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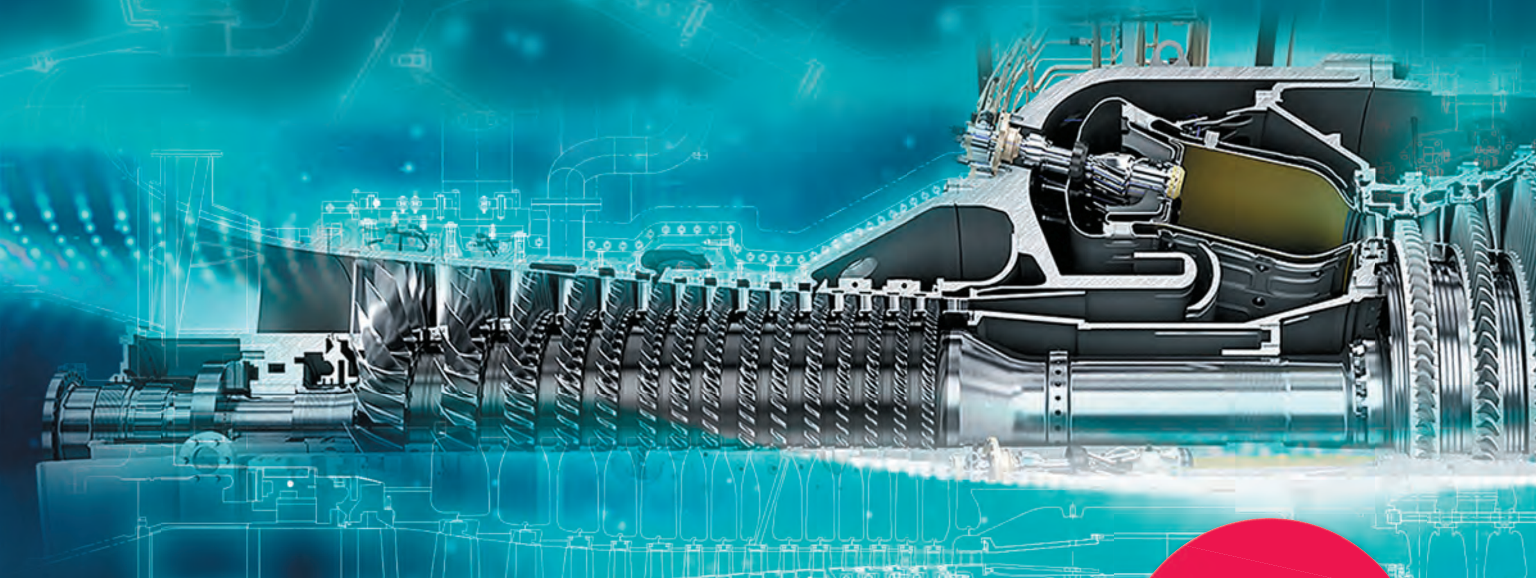
UBM

HYDROGEN AND FUEL SWITCHING



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SPECIAL PUMP SUPPLEMENT
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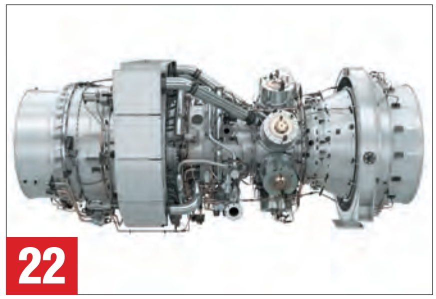
COVER STORY

18 FUEL SWITCHING

Gas turbines running on hydrogen or a natural gas and hydrogen mixture could aid in emissions reduction. Companies, such as Siemens, GE, MHPS, and Ansaldo Thomassen, are actively working on this technology. It holds the potential to lower and ultimately eliminate carbon emissions from turbomachinery.

One day, we may even see a machine that functions on 100% hydrogen. Hydrogen fuel offers many advantages in energy production. It is a carbon-free fuel that can decarbonize power and heat generation, and transportation, to help meet long-term CO_2 emission-reduction targets.

Burning hydrogen produces no CO_2 emissions. But technical challenges remain, such as how to avoid flashback and auto ignition in the premix zone.
Drew Robb



GAS TURBINES

22 AERODERIVATIVES VERSUS RECIPS

This article discusses the merits of aeroderivative gas turbines versus reciprocating engines in modern power grids. The conclusion is that aeroderivatives offer a flexible, fast-responding, and economical solution to the challenges facing electricity markets due to a growing penetration of renewables.
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Active magnetic bearing solutions deliver flexibility, reliability and improved economic performance.
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A combined physical and digital view into a Siemens SGT-800 gas turbine.

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44 MYTH: THE PARTICULARS ABOUT PARTICULATES ARE IMPORTANT

Natural gas-fired gas turbines may be more of a solution than a problem where particulates matter. These GTs have extremely low PM emissions. Often, because of their fine inlet filtration and the massive amount of air captured, GTs act as an air filter than a particulate matter emitter.

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PEOPLE
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HYDROGEN POWER

In 2003, the U.S. and the European Union agreed to speed up the development of what was then termed the "hydrogen economy." This collaboration aimed to:

- Convert transportation fuels from petroleum to clean-burning hydrogen
- Reverse the growing dependence on foreign oil
- Commercialize hydrogen-powered fuel cells
- Lower emissions
- Develop by 2020 vehicles running on hydrogen fuel cells.

"Hydrogen fuel cells represent one of the most encouraging, innovative technologies of our era," said President George W. Bush.

Things didn't quite work out that way. Electric- or CNG-powered vehicles and battery technology have far outpaced hydrogen-fueled cars on our streets. Hydrogen generators are available on the market, but not widely deployed. Gas turbines can now be run with a higher hydrogen content, although the technology is not in high demand.

That may be changing, though. Our cover story delves into what some of the OEMs are doing with hydrogen. Most have systems that can run with a higher concentration of hydrogen. A mix of natural gas and hydrogen is viewed as a way to lower carbon emissions, and lower costs by taking advantage of opportunity fuels, for example, process off-gases that often have a high hydrogen content.

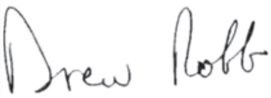
But challenges remain. A viable source of cheap and easily available hydrogen is one. Another challenge is developing a combustor that minimizes auto ignition and flashback in the premix zone. You can read how MHPS, GE, Siemens, and Ansaldo Thomassen are addressing these issues. But don't hold your breadth waiting for an all-hydrogen machine any time soon. MHPS, for example, has set 2030 as the target for the production availability of a combustor able to run on 100% hydrogen.

Features in this issue include streamlining the lube oil system with a transfer barrier accumulator, aeroderivative gas turbines versus reciprocating engines, maximizing compressor performance via active magnetic bearings (AMBs), non-destructive testing of steam turbines, a Q & A on asset performance management, and a Mythbusters about small particulate matter.

Our product pages, too, are full of new developments, such as a narrow section gas seal, upgrades to existing gas turbines, and turboexpanders using AMBs.

We also call your attention to our annual Pump Supplement. It offers practical advice to those interesting in specifying, selecting, designing, and maintaining centrifugal pumps. Further tips discuss the value of vertical pumps, related piping, suction, cavitation, and fitting pumps with variable speed drives.

It's a big issue as befits the annual Turbomachinery Symposium in Houston, Texas. We look forward to seeing you there. ■



DREW ROBB
Editor-in-Chief

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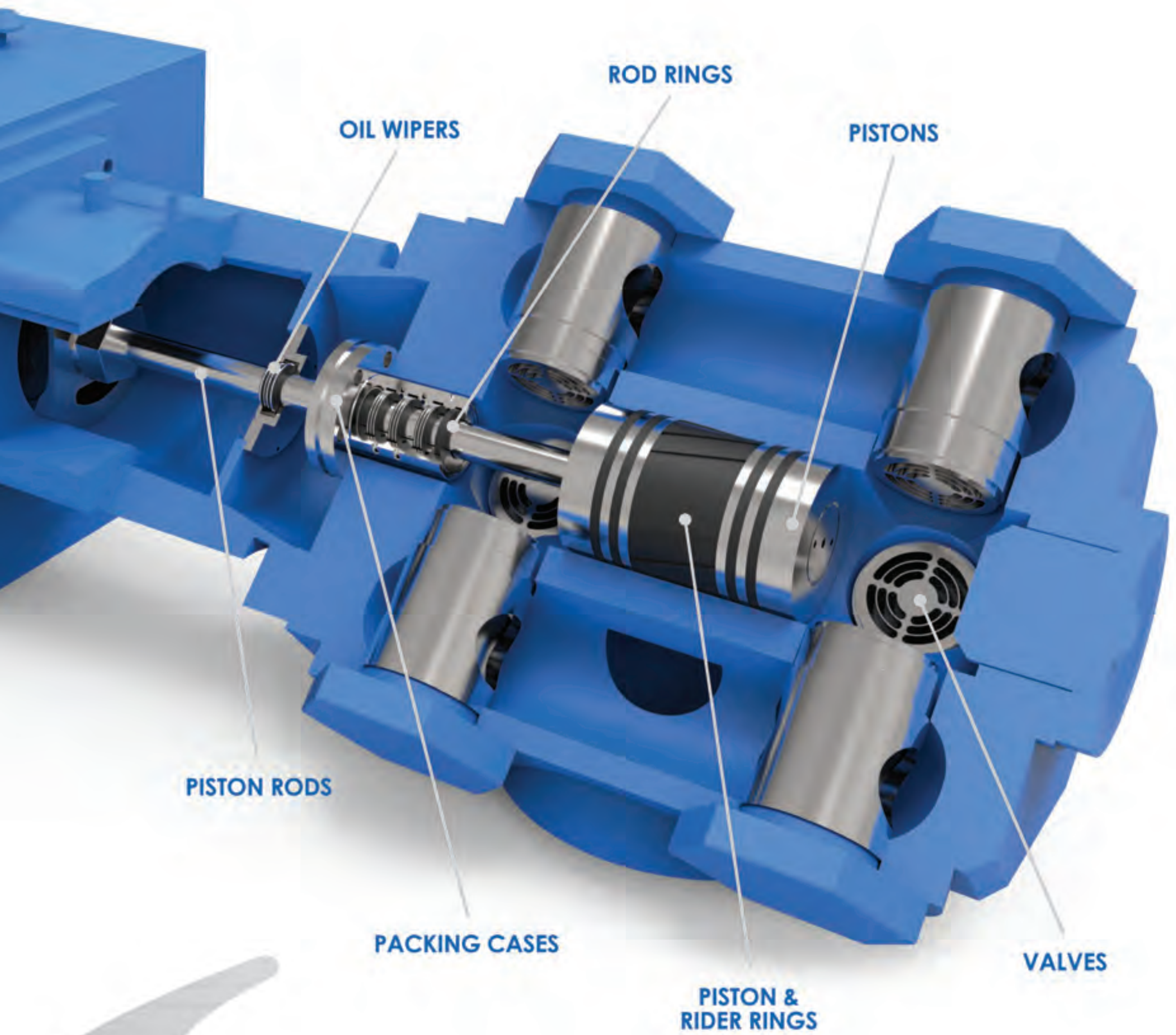

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The Baker Hughes GE yard in Italy

BHGE digest

Baker Hughes GE (BHGE) has completed the assembly of the first gas turbine (GT) module to be installed in the Tengiz oil field in Kazakhstan, operated by Tengizchevroil (TCO). It is designed to integrate a Frame 9 GT in an air-conditioned module with stringent dimensions. This module is a prerequisite to successful operation in the site's harsh environment, which is characterized by extreme temperatures.

Located in Western Kazakhstan, Tengiz is one of the world's largest oil and gas fields. In total, BHGE will supply five 130 MW power generation modules, all erected in BHGE's yard in Italy. In May 2018, the first ever full load string test was performed on a Frame 9 for a power generation application on BHGE premises.

Global LNG Services (GLS), which has selected BHGE for its rotating equipment, is progressing on the Main Pass Energy Hub (MPEH) Deepwater Port project, owned by its U.S. subsidiary MPEH and located 16 miles offshore of southeast Louisiana in the Gulf of Mexico.

Two Liqui-Max vessels, capable of producing a total of 24 million tonnes per annum of LNG, will be permanently stationed at MPEH. GLS Liqui-MaxVessel design has enabled it to introduce a floating tolling fee model with a floor rate of Henry Hub + 15% +$1.50/MMBtu for pre-processing and liquefaction, and 50/50 sharing of the liquefaction netback value above the $1.50 level.

Gas will be sourced through interstate pipelines and pre-processed onshore in the Louisiana, Mississippi, and Alabama region. BHGE was selected by GLS for LNG equipment and services. The new GE LM9000 GT has been selected for the project.

Better sensors

A Purdue University-affiliated startup is developing instruments to measure pressure, temperature and other analytics inside the harsh environments of rocket engines and GTs. Known as Petal Solutions, it has expertise in computational fluid dynamics (CFD) and is pushing the boundaries in cooling and design probe technologies.

The company said conventional instruments are limited in the maximum temperatures they can withstand, and how fast they can react. The researchers say they will be able to tailor products to create sensing devices and in-house software packages users need.

They have designed a device that is 4 millimeters in diameter that can mount inside engines and track parameters, such as pressure and flow direction in high temperature environments with accuracy. They are working on a prototype that can withstand temperatures up to 1,300°F. By next year they plan to have a prototype that can withstand temperatures up to 3,000°F.

Better fracking

GTI is leading a program on Hydraulic Fracturing Test Sites (HFTS) in the Permian Basin of Texas. It brings together government and industry to improve recovery and advance environmentally responsible methods of optimizing production. It has lowered costs in the Midland and Delaware Basins.

Funding comes from the U.S. Department of Energy National Energy Technology Laboratory (DOE/NETL). Anadarko and Shell plan to co-host a new field test site in the Delaware Basin, where multiple experiments to evaluate well completion, optimize design, and quantify environmental impact will be carried out.

Work will commence in late 2018. The new field test site in Loving County, Texas will feature different depth, pressures, and permeability than the site of GTI's first collaborative project, HFTS1–Midland. Each location requires specific techniques for optimal production based on local geologic complexity.

The Permian Basin in West Texas is considered one of the largest hydrocarbon resources in the world, covering 86,000 square miles and encompassing 52 counties in New Mexico and Texas.

An increase in shale production from the Permian alone could set the U.S. toward energy security. Current oil production is about 2.4 million barrels per day, and projections suggest that this could more than double over the next 7-to-10 years. Natural gas production in the Permian Basin is likely to triple by 2020 from its 2010 level.

LNG carrier

South Korean shipbuilder Daewoo Shipbuilding & Marine Engineering (DSME) has completed its first LNG carrier equipped with a full reliquefication system. The ship in question is the 180,000 m^3 LNG Schneeweisschen, the first LNG carrier built by the yard with dual-fuel, two-stroke engines developed by Winterthur Gas & Diesel (WinGD).

