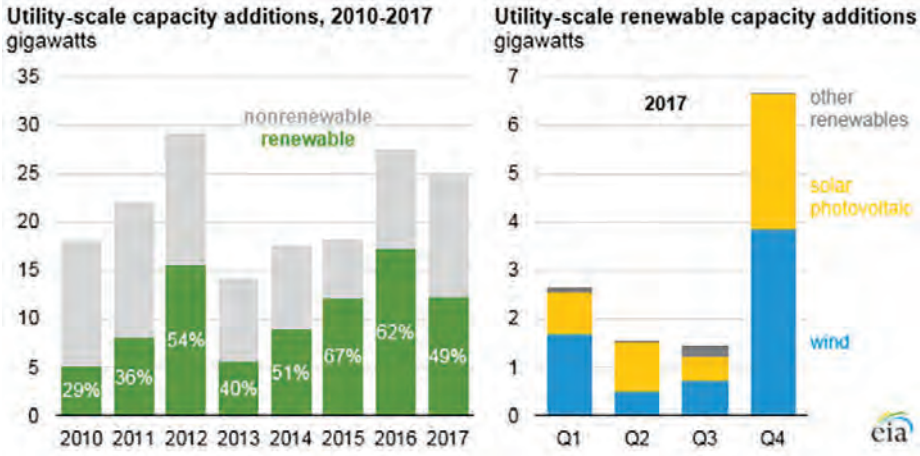
Chuck Casey

He noted that the Federal Clean Power Plan (CPP) is mandating historic levels of renewable energy on the grid. This is causing coal and nuclear plants to be decommissioned simultaneously. Natural gas generation is also suffering in states, such as California, as wind and solar power are given priority. Increased subsidies for energy storage will put additional pressure on natural gas generation.

But all was not gloomy. Natural gas prices are maintaining a low range, amplifying the feasibility of GTs.

"There is no doubt that social influ-





Source Energy Information Administration

ence through government, social media and environmentalists is affecting us," said Casey. "To stay relevant, you must fit your aeroderivative engines to be limber and flexible."

Distributed energy resources (DER) are another factor. Customers are no longer happy just to have power. They are beginning to demand that their energy come from certain places. This is causing power producers to think and act differently.

Casey gave the example of a joint Southern California Edison (SCE), GE and Wellhead project to create a battery-gas turbine hybrid system in Norwalk, California. The LM6000 Hybrid Electric Gas Turbine (Hybrid EGT) offers quick start, and fast ramping capabilities to support SCE's growing renewable portfolio. A 10 MW battery energy storage system works in conjunction with a 50 MW LM6000 aeroderivative gas turbine at the facility.

California sets the bar high

The State of California has committed itself to derive 50% of its electricity from renewable sources by 2030. The Hybrid EGT helps balance variable energy supply and demand, during the daylight and evening hours. The control system blends output between the storage battery and the gas turbine.

It allows enough time for the GT to start and reach its designated output. There is no need to burn fuel while keeping the turbine on in standby mode. Demineralized water consumption is reduced by 45% at the plant. Casey said the LM6000 in this hybrid example is basically providing a new form of spinning reserve.

Statistics from the Energy Information Administration (EIA) were also cited during the keynote. Out of 25 GW of utility-scale electric generating capacity added to the grid during 2017, nearly half are using some form of renewable technology. For example, another 3.5 GW of small-scale solar power net capacity additions came online in 2017.

More than half of these renewables came online during the fourth quarter. Renewable capacity additions are often highest in the final months of the year in order to qualify for federal, state and local tax incentives.

It should be noted that in early spring, California's total share of gross electricity demand coming from solar energy exceeded 50% during the mid-day hours. This resulted in negative pricing. In other words, the state paid its neighbors to take the power off its hands. In 2017, U.S. monthly electricity generation from wind and solar exresources ceeded 10% of total U.S. electricity generation for the first time.

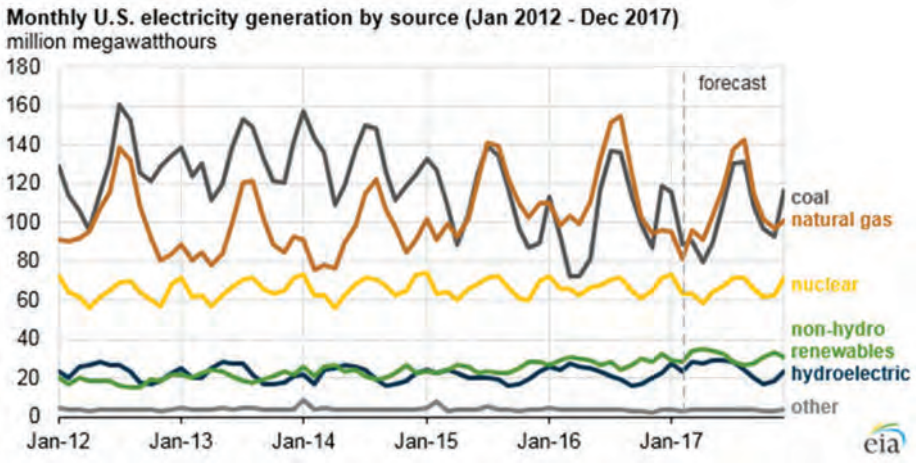
Casey acknowledged the problem, but believes the industry can adjust, and that it can find its place in the future energy mix. He noted that coal generation has fallen from 50% of the total of U.S. electric generation to less than 30% of the total generation over the past 12 years. During that same period, natural gas has risen from 20% of total electric generation to about 33% today.

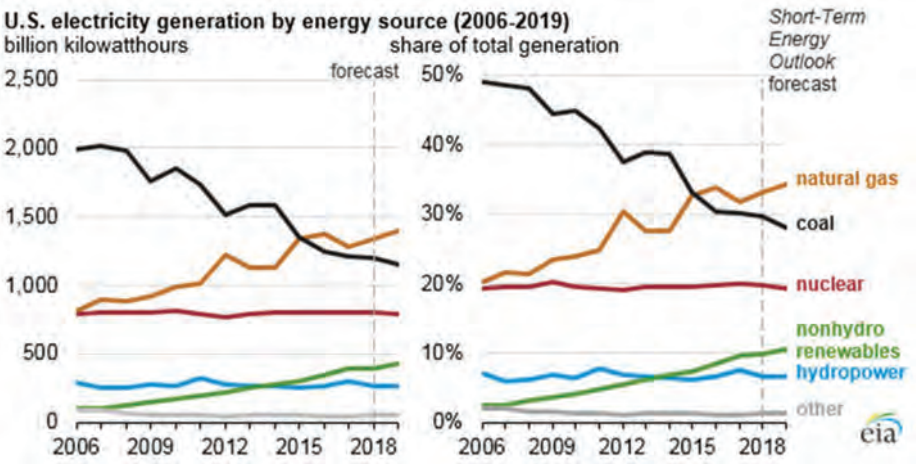
"For the third consecutive summer natural gas beat coal as an electricity generating source," he said.

Depot briefings

Four major GE-authorized vendors offer aeroderivative turbine services: Air New Zealand Gas Turbine (ANZGT), MTU Power, TransCanada Turbine (TCT) and

(Continued on p. 16)





IHI Japan.

ANZGT kicked off the depot briefings. With GE having ended support for the LM5000, it falls mainly on ANZGT to serve the small user base that remains: ten units are still operating in Europe, one in the Middle East, two in Latin American, nineteen in North American and only one is still running in Asia. Beyond its work on the near end of life LM5000, ANZGT considers the LM2500 to be the mainstay of its business.

IHI Japan is involved in more than GTs. It also serves the boiler, Heat Recovery Steam Generator (HRSG), air quality control system, and gas process storage markets. On the GT side, it focuses primarily on the LM6000.

IHI Japan offers is own packages and controls, as well as conducting field and depot maintenance. However, its has a strong presence outside of Japan. In North America, for example, the company has a Cheyenne Service Center in Wyoming (which is a Level II facility), as well as Kansas, Chicago, Houston and Southern California branches.

MTU Power is the new name of the company that used to be known as MTU Maintenance. It services commercial aircraft, military jet engines, aeroderivative GTs and industrial GTs. The company has a Level II service shop in Dallas, TX. But its premier facility is in Berlin, Germany, which is a Level IV shop. MTU Power can service the entire LM range of engines, including the LM5000.

More than a change of name to MTU Power, this move consolidated the existing GT engineering, manufacturing and aftermarket expertise and services from three business units: Aero Solutions, Brush Seals and MTU Maintenance.

Aero Solutions specializes in development, testing, design optimization and manufacturing of turbines and compressors for original equipment manufacturers. In addition, MTU has its own brush seals team. Brush seals are made up of thousands of thin bristles. These are fixed together using core wire and a clamping tube to form a flexible seal. Brush seal technology is said to outperform conventional sealing systems, such as labyrinth seals.

TCT was the last depot to address the WTUI keynote session. The company works mainly on the LM6000 and LM2500, as well as the Siemens RB211 and Avon (formerly part of Rolls-Royce). Its parent companies are Wood Group and TransCanada. Headquartered in Airdrie, Calgary, TCT operates four Level II shops: Bakersfield, Houston, Syracuse in the U.S. and one in Glasgow, UK.

The exhibit hall at WTUI featured hundreds of booths

After the depot presentations, Mark Axford and Tony Brough presented the annual state of the gas turbine market report. Their briefing highlighted a serious decline in GT sales and ongoing trends that have resulted in big changes within the turbomachinery landscape (see p. 22).

Scott Strazik, President and CEO of GE Power Services, followed with a bullish briefing about the evolving marketplace for aeroderivatives.

Strazik stressed that aeroderivative GTs remained "incredibly important for us," naming aeroderivative gas turbines as a priority market for his division of General Electric going forward.

Strazik believes market forces are transforming the industry. The California duck curve (a sharp falloff of renewable power in the afternoon) is taking place now in Hawaii and Texas.

"Aeroderivative gas turbines need to be positioned correctly in the market," said Strazik. "We need to provide machines with faster ramp rates and that are comfortable with more starts. Ancillary services will be given a bigger role, including the management of emissions and providing spinning reserve."

Breakout sessions

Attendees to WTUI are offered extensive breakout tracks for users of the LM2500, LM5000, LM6000 and LMS100 aeroderivative gas turbines. They consist of several days of in-depth briefing, review and closed-door user Q and A on details of machine performance and maintenance.

This year, *Turbomachinery International* sat in on some LM2500 sessions. Despite being about fifty years old, the relliability and durabiliity of the LM2500 made it the highest selling aeroderivative engine of 2017.

The LM2500 evolved from the CF6 aircraft engine, which has 490 million running hours. Over the decades, it has earned a reputation for dependability, with over 93 million total fleet hours.

Several versions of the machine are available:

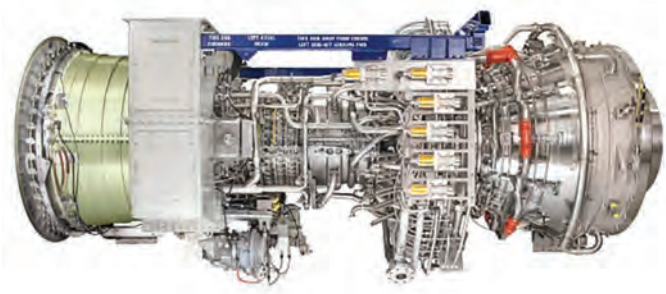
- The LM2500+4 provides up to 34.3 MW at 38.4% efficiency, with 562 units sold worldwide
- The LM2500+ provides up to 31.3 MW at 38% efficiency, with a total of 732 units sold
- The original LM 2500 provides up to 23.8 MW at 35.9% efficiency, with 1,174 units sold.

Overall, more than 2,460 units have been shipped by GE. While most are deployed in Europe and North America, they can be found all over the world.

Two combustor versions are available:

- Single Annular Combustor (SAC) units, with 1,767 in operation, the first sale taking place in 1969
- Dry Low Emissions (DLE) LM2500 first sold in 1992. Some 701 units are in use with this combustor.

The LM2500 track consisted of briefings from GE and depot personnel about the status of known maintenance issues, performance numbers from Strategic Power Systems (SPS), and user Q and As, which delved into various problems and fixes.



GE LM6000 PF+. WTUI showcased GE's entire range of aeroderivative gas turbines including the LM2500, LM5000, LM6000 and LMS100.

GE representatives informed the crowd on various fixes for their engines. This included how to address problems with variable stator vane (VSV) turnbuckle wear that had been noted on some LM2500+G4 high pressure compressors (HPCs).

Wear is caused by metal-to-metal contact between the turnbuckle and clevis walls due to misalignment. GE has come up with a fix that includes a washer that prevents contact, as well as anti-rotation links to dampen turnbuckle rotation.

Premixer shroud oxidation was found on two LM2500 engines. This was indicated by the presence of elongated fuel discharge holes and distress at the pigtail/premixer flange.

The causes of this problem were on-off cycles being near maximum power, and backflow of combustor air near the premixer resulting in auto-ignition. The GE solution was to place tunable switches in the control software to prevent cycling of the fuel flow.

GE showcased several other active engine programs for the LM2500. These ranged from programs dealing with the DLE gas manifolds to issues with the high-pressure turbine (HPT) Stage 1 and 2 blades and bearing improvements.

LM2500 switchover

Ruptures to the DLE gas fuel hose were noted after LM2500 units that had been running on liquid were then switched over to being run on natural gas. During extended liquid fuel operation, water can sometimes accumulate in the gas manifolds in moist environments.

Rapid evaporation of water to steam can over-pressurize the gas hose. Heavy hydrocarbon condensation in the gas hose and subsequent auto ignition with combustor air contributed to one event.

Enhancements from GE include check valves to prevent pre-mixer to pre-mixer cross-talk as well as eliminating the water source.

HPT Stage 1 blade oxidation was found in some LM2500+G4s, especially at the trailing edge near the mid-span location. This was more pronounced in SAC applications, causing early blade removal and higher scrap rate at overhaul.

Enhancements introduced by GE included changing the thermal barrier coating (TBC) process to minimize variation. The OEM is evaluating a more capable bond coat for SAC applications.

A new casting design is also being introduced in 2019 to improve durability. Meanwhile, GE recommended that users conduct regular borescope investigations on the hot section.

GE chose WTUI to promote several other technologies. It is touting a clutchless synchronous condensing approach to provide reactive power to the grid due to the increased presence of renewable energy.

This is done via an LM2500 control system upgrade, which allows the generator to provide frequency and reactive power support to the grid. This upgrade requires the following additions: a sump evacuation system, and a new controller: either the Woodward MicroNet+, GE Mark Vie or Woodward Flex500 controls.

GE's latest SAC control upgrade is said to reduce certain trip events and may help increase power reliability. It takes advantage of Woodward Flex500 controls.

Additionally, an upgrade is available from SAC or DLE 1.0 to the DLE 1.5 (a triple annular combustor with new gas manifolds and gas metering system). This new combustor burns fuel at a lower temperature over a larger cross-sectional area to achieve the same bulk gas temperature rise as a single set of nozzles burning at a higher core temperature.

Gas fuel is introduced into the combustor through 75 air/gas premixers. This new approach to combustion can be of value in lowering emissions.

Reliability analysis

The second day of the LM2500 track began with a presentation by Bob Steele, Vice President of Systems and Infrastructure at Stategic Power Systems (SPS). He detailed numbers derived from the SPS Operational Reliability Analysis Program (ORAP) which has been in operation for many years.

ORAP captures data from global operating power plants (gas, steam and wind) as well as reciprocating engines. Steele specifically detailed the LM2500 fleet numbers. Understanding these numbers enables turbine owners and operators to compare the performance of their own equipment to overall fleet averages.

For a simple cycle plant, from November 2016 to October 2017 the fleet averaged 92.8% availability. When operating as peakers, that rises to 97.3%, when cycling the average is 93.7% and at baseload it is 92.4%. Overall, availability was down approximately 1% for the same period in the previous year. Steele said this was mainly due to other balance of plant (BOP) equipment outages at some of the plants.

Every year, SPS provides WTUI attendees with a rundown of the various causes of outages. Some 88% of the forced outage hours in 2017 were due to station (BOP) equipment. For example, there were many incidents related to gas fuel supply and these were mainly caused by low gas pressure or supply problems.

Other problem areas, said Steele, were controls and communication systems going down, difficult environmental conditions (such as icing), instrumentation issues and grid instability. These areas were among the leading causes of forced outages on the LM2500 for the year.

Specific to mechanical drive, outage sources included pipeline instability, anti-surge, gas seal leaks and outlet temperature. Power turbine-based downtime, on the other hand, was traced to areas, such as vibration trips and combustion system issues (due to flameouts and acoustic incidents).

This is just a smattering of the extensive performance and downtime data SPS provided to LM2500 users. Those enrolled in the ORAP program gain full access to all fleet-wide statistics.

Closed-door sessions

There comes a point in the WTUI user tracks when OEMs and vendors are asked to leave the room. This allows users to have an unrestrained discussion about the various problems they face with their own engines. Many of the other users pitch in with how they addressed those issues.

Over several days, users took up a long list of operations and maintenance topics. The discussion was moderated by Garry Grimwade, Chair of the LM2500 track. Apart from his WTUI duties, he is Utilities Generation Technician at Riverside Public Utilities.

Grimwade began the session by taking up speed transducer failure in the power turbine of the LM2500. This, he said, set off multiple vibration alarms, as well as an alarm that a sensor had failed.

After checking the Bently Nevada 3500 system on his LM2500 to find the vibration issues, he isolated the fact that a faulty transducer made it look like vibration trouble. He recommended that users experiencing the same problem replace the transducer themselves without the need to call in an authorized service provider.

Grimwade took up other areas, such as combustor and hot section damage, borescope inspections, cracking of the combustor, and liberation of metal causing damage to the HPT.

In his case, the second stage blade of his LM2500 gas turbine needed to be replaced. His advice to users was to look frequently in this area for possible damage. He also noted that water injection LM2500 engines were the ones primarily suffering from this problem.

"The high flow of water causes rapid thermal expansion," said Grimwade. "GE is looking into this and helping users resolve any issues."

A large number of technical sessions on the second day of the conference was kicked off with Dean Webb, Combustion Turbine Reliability Specialist at Nova Scotia Power. He covered predictive maintenance and asset management of turbomachinery. He looks after seven Pratt & Whitney (PW) GG4Cs.

Power plant in California using the GE LM100 gas turbine. Plant owners and operators from plants using GE aeroderivatives from all over the world gathered in Palm Springs in March 2018

Six are in active service and the other is being restored to service. Despite their age, the utility believes the inventory of available spare parts should be able to keep them running for a while longer. They are being used for synchronous condensing and for peaking power.

In addition, Webb looks after two LM6000 PCs as well as a spare engine. Over the past 15 years, he has been involved in around 14 LM engine removals. These machines are used for baseload and for load following.

"Even with monitoring and predictive maintenance, you still need operational surveillance," said Webb.

Non-destructive testing

Webb regularly carries out non-destructive testing (NDT), vibration analysis, oil analysis and periodic health assessments. Critical for borescope inspections, he said, is an intimate knowledge of the equipment. The operator must have a keen sense of spatial orientation to be able to visualize the location of the borescope's probe tip. His company conducts borescopes during scheduled annual outages, as well as during some forced outages.

He gave an example of an impending vane liberation on the HPC Stage 10 stator in a PW unit. No vibration or performance indications had been observed. Yet the borescope inspection found the problem in an area that was difficult to get into due to the unit having very few ports of entry.

"We noticed the worn disc, that the stator vanes had liberated and were being pulled into the disk," said Webb. "They were on the verge of falling out and could

Nova Scotia power found ice damage on Stage 0 of this low pressure compressor using a borescope inspection. This caused the LP rotor blades to be out of alignment as the blade had gone into the casing.

have caused damage."

Another issue: The LPC Stage 0 had suffered a soft-body impact. Related to that situation, the operator had first noticed a change in the sound emitted from an area adjacent to the inlet volute, as well as a shift in vibration.

A borescope inspection determined that a blade was out of alignment. This was traced to icing that was traced to a small leak in the SPRINT water injection system. Result: A five-centimeter ball of ice had formed. This caused the damage to the blade.

"We experienced no trips, but we found the problem early enough due to vibration analysis and borescope inspection," said Webb.

Oil analysis is another tool used by Nova Scotia Power. This proved to be of assistance with a bearing problem. Debris found in the oil during oil anlaysis was found to be due to wear in the oil wetted system.

Oil analysis targets contaminants

Matthew Holmes, Senior Reliability Engineer at Acuren Group, assisted Nova Scotia Power with this investigation. Oil analysis targeted contaminants, wear metals, additives, viscosity, water presence, acidity, particulate and varnish.

"This helps us understand if there is bearing degradation," said Holmes. "Vanadium indicates a main bearing issue in the LM6000. You can also check the filters and analyze the debris. That provides an indication of wear and other issues."

In addition, Acuren helped the utility with vibration monitoring on the LM6000. More sensors were added as the LM6000 has only a few sensors for vibration analysis. The regular sensors failed to detect that anything was amiss. But the added sensors picked up vibration problems.

"We looked in the engine and found the LP rotor blades to be out of alignment as a blade that had gone into the casing," said Holmes. "The cause was found to be LP rotor unbalance."

He recommended installing more sensors, establishing baselines and then monitoring for changes in vibration. Several sensors should be added to the compressor, gear box and bearings.

It is a good idea, then, to combine several analysis technologies as well as borescope inspections to make informed maintenance decisions, said Holmes. Monitoring the oil sump for metallic particles, for example,

(Continued on p. 20)

Fog skid deployed at APR Energy site on Pratt and Whitney FT8 MobilePac gas turbine in Libya. Courtesy of Mee Industries

yielded information about a bearing failure in a gearbox.

Air quality affects the entire engine due to the sump pressurization air circuits, component cooling and recoup air circuits, added Webb. Poor air quality can accelerate corrosion, affect coatings, lessen component cooling and degrade performance due to compressor fouling.

Similarly, water quality affects the hot section of the engine. Off-spec NOx water spray patterns, for example, may impact

Thermal Barrier Coatings (TBCs), cause pitting and lead to gypsum build.

Emissions control

During a later technical session, John Hutson, Plant Manager for Orange Grove Energy (OGE) in Southern California outlined an emissions control improvement project. His 98.5 MW plant, which began operation in 2010, has two simple cycle LM6000 PC SPRINT units.

Mechanical inlet chilling is done at the facility with the inlet temperature kept in the range of 46 to 86°F. Further, the units use Woodward controls, have fuel gas compression, and use water injection for emissions control.

Due to its location in the desert climate of Northern San Diego County, California, and recent state restrictions on water usage, 100% of the facility's water is trucked in. It is demineralized on site. Emissions controls include a back-end CO catalyst that keeps CO below 6.0 ppm and an SCR system to keep NOx below 2.5 ppm. NOx emissions are also keep down via water injection.

"We have no margin for error at the plant due to stringent emissions regulations that make compliance a continual battle," said Hudson.

In such a regulatory environment, the facility pays attention to the smallest of details. For example, it addressed poor thermal control of the outer exhaust liner, as a contributing factor to higher emissions. This impacted ammonia control, which was too slow to properly control NOx when the turbines ran at full load.