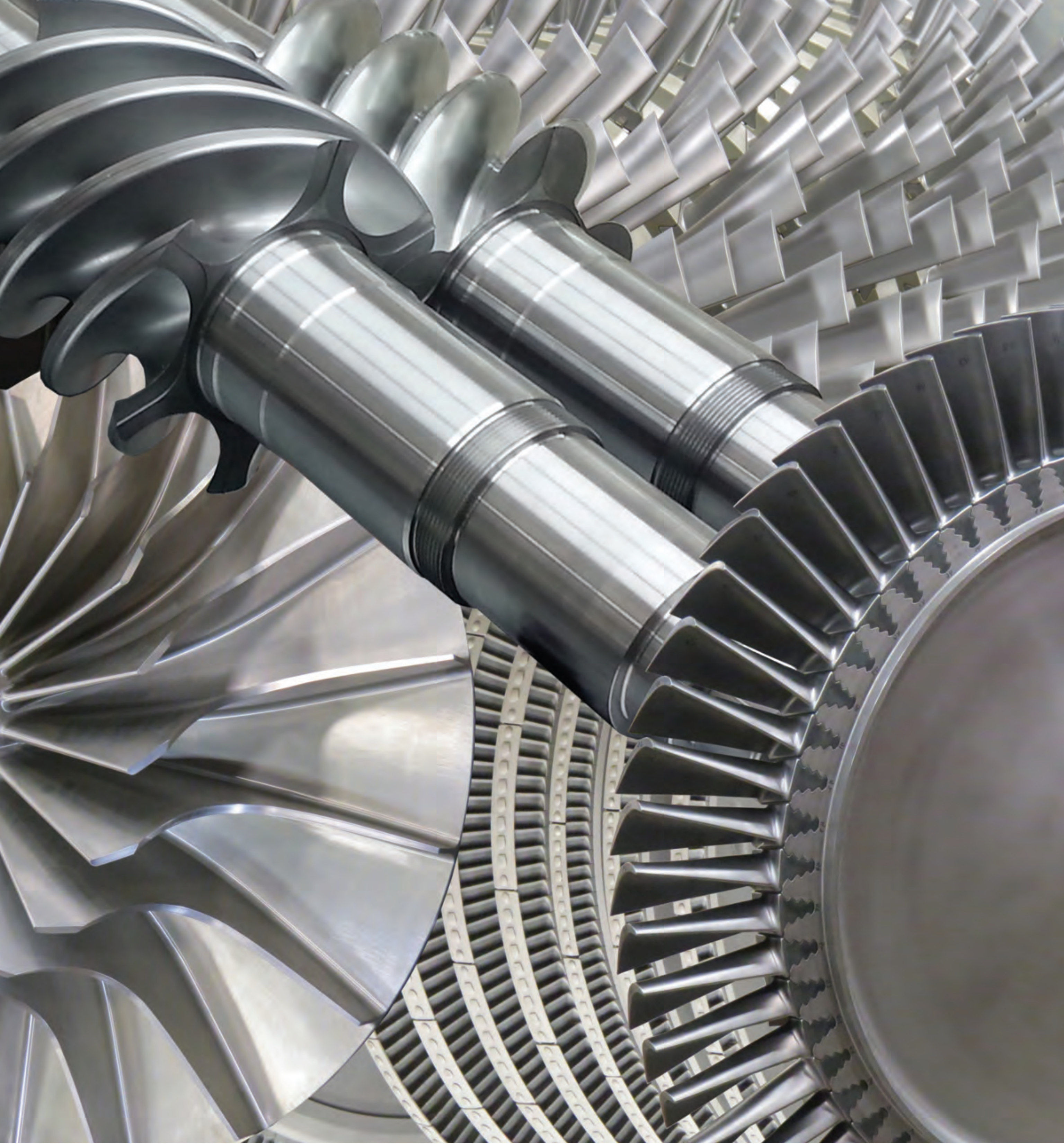
WinGD terms these propulsion units its Generation X dual-fuel (X-DF) engines. DSME developed a partial reliquefication system (PRS) several years ago for use with LNG carriers propelled by M-type, electronically controlled, gas-injection (ME-GI) engines developed by MAN Turbo & Diesel.

Low-pressure X-DF and high-pressure ME-GI engines are both dual-fuel, two-stroke units that have gained favor for gas-powered vessels in recent years due to their high efficiency and low operating costs.

Natural cargo boil-off gas (NBOG) rates on LNG carriers provide more fuel than these engines require when operating at lower speeds. Based on the reverse Brayton cycle, the refrigeration system uses NBOG as a refrigerant. Because a redundancy fuel gas compressor is used as a refrigerant compressor in X-DF applications, there is no need for additional refrigerant compressors.

Turboexpander market

The global turboexpander industry is mainly concentrated in China, Europe and



MHPS digest

Mitsubishi Heavy Industries (MHI), Mitsubishi Heavy Industries Compressor (MCO) and Mitsubishi Hitachi Power Systems (MHPS) have announced their collaboration with ExxonMobil to develop and explore new applications for their latest H-100 GTs as well as compressor technologies to reduce liquefied natural gas (LNG) unit costs.

The aim is to reduce the complexity of LNG processing plants, lower lifecycle costs, and cut plant emissions through enhancements to MHPS's existing two-shaft GT technology. Two-shaft GTs for LNG mechanical drive offer reduced footprint, broad variable-speed operation and full-pressure start-up. ExxonMobil has qualified MHPS' H-100 GT for use in LNG facilities.

The 119.9 MW H-100 GT has achieved full qualification status for mechanical drive operation by Shell's Technical team based in The Hague. This involved a rigorous testing regime to validate the mechanical drive performance of their 2-shaft H-100 equipped with a low NOx (single digit ppm) combustion system.

Shell has already qualified Mitsubishi Compressors by Enterprise Frame Agreement effective in 2011, clearing the way for MHPS and MCO to supply all components for future Shell LNG compression systems.

MHPS and Peruvian power developer Gaz Energie signed an agreement to develop a 515 MW natural gas power project. The Humay PS Project will be in the Ica region of Peru and will leverage an MHPS JAC GT power island. The plant will enter commercial operation in 2021.

Mitsubishi and GE are forming a joint venture with a Bangladesh private power firm to invest $3 billion in setting up a 2,400 MW thermal power plant and oil and liquefied natural gas terminals.

Summit Group, a Bangladeshi firm, will hold a 55% equity stake while Mitsubishi will take 25% and GE 20%. The project involves four thermal units of 600 MW each, a 380,000 cubic-meter capacity LNG terminal and oil terminals with 100,000 metric tons of capacity.

North America, according to a market study by Global Info Research. The leading players are Cryostar, Atlas Copco and Baker Hughes GE, which accounts for 34.97% of total consumption value. In China the market leaders are Hangyang Group, SASPG and HNEC. The worldwide market for turboexpanders is expected to grow at 2.9% over the next five years. It will reach $620 million in 2023, from $520 million in 2017.

Epic CEO

Epic International's Board Chairman Joe Winkler, announced that John Sargent has been named Epic's new CEO. He will lead Epic's growth initiatives for both the reciprocating and centrifugal compressor aftermarket businesses.

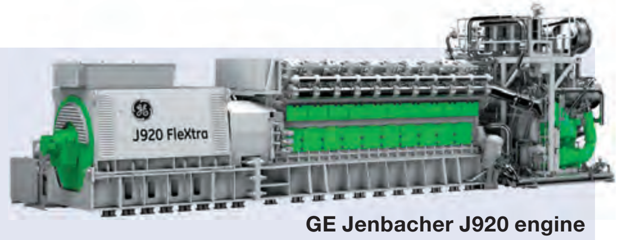
John Sargent of Epic International

John is a compressor industry veteran with over 24 years of domestic and international experience. Most recently, he served as Vice President of

(Continued on p. 14)

GE digest

GE signed an agreement to sell its Distributed Power business to Advent International, a private equity investor. The transaction includes Distributed Power's Jenbacher and Waukesha engines, as well as manufacturing sites in Austria, Canada and the U.S.



GE Jenbacher J920 engine

These gas engines generate 200 kW to 10 MW of power. With 3,000 employees and three main facilities, GE Distributed Power has delivered more than 48,000 Jenbacher and Waukesha reciprocating gas engines around the world.

GE Power's Steam Power has started manufacturing the first rotor of the Arabelle ST for the Hinkley Point C (HPC) nuclear power project in the UK being developed by Electricite de France (EDF).

Production work is being carried out at GE's center of excellence in Belfort, France. The initiation of first-line rotor manufacturing activities is a key step in the execution of the HPC project as it enables the manufacturing process of further turbine components.

The contract, awarded in May 2016, and is said to be on track to have its first 1,770 MW EPR reactor unit completed by 2025. GE will be responsible for delivering two conventional power islands for HPC, including the Arabelle ST, generator, and other critical equipment.

With an ability to generate 2% more power than a traditional configuration, HPC's Arabelle turbines are reportedly longer than an Airbus 380 and will have the capacity to produce 1,770 MW each.

A combined cycle power plant (CCPP) in Waad al-Shamal Mining City, Saudi Arabia has started operating with a locally made GE 7F.05 GTs. GE is supplying four GE 7F.05 GTs and a GE steam turbine (ST). The 1,390 MW plant will include a solar component of 50 MW.

Elektrownia Ostrołęka and GE Power have signed a contract to build Ostrołęka C, an ultra-supercritical (USC), 46% efficient coal power plant in the northeast of Poland. GE Power will design and build the plant as well as manufacture and deliver the ultra-supercritical boiler and ST generator. GE Power will also supply air quality control systems that meet with the latest EU standards for emissions. The Ostrołęka plant will be designed for operational flexibility, to improve start time, start fuel, ramp-up and turn-down rate, and minimum load. This plant will reach full load in less than 30 minutes.

Energy for Epic and previously spent the last two decades in various sales and operations roles with El Paso Corp, Cameron International, and Spitzer Industries.

Sargent will maintain his role as the leader of Epic's Energy Division until a replacement can be named. Founded in 2015, Epic International provides aftermarket services, including OEM-quality parts, repair and technical support, for the world's fleet of reciprocating and centrifugal compressors.

APG expansion

Allied Power Group (APG) has acquired Eta Technologies, an independent provider of new and aftermarket parts and maintenance solutions for Siemens V-Series industrial GTs. Richard Curtis and John Kearney, the founders of Eta, will join APG in leadership roles.

This enhances APGs capabilities in turbine component repair, rotor repair, new parts manufacturing and field service. APG has also acquired full ownership of its once-leased Houston-based, 120,000 ft^2, fit-for-purpose repair and manufacturing facility; APG had been leasing the property since 2009.

ORC system

Turboden has signed two new contracts with glass company, Saint-Gobain. This is for a 1.2 MWe unit in India and 1.2 MWe in Italy. The Indian Organic Rankine Cycle (ORC) plant recovers heat from glass production exhaust gas. The Italian heat recovery plant produces electric power and compressed air, needed in the glass production plant.

John Crane acquisition

John Crane has purchased Seebach GmbH, a German provider of engineered filtration solutions for use in polymer, oil and gas, mining and other high-end applications. Located in Vellmar, Germany and Pune, India, Seebach will complement John Crane's existing filtration business, and provide the capability to expand into the chemical and process industries.

Vacuum pumps

According to a research report by Global Market Insights, the vacuum pump market will hit $6.5 billion by 2025. Chemical manufacturing and processing industry growth is a major influencing factor for sales.

China accounted for close to a quarter of the global chemical consumption and will continue to hold sway over the forecast period with the presence of several small- and medium-scale enterprises catering to local demand. Industrially emerging nations, such as India, Indonesia and Thailand, also offer promising markets.

The rebound of the petrochemical sector will also boost the vacuum pump market in the coming few years. Applications for vacuum pumps include oil & gas recovery, field gas boosting and vacuum reactors.

With the increase in the crude oil prices, the U.S. oil & gas companies are responding by increasing the expenditure in drilling activities. The quick recovery of the country's shale oil producers after 2014 will further propel the vacuum pump demand over the forecast period.

The vacuum pump market has been segmented, based on lubrication, into dry and wet types. Wet vacuum pumps include water, as well as oil-lubricated machines, capable of providing higher pumping speeds than the dry types. This segment will witness annual growth of around 6% from 2018 to 2025.

Based on vacuum pump technology, the market is classified into gas capture and binding, and gas-transfer types. Gas-transfer products are further classified into kinetic and positive displacement types.

The kinetic pumps segment will witness healthy growth, crossing $3 billion in 2025. Gas capture and binding products will generate more than $1 billion annually by the conclusion of the forecast span.

Turboexpander performance

L.A. Turbine's L3000 turboexpander-compressor, in a UOP Russell cryogenic natural gas processing plant in Eddy County, New Mexico, has exceeded its designed 200MMSCFD flowrate by 10%.

The skid-mounted LAT 575EC turboexpander includes a seal gas system and local programmable logic controller (PLC) unit. It is designed for operational flexibility with a wide operating range, no speed limitations, and users can reduce or slightly increase the capacity to suit varying operating conditions. The design of the expander wheel and guide vanes contribute to the unit's ability to exceed flowrate capacity.

Air filter classification

As of July 1, 2018, ISO 16890 has been the sole international testing standard for classifying air filters, replacing EN 779.

This brings a radical change in the evaluation of air filters, such as greater transparency and practical relevance. The separation efficiencies of filters are now differentiated across a broad particle spectrum using four dust classes, while the evaluation parameters correspond to those of the World Health Organization (WHO) and environmental authorities.

EN 779 was limited to a single-particle size and neglected a large proportion of fine dust particles. The laboratory values did not correspond to actual filter behavior. Filter testing now takes the actual particle sizes present in the air and specifies separation rates to an accuracy of 5%.

"This enables users to select the best possible filters for their individual requirements," said Dr. Thomas Caesar. Director of Filter Engineering Industrial Filtration at Freudenberg Filtration Technologies, who was involved in the development of ISO 16890.

Continued on page 16

Siemens digest

Siemens and State Power Investment Corporation (SPIC) of China entered into a Memorandum of Understanding for technology collaboration in heavy-duty GTs. Joe Kaeser, President and CEO of Siemens AG, and Qian Zhimin, Chairman of SPIC, signed the MoU in Berlin in the presence of German Federal Chancellor Angela Merkel and Chinese Premier Li Keqiang during his official visit to Germany.

Siemens will support SPIC in conducting research and development and provide training and technical consultation. This is in support of China's goal to independently develop and build a heavy-duty GT.

Senseye, a provider of predictive maintenance analytics, has a partnership with Siemens to make Senseye's condition monitoring and prognostic software available to manufacturers through the Siemens MindSphere Industrial Internet of Things (IIoT) operating system.

MindSphere is an open cloud environment for collecting and processing data produced by industrial machinery. Senseye receives and analyzes data from machines connected to MindSphere, enabling manufacturers to understand the health of their industrial assets and schedule maintenance activities more accurately, without any additional sensor or application investment, specialist staff or training.

Siemens has received an order for three SGT5-4000F GTs from United Arab Emirates (UAE). The turbines will be used in Unit H Phase 4 of the Al Aweer power plant complex near Dubai.

DEWA has awarded the EPC contract to Siemens. With a capacity of about 815 MW, the turbines will increase the total output of the power plant complex to more than 2.8 GW.

The commercial commissioning of the three GT trains is scheduled for spring 2020. Siemens' scope of supply encompasses three SGT5-4000F GTs, three SGen5-1200A generators and the control system SPPA-T3000, as well as assembly and commissioning on site. As a peak load power plant, it will operate primarily in the summer months.

Siemens and STEAG GuD Herne signed an agreement on the turnkey construction of a CCPP with district heat extraction. They also entered into a long-term service agreement. The Herne 6 plant will have an electrical capacity of more than 600 MW. Steam will also be extracted, and the thermal energy will be used for the district heating grid of Germany's Rhine-Ruhr metropolitan region. The fuel efficiency of the natural gas used thus climbs to more than 85%.

In its role as general contractor, Siemens will build the plant on the site of an existing power plant owned by STEAG. Key components will be manufactured in Germany: the ST and generator in Mülheim and the H-class GT at the GT factory in Berlin. Starting in the spring of 2022, the new gas-fired CHP plant is expected to generate electricity and supply the Rhine-Ruhr region with district heat.