As the plant skated dangerously close to exceeding its air permits, this limited options to increase power output. The solution to this problem included an ammonia control logic upgrade, a remodeled exhaust plenum, as well as better SCR and CO catalyst operation.

Inlet cooling

Dharam Punwani, Executive Director of the Turbine Inlet Cooling Association. (TICA), gave an overview of inlet cooling technologies.

He briefly covered the fundamentals: An increase in ambient temperature reduces the generation capacity and efficiency of GTs (up to 19% capacity loss and 4% efficiency loss for an aeroderivative, which is higher than the losses experienced by an Industrial Frame turbine).

That is why U.S. generation capacity is significantly lower than the actual nameplate capacity; fuel use and CO_2 emissions increase during peak demand periods in summer due to the use less efficient systems to meet demand.

"The solution is to cool or chill the air before it goes into the compressor section using proven technologies, such as evaporation cooling, fogging, wet compression and chilling," said Punwani.

"Thousands of plants are using these methods: each technology has its pros and cons."

Wetted media evaporative cooling is the least capital cost. Fogging is slightly more costly but generally produces more cooling than wetted media. Further, it can be augmented with wet compression.

Fogging, though, has a low parasitic load. Chillers may be the most expensive, but they are more effective in terms of the amount of cooling and capacity enhancement that can be accomplished, independent of the humidity — down to 42°F (any lower could lead to icing). The parasitic load in chilling, however, is higher.

Punwani explained that technology selection is site-specific. It depends on many factors that include: the market value of electricity in the area, local weather data, fuel cost and the anticipated or desired payback period. He ended with many examples of recent (2015-2017) installations of all of these inlet cooling technologies.

The WTUI show will return to Las Vegas in March of 2019. ■

TOUGH TIMES FOR GAS TURBINES

SALES ARE DOWNTRENDING AS THE MARKET VEERS RELENTLESSLY TOWARD RENEWABLE ENERGY SOURCES

BY DREW ROBB

Every year at the Western Turbine Users Inc. (WTUI) show in the Western U.S., Mark Axford of Axford Consulting delivers a breakdown of the gas turbine (GT) marketplace. He always begins with a light-hearted review of his prediction from last year's show.

Usually he gets it right, but Axford said, "For 2017, I have never been so wrong. I take no comfort in the fact that GE and Siemens also had a major miss in the forecast."

Back in March of 2017, he said that U.S. GT orders would be up 10% and worldwide orders would be down about 10%. However, the actual results were U.S. GT orders down 36% and worldwide down 28%.

"We are witnessing the continuing collapse of the GT market," said Axford.

Tony Brough

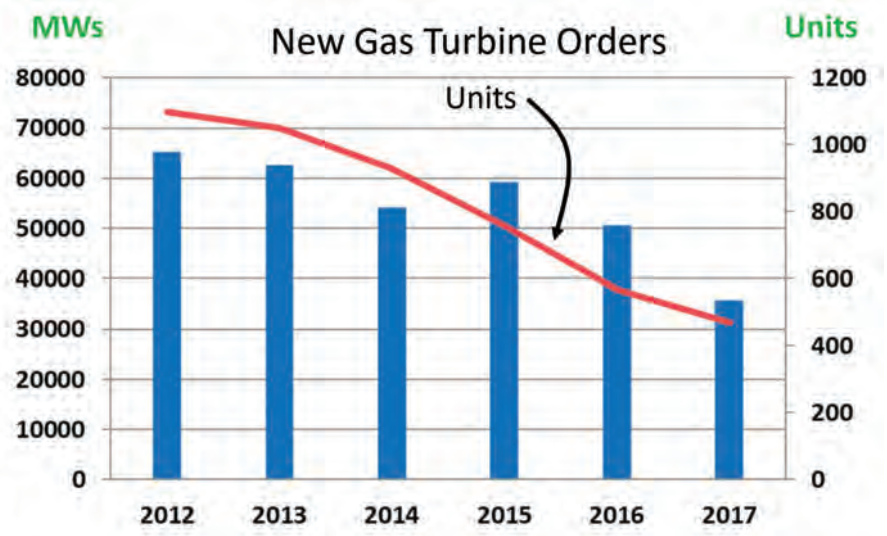
He turned over the stage to Tony Brough, President of Dora Partners. Brough provided specifics from market and data collaborators, Dora Partners research and McCoy Power Reports, which provide a detailed forecast of over 90 gas turbine models.

Brough explained that worldwide MW orders for the year were down 29% with unit orders down 17%. "More worrying is the fact that MW orders since 2012 are down 45% and unit orders are down 60%," said Brough. "The unit order decline has a stronger impact on future aftermarket growth."

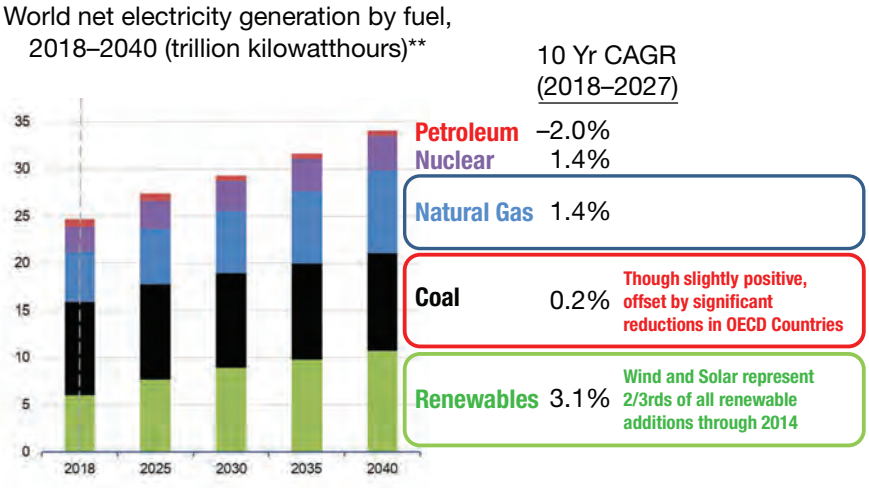
Predictions for worldwide net electricity generation by fuel indicate that natural gas will remain a strong long-term player in the electric energy field. Natural gas is expected to grow by 1.4% per year over the next ten years while coal and petroleum fade. Renewables, though, are predicted to increase by 3.1% per year in that same period.

"The growth areas for natural gas are in Africa and parts of Asia," said Brough. "If you are a service provider, you need to have people in those areas."

Brough also analyzed the levelized cost of electricity (LCOE) for the various technologies. He highlighted big LCOE gains for renewables assisted by subsidies. This is causing combined cycle GT plants to



MW orders for GTs on the left axis; total unit orders on the right axis. Both are trending down.



** Energy Information Agency, 2018 Data Dora Partners & Company

World net electricity generation by fuel, 2018 to 2040 (trillions of kWH). Petroleum in red, nuclear in purple, natural gas in blue, coal in black and renewables in green. Source: EIA

lose their price advantage over wind and solar in some cases.

"Renewables don't always beat GTs on LCOE, but it is highly situational," said Brough.

A breakdown of the GT market highlighted both strengths and weaknesses. The 150 MW to 300 MW range has a 46% share of market in terms of capacity. But the 40 MW to 100 MW segment, and the 20 MW to 30 MW segment, are also doing well relative to other parts of the chart.

The OEM picture is more straightforward. GE and Siemens account for more than 80% of capacity and 49% of all units installed. Solar Turbines boasts 41% of units installed.

The electric power utility sector dominates all gas turbines deployed (85% of capacity). But oil & gas has almost half the units. Equipment and service providers in the O&G sector enjoy higher prices and greater commitment to specific OEM's and technologies.

Despite its age, Brough said the LM2500 is continuing to perform well, particularly in oil & gas.

Heavy duty industrial turbines take up 84% of installed MW capacity and 37% of units. Aeroderivatives, on the other hand, account for only 11% of capacity and 19% of units.

The Africa and Asia Pacific regions exhibit the highest anticipated growth rates. But Brough believes aeroderivative technologies will play a major role in serving the O&G sector and key power generation sectors, such as peaking.

Within the aeroderivative space, the LM2500 dominates, followed by the LM6000. In 2017, the LM2500 outsold the LM6000 by 15 to 1, in the U.S. On a worldwide basis, the LM2500 grabbed almost 50% of orders in 2017. The LM2500 has a fleet of more than 2,000 units, followed by the LM6000 with more than 1,100. The LMS100 has yet to crack the 100 mark.

Despite its age, Brough sees the LM2500 as continuing to perform well, particularly in oil & gas. There is also rising demand for trailer-mounted units, as well as in overhaul and repair. Brough sees the aeroderivative aftermarket potentially worth $2.28 billion per year.

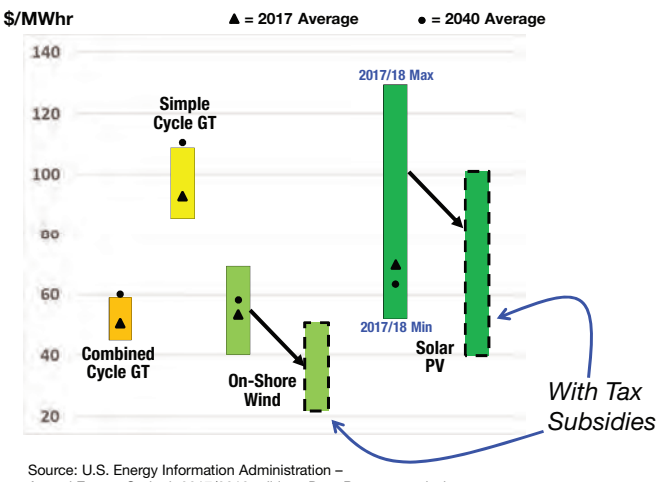
Axford continued the narrative. He said that over 205,000 MW of net capacity would be added to the U.S. grid between 2018 and 2021. Natural gas will gain about 80,000 MW, but wind and solar dominate.

A lot of this market, said Axford, will consist of large-scale combined cycle plants.

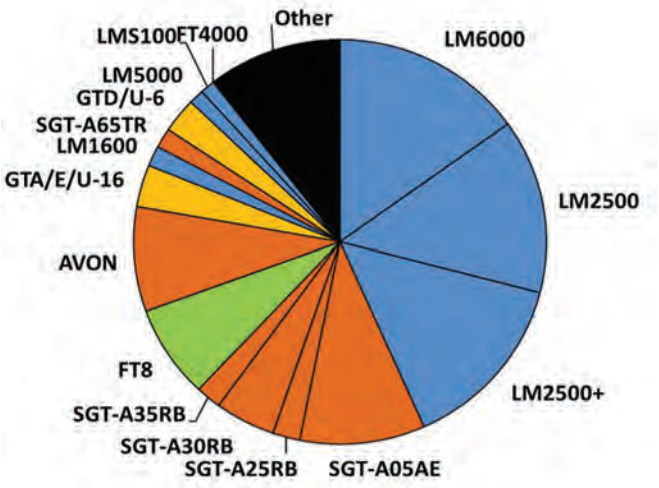
"A 500 MW combined cycle plant was considered big a few years ago, but now it's up to 1,200 MW," he said. "That upward push is only going to continue."

The trend, then, is away from the traditional stratification of the GT market (small, medium, large and extra-large seg-

(Continued on p. 25)

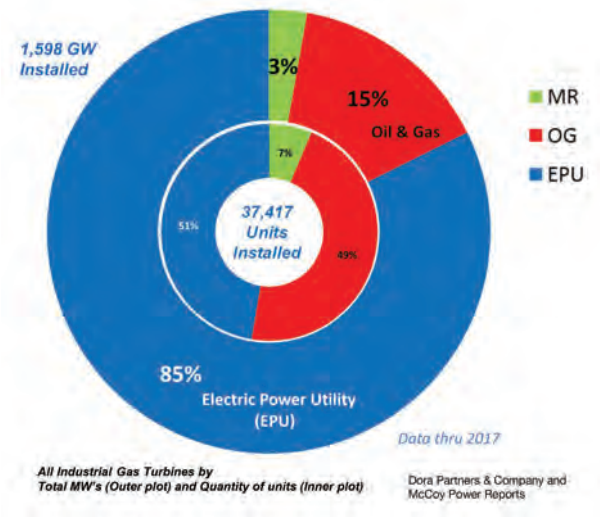


Source: U.S. Energy Information Administration – Annual Energy Outlook 2017/2018 editions Dora Partners analysis

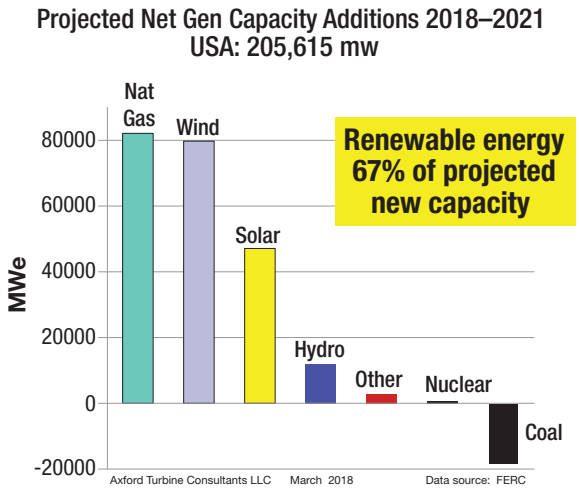


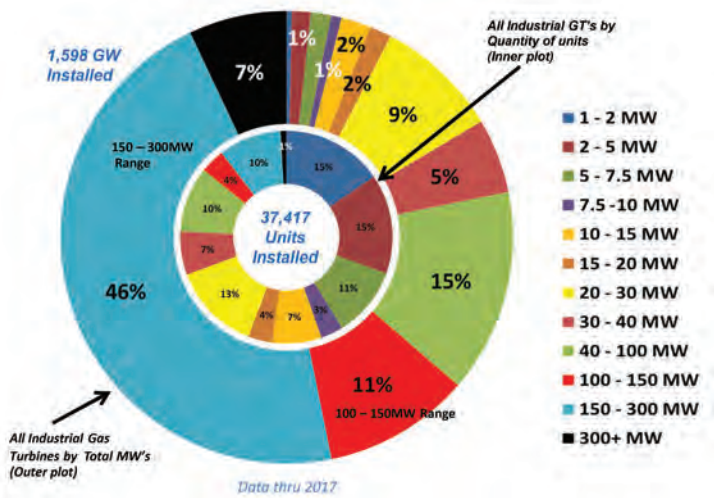
Aeroderivative global fleet

Source Dora Partners and McCoy Power Reports



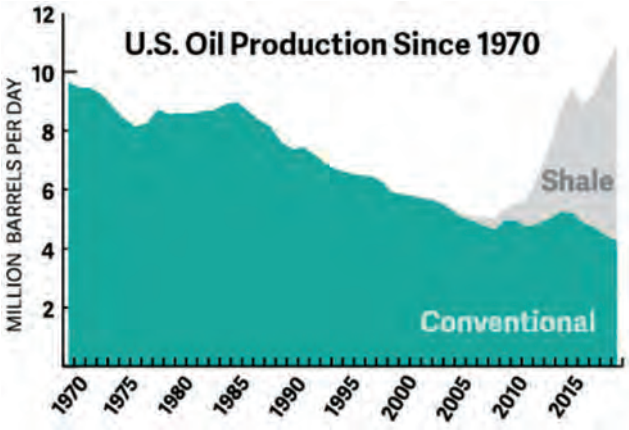
The U.S shale industry offers huge reserves of oil. As the price of oil varies, production can easily be ramped up or down





Industrial GTs by unit volume and capacity.

Source Dora Partners and McCoy Power Reports



Soure: EIA

ments). Now, said Axford, it is destined to consist mainly of small and extra-large.

Competition is intensifying on all fronts. Reciprocating compressor specialist Wärtsilä received orders of 3,800 MW in 2017.

Axford expects the lean years for GT sales to continue. He explained that the structure of wind subsidies has left a backlog of 27,000 MW in wind projects that has to come onto the grid. These projects have already been given federal dollars, so they will be given priority over other types of generation.

Oil & gas gains

All was not glum, though. The price of crude oil has recovered from the $40-50 per barrel range to above $60. The expected trading range for the balance of 2018 is $60-70 per barrel. That bodes well for sales of pipeline compressors, as well as small gas turbine generator sets at oil and gas production facilities.

"The U.S. has become a peaking plant for oil — production stops when the price is down and starts again when it comes back up," said Axford. "During the course of this year, the U.S. may exceed Russia and Saudi Arabia to become the biggest oil producer in the world."

Mark Axford

U.S. LNG production, too, will surge. The first exports of LNG from the Cheniere facility in the U.S. took place in 2017. There are now two operating LNG export facilities in the U.S. and three more in construction.

This drives turbine and compressor orders delivering gas to these facilities. Cheniere LNG, for example, already has 29 LM2500s running. Cheniere's fleet could grow to as many as 60 units during the next few years.

"U.S. LNG adds up to a lot of power and mechanical drive sales and purchases," said Axford.

Most American LNG is shipped to Asia — mainly to China, as well as Japan, Korea and India. Some LNG also went to Brazil and the UK. Currently, the U.S. comprises 2% of the world LNG market. Qatar owns 30% and Australia 17%.

U.S. LNG growth could benefit from development work on the Alaskan LNG project, which offers a short route to Asia. But it will need an 800-mile pipeline and the building of a terminal in Alaska. It remains to be seen how things will transpire in the region, an environmental hotbed.

Axford noted California's negative prices for power due to a surplus of solar energy during mid-afternoon hours. "As California makes more solar power than can be consumed, it has been paying Oregon and Arizona to take some, especially during the spring," said Axford. "Similarly, Texas often sees the wholesale price of power become negative at night due to a surplus of wind generation.

This raises the issue of energy storage. California has ordered utilities to buy storage and stepped up subsidies for it. It added 500 MW of storage to the mandate during 2017, nearly all lithium ion batteries.

Axford focused on the price decline curve for battery technology. Right now, the cost of batteries is $209 per kWh and falling about 20% per year. "The goal is to get it down to $100 per kWH," said Axford. "If it gets there, that will be the end of peaking gas turbine plants."

He ended with his customary gas turbine prediction for the coming year: Both U.S. and worldwide GT orders will be down at least 10%. ■

STRESS CORROSION CRACKING

UNDERSTANDING THE CAUSES CAN HELP MINIMIZE DOWNTIME AND IMPROVE RELIABILITY

BY EESAN VAMADEVAN

Steam turbines are used across the world as a source of power for many different industries. Even with the best maintenance procedures and preventative maintenance techniques, problems can arise.

Older steam turbines, for example, are prone to stress corrosion cracking of the turbine blades. Understanding the causes can help minimize downtime and improve reliability.

Take the case of an integral steam turbine rotor that developed cracks in the root sections of the row six disk. The turbine had an operating speed of 9,900 rpm and the steam inlet temperature was 400°C (750°F). The equipment had been well maintained.

The hook section of the disk, however, was under high stress. The design of this rotor used two root lengths to offset the stress loading and minimize the risk of cracking in the disk. Despite this, seven roots with cracks were identified using a magnetic particle inspection (MPI) process.

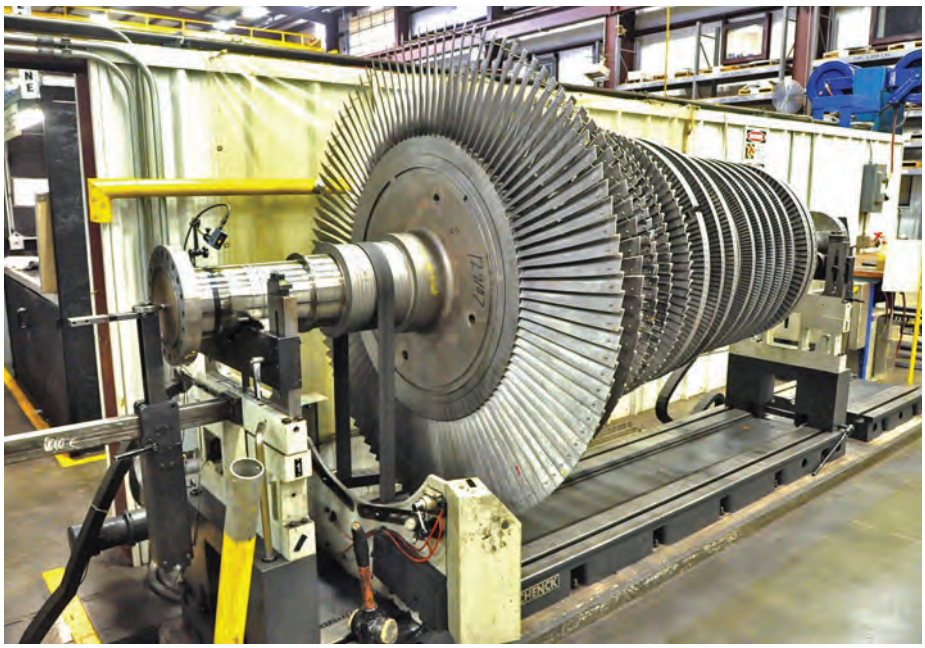
Engineers conducted inspections to determine the cause of the cracks. Four cracks were opened mechanically to examine the fracture surfaces using a scanning electron microscope (SEM). This highlighted evidence of intergranular cracking. Other fracture mechanisms, such as fatigue, appeared to play no role in failure.

Optical metallography was also used to examine a section of the cracked area and found branched cracking immediately below the fracture surface. In conjunction with the findings from the SEM observations, the cause of the cracks was confirmed as stress corrosion cracking.

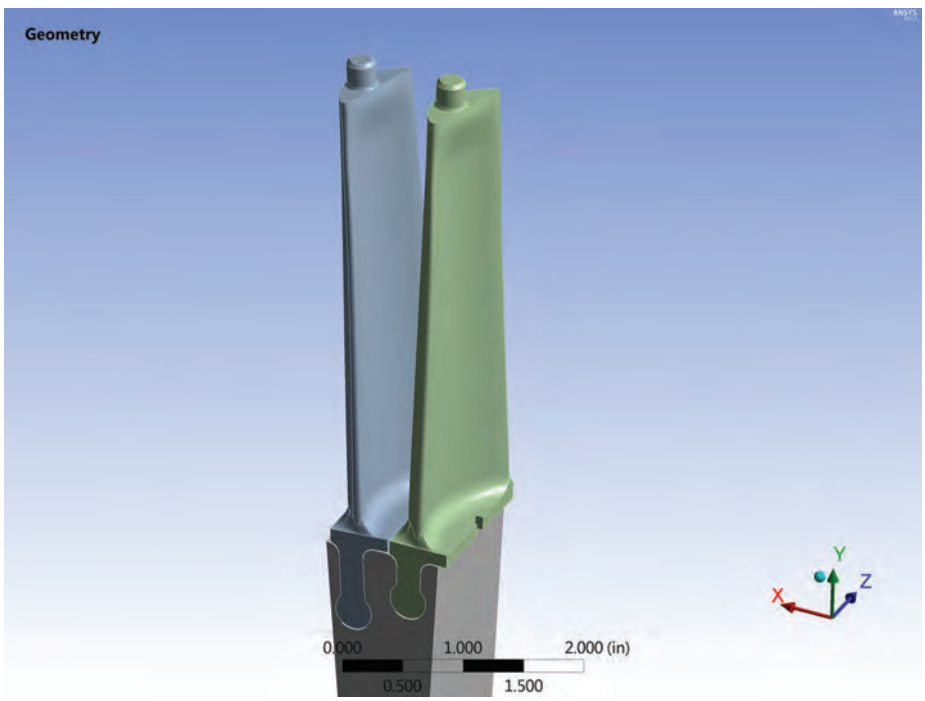
Material composition

Chemical analysis and testing of the mechanical properties of the components involved in any failure is important. The ASTM A470 Grade C alloy used in the composition of the rotor disk was found to have higher tensile strength that the maximum value specified. This can often lead to increased susceptibility to corrosion.