Texas A&M Turbomachinery Laboratory projects

The Turbo Lab's Research Consortium has announced newly approved projects for the year:

- Measurements to Quantify the Effect of a Reduced Flow Rate on Tilting Pad Journal Bearing Performance — Static and Dynamic, by Dr. Luis San Andrés and Jon Toner
- A Computational Model for Integral Squeeze Film Dampers and Experimental Verification, by Dr. Luis San Andrés and Bonjin Koo
- An Experimental and Computational Investigation of the Rotordynamic Coefficients of a Labyrinth Seal, by Paul Cizmas and Adolfo Delgado

New MAN Identity

MAN Energy Solutions is the new brand for MAN Diesel and Turbo. This represents the company's expansion into sustainable technologies and solutions. MAN's product range is being expanded to include hybrid, storage and digital service technologies.

The company sees great potential in power-to-gas technology, which allows energy generated from renewable sources to be converted into synthetic fuels, such as natural gas. MAN also sees electrical energy in the future generated either from renewable sources or by decentralized, flexible power plants that will increasingly be powered by carbon-neutral fuels. In relation to this, and together with ABB, MAN recently introduced ETES (Electrothermal Energy Storage), a storage solution that can supply neighborhoods with electricity, heating and cooling.

Kuwaiti microturbines

Capstone Turbine Corp. has secured a 3.4 MW order for a gas processing facility in Kuwait. The order includes a C600 Signature Series microturbine, a C800 Signature Series microturbine and two remanufactured C1000R microturbines, which will provide prime power for the facility.

Specto International, Capstone's distributor in Kuwait, secured the project, which is expected to be commissioned in late 2018. The C1000R packages will receive a factory inspection, be upgraded to include the latest Signature Series product updates and will receive a full factory performance and acceptance test prior to their shipment and installation in Kuwait.

Ansaldo Energia is helping Chinese partners develop a new GT

Ansaldo in China

In Beijing, China, Ansaldo Energia has signed a Memorandum of Understanding with Shanghai Electric Group (SEC) and SPIC (State Power Investment Corporation Limited) to develop a new GT. Ansaldo will support SPIC in its independent research and development work on heavy duty GTs and provide specialized training and technical advice to SPIC engineers. This is part of Ansaldo Energia strategy to reinforce its alliance with key players in the Chinese power generation sector. SEC already holds an equity stake of 40% in Ansaldo.

Energy storage leader

Nidec Industrial Solutions is the world's leading supplier in the energy storage market for the fifth consecutive year, according to the Bloomberg "New Energy Finance" report. Nidec ranked first in the battery energy storage system market, with an aggregate installed in utility scale systems of 268 MW as an EPC contractor.

In one year, the company installed 116 MW, which includes one system with a capacity of 90 MW for the German company STEAG. Nidec recently developed a new Ultra-Fast Charger (UFC) for recharging electric vehicles in less than 15 minutes and guaranteeing a range of 500 km.

Gas plant

BCCK Holding Company (BCCK) has entered into an engineering, procurement and construction (EPC) contract with Discovery DJ Services (Discovery) for delivery of a 225 MMSCFD gas plant in Weld County, Colorado. The new plant will take Discovery's processing capacity to about 500 MMCFD in the first half of 2019. BCCK will provide ethane recovery and ethane rejection and will perform all engineering, fabrication and construction services for the project. ■

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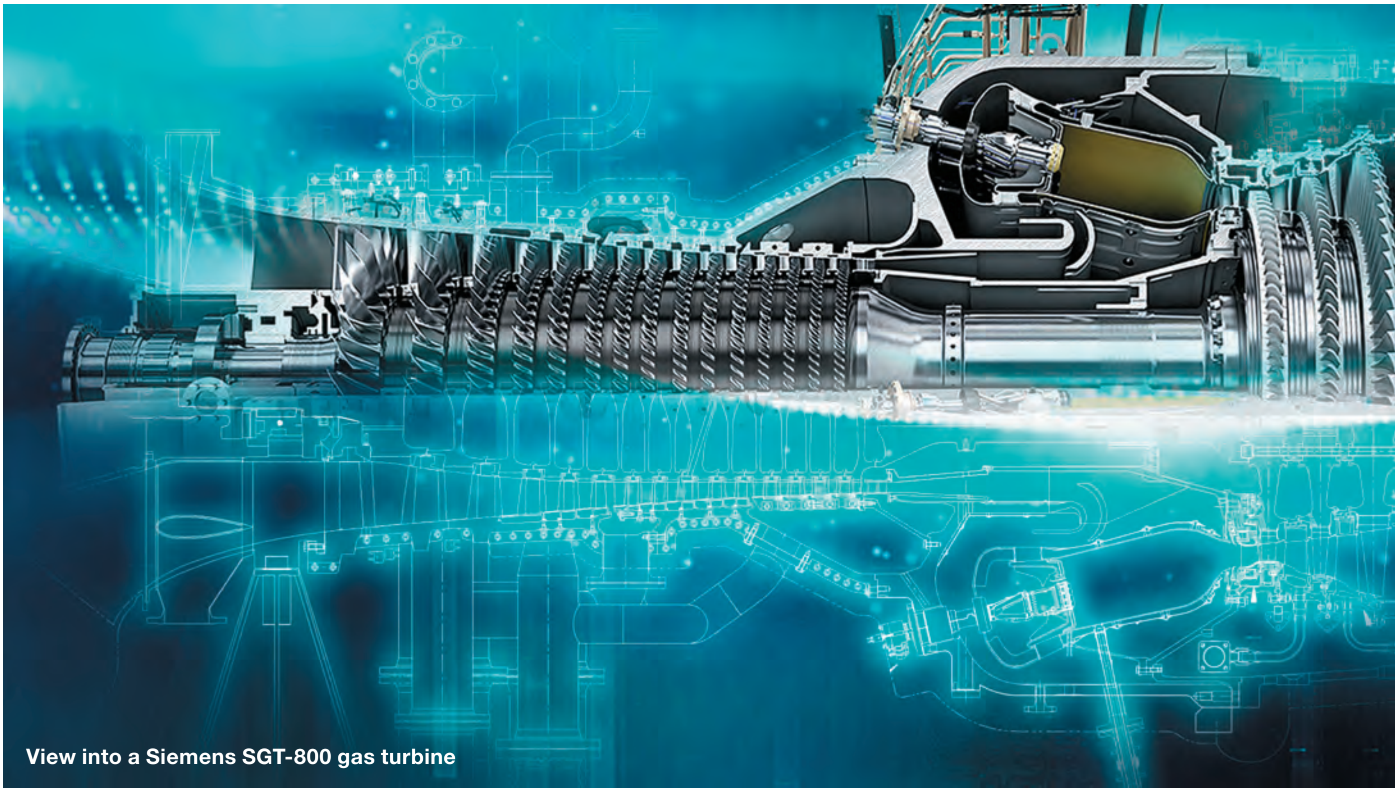


View into a Siemens SGT-800 gas turbine

FUEL SWITCHING

GAS TURBINES RUNNING ON HYDROGEN OR A NATURAL GAS AND HYDROGEN MIXTURE COULD AID IN EMISSIONS REDUCTION

BY DREW ROBB

For many years, natural gas has been looked upon as the benign fossil fuel, offering far lower emissions than oil or coal. Its place had been established in a clean, or at least, cleaner energy future.

That began to change about a decade ago when natural gas was thought of as a "bridging technology" between polluting fuels sources and renewable energy. Once that bridge was crossed, natural gas-fueled technologies would be phased out, much like coal plants.

Today, national and international energy regulators are mandating that utilities purchase and install renewable power resources. This policy shift to carbon neutrality — achieving net zero carbon emissions — has moved natural gas from the "benign" to the "menace" category, in the eyes of some. Others, however, understand the necessities of the grid and see a role in it for the gas turbine (GT).

Companies, such as Siemens, GE, Mitsubishi Hitachi Power Systems (MHPS) and Ansaldo Thomassen, are actively working on fuel gas mixtures of natural gas and hydrogen that can lower and ultimately eliminate carbon emissions from turbomachinery. They are also developing machines that, one day, may even function on 100% hydrogen.

The promise of hydrogen

Hydrogen fuel offers many advantages in energy production. It is a carbon-free fuel that can decarbonize power and heat generation, and transportation, to help meet long-term CO_2 emission-reduction targets. Burning hydrogen produces no CO_2 emissions.

NOx emissions are a different matter. The more hydrogen is added to a natural gas and hydrogen combustion mixture, the higher NOx rises. Adding diluent gases, such as nitrogen and steam, however, has been shown to bring NOx down to single-digit levels.

Several sources of hydrogen are being studied. It can be generated from natural gas by steam reforming. Biomass can also be subjected to steam reforming or gasification to produce hydrogen. And hydrogen can be generated via electrolysis from excess renewable energy.

"One route towards a hydrogen economy is to combine renewable power generation with electrolysis and long-term or short-term storage," said Michael Welch, Industry Marketing Manager, Power and Gas Division, Siemens. "The idea is to use 'surplus' renewable electricity to create hydrogen that can be used to generate zero-carbon electricity at times when renewable power generation volumes are low."

Most hydrogen today is generated from natural gas, using steam methane reforming. Generating enough hydrogen for large-scale power generation via electrolysis or gasification will require tremendous volumes of feedstock (i.e., water or biomass), said Dr. Jeffrey Goldmeer, Director, Gas Turbine Combustion & Fuels Solutions for Gas Power Systems at GE Power.

"Although is it technically feasible to generate hydrogen via reforming natural gas, electrolysis of water, or gasification, they all require significant improvements in technology to raise overall efficiency and reduce cost," said Goldmeer. "Or they require a change in regulations to be economically viable."

If hydrogen production can be solved viably, it could potentially be transported over existing pipeline networks, ships or trucks. It could also be stored in liquid form in tanks in a mixture with ammonia and other organic substances. Some envision pressurized hydrogen being stored in salt caverns.

Hydrogen has one-third the heating value (on a volumetric basis) relative to methane, thus requiring roughly three times more fuel flow to the gas turbine. Hydrogen is a smaller molecule than methane, so mechanical seals configured for methane may not seal against hydrogen creating potential fuel leakage. In addition, the flame speed of hydrogen is ~10x that of other hydrocarbons.

Overcoming the hurdles

OEM research on the use of hydrogen fuel in gas turbines has been an ongoing effort, as illustrated below. But it is not without its technical hurdles, such as avoiding auto ignition in the fuel premix zone and flashback, in which the flame moves from its desired position in the combustion can back towards the fuel injectors.

MHPS

MHPS has almost five decades of experience in the deployment of hydrogen in various forms in gas turbines. Some 31 units have been running on syngas, refinery gas, coke oven gas (COG), and blast furnace gas (BFG). Many of them use a diffusion-type combustor which typically requires water or steam injection.

When switching fuels, it is important to consider their physical and combustion characteristics and the impact to GT systems and operability.

Currently, MHPS is refining its existing natural gas-fired combustors to cope with a larger volume of hydrogen. Its Dry Low NOx (DLN) combustor has traditionally mixed the fuel with sufficient air in advance of the combustor, so burning can take place in a lean atmosphere to maintain a relatively cool flame and keep NOx down.

That approach does not work so well when more hydrogen enters the picture due to auto ignition occurring in the premix zone. As a result, the combustor is being modified at the MHPS Takasago Works facility in Japan to achieve a mix of hydrogen and natural gas that could be used in large-frame GTs.

The company already has diffusion-type combustor technology where fuel and air are supplied separately. Hydrogen, though, burns with a hotter flame, leading to higher combustion temperatures and the formation of local hot spots. These, in turn, can cause NOx to increase. The solution is to cool the flame by use of diluents, such as demineralized water, steam or nitrogen. As well as reducing NOx, this also reduces efficiency compared to a DLN combustor.

Those findings were the driver for the development of the multi-cluster diffusion burner to protect against flashback. Each nozzle can mix air and hydrogen. This means a smaller diffusion flame, faster and better mixing, a lower overall combustion temperature, and lower NOx.

Work on this project is in the early stages. The new combustor has been tested on a small gas turbine using Liquefied Petroleum Gas (LPG). It calls for replacement of the fuel nozzle, combustor basket, transition piece, ignitors and flame detectors. Fuel lines must also be augmented to cope with a larger fuel flow.

MHPS wants to retrofit this technology into existing GTs. However, the attainment of a combustor running in a gas turbine on 100% hydrogen is not targeted for commercial operation until 2030. In the meantime, the company has successfully completed a firing test with 30% hydrogen using DLN technology at 1,600°C. This resulted in CO_2 emissions 10% lower than those running only on natural gas.

Siemens

Siemens' interest in fuel switching stems from a desire to make use of "opportunity fuels" to reduce operational costs. Opportunity fuels, some with high hydrogen content, are typically process off-gases, such as refinery gas or coke over gas that would otherwise have been flared or used in low-efficiency energy production processes.

Siemens is addressing several challenges facing hydrogen-enabled turbomachinery: getting the fuel into the combustors safely, burning it stably and reliably, and controlling the combustion emissions.

"With a higher flame temperature than natural gas, NOx emissions will be higher with hydrogen as the fuel source if no additional measures are taken," said Welch. "But as hydrogen is not a new fuel, the safety record of gas turbines on high-hydrogen fuels is excellent."

Siemens research on high-hydrogen fuels is moving away from diffusion flame combustion systems to DLN combustion. It seeks to mitigate flashback risk and combustion instabilities. According to Welch, reducing NOx while maintaining combustion stability without needing "wet" NOx reduction methods or SCRs is a big challenge going forward.

At low levels of hydrogen (up to 20% by volume), no changes to the fuel system or combustors are required, according to Siemens. At higher levels, material selection and sizing of the fuel system needs to

Blending spools for fuel mixing

be considered, and care must be taken in the combustion system design and operation to avoid flashback. Siemens is incorporating 3D printed components into fuel injector design to ensure safe operation with hydrogen.

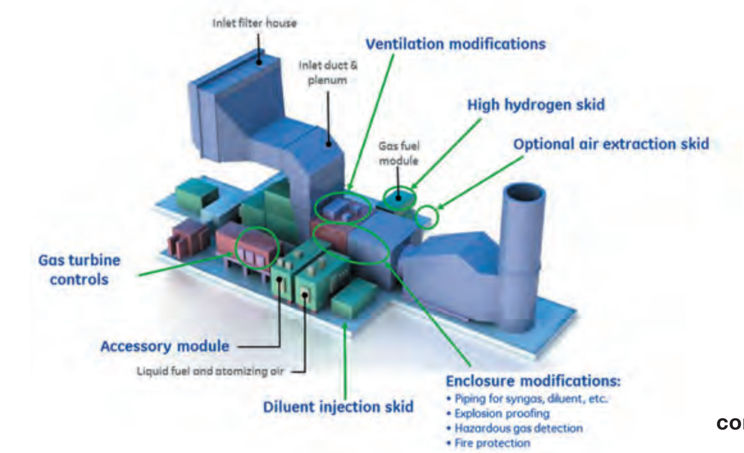
"The mixing of natural gas and hydrogen should be undertaken before the fuel mixture reaches the turbine itself," said Welch. "If this is done, then the fuel system and combustion system can be optimized for the potential range of hydrogen concentrations expected."

Siemens has hydrogen capability at various levels across its GT portfolio from 4 MW to 567 MW. It also has decades of experience of operation on high-hydrogen fuels. Most recently, progress has been made on enhancing the hydrogen capabilities of its DLE combustion systems. Its SGT-600, -700 and -800 GTs (24 MW to 57 MW) offer up to 60% hydrogen in natural gas on a volume basis with NOx emission levels as low as 25 ppm.

Due to the combustion characteristics of hydrogen, there are limits on the allowable concentrations in current premixed combustion systems, said Welch. The limits on hydrogen concentration are set to ensure stable and safe operation with regard gas turbine operability, i.e., undesired flame propagation and combustion dynamics outside of a preferred range. Today, operation on 100% hydrogen requires the use of a diffusion flame combustor, which avoids mixing of fuel and air upstream of the reaction zone.

"We are currently working on a capability-expansion project to enable the burners to be able to operate on up to 100% hydrogen as a fuel," said Welch.


GE's High hydrogen-fueled 6B gas turbine in South Korea



Example of a hydrogen fuel conversion retrofit

GE

GE's experience with hydrogen-containing fuels, includes its aeroderivatives, E- and F-class GTs operating in steel mill plants, integrated gasification combined cycle (IGCC) power plants, refineries, and petrochemical plants with waste or process gases containing hydrogen.

As part of the U.S. Department of Energy High Hydrogen Turbine Program, GE has developed a premixed combustor capable of operating on high-hydrogen fuels. This combustor, called the DLN 2.6e, is now shipping on 9HA gas turbines. Based on preliminary lab testing, this combustor is capable of operating on a natural gas blend with about 50% hydrogen (by volume).

GE offers upgrade packages, so its gas turbines can run on fuels beyond their initial configuration. "This may aid in providing financial security for the plant owner or operator; and may also aid in providing energy security for the electrical utilities, since gas turbines can be re-configured to consume other fuels as situations require," said Goldmeer. "The ability to switch fuels may prevent the operator from being locked into a fuel prone to major price increases or unavailability."

When switching fuels, it is important to consider their physical and combustion characteristics and the impact to GT systems and operability. "Combined, these differences create an increased potential for fuel nozzle distress," said Goldmeer. "Once the differences in the fuels are defined, the current fuel and combustion configuration for a specific site can be evaluated to define the required changes to switch fuels."

Ansaldo

Ansaldo Thomassen (AT) is Ansaldo Energia's service team for non-Ansaldo GTs. It comprises PSM, Ansaldo Thomassen and Ansaldo Thomassen Gulf. AT is working on combustion technology for fuel mixing and greater hydrogen content.

Dr. Peter Stuttaford, AT's CEO, agrees that the high flame speed of hydrogen used in DLN systems is a challenge due to flashback margin reduction, NOx increase and shifting flame position potentially overheating components.

"Fuel skid and controls require special attention to avoid leakage and safe turbine control," he said. "However, these items can be solved with the right system design."

Rapid premixing, independent of Wobbe index variation, is needed, said Stuttaford. High premixer exit velocities can provide the needed flashback margin, with careful treatment of boundary layer shear and the fuel-air ratio.

It is also necessary to provide a strong flame stabilization mechanism that does not shift substantially with fuel reactivity. AT's LEC combustor is available for up to 25% hydrogen. Its Flamesheet combustor can tackle up to 40% hydrogen.

"Tests are ongoing to demonstrate 80% hydrogen capability for Flamesheet, and development work is ongoing for a 100% hydrogen demonstration," said Stuttaford. ■

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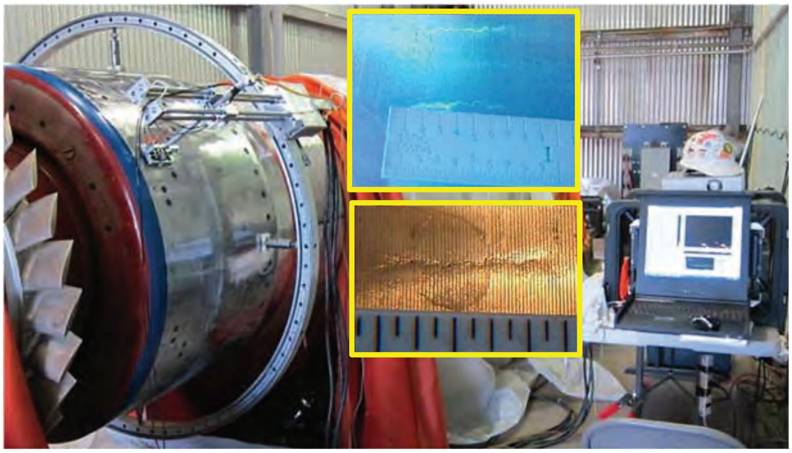

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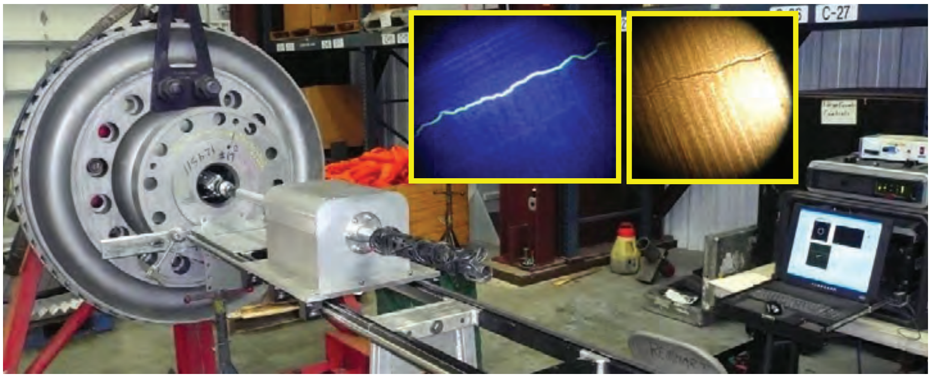

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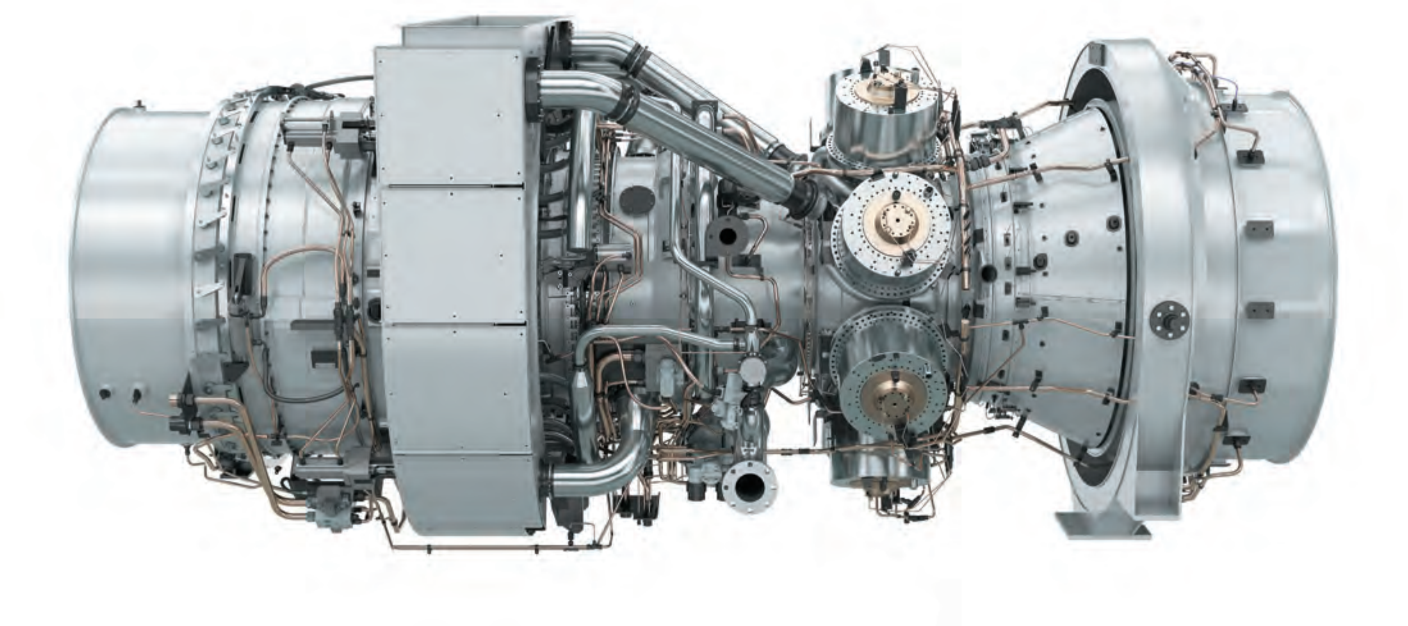

Siemens SGT-A65 aeroderivative gas turbine

AERODERIVATIVES VERSUS RECIPS

DEMANDS OF THE MARKETPLACE LARGELY FAVOR THE AERODERIVATIVE

BY VINCENT PEREZ

Over the past few years, the momentum behind renewable energy has accelerated considerably. To ensure supply and demand match, system operators need controllable resources with ramping flexibility and the ability to start and stop multiple times per day as dictated by real-time grid conditions.

Both over supply and under supply must be mitigated by making sufficient flexible controllable capacity available. Over supply happens when all anticipated generation, including renewables, exceeds the real-time demand. It requires manual intervention of the market to maintain reliability.

During oversupply times, wholesale price can be very low and even go negative (i.e., generators paying utilities to take the energy). Under supply results in grid frequency drop, system failures and potential black-outs or services interruptions. Certain grids are already facing these problems (Figure 1).

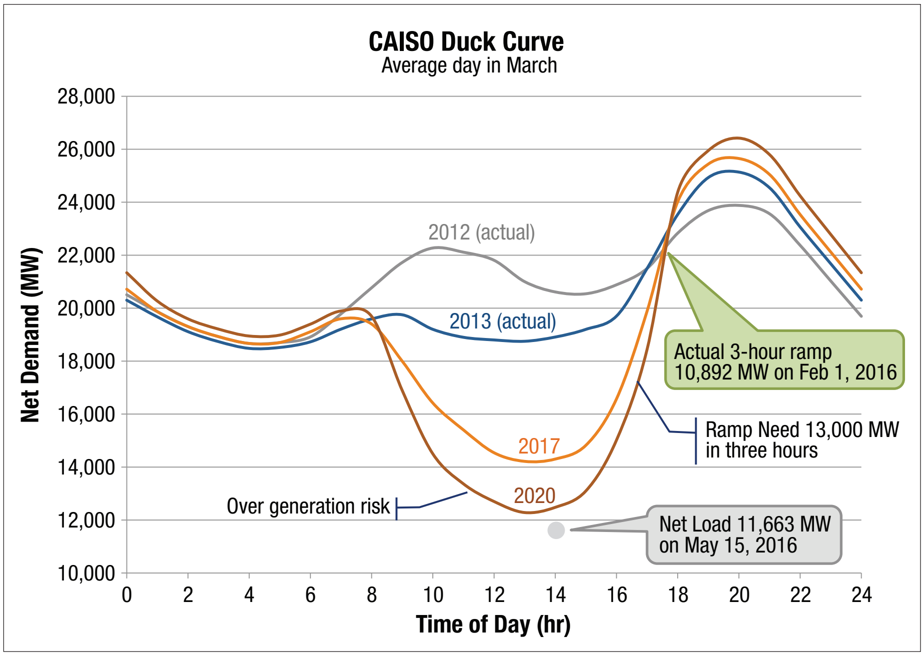

Figure 1: Power demand variations within the California grid with high penetration of renewable energy

Natural gas-fired generation has an important role to play in supporting a flexible, cost-effective, environmentally friendly power grid. Aeroderivative GTs and reciprocating internal combustion engines (RICE) are the two most commonly employed simple cycle power generation options available to system operators to cope with the challenges posed by the high content of renewable energy.

Larger RICE units have power outputs ranging from about 10 MW to 20 MW. Therefore, large power plant specifications must be met via multiple units with consequences, such as economies of scale and site infrastructure costs.

As an example, GTs up to 100 MW typically operate within their own weather proof enclosure. Larger RICE units, on the other hand, require a building. In addition, an array of fin-fan coolers is needed to cool RICE jacket water. This adds to the cost of buying and operating the equipment as well as on-site infrastructure work.

The size of the required building and infrastructure depends on the power density of the generating equipment; both from a MW/kg viewpoint driving the type of foundation and MW/m^2 driving the footprint and land cost of the plant (Table 1).

Aeroderivatives come out ahead on power density. Note also that recip pistons generate low frequency vibrations that can necessitate anti-vibration mounts, isolating pads, and sometimes floating concrete foundations.

A 20 MW RICE will typically require a 1.5m concrete raft per engine. An aeroderivative will need around 4.5 times less concrete. For a RICE plant, however, the engine hall only represents about one third of the equipment footprint. Another third is occupied by the silencer and emission treatment system and the last third by the secondary water system array of fin-fan coolers (Table 2).

Table 1: Comparison of energy density for a 20 MW recip versus a Siemens SGT-A65 aeroderivative

	Large RICE 20 MW Class	SGT-A65
Footprint (m)	4.1×13.7	2.8×4.4
Weight (metric tonne)	250	11
Power (MW)	18.8	Up to 70.8
Density (kW/m^2)	335	5,746
Density (kW/tonne)	75.2	6,436

Table 2: Footprint and power density comparison for a 300 MW power plant

	Large RICE 20 MW Class	SGT-A65
Reference site	Edinburg, Texas, USA	Bayonne, New Jersey, USA
Power (MW)	220	512
Units	12× Large RICE	8× SGT-A65
Footprint	32,000 m^2 (7.9 acres)	28,600 m^2 (7.1 acres)
Density (kW/m^2)	6.8	17.9
Scaled to 300 MW		
Units	17× Large RICE	5× SGT-A65
Footprint	10.7 acres	4.1 acres

A modern natural gas-fired plant might have a minimum of one daily start for the afternoon demand surge and one shutdown either at the end of the day when this peak disappears (peaking application, approx. 1,700 h/year), or the next day when by the end of the morning the renewable surge drives the grid towards an over generation risk (mid merit, approx. 5,300 h/year).

The number of daily starts could be increased further if the plant is used to balance the slight increase in demand in early morning before renewables capacity fully kicks in (2 starts); or if it is used to offset the sharp variations that could occur during the day and not represented in this curve because of the scale.

Under these conditions, wear and tear of equipment will mostly be caused by fired hours for RICE units and aeroderivative gas turbines. Thermal stress levels are more likely to impact ramp rates and cycling capabilities.

The architecture and materials used in aeroderivatives are intended for multiple starts, stops, and sharp power spikes without maintenance or life penalty. RICE units show the same resilience to cycling operations.

Time to start and reach full power also needs to be considered within the start cost through fuel burnt cost: starting time could range from two or three minutes for the 10 MW class of RICE under "readiness to start" conditions. For 20 MW-class RICE, this rises from seven to 18 minutes. This compares to five- to 10-minute start times for large aeroderivatives.

The cost of keeping units and plants in "starting mode" also should be considered. GTs usually start from cold iron. Only trace heating is employed to maintain fluids above freezing temperature as well as mandatory enclosure ventilation.

To meet fast start conditions, RICE jacket cooling water and lubricating oil are preheated and maintained above a minimum temperature (typically 70°C for the cooling water), engine bearings are continuously pre-lubricated, and the engine is slow turning (typically driven by an electrical motor).

Preheat to start

Large RICE units typically require some form of preheating to start after 12 hours of down time, but it could be required as early as 1 hours after shutdown to retain fast-start capability.