Further investigation used energy dispersive spectroscopy (EDS) to determine



Multiple conditions must be present for stress corrosion cracking to occur



A 3D CAD model of the blade was created to perform finite element analysis (FEA) to investigate possible causes of rotor disk cracks

the chemical composition of the material at the fracture surface. Aside from the expected elements in the base metal alloy, EDS identified sodium, magnesium, tin and chlorine. The most likely source of these elements was steam used to power the turbine.

To address all the possible causes for rotor disk cracks, an investigation into stresses was carried out using finite element analysis (FEA). A 3D computer-generated model looked at maximum stress values while the rotor operated at its maximum continuous operating speed (MCOS).

The stresses in the disk at the short blade root exceeded 100 ksi along the root axial width. However, this was less than the measured yield strength of the material of 125 ksi. This provided further evidence that stress alone was not sufficient to cause the material to yield. Stress corrosion cracking was the primary cause of the failure.

When cracking occurs

Stress corrosion cracking occurs due to the presence of three conditions:

- The alloy is susceptible to stress corrosion cracking
- The stress intensity factor is above the threshold value
- A corrosive environment is present.

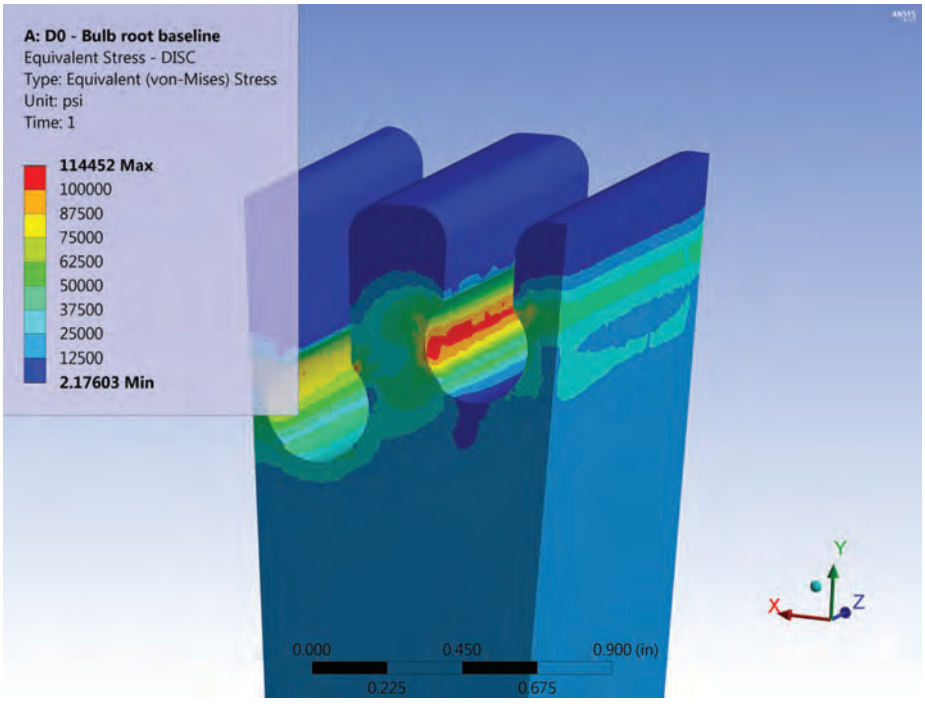
In this example, higher tensile strength levels made the alloy more susceptible to corrosion. The location of the high-stress region within the disk corresponded with the crack initiation locations found during the MPI. The presence of chlorine at the fracture site indicated a corrosive atmosphere, which further confirmed stress corrosion cracking as the cause of failure.

To avoid stress corrosion cracking, it is only necessary to remove one of the above conditions. Modern steam turbine components use the latest alloys as well as different blade root designs.

In this case, redesigning the blade root to reduce the peak stress levels was not feasible as the ball root design was compact and would not allow for much improvement in the stress profile. Therefore, the best approach was to improve steam quality by eliminating corrosive agents.

Failure of the row six disk's root section was also investigated. Apart from some minor variations in material quality, the major mechanical property that did not meet the required specification was the measured impact value. It was found to be considerably below specifications.

Further SEM investigation showed that the entire fracture surface exhibited an intergranular failure mode. This was confirmed after assessment of a polished section inspected using optical microscopy. It also indicated branched cracking.



FEA identified maximum stress levels at the operating speed

A range of investigation techniques, including optical microscopy, are required to determine the causes of failure

In addition, EDS analysis found heavy oxide on the fracture surface. These findings confirmed stress corrosion cracking as the cause.

Chemical etching of a polished sample of the fracture surface made it clear that the microstructure did not show fully tempered martensite. Combined with the low-impact values, this indicated that the forging had not been properly heat treated. This may have accelerated crack propagation in the disk. ■

Eesan Vamadevan PhD, is Senior Metallurgist at Sulzer, an independent repair specialist that can provide turnkey solutions for steam turbines; from inspections to preventative maintenance and complete overhaul, including redesigning components for improved efficiency and reliability. For more information, visit www.sulzer.com/en/services

AIR FILTERS

IMPROVING CORROSION PROTECTION AND POWER OUTPUT VIA INLET AIR FILTRATION

BY JOSHUA KOHN

Test results show CamGT had twice the protection against corrosion compared to the other filters

It is not uncommon for gas turbines in coastal areas to suffer from corrosion due to poor inlet air filtration. In environments where salt and other hydrophilic (moisture absorbing) contaminants are present and humidity spikes are frequent, particles on some filter media can swell, causing pressure drop (dP).

High filter dP reduces compressor efficiency and ultimately power output. In an extreme case, it can set off a turbine alarm and force operators to derate.

Furthermore, high dP increases the risk of salt migration through the filter media. In the presence of salt, the risk of hot-end corrosion increases, leading to costly turbine repairs.

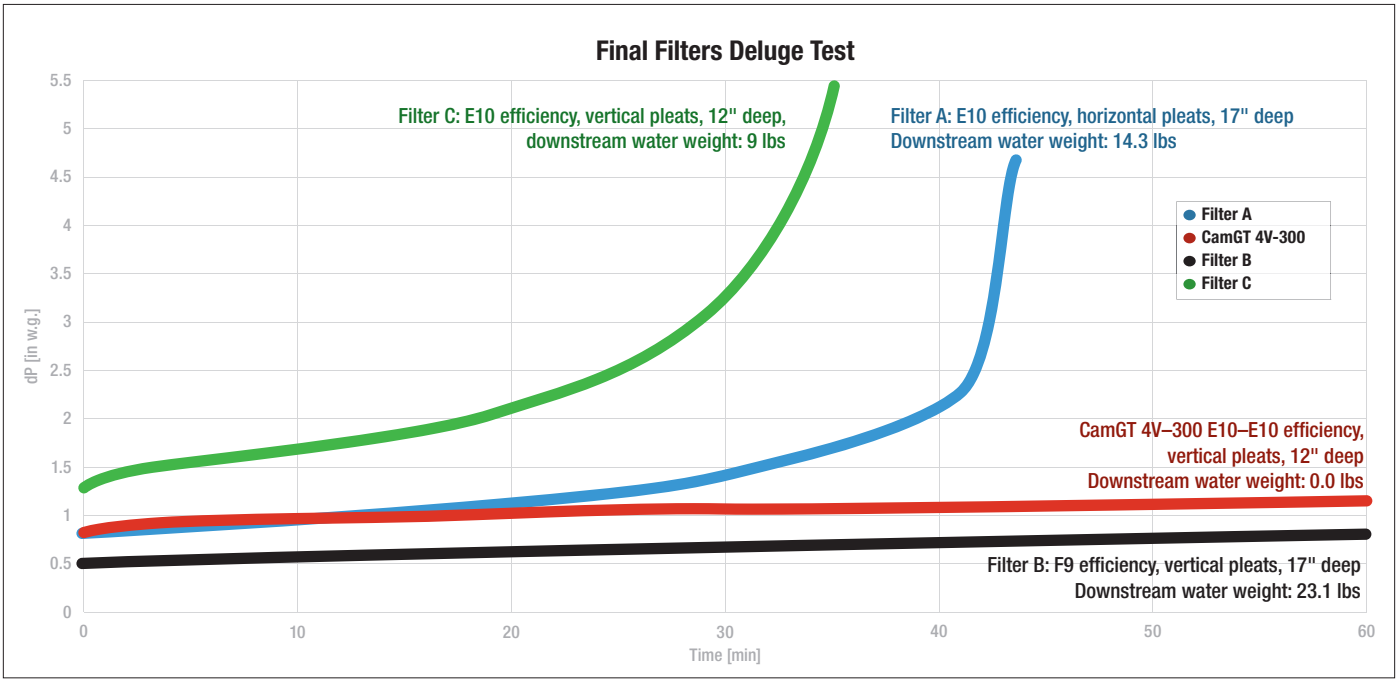
Filters with a high efficiency EPA class rating, good hydrophobicity (water resistant), and drainage capabilities will prevent salt carryover.

Salt and contaminent problems

Without them, water can dissolve salt and other contaminants present on the filter surface and carry them onto the clean side of the air inlet where they can be ingested by the gas turbine.

In the presence of salt, the risk of corrosion increases. This can cause the turbine to be less efficient, and lead to maintenance issues.

A one-piece, poured-into-place endless gasket instead of the typical four pieces will prevent bypass. Four-piece gaskets have the potential to allow water and particulates to migrate downstream due to the joints between the gaskets. Media is often glued to the filter header in two-to-four steps. A double-sealing design that uses a six-step glue technique to prevent leakage is recommended.



Deluge and efficiency testing led an LA plant to upgrade its filtration system to CamGT 4V-300 E10 filters. Other filters in the test had more than 20% water bypass, The CamGT was the only one to last 60 minutes without substantial water bypass and to end at a low dP.

Depth loading with synthetic glass media offers an optimal balance between wet performance and dust holding capacity.

Vertical pleats and patented interrupted hot melt separators are designed for efficient water handling.

Horizontal pleats and uninterrupted hot melt separators, however, can trap water in the media, causing increases in pressure drop, which can force dissolved contaminates through the filter.

Take the case of a plant on the Pacific Coast in Los Angeles. It is situated in a deep hollow, where a thick marine layer (fog) comes in from the ocean. This leads to high humidity for long periods.

The engineering team conducted a borescope inspection on two Siemens 501F gas turbines, where standard F8 efficiency filters were installed on site.

The inspection found corrosion on both engines. This lead them to evaluate higher efficiency final filters to reduce ambient salt.

Standard F8 efficiency filters were installed on site. The team decided to evaluate a higher efficiency final filter to reduce ambient salt on the turbine air inlet and the gas turbines.

F8 grade filters are rated per EN779:2012 while E10 grade filters are rated per EN1822:2012. F8 filters at 0.4µm are required to meet a minimum 55% initial efficiency per EN779:2012, while a typical E10 grade filter rated per EN1822:2012 offers 98% efficiency at 0.4µm. Upgrading to an E10 efficiency class reduces particle penetration by a factor of 20:1.

A CamLab, a mobile laboratory for testing filters, was used to perform a blind test on site for 2,100 hours to compare four filters from different manufacturers. All had a 24 × 24-inch face area but slightly different filter element depths.