In an environment, such as California, RICE units could require 16 hours or more per day of heating, lubricating and turning to retain their fast start capability with energy consumption exceeding 5 MW for a 300 MW plant. For an aeroderivative plant, the same conditions could require less than 0.9 MW of energy consumption.

Overhaul and maintenance

Overhaul and maintenance strategies are different for RICE and aeroderivative gas turbines. Aeroderivatives have long intervals between maintenance inspections based on running hours, typically around 25,000 fired hours before the "hot section" inspection and basic maintenance.

At 50,000 fired hours, a more complete overhaul is typically performed. This pattern generally repeats at 75,000 and 100,000 hours. The latest equipment tends to extend these period intervals toward 36,000 hours.

In addition, borescope inspections are typically performed every 12-to-18 months without the need for disassembly. Downtime can be decreased through a core exchange program offered by the OEM, or through the installation of a leased engine into the package to restore full operations within 48 hours.

RICE units will have more frequent and longer maintenance events. Piston rings, cylinder liner and head, and inlet and exhaust valves will typically have repair intervals ranging between 16,000 to 24,000 hours. Some of these components have similar replacement intervals, depending on the fuel and operating conditions, or up to 60,000 to 100,000 hours for pistons and cylinder liner and heads (Table 3).

The sheer size of large RICE unit (over 250 tonnes for the engine, 1.2 tonnes for a cylinder head) will require regular in situ maintenance operations to be planned and staffed accordingly, with cranage within the building and free space above and around the units for maintenance access.

As regular maintenance is based on fired hours, RICE overhaul costs are quoted per MWh; around $8.5/MWh for

Continued on page 26

Table 3: Typical inspection events schedule for large RICE units

Operating (fired) hours	Event	Estimated duration (2×12h shifts)
Routine checks	Checking filters, lube oil, cooling water	During operation
8,000h	Minor Inspection (plus repair of gas valves)	2 days
12,000h	Minor Inspection	3 days
15,000h	Intermediary Inspection (cylinder head & bearing)	9 days
24,000h	Minor Inspection	4 days
32,000h	Intermediary Inspection (plus replacement of inlet valves)	10 days
48,000h	Major Inspection (crank shaft inspection)	10 days

10 MW class engine and $6.5/MWh for the 20 MW one. This is based on number of operating hours at full load. Part load operation means higher maintenance costs per MWh for RICE. Gas turbines will typically benefit from extended operations hours or reduction of maintenance for part load operation.

Efficiency is an area where large RICE units have an advantage. RICE range from 45% to 48% for simple cycle efficiency for large units (at the generator terminals). Large aeroderivative turbines have a simple cycle efficiency of around 43% in some cases.

However, RICE units require higher auxiliary loads than aeroderivatives to drive lubricating oil pumps, heating ventilation and air conditioning (HVAC) for the engine hall, as well as cooling water pumps and fin-fan cooler motors.

These loads result in about a 2% efficiency penalty. In addition, the combustion tuning of large RICE units to combat emissions has an efficiency penalty of around 1.5%.

Lube oil consumption

RICE units generally consume lube oil at a rate of 0.5kg/MWh. Regular oil changes or continuous conditioning of the oil is required. Oil consumption in aeroderivatives is negligible and the oil can sometimes last for the life of the machine.

These factors should be taken into consideration in any analysis of running costs of RICE versus aeroderivatives, as RICE high maintenance cost and oil consumption and disposal costs can cancel-out high efficiency fuel cost savings.

Operational flexibility

The capacity for the plant to generate revenue in different market environments should always be included in technology selection. These can range from energy-only markets with real-time, day-ahead, and ancillary service markets to capacity markets or operating reserve markets.

Flexibility demands characteristics, such as the ability to rapidly ramp up and down, fast start, low load operation, reliability, accurate forecast operating capability and high availability. Based on the factors noted above, the demands of the marketplace largely favor the aeroderivative.

The ramp rates, load acceptance and shedding characteristics of aeroderivatives allow operators to balance the grid with up to 4 MW/s per unit when under-supplied grid sees frequency drop and a fast supply is required to prevent system collapse.

This also allows operators to switch on/off large equipment as up to 20 MW instantaneous load can be accepted by a unit idling at 0 MW. Some 35 MW can be accepted by a unit at 25 MW (i.e., over 2,100 MW/min). Alterna-

Continued on page 28

tively, a unit at 50 MW can instantly shed the full load (i.e., over 3,000 MW/min) and stabilize at synchronous speed at 0 MW without tripping, ready to respond to new demand.

The starting flexibility of aeroderivatives also allows operators to optimize dispatch at the plant level. They can either maximize part load efficiency by switching units on/off to match demand or share load between several units to maximize the spinning reserve in a capacity market (Figure 2).

As a result, large aeroderivative gas turbines can participate in all revenue schemes for which large RICE units qualify. They can outperform RICE units in terms of start capability, time to base-load, ramp rate, and load acceptance and shedding.

The inertia of the power train is another factor to be taken into account when considering grid frequency stabilization. The rotary movement of GTs and the mass of the larger electrical generator provides greater grid stabilization benefits than a battery or smaller RICE unit.

This is even more important when considering that renewable energy with low or zero inertia displaces traditional power generation equipment with large inertia.

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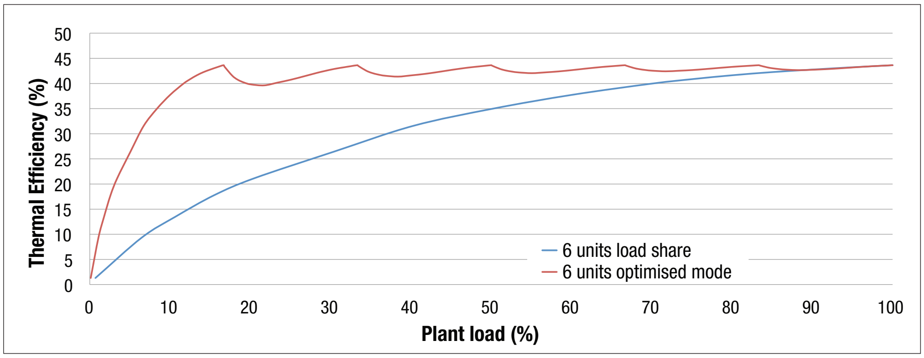

Figure 2: 300 MW plant efficiency as a function of load

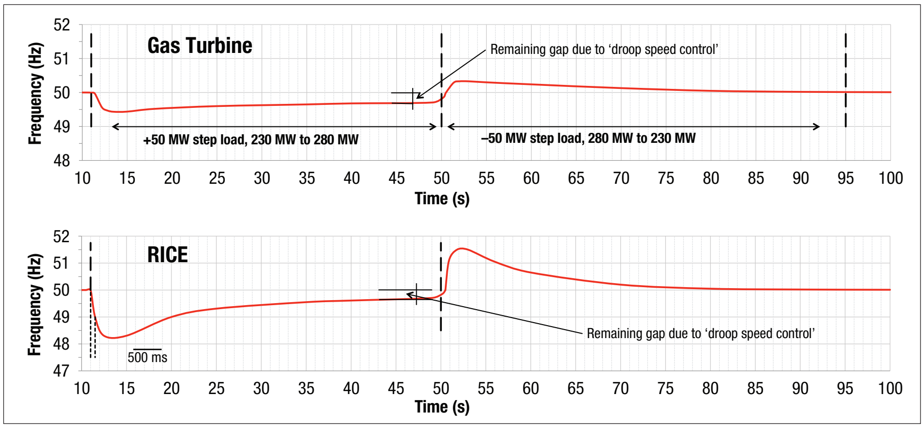

Figure 3: Grid frequency regulation during a 50 MW step load between 230 MW and 280 MW for a RICE supported grid (20 MW unit) vs. a gas turbine supported grid (50 MW/unit)

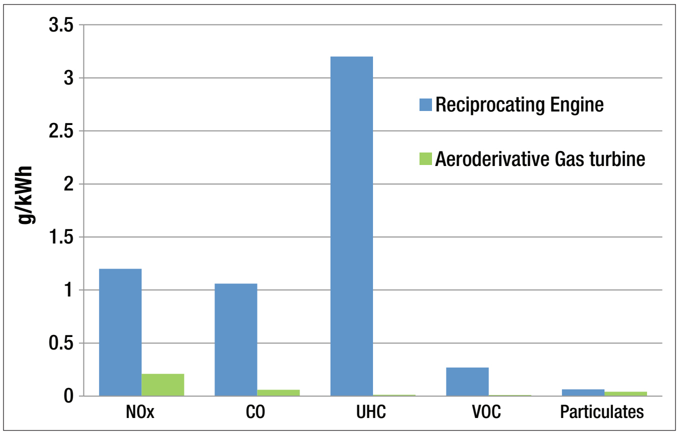

Figure 4: Emissions for natural gas fuel plant without exhaust treatment. Untreated, RICE units will emit more than four times the NOx of aeroderivative gas turbines.

Take the case of a 50 MW step in a 280 MW small grid. This might be due to a single point failure, such as an electrical transformer failure (corresponding to a single GT or three large RICE units connected to a large transformer and breaker) in island mode.

The large frequency excursion in the RICE supported grid risks damaging the driven electrical equipment. It may also cause trips and upset grid stability (Figure 3).

Large aeroderivatives retain more grid stabilizing inertia while displaying higher ramp rates per unit and similar cycling capability than RICE units.

Environmental impact

Although RICE units and GTs may often be used for the same power generation application, due to the different technologies, different regulations typically apply.

Despite being compliant with mandatory applicable regulations, RICE units tend to be more polluting. They also require the purchase and upkeep of exhaust catalysts and scrubbers (Figure 4)

Additionally, RICE units will burn lube oil on the cylinder walls (about 0.5g/kWh) which will result in emissions of approximately 9mg/Nm³ SOx on gas fuel, typically not treated by emission abatement processes.

Beyond NOx and CO, the most striking difference is unburned hydrocarbons, which would include what is referred to as "methane slip". Due to an explosive combustion cycle, RICE units will have unburned hydrocarbons escaping through the exhaust.

This amounts to between 3 g to 6 g/kWh at 100% load and from 13g up to 40 g/kWh at 25% load. A GT will typically emit UHC over two orders of magnitude less than a full load RICE unit.

Methane, which degrades slowly over time when released into the atmosphere, is 84 times more potent a Green House Gas (GHG) compared to CO_2 over a 20-year horizon, and as a result 'methane slip' negates RICE environmental benefit of higher efficiency and less fossil fuel burn.

Aeroderivatives, then, offer a flexible, fast-responding, and economical solution to the challenges facing the electricity markets faced with a growing penetration of renewable power generation.

They offer superior power density, transient response to grid balance requirements and economics, availability, in addition to far lower impact from exhaust emissions. ■

Vincent Perez is Advanced Projects Manager for gas turbines in Siemens Canada. For more information visit Siemens.com/energy

23 MW (30,000 hp) direct-driven compression train with synchronous motor in double-end-drive configuration situated at Schaapbulten, Netherlands

MAXIMIZING COMPRESSOR PERFORMANCE

ACTIVE MAGNETIC BEARING SOLUTIONS DELIVER FLEXIBILITY, RELIABILITY AND IMPROVED ECONOMIC PERFORMANCE

BY DR. RAINER GAUSMANN AND FRANK HEIDTMANN

As oil and gas fields age, pressure can drop, and output diminishes. Left unchecked, this can signal the end of viable production for that site. Take the case of the Groningen field in the north of the Netherlands.

Currently it produces 20 billion cubic metres (bcm) of gas annually. But well depletion has taken its toll after 35 years of operation. In response, the Groningen Long Term Project was begun. This involved the installation of a compression stage on 20 gas production clusters. This boosted the gas pressure to the required 65 bar (940 psi) grid pressure.

Afterwards, however, pressures continued to decline. A second compression stage was required to handle the yearly and daily gas demand fluctuations while adding reliability in the face of a demanding duty cycle. The facility also wanted the capability to deliver fast starts, multiple starts per year, a large turndown ratio and a wide speed range.

A recent upgrade focused on the development of an accelerated cluster. Requirements included speed ranging from 10% of maximum to 105%, a turndown ratio of 1:24 and up to 260 starts a year for the compressor train.

Three compressor concepts were evaluated: a new compression unit; a drive-through concept; and a double-end concept. Both the double-end and drive-through concepts offer the benefit of using the potential of the existing motor.

Shorter shut-down times

However, when compared with the drive-through design, the double-end concept has improved maintainability and operability characteristics. It also has shorter shut-down times for maintenance due to the configuration of the inner casing. The double-end technology was selected for further development.

A second design choice focused on the use of active magnetic bearings (AMB). The general business trend to operate at higher circumferential speeds in the turbomachinery industry is limited by material properties, such as yield strength.

Other limitations include excessive pad temperatures and large shear power losses in conventional fluid film bearings. Rotors supported on AMBs have the potential to overcome this last limitation. In contrast to passive fluid film bearings, an AMB is an active component that requires a closed control loop to stabilize the rotor in the center of the air gap.

Rotordynamic analysis of fluid film bearings is afflicted with uncertainty in the prediction of dynamic force coefficients for tilting pad bearings and gas labyrinth seals. In contrast, an AMB is predictable in terms of its frequency-dependent behaviour expressed in the form of a transfer function relating the bearing force to the rotor position (Table 1).

The stable properties of AMBs also include the transfer behavior of the sensor,

Table 1: Properties of oil lubricated bearings vs. AMBs

	Motor or Turbomachine with	
	Oil Lubricated Bearings	Active Magnetic Bearings
Specific load	High	Low
Stiffness	High	Low
Damping	Moderate	High
Circumferential Speed	<100 m/s (<330 ft/s)	<200 m/s (<660 ft/s)
Losses	Moderate	Very Low
Speed Range	Typically Limited	Continuous
Complexity	Low	High
Environment	Risk To Leak	Yes
Maintenance	Periodical Oil And Filter Checks	Nearly No

the amplifier and the force-control current relationship, and the control law, which is designed individually for each rotor. AMBs provide a large operating range and high dynamics over a wide frequency range. This allows them to deal with highly unbalanced situations and to respond to upset conditions, such as surge events, power dips and the like.

Having determined the key design considerations and technology choices, a development assurance program was followed by a qualification based on a Technology Readiness Level (TRL) assessment. Introduced by NASA for space technology, the TRL method has been adapted for the oil and gas industry. Divided into eight levels, the TRL process as used within Shell includes a procedure to assess the maturity of new technologies to avoid and to manage risks in a systematic way.

Full-scale testing

TRL5 is defined as a full-scale component test in a relevant environment and with full interface and functionality tests for compressor bearings and motor bearings. Developed with the intent of ensuring that technical risks were identified and addressed as far as possible prior to field implementation, the magnetic bearing system was initially full-scale tested in a 5 MW (6,700 hp) high-speed asynchronous motor.

TRL6 addressed the applied technology qualification for the engineering, manufacturing and testing of machinery destined for the gas processing plant. This test rig consisted of a five-stage compressor rated at 23 MW (30,000 hp) and with a 120 bar (1,741 psi) design pressure.

Operating in closed-loop conditions with a nitrogen working fluid, the test bed unit was driven by a shop motor with a step-up gear and a mechanical safety brake (Figure 1). TRL6 was achieved by fulfilling the requirements of the project's quality control plans, including mechanical running tests, as well factory performance tests of both compressors and a factory acceptance test for the driver.

TRL7 handled the string design qualification, including installation and commissioning. This was achieved by a design review of the integrated string and a third-party check of the lateral, axial and torsional dynamics.

At TRL8, the compression train proves reliability and high availability on location during a specific operation period. This is accompanied by specified tests and activities, such as robustness tests, power dip tests, 72-hour full-load tests, operation map verification, and others. After completing a rigorous test program including axial and radial static load tests, axial

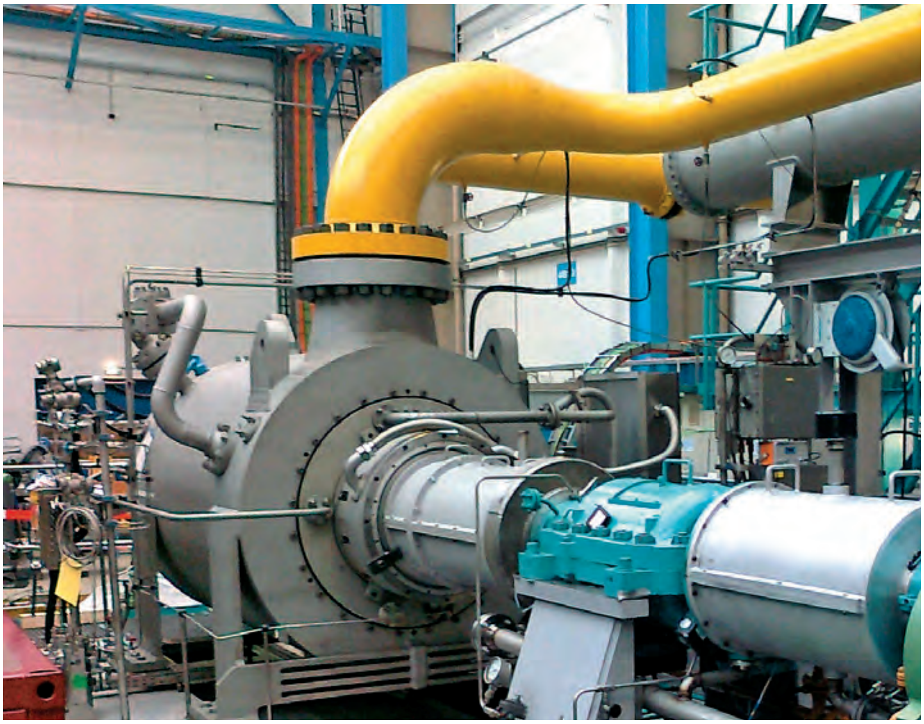

Figure 1: AMB-supported test compressor

dynamic load tests, unbalance and stability tests, endurance test and advanced safety functions tests, the compression train successfully passed TRL1 to TRL8.

Groningen installation

Constraints for the revamp project were the reuse of the existing motor stator and housing. This included the mottor's whole electrical drive and control technology (power supply, switchgears, variable speed drive system, and so on.) as well as the existing compressor casing.

The existing compression string comprised a 23 MW (30,000 hp) variable speed synchronous motor and a directly driven inline compressor, both levitated by magnetic bearings. With the new additions, the compression train now consists of a modified double-end-drive motor rotor and a directly driven low-pressure compressor (1st section) on one side and a directly driven high-pressure compressor (2nd section) on the other side of the motor, all on AMB systems.

The existing compressor motors were formerly levitated by three magnetic bearings (two for the main motor and a third one at the exciters non-driven end). The double-end-drive concept asked for a newly designed drive-through exciter in which the third bearing is omitted.

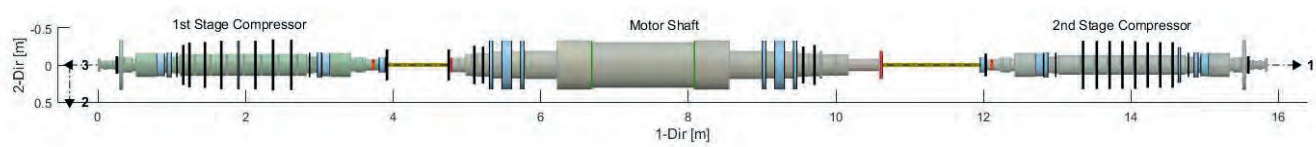

Figure 2. Rotordynamic lateral model of the 16 m compression train with directly attached high speed motor, supported by AMBs. It includes the marked positions of the radial compressor AMBs (small triangles)

A smaller amount of hardware led to a reduced plant footprint, as well as simplified commissioning and higher overall reliability. The control cabinets include a standard high-power inverter of the type normally used to drive torque motors and linear motors in machine tool applications. However, the software was modified for this new application.

The pilot plant started production towards the end of 2013. The novel compression string with a seven- and eight-stage compressor is about 16 m (52 ft) long, with up to 14 mm (0.55 inch) axial thermal elongation. It is supported by six radial AMBs and two axial AMBs at the train's non-driven ends (Figure 2). String design aspects also included the latest field and operational experiences concerning experimental torsional string analysis and sensor lane run-out effects in combination with the closed loop AMB controller design.

Technical challenges experienced during this development included the size of the double-end drive (9-ton rotor), modifications required to the dry gas seal design, and the incorporation of AMBs.

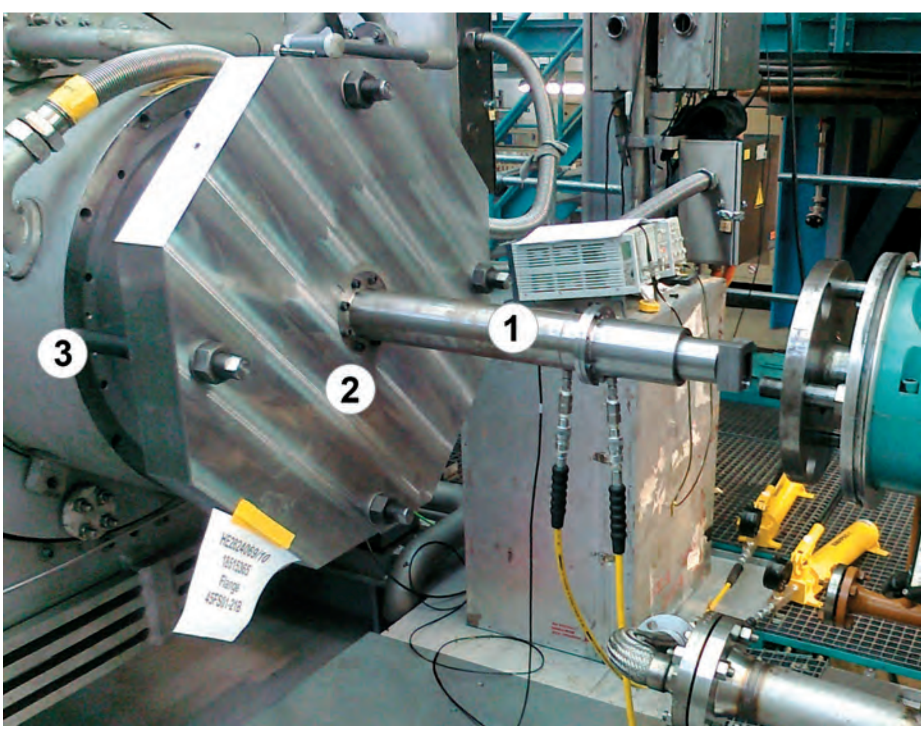

Figure 3: Test set-up for axial dynamic step response test with special tool (1) for step-load application, installed by a counter holder (2) at the compressor drive-end (3)

Figure 4: Ready-to-use container solution with AMB cabinets is air conditioned, suited to desert conditions, and adaptable to desired IP (international protection) rating defining the sealing effectiveness against intrusion from foreign bodies such as dirt and water.

Trade-offs were required in coupling selection, resonance frequency optimization, fatigue and mechanical short circuit resistance, axial train dynamics (Figure 3), tolerable thermal expansion of the 16 m-long train, (overhang) coupling masses, and the degree of lateral decoupling in between the motor and the two compressors.

In comparison to an oil bearing system, AMBs offer a clean, oil and contamination-free system that is virtually maintenance free with no mechanical wear parts.

Figure 5: Interior view of container

However, it should be noted that AMB systems require a different set of supporting auxiliaries and control electronics.

Since commissioning of the pilot compression train at Groningen, the AMB system has been working satisfactorily. Availability and reliability figures for the prototype application are above 99.9% in the first year of operation.

Experience in commissioning of the compressor train has revealed the potential for a further reduction in the commissioning time by means of a container which houses tested and pre-commissioned AMB cabinets. This container solution, (Figure 4 and 5) has been successfully applied for a 1st stage revamp of another Groningen plant.

At the Groningen gas field, the upstream two-AMB double-end drive-through compressor solution is reliably maximizing economic returns. With fast starts, multiple starts per year, a large turndown ratio, and a requirement for a wide operational speed range, this approach offers a solution for depleting gas field applications, as well as for pipeline and gas storage applications. ■

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NON-DESTRUCTIVE TESTING

CIRCUMFERENTIAL CRACKING OF STEAM TURBINE AND GENERATOR ROTORS

BY TEODORO LEON-SALAMANCA

Service-induced defects of steam turbine (ST) rotors can begin in several areas. This includes at the surface, either peripheral areas, inside diameter (ID) bore connected areas, dovetail areas under blading, and areas under shrunk-on disks. These service-related defects will propagate perpendicular to the stress that is induced during service.

For example, bore circumferential or hoop stress can be caused by thermal and mechanical stresses during startup and operation. These stresses, in turn, induce axially oriented bore surface connected defects. Axial and bending stress applied on the shaft by thermal and mechanical forces will induce surface connected circumferentially oriented defects.

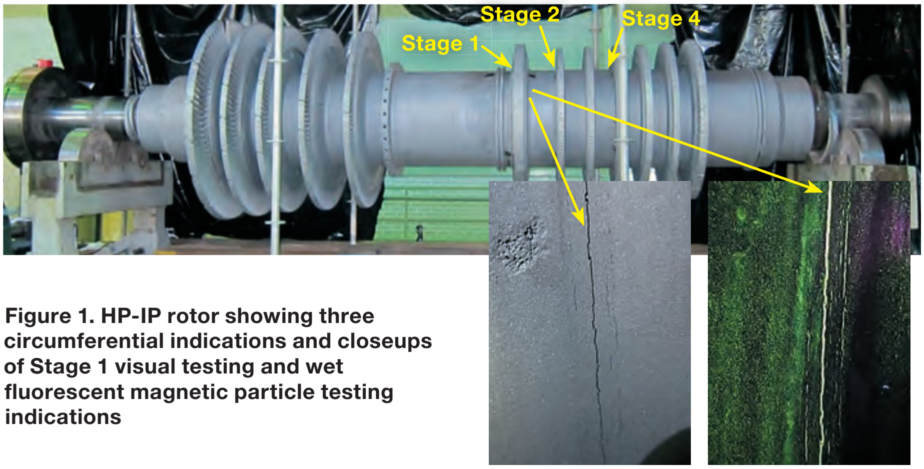
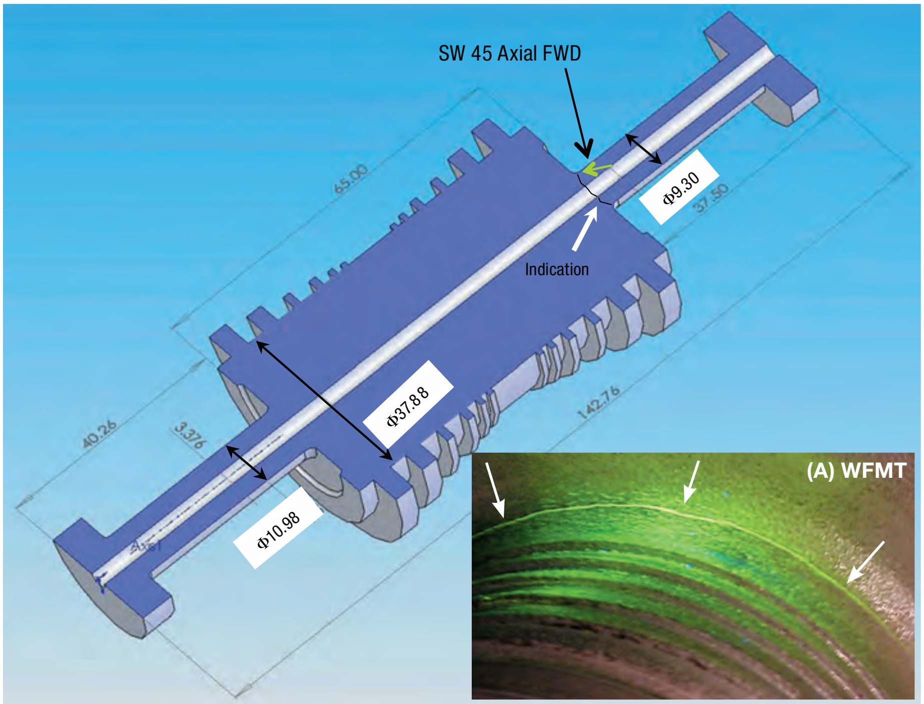
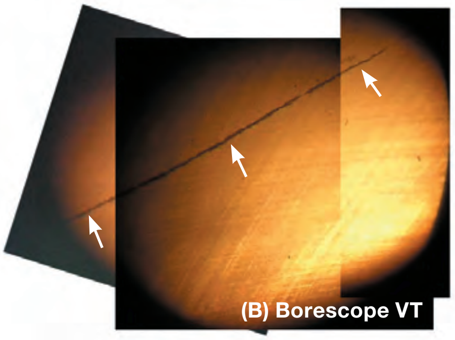


Figure 1. HP-IP rotor showing three circumferential indications and closeups of Stage 1 visual testing and wet fluorescent magnetic particle testing indications





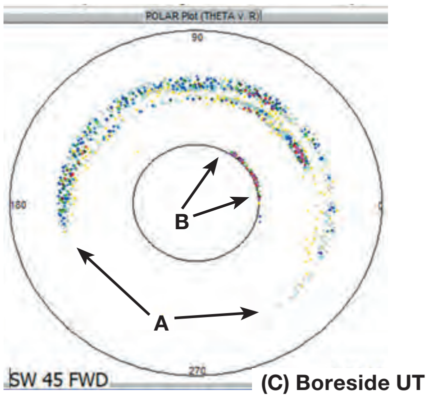


Figure 2. DFLP rotor through wall indication from shaft OD to bore ID surface connected circumferential indication detected by VT and WFMT sized by Boreside UT (OD is 260 degrees long or 21.1 inches and ID is 51 degrees long or 1.5 inches).

A study was conducted of twelve rotors that showed significant service-related circumferential defects. These rendered the rotors temporarily unusable. Some required costly repair procedures before being returned to service. Others were completely retired from service.

Out of the 12 rotors, seven were High Pressure—Intermediate Pressure (HP-IP), four were Double Flow Low Pressure (DFLP), and one was a generator rotor. All had a central bore manufactured by a variety of OEMs.

Circumferential cracking causes

A combination of causes contributed to this type of service-induced defect. This includes: changing service duty cycle from base load to peak load; rotor misalignment and unbalance; reaching design fatigue life (30–40 years of service); excessive amounts of manufacturing defects (non-metallic inclusions, stringers); inappropriate bore machining (not concentric); inappropriate overbore machining (small wall between bore transition and periphery); and fretting on rotor slots caused by rotor wedging (generator rotor).