Measured parameters

During the test, the filters were exposed to on-site contaminants and atmospheric conditions. Measured parameters included ambient dust concentration, airflow, pressure drop, filter efficiency, temperature, and relative humidity.

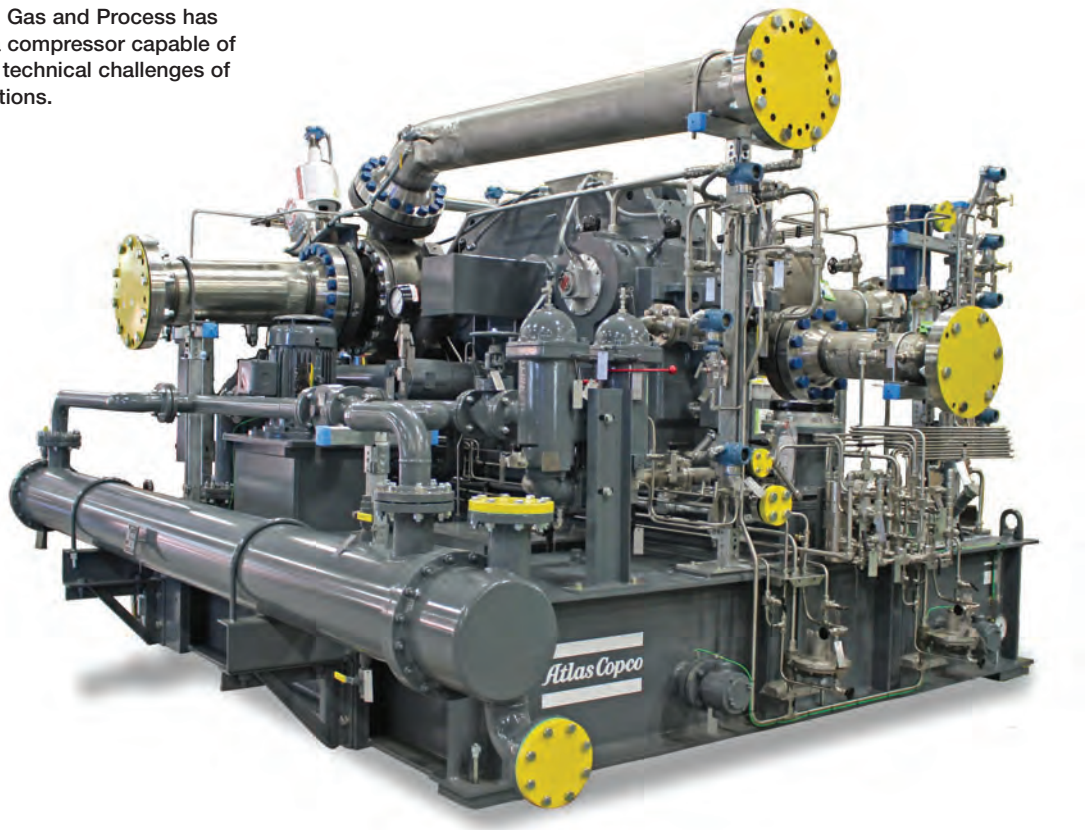
Copper corrosion coupons were installed downstream of each filter duct to provide an additional reading of performance (measured according to ISA 71.04:2013 for change in thickness). After site testing, they were retested under controlled laboratory conditions.

Additionally, a deluge test on the dust-loaded filters determined resistance to water penetration and rate of pressure increase on the filters. Water was sprayed until the pressure reached over 4" w.g. (inches of water gauge) or one hour had passed, whichever had occurred first (Figure).

Effective filtration should be hydrophobic (to at least the typical operational dP) to prevent water and salt penetration. The right filtration for gas turbines in humid areas should also have efficient water drainage, a high rate of filtration efficiency, should demonstrate low dP in wet conditions, and have high burst strength.

Operational benefits of effective filtration include fewer maintenance shutdowns, increased availability and reliability, higher and more stable power output, extended turbine life, and reduced life cycle costs. ■

Joshua Kohn is Chief Engineer, Camfil Power Systems, a company that develops clean air solutions for turbomachinery. For more information: visit www.camfil.com/ps, or email joshua.kohn@camfil.com



Atlas Copco Gas and Process has developed a compressor capable of meeting the technical challenges of CO_2 applications.

MAKING CLEAN POWER POSSIBLE

A GAS TURBINE-DRIVEN, INTEGRALLY GEARED COMPRESSOR SOLUTION FOR THE SCO_2 ALLAM CYCLE

BY TUSHAR PATEL AND JACOB DUFFNEY

To meet global emissions targets, traditional power generation cycles have aimed to reduce and capture greenhouse gas emissions, such as CO_2 and other pollutants. However, the equipment needed to do so often requires significant expense.

The system's effectiveness comes at the cost of the cycle's efficiency. Electrical costs, for example, have increased markedly in cycles using external removal systems to capture, at most, 90% of the CO_2 released.

An oxy-fired, trans-critical CO_2 Allam Cycle with a low-pressure-ratio turbine has been found to be efficient and effective. It captures the CO_2 produced by the combustion of hydrocarbon fuels and uses a combination of heating, cooling and compression to transform it into a supercritical state whereby it can be recuperated and recirculated. This has the potential to realize low cost and clean generation.

A key design choice is the use of a combined turbine-compressor train. However, implementing a supercritical CO_2 compressor-turbine train poses certain challenges. An initial design consideration is to find the type of compressor solution best suited for this application.

Operating in the environment of sudden higher CO_2 density and increased force levels on rotating equipment, the Atlas Copco compressor provides reliability and high-efficiency values. This allows it to use around 30% less energy than a standard single-shaft compressor.

Supercritcal pressure

This compressor also delivers high-pressure CO_2 in supercritical CO_2 power cycle applications. Today, applications require more than gaseous CO_2. CO_2 must be delivered under high, sometimes supercritical, pressure and in large quantities.

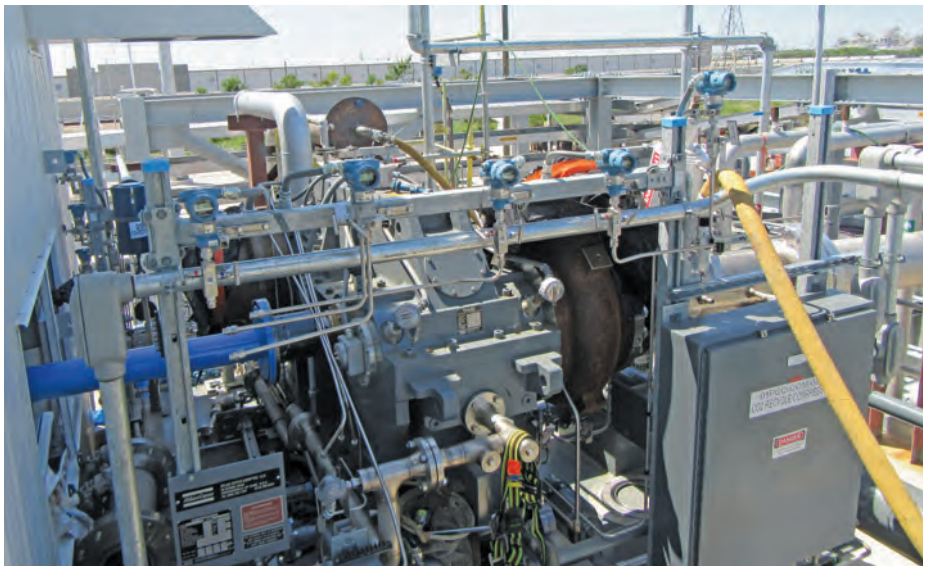
The emerging power cycle through oxyfuel combustion uses supercritical CO_2 (sCO_2) as a working fluid and operates above the supercritical point of CO_2, where distinct liquid and gas phases do not exist.

Instead of conventional phase changes to recover the energy, sCO_2 undergoes drastic density changes over the small temperatures and pressure gradients at high temperatures. This allows energy recovery in relatively smaller equipment.

The entire cycle depends on efficiency of the CO_2 compressor and its design. For instance, in the high-pressure stages, dry face seals enhance the machine's reliability and minimize seal leakage losses while providing savings on operating expense.

By segregating the stages of the inline compressor, intercooling can be implemented between stages. This increases efficiency by creating an even isothermal compression process.

The machine is designed to handle high forces that result from a dense, su-



Integrally geared compressor installed in supercritical CO2 power generation plant.

percritical gas. The high-pressure ratio and efficiency of an integrally geared (IG) compressor can adapt rotor speeds to the impeller behavior.

One application of this technology was a CO_2 compressor with an inlet pressure of approximately 30 bar, and inlet temperature of near ambient (achieved via cooling by conventional cooling towers). It also had a discharge pressure sufficiently high to achieve a specific gravity near liquid water when cooled to near ambient temperature again. The outlet pressure was about 90 bar.

A large range in pressure means the compressor must accommodate variations in volumetric flow. Furthermore, to facilitate startup and other modes of operation, it requires inlet guide vanes (IGVs) on the first stage that have the potential for a flow turn-down of up to 35%. Given the large amount of flow sent through the CO_2 compressor, inter-cooling became necessary to reduce power consumption.

Note: the demonstration nature of the coupled turbine resulted in a compressor driver speed that was higher than typical synchronous speeds. Nonetheless, eliminating the use of an intermediary gearbox was preferred.

Delicate balance

Due to its nearly closed-loop process, the sCO_2 Allam Cycle relies on a delicate balance of heating, cooling, compression and venting. Every aspect of the compressor-turbine train, from aerodynamics and process control to lube oil and seal support systems, must be carefully considered to prevent damaging or hazardous conditions.

The CO_2 centrifugal compressors, including the referenced gas turbine-driven centrifugal compressor used in the sCO_2 Allam Cycle, have typically been offered and supplied as in-line (between bearing) API 617 Ch.2 technology. Although this approach has had a long and proven his-

tory, it also presents limitations and drawbacks when it comes to CAPEX, maintenance and flexibility.

An IG compressor addresses these limitations. However, a typical gearing arrangement limits the size and number of stages that can be mounted on the machine.

An external intermediate gearbox can be used to vary the IG compressor input speed. But the industry typically rejects this solution due to the perceived complexity of two separate gearboxes.

Technological challenge

Along with the technological challenges of allocating the necessary combination of machine components in a compressor-turbine-generator train, there are additional considerations. These range from aerodynamics and rotordynamics to the design of the process sealing system, lube oil, and control systems.

With in-line compressor technology, the aerodynamic components are mounted on the same shaft, requiring them to be sized-based on a given driver speed. IG compressors have stage design speeds that can be selected independent of the optimum driver speed.

This makes it possible for components to be tailored to thermodynamic requirements without being bound by speed and enables higher loading per compression stage.

As each impeller is a stage with its own casing and inlet and discharge connections, IG compressors accommodate intercooling between stages to reduce adiabatic losses.

This allows for greater flexibility and more efficient compression. IG compressors are considered high-head compressors due to their ability to match stage speed to aerodynamic requirements. As a result, fewer impellers are needed to reach the same compression-ratio-to-head requirement, providing a more compact footprint.

IG compressors offer ready access to major components due to their horizontally split gearbox design. Any compression stage can be accessed separately and repaired onsite, without removing the process connections to the other stages, thus reducing downtime for maintenance.

IG compressor casings can also be rotated to orient the nozzles in any direction, allowing for significant layout variability and therefore compact machine footprints.

The typical gearing arrangement of the IG compressor limits the size and the number of stages that can be mounted on the machine. When an IG compressor is employed in a gas- or steam-driven train, it is often offered with an external intermediate gearbox to vary the input speed, or it is driven through a pinion. ■

Jacob Duffney is a Development Team Leader in the Atlas Copco Gas and Process Division focused on gearbox development. He earned a Bachelor and Masters of Science degree in Mechanical Engineering. jacob.duffney@de.atlascopco.com

Tushar Patel is the Marketing Manager for Atlas Copco's Gas and Process Division. He has Bachelor's degree in Mechanical Engineering and Master's in Marketing Management. tushar.patel@us.atlascopco.com For more information: visit www.us.atlascopco.com

THE EVOLUTION OF VIBRATION MONITORING

Randall Chitwood, Vice President of BK Vibro America, discusses his history with Bently Nevada, and how vibration monitoring systems are evolving to meet the needs of modern equipment.

Please tell our readers about Brüel & Kjær Vibro.

Brüel & Kjær Vibro (BK Vibro) is recognized as a leader in monitoring the condition of wind turbines, but the company does much more. With the acquisition of the SetPoint product line, the company now can deliver machinery protection as well as condition monitoring hardware and software.

We serve the power generation and oil & gas markets with solutions ranging from balance of plant to critical machinery. This includes solutions for API 670 machinery protection with the SetPoint and VibroControl brands, as well as condition monitoring software sold as SetPoint and Compass solutions. BK Vibro can deliver full global projects or a simple rack retrofit.

What was your involvement in the Bently Nevada 3300 series monitoring system?

When I first joined Bently Nevada in 1978, the flagship monitoring system was the 7200. I designed monitors for that platform during my first few years with the company. In the early 1980s, it developed a digital monitoring system branded Smart Monitor.

This system was unsuccessful, but it became the genesis of the 3300 monitoring system that I designed. Don Bently was key in driving two important factors in the 3300 development: It had to be 20% less expensive than the 7200; and it had to be reliable and simple. I led a team of about eight engineers that then designed the 3300 system.

Why do you think the 3300 series was so successful?

I don't know how many 3300 systems were built, but 50,000 seems like a conservative number. As the 3300 achieved the two above criteria, the market embraced it. Compared to standard technology of the 1980s, the 3300 was a good blend of digital and analog technologies that kept cost down and reliability high.

What is different in API 670-compliant continuous vibration monitoring systems?

API is a normative standard that provides a minimal set of standard features that the industry has learned are important to protect and monitor critical rotating machinery. Although API has its roots in oil & gas, the standard has found acceptance in the thermal power industries. When a user buys a non-API compliant system, there is some risk that the system could lack key features. Most serious vendors operating critical rotating machinery look to API as a way of reducing risk, and most insurance providers reward this behavior.

How were vibration monitoring systems designed in the 1980s and mid-90s compared to today?

The process of designing electronic systems has not changed much from the 1980s. Agile processes have helped empower design teams and have kept project milestones fluid and customer-focused. This has been a good thing. But design still demands a great knowledge of the application, attention to details and a no-compromise attitude on both features and reliability.

How have customer needs shifted in the turbomachinery world during that time?

With fewer machinery experts at most plants, we see customer needs shifting from local independent systems to systems that support remote diagnostics and the ability to make the vibration data more valuable by correlating it to process data.

This makes it more practical for one machinery expert to support multiple sites. Also, remote diagnostics enable corporations to have more detailed oversight capabilities over critical and safety related assets.

More users are asking for flight recorder capabilities so machinery protection systems that are not connected to any network can still deliver critical data when it is needed to evaluate machinery condition. This can take the risk out of critical questions like, "Is it okay to restart this machine after a trip."

What makes today's systems better equipped to address industry needs?

Modern systems are simpler, with fewer parts that do far more. They are easier to purchase, commission and ensure the right spares are on hand. They share data easily across an enterprise or around the globe. With embedded analytics, they can operate with or without a network and still provide data, visualization and expert advice. This can be done without the cost and maintenance of a standalone vibration analysis client server network.

How do you see vibration monitoring systems evolving?

In the next 10 years, vibration data will converge with other plant data and will no longer be housed on independent servers. This data will mostly be processed at the edge of the network and fed to data analytics engines for processing of alarms and day-to-day monitoring of assets.

We will continue to see balance-of-plant equipment to be monitored with wireless sensors. However, I believe it will be much longer before critical machinery protection systems become wireless.

Vibration systems were the pioneers of big data in many industrial plants. But now users are expecting the next wave of productivity. It will be based on machinery data and process data used in concert. Our Setpoint system embodies this philosophy by using the OSIsoft PI System for data storage and correlation rather than a purpose-built vibration server. It also features an embedded flight recorder for use without a network or software infrastructure. ■

Microphone ring array with intelligent acoustic measurement technology by Fraunhofer

Acoustic condition monitoring

Fraunhofer Institute for Digital Media Technology (IDMT) has combined acoustic sensor technology and data processing for automated process control and quality assurance. Fraunhofer researchers leveraged sound recording over microphones, automatic audio signal analysis, and machine learning. Defective parts or components can be detected by their sound. Inspection can be done at distance with no direct contact.

Fraunhofer IDMT has also developed condition monitoring for axial piston pumps. Sensors record the noise of the pump via the air, process it, compare it with reference audio data and send information wirelessly to a digital evaluation unit. It can detect early stage problems.
idmt.fraunhofer.de

Safety system

Rockwell Automation has introduced the Allen-Bradley Guardmaster GuardLink safety system. This safety-based communications protocol helps operators reduce and improve machine diagnostics and downtime while increasing productivity.

Traditionally, safety devices are wired to separate safety inputs, which introduces more potential fault points. When wired in this series connection, users lose the ability to distinguish information from each device. With GuardLink, safety devices are connected in series while providing access to individual device diagnostics. This system provides safety, diagnostics, remote reset and lock command over a single four conductor cable with up to 32 devices per link.

GuardLink integrates with Allen-Bradley Guardmaster safety relays and components. The GuardLink safety system integrates with the Logix platform with predetermined tag names in the Rockwell Software Studio 5000 application. Its simplified design and reduction in wires allows for plug-and-play installation.

Rockwell Automation has also released a micro programmable logic controller (PLC) to optimize the control architecture in large standalone machines or systems. The Allen-Bradley Micro870 PLC can support smart micro applications that require up to 304 I/O points, 280 kB of memory and 20,000 program instructions. The controller communicates via EtherNet/IP and includes multiple embedded communications options, including a USB programming port, a non-isolated serial port and an Ethernet port.
rockwellautomation.com

Voith drive

Voith Turbo has launched a self-contained Closed Loop 4Q Pump (CLSP) servo drive, a hydraulic linear axis from the Voith product family of self-contained drives. Features include energy efficiency, overload protection and virtually wear-free operation. It features automatic, load-dependent shifting of the hydraulic transmission to reduce connected load. Motor and inverter sizes are more compact.

The CLSP servo drive can be used for all direct linear motions, particularly when dynamic response, reproducibility and reliability are required. The drive operates with a force of up to 500 kN. Its maintenance intervals are either three years or 20,000 hours of operation. The CLSP is typically used in the automation of all types of linear motion, handling, and machines with bending, cutting and forming processes. It consists of the servo motor, a 4Q internal gear pump, and a directly coupled hydraulic cylinder.
voith.com

lightweight marine GE LM2500

Marine LM2500

GE Marine Solution has completed the acoustic attenuation and weight comparison testing between its new lightweight composite LM2500 gas turbine module and the steel enclosure. The results verified a 2,500-kilogram weight reduction and a 60% improvement in noise attenuation compared to its steel predecessor.

The one-piece carbon fiber design reduces wall weight and noise. Life cycle costs associated with rusting steel components are eliminated. The design also provides improved access to the engine. With wall temperatures 25 to 50 degrees cooler, there is less heat rejected into the engine room. The U.S. Navy, General Dynamics Bath Iron Works and GE collaborated on this new enclosure. Digital sensors and components, such as transducers, heaters, and flame and ice detectors are being modernized. The first composite enclosure will be ready in 2019; initial applications are on the U.S. Navy's DDG 51 destroyers.
GE.com

Sealless pumps

Sundyne has enhanced its GSPLF OH2 sealless pumps, which are designed for applications requiring low flow and high head in the oil and gas production, chemical, petrochemical and refining industries. These magnetic drive pumps feature an open impeller, Barske wheel design with straight blades, and a tapered conical diffuser, which produces efficient performance at low flows. The combination of the impeller design and Sundyne's HMD Kontro sealless magnetic drive pumps produces higher pressures than traditional backswept Francis Vane impellers.

The latest GSPLF sealless magnetic drive pumps handle flows from 18 to 132 gpm (4 to 30 m^3/hr), and deliver head pressures up to 490 ft (150m). Temperature ranges have been widened to accommodate -40 to 500°F (-40 to 260°C), and standard design pressure can handle up to 580 psi (40 Bar). They meet the requirements of API 685.
sundyne.com

Bearing lube testing

GTI Predictive Technology announced the availability of GTILube for testing bearing lubrication and condition. The GTILube app uses UE System's sensor technology to baseline and measure changes in an ultrasound signal to determine when a bearing needs lubrication.

It uses NASA standards for ultrasound measurement — an 8 dB increase signals a need for lubrication. A 12 dB increase indicates early bearing failure. It includes a calculator for determining an acceptable amount of lubrication for the bearing based on its geometry. This value is displayed on-screen when the measurement exceeds the Alert level. Users can also enter and display the type of grease for each bearing.
gtipredictive.com

Wireless lubrication monitoring

The Assalub WLubeMon system monitors all types of grease lubrication systems including manual lubrication. The meter (LubeMon) has been available some years already but with cable transmission. The disadvantages have been high cost of cable installation as well as risk of cable damages.

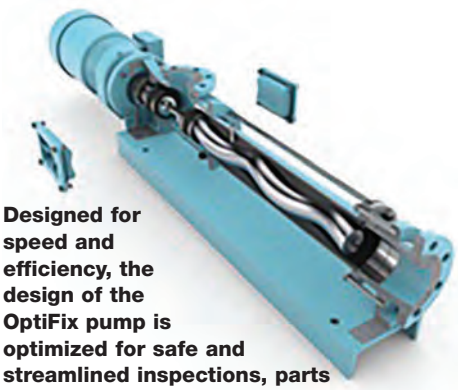
The WLubeMon comprises a precision grease meter that measures the amount of

The Assalub system monitoring lubrication wirelessly

lubricant fed into the lubrication point. The meter communicates wirelessly with a control unit. It provides alarms for too-high and too-low volume as well as statistics and log functions. The control unit can monitor up till 20 individual meters. The battery lasts at least 15 years
assalub.se

Cavity pumps

Allweiler OptiFix progressing cavity pumps can be disassembled in five steps. This reduces mean time to repair while reducing downtime, maintenance and service expenses. You can remove the rotor and stator without taking off the discharge and inlet casing.
circorpt.com



Designed for speed and efficiency, the design of the OptiFix pump is optimized for safe and streamlined inspections, parts removal and service operations

3D printed parts

Last year, Siemens finished its first full-load engine tests for gas turbine blades produced using 3D printing. Now it is producing steam turbine replacement parts, reducing lead time by as much as 40%. It has begun with two oil sealing rings used in keeping oil separated from steam inside the steam turbine using pressurized air. The rings are being installed as replacement parts on the SST-300 industrial steam turbine operating at the JSW Steel Ltd. plant in Salem, India.
Siemens.com

Grinding wheels

Saint-Gobain Abrasives has introduced its new Norton Quantum3 Combination Wheels to its NQ3 line of depressed center grinding wheels. Benefits include 50% longer life, faster cutting and grinding capabilities. They are suitable for general fabrication, oil rig building and repair, rail, container and pipeline manufacturing. They feature a proprietary grain along with a tougher bond system containing a combination of fillers and bonding agents.
nortonabrasives.com

Force testing

The L.S. Starrett Company has introduced a series of motorized digital test frames for high volume in situ lean manufacturing force testing applications including tension, compression, flexural cyclic, shear and friction. They are part of the Starrett L1 Line of entry level computer-based force measurement solutions. Optimized for production and quality control testing, the versatile, innovative architecture of the L1 system is designed for fast, easy-to-use, reliable and repeatable operation. They can be used with Starrett L1 software for computer-controlled testing, or a Starrett DFC Digital Force Gage. They are available in three force capacities: 110lbf, 330lbf and 550lbf (500N, 1500N and 2500N).
starrett.com

Laser scanner

Exact Metrology has released the Artec Ray laser scanner. It can scan large objects like wind turbines, ship propellers, airplanes, and buildings, from as much as 110 meters away. It offers submillimeter distance accuracy angular accuracy. Data capture is cleaner than with other 3D scanners of this type. It keeps noise levels to a minimum. Once scanned, the data is processed directly into Artec Studio and exported to Geomagic Design X.
exactmetrology.com

Hybrid ceramic bearing

Process industry, chemical and petrochemical applications require high amounts of process steam. Mechanical vapor recompression (MVR) is frequently used to minimize the use of this energy. A fan compresses the vapor, boosting it to a higher pressure and adds heat until the required temperature has been reached.