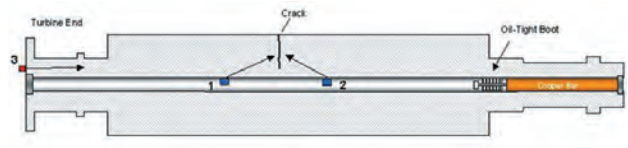
Figure 1 shows a photo of an HP-IP rotor with three areas containing circumferential crack-like indications, i.e., Stage 1, Stage 2 and Stage 4. Close-up photos of visual testing (VT) and wet fluorescent magnetic particle testing (WFMT) of Stage 1 are also shown. The damage was the result of cycling a rotor designed for base load duty.

Nondestructive evaluation

The conventional methods used for nondestructive evaluation (NDE) of a steam rotor periphery include visual testing (VT), wet fluorescent magnetic particle testing (WFMT), liquid penetrant testing (PT) and ultrasonic testing (UT). There are also more specialized NDE methods such as phased array ultrasonic testing (PAUT).

There is also boresonics, which is performed from a center bore on hollow rotors and include boreside VT, WFMT or eddy current testing (ET), and UT. Further methods include surface replication and hardness testing.

Figure 2 shows a DFLP rotor with a circumferential crack-like indication detected by boreside VT, periphery WFMT and boreside UT. The indication initiated at the change in OD radius area and propagated through the thickness of the rotor shaft from the OD surface to the ID surface of the rotor bore. The damage was the result of having reached its design life as well as poor material properties.



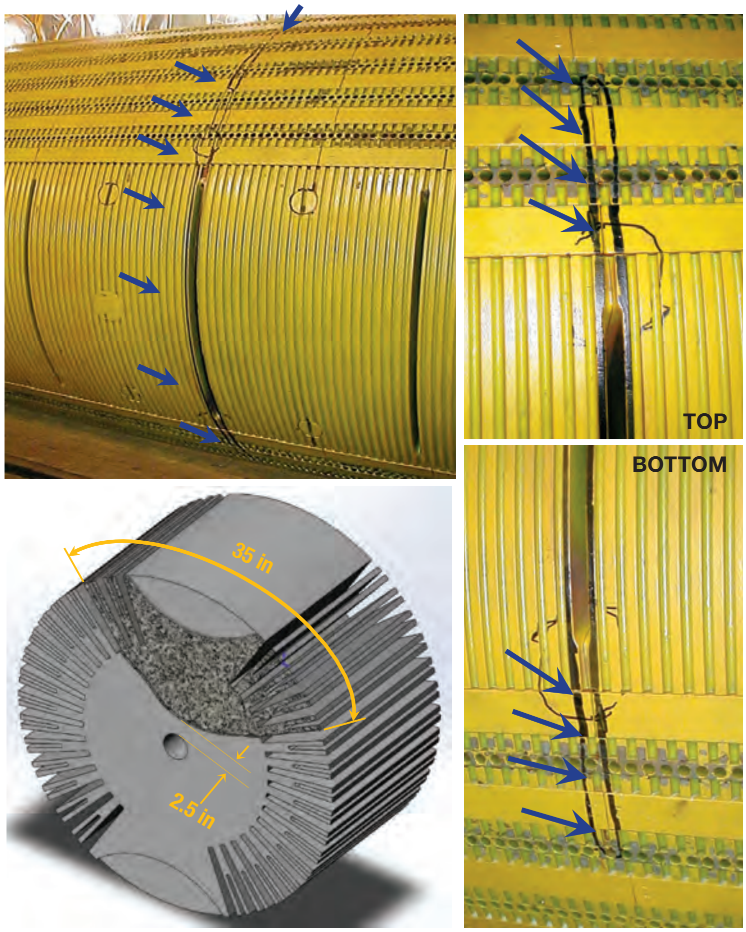


Figure 3. Generator rotor circumferential indication extending 35 inches on the OD surface and 2.5 inches from the bore surface.

Figure 3 shows a generator rotor with a circumferential crack-like indication detected visually by VT and sized by boreside UT 45-degree axial scanning. The generator rotor was reported as having increasingly larger amplitude vibration when the unit was in the startup process.

The peripheral VT examination revealed that the OD surface connected indication was 35 inches long and the boresonic examination revealed that the indication was about 2.5 inches from the bore ID surface.

The crack-like indication apparently initiated at the generator rotor teeth dovetails by a combination of fretting fatigue damage caused by wedge movement combined with negative sequence event localized damage and large number of start-stop cycles. The indication propagated toward the flex slot that aligned in the circumferential plane and radially toward the bore surface.

Circumferential-radial cracking can be generated by normal or high thermo-mechanical stress in steam turbines and by fretting fatigue in generator rotors. In hollow rotors, it starts at the outside surface and propagates inwards toward the bore inside diameter (ID) surface. If undetected at the onset, it can propagate until the rotor becomes unstable. Circumferential-radial crack propagation may cover part or all the outside surface.

Based on the findings of these 12 rotors, the rotor owner as well as inspection companies must require 100% periphery examination with emphasis in the following areas:

- For HP-IP rotors, examine the radius area between stages at the root of each disk, especially in the impulse stage and the first three IP stages.
- For DFLP rotors, examine the radius area from the last stage blading to the shaft extensions.
- For generator rotors, examine the rotor teeth dovetail loading surface of the first and second slots next to the pole faces paying special attention in the area where individual wages meet and align with the rotor flex slots. ■

Teodoro Leon-Salamanca Ph.D, is President of Reinhart & Associates, a company that has nondestructively examined more than 1,000 steam turbine and generator rotors. Contributing authors: Mike Monaco, VP and Stan Kaminski VP. For more information, visit reinhartassoc.com

STREAMLINING THE LUBE OIL SYSTEM

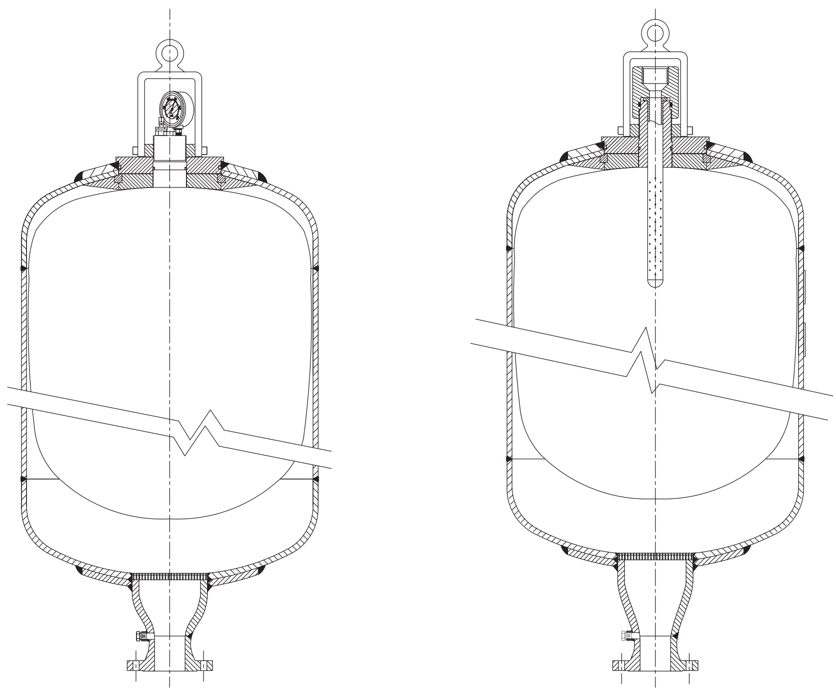
TRANSFER BARRIER ACCUMULATORS CAN SLIM DOWN YOUR LUBE OIL SKID AND PROTECT THE ENVIRONMENT

BY JOE CHEEMA

Lube oil systems provide lubrication and cooling to gas turbines and other industrial equipment. In turbomachinery, they are important for hydrodynamic bearing performance. The system assists in dissipating or settling contaminants, providing for temperature fluctuations and storing oil.

One of the main causes of lube oil system failure is loss of lubricant flow. This can lead to excessive wear and premature replacement of bearings. Accumulators act as a safeguard against such failures by providing a temporary supply of lube oil in the event of flow disruptions, thereby preventing a pressure drop during a power outage or a switchover between oil pumps. Accumulators also help maintain a constant oil pressure during temporary changes in demand.

Lube oil systems for turbomachinery consist of three elements: a high flow-rate pump, a reservoir and an accumulator. Lube Oil System Accumulators (LOSA) prevent bearing damage and increase bearing life by supplying oil to the bearings when a power failure shuts down the pump, or when changing between the primary and backup oil pump.



Standard Accumulator — Transfer Barrier Design

An accumulator is a pressure vessel that stores oil and contains a mechanical means of maintaining pressure when the pump shuts down, thus cushioning fluctuations in oils pressure. Accumulators differ on the type of mechanical means used, such as spring, gravity and gas load.

Spring accumulators use a spring-loaded position in a cylinder. As the oil line pressure increases, more oil flows into the cylinder and compresses the spring, with the spring pressure matching the hydraulic pressure.

Then, when the pressure drops, the spring forces the oil back out of the cylinder into the system. This kind of accumulator has limited use in high-cycle applications, as the spring fatigues and loses its elasticity. In addition, they struggle to maintain a constant pressure.

Gravity-loaded accumulators use weights to drive a piston and provide the desired pressure. While these accumulators achieve near constant pressure, they are larger, heavier and more costly than other types.

Gas-loaded accumulators, on the other hand, use compressed gas to provide the necessary pressure. They can be divided into two main categories: separator and non-separator accumulators.

Non-separator accumulators do not have any barrier between the gas and the liquid. While this is the simplest design and can store the greatest amount of oil, the downside of non-separator accumulators is that the fluid may absorb gas at high pressures, since there is no barrier separating gas from oil. As pressure drops, the absorbed gas forms bubbles in the oil, which may cause foaming in the oil resulting in damage to many components of the system.

The better approach for LOSA applications is to use a barrier between the gas and the fluid, such as a rubber bladder. This is where the second type of gas-loaded accumulator comes in—the bladder-type. It consists of a metal cylinder containing a pressurized bladder. See footnote.

In accordance with API standards, these accumulators are made of 300 series stainless steel and can withstand maximum pressures of about 1,500 psi. Because of its high flexibility and low weight, the bladder has a rapid response time, allowing the accumulator to quickly compensate for pressure drops in the system and prevent damage to the bearings and other components. This kind of accumulator forms the basis for the transfer barrier accumulator.

Slimming Down the Skid

Due to the volume of oil and the required amount of flow, lube oil skids often accommodate multiple gas-loaded accumulators to contain enough standby oil to keep the system functioning.

To enable the lube oil system to feed oil at rates of 400-500 gallons per minute, for example, at least 100 gallons of oil must be stored under high pressure. That may require 8 or 10 accumulators tied together to provide the necessary volume of oil.

A better solution is to use one or two large transfer barrier accumulators on a lube oil skid to perform the same function.

As well as serving as part of a lube oil skid for a turbine, transfer barrier accumulators can be used with turboexpanders and compressors.

A further use is for storage of discarded fluids—once the tank is full, these fluids can be pumped out. For example, this kind of accumulator is currently used for sub-sea drilling of oil. Once the accumulator fills up with discarded fluids, they can be pumped to the ocean surface for safe environmental disposal.

Further, transfer barrier accumulators are used in applications where two fluids must transfer pressure without mixing the fluids together. For example, water would be used on the inside and oil on the outside of the bladder, or alternatively clean oil would be on one side and dirty oil on the other. Transfer Barrier accumulators can also be used to cycle different pressurized fluids in and out of chambers.

Their design enables them to deal with two different types of fluid and to transfer pressure and a small amount of volume from one medium to another. As such, these accumulators can be used as a substitute for a hydraulic pump for transferring or transmitting fluids, with the bladder being operated as a piston to let a fluid flow into and out of the accumulator intermittently.

The transfer barrier accumulator has a gas bottle on the side which allows the gas to be removed from inside the accumulator via an opening at the top of the bottle. When a backup gas bottle is included, the transfer barrier accumulator can supply a large volume of fluid even when the system pressure difference is low.

Yet another application is known as the B-type transfer barrier accumulator. It is used to transmit pressure between dissimilar fluids. A tube inserted into the bladder has many holes. This prevents fluid from attacking one spot of the bladder inner wall and protects the bladder from damage. ■

Footnote: American Petroleum Institute (API) Standard 614/ISO 10438 covers lubrication systems, as well as ASME Pressure Vessel and Boiler Code, Section VIII, DIV. 1.

Joe Cheema is General Manager at Fluid Energy Controls, a provider of accumulators and fluid power products. For more information, visit fecintl.com or call Tel: 323-721-0588

ASSET PERFORMANCE MANAGEMENT, ANALYTICS, DIGITALIZATION AND AUGMENTED REALITY

Dr. Kang Ju Lee, Technical Sales Leader for Asia Pacific at Aveva, discusses asset performance management, digitalization, augmented reality, and the company's recent merger with Schneider Electric's industrial software business.

Tell our readers about Aveva.

Aveva is a global leader in engineering and industrial software driving digital transformation across the asset and operational lifecycle of capital-intensive industries. The company's engineering, planning and operations, asset performance, and monitoring and control solutions serve over 16,000 customers across the globe.

Our customers are supported by an industrial software ecosystem that includes 4,200 partners and 5,700 certified developers. Aveva is headquartered in Cambridge, UK, with over 4,400 employees at 80 locations in over 40 countries.

What is the latest news?

Schneider Electric recently merged its industrial software business with Aveva. This integrates Aveva's design, engineering and construction capabilities with Schneider Electric's industrial software business, which includes capabilities that range from simulation to real-time manufacturing operations management. It creates a path to digitalization from conceptual design to commissioning, and from operations back to revamps. Customers can benefit from improved profitability, efficiency and performance.

How important is digitalization?

Some 88% of leaders in capital-intensive industries say that digitalization would increase their revenues. Yet less than half of these companies are in the process of adopting a digital strategy. Digitalization demands a fundamental rethink of the way organizations operate. Companies need to be confident that their technology investment will deliver a high return on capital and lower the total cost of asset ownership.

What do you offer the turbomachinery industry?

Turbomachinery is critical to any oil and gas facility. Due to the asset-intensive nature of the industry, any slight improvement in asset utilization can result in a huge gain in revenue and cashflow. Therefore, keeping these operating assets running with minimum unplanned outages is key to improving profitability and maximizing returns on projects. However, maintaining uptime can get harder over time due to changes in loading profiles when oil and gas production rates decline. Aveva offers a way to maximize uptime.

How is this achieved?

Our Predictive Asset Analytics solution enables modelling of equipment performance using pattern recognition and machine learning algorithms to identify and diagnose potential operating issues days or weeks before failures happen. Operating models, including past loading, ambient and operational conditions, are created through advanced process modelling and simulation.

An asset signature is created for turbines, compressors, pumps or any other critical piece of equipment. Real-time operating data is compared against these models to detect subtle deviations from expected equipment behavior, allowing reliable and effective monitoring of different types of equipment with no programming required. Early warning notification allows reliability and maintenance teams to assess, identify and resolve the problems.

In what other ways can asset performance management assist turbomachinery operators?

As oil and gas production fields are often in remote locations, it can be challenging to inspect and maintain non-instrumented assets. Having accurate data and information available is the foundation to optimizing asset performance. Our Mobile Operator Rounds leverage a platform to facilitate inspections and reliability checks of assets in a thorough and fully verifiable manner, delivering the data you need to keep your assets productive and operating at peak efficiency.

What best practices do you recommend?

Implementing asset performance management solutions can greatly assist in turbomachinery operations and maintenance. Whether the maintenance and operations team has a maintenance strategy in place today, or is looking to implement a more robust and holistic solution, there are toolsets available in the market, such as condition-based maintenance, predictive analytics and mobile solutions to empower the workforce.