TLT-Turbo has developed a fan series with a hybrid ceramic bearing for this purpose. Since the bearing is permanently lubricated, it requires no external oil supply.

These MVR fans take advantage of bearing technology that was used mainly for wind power plants and machine tools. The rings in the rolling bearing are made of steel and the rolling elements are made of ceramic components.
tlt-turbo.com

Alliance Sensors' new signal conditioner

Signal conditioner

H.G. Schaevitz dba Alliance Sensors Group has introduced the SC-200 LVDT signal conditioner. It offers fast setup and works with a wide range of LVDTs, RVDTs, and inductive half-bridge sensors including 3-wire industrial LVRTs. The signal conditioning module has cyber security tamper prevention and notification features. It offers fault or failure detection for high reliability applications like nuclear power plant steam turbine controls. The SC-200's diagnostics can detect at least 11 fault conditions.
alliancesensors.com

Gas bearings

New Way Air Bearings' line of gas bearings for turbomachinery (Bently Bearings) are externally pressurized porous (EPP). They can replace hydrodynamic oil bearings in large rotating equipment. These radial bearings can be a direct replacement for existing sleeve or tilt pad arrangements.

Reasons to entertain replacing oil bearings with gas bearings include eliminating oil, having no wear, not having dry running at start-up, and being able to operate in high temperatures (carbons and graphite withstand at least 400°C before oxidation starts). In addition, EPP gas bearings reduce power loss.

New Way relies on the natural porosity of graphite or carbon to restrict and damp the flow of pressure to the bearing face. For example, a 3-inch diameter journal bearing 1.75 inches long, with a 0.002 inch thick oil film would result in 35 kW worth of power loss at a speed of 20,000 RPM. New Way Bently Bearings make only about 50 W of shear loss for the same size bearing and speed.
newwayairbearings.com ■

TORSIONAL OSCILLATIONS ARE NO PROBLEM IN CENTRIFUGAL COMPRESSORS

Those of us who have used gas turbines as drivers for compressors have, for many years, thought that the problem of torsional train excitation was well understood and easy to deal with. Even long compressor trains with two or three multi-stage compressors, and possibly including a gearbox, were found to be manageable.

The major method of avoiding operation at torsional critical speeds is the modification of coupling stiffness. Since the excitation was limited to 1x of the running speed, the problem was always solvable.

The components of a compressor train, such as the driver, gearbox, couplings and compressors, all provide a certain level of torsional stiffness, as well as a polar inertia. Therefore, the train has torsional natural frequencies or critical speeds.

If the train gets excited at or near these speeds, torsional vibration amplitudes will increase. Generally, the damping in these torsional systems is relatively low, leading to a high amplification of torsional vibration. Therefore, operation at or near these speeds can lead to high cycle fatigue and possibly major mechanical failures.

Enter electric motor drives, especially variable speed drives (VFDs), but also constant speed machines. VFDs tend to excite additional frequencies that can be above or below running speed, and some drives may even change the frequencies and magnitude they excite depending on the operating mode.

Additionally, both constant and variable speed motors can introduce transient torque spikes into the train if line faults or short circuits occur. Constant speed motors will additionally tax the train with high inrush torques at starting.

It is quite complicated to avoid all critical frequencies along a wide range of operating speeds. If we cannot avoid these torsional excitations, we can learn to deal with them. Since the torsional response is proportional to the damping, we are in desperate need of torsional damping in the train.

Electric motor driven compressors using variable speed hydraulic gearboxes tend not to have this problem. The motor runs at constant speed, and the gearbox, due to its design, provides ample damping.

Where does torsional damping come from? This is one of the problems, because there is very little material damping. The major source of damping may be a gearbox if included in the train.

"There is also an insidious problem with torsional vibrations. They are silent killers."

Couplings are available that use rubber blocks that can provide a good amount of damping if they are installed. However, these couplings (to our knowledge) only exist for lower speeds and are usually better at handling transient torque events like startups versus high levels of steady-state vibration from exciting a critical speed.

Thus, compressors driven by high speed motors lack the damping that would come from a gearbox. With this little torsional damping, we find many instances in the literature where the operating speed range of such compressors must be limited, or certain speeds within the operating range must be avoided.

This is obviously somewhat unsatisfactory: one of the great advantages of centrifugal compressors is seen in its capability to operate without "holes" in its operating map.

There is also a somewhat insidious problem with torsional vibrations if they occur: they are silent killers. In many instances, the first indicator of a problem is a broken coupling, cracked shaft, or other mechanical damage to the equipment.

Generally, torsional vibrations are not monitored, and most machinery trains do not include instrumentation to do so. Obtaining torsional measurements often requires devoted testing with specialized instrumentation.

More permanent torque measuring devices, such as torque-meter couplings, are not installed as standard equipment, and are often setup to measure mean torque as opposed to torsional vibration. With this typical lack of torsional measurements or monitoring, the need for a proper torsional rotordynamic analysis is that much greater.

Torsional vibrations can be a serious silent problem in your machinery train. Furthermore, electric motor drives can bring numerous torsional excitations, making avoidance of critical speeds nearly impossible.

Careful consideration should be taken to manage torsional vibration, including a proper torsional analysis, to ensure long-term machinery reliability. (Chris Kulhanek of Southwest Research Institute contributed to the column.) ■

Klaus Brun is the Machinery Program Director at Southwest Research Institute in San Antonio, Texas. 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, Southwest Research Institute or any of their affiliates.

Turbomachinery INTERNATIONAL HANDBOOK 2019

ACCEPTING LISTINGS *NOW!*

The most comprehensive search database used by over 100,000 specifiers of turbomachinery technology, products and services worldwide.

Get your **FREE company listing** for the online and printed Handbook @ **www.TurboHandbook.com**

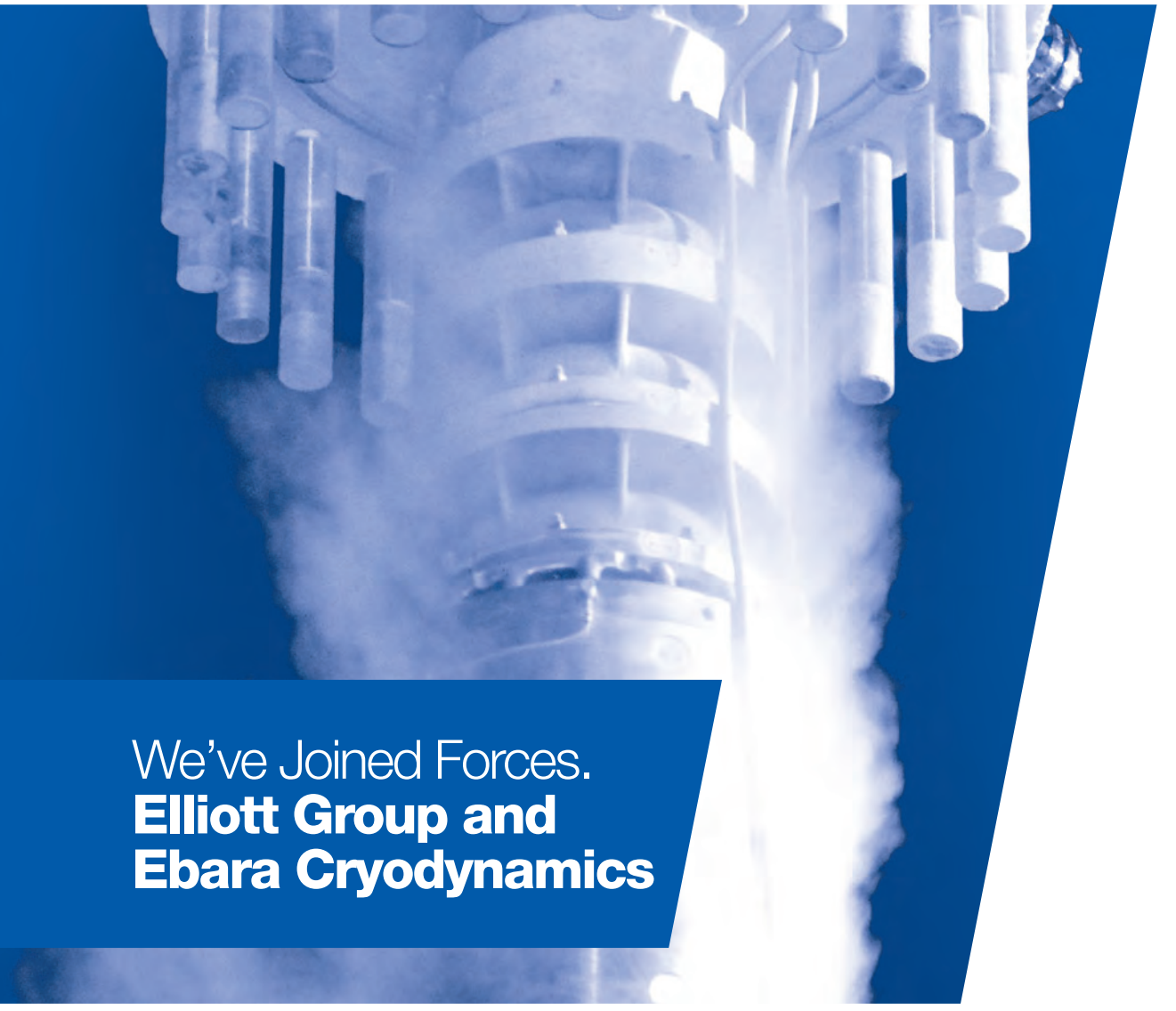
Immediate **online Handbook exposure** and the ability for other companies to search and find you for NEW business.

Distribution at **every major turbomachinery industry trade show**, conference & exhibition and user group meeting that we attend.

BACKGROUND: MASTER3D/SHUTTERSTOCK.COM

Turbomachinery INTERNATIONAL
THE GLOBAL JOURNAL OF ENERGY EQUIPMENT

Contact Bob Maraczi for more information.
P: 203.523.7040
E: Bob.Maraczi@UBM.com



EBARA CRYODYNAMICS

We've Joined Forces.
Elliott Group and Ebara Cryodynamics

We turned to each other to provide

enhanced capabilities and a superior customer experience in liquified gas applications.

From reliable refrigeration compressors to submersible cryogenic pumps and expanders, Elliott Group and Ebara Cryodynamics have supported the LNG industry for decades with proven experience and matchless expertise. Integrating the two businesses will provide a key advantage for our liquefied gas customers. Who will you turn to?

COMPRESSORS ■ TURBINES ■ GLOBAL SERVICE

ELLIOTT GROUP
EBARA CORPORATION

The world turns to Elliott.
www.elliott-turbo.com