Predictive analytics software uses pattern recognition and machine learning for early warning detection and diagnosis of equipment problems to prevent failures and ensure high performance.

What trends do you see driving companies to digitalize their asset management?

Ageing demographics within the industrial sector is leading to a scarcity of skilled workers to properly maintain specialized equipment. Thus, companies are seeking digital solutions to enable more efficient monitoring of specialized equipment with fewer skilled workers.

In addition, technology evolution, via the Internet of Things (IOT), big data, cloud infrastructure, analytics and mobility, is in high demand. Companies in the turbomachinery sector view these technologies as a way to reduce costs and to take operational efficiencies to the next level.

What trends do you see developing in asset management?

There is growing adoption of augmented reality (AR) and virtual reality (VR) in training. Unlike a traditional classroom environment, VR facilitates interaction between equipment and the environment, as well as providing a simulation close to actual conditions.

This accelerates the transfer of knowledge and rapid learning of best practices. Operators can practice operating procedures of real experiences until they achieve perfect execution in a safe and controlled classroom environment. Trainees get up to speed earlier with better retention and can hit the ground running in a production setting.

How applicable could this be to maintenance?

Utilization of AR technology in maintenance activities allows field operators to quickly access and visualize performance data of the operating assets at a remote site. This facilitates inspection and troubleshooting without the need to rely on inefficient communications to get information from the DCS operators at the control room. ■

John Crane Gas Seal Technology Reduces Methane Emissions

John Crane has launched its latest gas seal technology designed to be retrofitted into centrifugal compressors with oil seals. It lowers operating costs, improves reliability and reduces methane emissions by up to 95%.

The Aura 120 narrow section gas seal enables this technology to be fitted into a larger percentage of older equipment, bringing the benefits of non-contacting design. It eliminates the need for oil lubrication associated with contacting seals and the resulting need to address harmful emissions entrapped in the oil. In the natural gas sector, centrifugal compressors equipped with oil seal technology are the leading source of offshore methane emissions and the fourth most significant onshore.

John Crane has developed a lifecycle cost calculator (LCC) that provides an analysis of the economic case for retrofit from oil seals to gas seals. The LCC takes operational data from rotating equipment and compares the lifecycle costs of the oil seal operation—including emissions—with the option of capturing the methane and routing to a flare device, capturing the methane and routing for another purpose, and retrofitting to gas seal technology.


John Crane Aura 120 narrow section gas seal

Converting to gas seal technology provides economic payback in a variety of scenarios, particularly when there is no spare compression and the operator owns the natural gas flowing through the compressor.

Earlier this year, John Crane was invited by a United Nations (UN) panel to showcase how the firm's technology is reducing methane emissions in the natural gas industry. The panel is examining the critical role gas will play in achieving Sustainable Development Goals. It established a taskforce to develop best practice guidance on reducing methane emissions along the gas value chain. Pioneered by John Crane, gas seal technology became widely available in the 1980s. It is the industry standard for all new equipment.

johncrane.com

GE turbine upgrade

GE Power and Vattenfall Wärme Berlin (a subsidiary of Swedish utility Vattenfall AB) announced the new MXL2 with Additive Manufactured Performance (AMP). This is an upgrade for GE's GT13E2 GT that uses 3D printed components. The addition of additive manufactured parts into the MXL2 solution can help gas plant power producers to save in fuel costs.

The new MXL2 with AMP components are made with a lightweight configuration and can be engineered to include advanced cooling channels. This helps the GT run more efficiently. The first-stage turbine vanes and heat shields are among the turbine's hottest-running components, and typically required for cooling air. Additive printing allows GE to use cooling designs that reduce the amount of cooling air the parts need, improving the turbine's performance.

This upgrade to the GT13E2 can reduce component cooling requirements by up to 25%, raise output up to 21 MW in combined-cycle configuration, boost efficiency by up to 1.6% and extend maintenance intervals up to 48,000 hours. The AMP upgrade has contributed to an electrical power increase of 21 MW and about 4 MW of thermal heat generation at Vattenfall's Heizkraftwerk Berlin-Mitte facility.

Gepower.com

New Metrix system

Metrix has launched a new version of the Digital Proximity System (DPS), Version 1.35. It can replace the proximity sensors at an entire plant, has universal spare parts and free software. A multitude of older probe systems, cable lengths, and target materials can be replaced with a Metrix DPS. It allows the user to change the configuration in the field for use with any Metrix, or major competitor, proximity probe and cable.

The Metrix DPS combines the performance of an API 670 compliant eddy-current proximity measurement system with digital configurability. Users can configure their transducer system in the field using a field-generated curve as well as factory pre-configured calibrations for a variety of probe tip diameters, manufacturers, extension cable lengths, target materials, and linear ranges.

Metrixvibration.com

Diverter damper

Boldrocchi has completed in-house testing at its facility near Milan, Italy, of functional testing for a new large 7m × 7m (23' × 23') diverter damper for a GT, one of three such units to be delivered shortly. Customers from GE Power, Ansaldo Energia, Saipem, Edison and Nooter Eriksen were on hand to witness the success of the test.

The diverter damper has a three-way valve that discharges exhaust gas from the GT, either into the atmosphere via a by-pass stack or into a Heat Recovery Steam Generator (HRSG). As well as high capacity, it surpasses the norm in terms of geometrical sealing, sealing pressure and closing time, while reducing maintenance and easing transportation and assembly. This new diverter also allows for a rapid transition from single cycle to combined cycle systems.

This large diverter damper is designed to withstand temperatures of up to 700 °C (1,300 °F), vibrations and gas turbulence, as well as elevated wear of components. The geometrical seal around the perimeter is more than 99.95 % effective.

The sum of all residual gaps in the free air passage section is less than 0.05% (less than 0.01% for this specific application). This percentage is the measure of the residual leakage areas between the blade and the landing bar, along the entire blade perimeter.

The diverter is equipped with an air-sealing system which allows the sealing degree on exhaust gases to equal 100 % (full tightness). The air-sealing pressure is > + 500 mm wc, whereas OEMs only require +50 mm wc.

Boldrocchi's diverter is equipped with hydraulic actuators, giving it a normal operation time of less than 60 seconds and an emergency closing time of less than 20 seconds. However, the diverter has been engineered and manufactured to obtain even shorter actuation times.

The sealing lamellas (the strength point) have, on some applications, lifetimes of up to 10 years. Additional benefits include self-lubricated, high temperature, maintenance-free internal bearings as well as a solution for internal thermal-acoustic insulation. The diverter is pre-assembled in a few pieces or can be delivered fully assembled (in one single part). It is engineered for easy installation under single cycle exhaust stacks, instead of existing bend ducts.

boldrocchigroup.com

Continued on page 40

Machinery protection

Machine monitoring specialists Sensonics have introduced measurement algorithm options for its Sentry G3 machinery protection monitor, which operates as a turbine supervisory system. The Sentry G3 system provides machine protection to the API670 standard, and a range of programmable algorithms in each module to enable plant engineers to identify abnormal conditions and better manage the dynamic behaviour of their rotating plant.

It consists of one module type for all measurements to improve flexibility and minimize spares holding. Algorithms can be loaded and configured in any channel position to provide the required measurement regime. The recent focus has been to provide gas turbine (GT) specific measurements, such as first order vibration tracking and dynamic pressure which are both requirements recommended by GT manufacturers. In addition, the speed algorithm has also been optimized to accept a wider range of speed probes.

sensonics.co.uk

Gas compressor

Vacuum pump and compressor systems specialist Pneumofore has launched its new line of K Series rotary vane gas compressor solutions. They are designed for industrial gas treatment and processing applications. With 2.5bar(g) to 10bar(g) pressure and up to 2,690m^3/h, the K Series cover the gas compression requirements of many industries, from the oil and gas and energy sectors to chemicals, from the metal industry to food processing.

The K Series' design meets stringent safety criteria. These compressors are certified for extreme and explosive environments according to the Atex directive for Zone 1 (Atex II 2/2G). They handle a wide range of gases, including methane (CH_4), ethane (C_2H_6), carbon dioxide (CO_2), nitrogen (N_2), biogas and natural gas.

Pneumofore.com

Position sensor

NewTek Sensor Solutions has introduced a miniaturized series of AC-operated position sensors with a lightweight and compact 3/8" diameter size that provides reliable linear position feedback in rugged industrial applications with tight space and weight restrictions. Resistant to harsh and high-pressure environments, the NewTek M-375 Series Miniature AC LVDTs provide high response dynamic measurement for machine operations. They can serve in the aerospace, oil & gas and manufacturing industries. With a corrosion-resistant, nickel-iron alloy housing and core, the sensors operate in temperature extremes of –65°F to +275°F (–55°C to +°135C), with optionally extended ranges of –65°F to 400°F (55°C to 204°C).

newteksensors.com

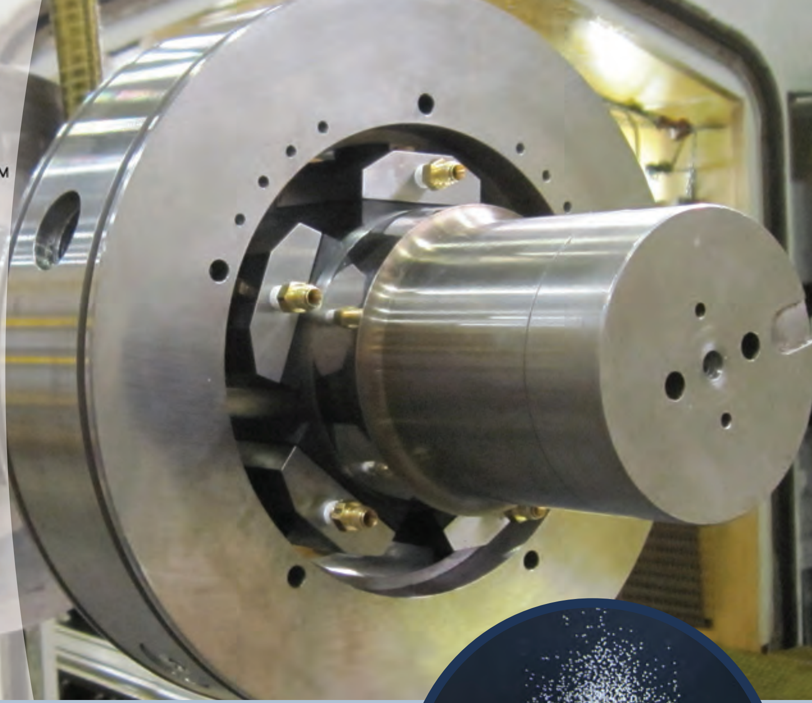
Flame sensor

Pyreos has announced enhanced performance and a digital interface for its TO-39 packaged flame sensors with the introduction of the ezPyro TO Flame Sensor. It will have wider applications in industrial settings than analogue equivalents in the same package because it has better detection distance. It also has a greater field of view than an equivalent digital sensor offered in a surface-mount package, enabling it to sense larger areas. It couples the Pyreos thin-film PZT pyroelectric sensors with integrated readout circuitry and a digital communications bus.

pyreos.com

Pressure relief valve

Cortec has introduced its new CRV26 Pressure Relief Valve (PRV). The CRV26 PRV is engineered to protect drilling systems against the dangers of over pressurization and is the first of its kind to be rated to 10,000



PSI systems. It is suitable for frac system relief, mud pump relief and managed pressure drilling (MPD) and is compatible with API 6A and NACE MR0175 requirements.
uscortec.com

Fluid analysis

Spectro Scientific has introduced TruVu 360 Enterprise Fluid Intelligence Platform, a web-based fluid analysis data management system. It streamlines the fluid analysis process. Closing the gap between maintenance recommendations on the oil analysis report and the impact on continuous process improvement. It provides a dashboard, so management can see the effectiveness of the program. TruVu 360 integrates Spectro's MiniLab on-site oil analysis hardware used in industrial applications in manufacturing, mining, oil & gas and power generation.
Spectrosci.com

Elastomer for pumps

Stronghold Coatings RepaCoat family of products are ideal for the sealing and repair of pumps. RepaCoat FX is a permanently elastic two-component polyurethane elastomer that is fast-curing, wear and abrasion resistant, and is easily applied on-site. It is temperature resistant to 120°C (248°F) continuous and 160°C (320°F) peak. It is resistant to aggressive environments and provides full elastic recovery even after multiple elongations and compression loading. With Venturi sprayers, RepaCoat FX allows economical, on-site application, making it is ideal for use on gaskets, conveyor belts, rollers, expansion joints, bridge piers, pipes and elbows, tubes, pumps, impellers, tanks, silos, and more.
strongholdone.com

Bluetooth sensor

ITT Industrial Process has released a Bluetooth i-Alert Monitoring sensor portfolio for rotating machines. The latest product improves battery performance, enables programmable monitoring intervals to detect faster transient fault conditions, and expands monitoring coverage to slower speed machines (such as cooling tower applications, air-cooled heat exchangers and large slow-speed pumps). It enables users to continuously monitor all types of machines.
itt.com

Siemens GT upgrade

Siemens has introduced a new SGT-800 performance enhancement that is applicable to all existing SGT-800 units with 43–47.5-MW ratings. The upgrade is designed to provide owners and operators with fuel savings and CO_2 emissions reduction. It offers up to a 3.5% increase of simple cycle efficiency and up to an additional 10 MW. For combined cycle applications, the enhancement could result in a power increase of more than 20 MW and a 3.5% lower heat rate, based on a combined cycle 2 × SGT-800 and one steam turbine (ST).

This upgrade is infusing the components included in the later versions of the SGT-800 (50.5–54 MW). An improved compressor blade design is included for increased aerodynamic performance, as well as optimized gas path mass flow and component cooling in the turbine section. The combined upgrades are designed to produce only a moderate increase in combustion chamber firing temperature. The upgrade is preferably installed in conjunction with a scheduled major overhaul.

Siemens is also recommending a move from the traditional fixed-interval maintenance based on Equivalent Operating Hours (EOH) to tailored maintenance plans in conjunction with this upgrade. A Flex-LTP with a tailored maintenance plan gives users access to specific OEM knowledge and optimization technologies that can also support extended time between overhauls.
www.siemens.com/energy

Mass flow meter

AW-Lake and KEM have expanded their Tricor line of Coriolis mass flow meters with the addition of TCD 9000 Series Transmitters that incorporate digital signal processing (DSP). The TCM Classic Series meets general industrial requirements out of the box while the TCMP Pro Series offers environmentally hardened units with advanced performance specifications and diagnostic capabilities for operation in challenging environments. The new TCD 9000 Series offers greater robustness, performance, diagnostics, and connectivity options. With an HMI interface and a stronger logging, the DSP transmitters provide users with a configuration and analysis tool.
tricorflow.com ■

AD INDEX

GAS BEARINGS

LUBRICATING TURBOMACHINERY WITH GAS BEARINGS

BY DREW DEVITT

Almost all fluid film lubrication applications in turbomachinery use hydrodynamic, (in the case of oil) or aerodynamic (in the case of gas) bearing technology. This type of lubrication uses the relative shear between the bearing faces and the rotor to drag lubrication into the natural wedge-shaped gap that forms between them.

The other type of fluid film bearing is a hydrostatic or aerostatic bearing. This bearing creates lift even at zero RPM as it employs an external pressure source and some type of restriction or compensation to create a pressurized film of gas to carry the load.

Dry gas seals

DGS are face seals that use machine work or etching to create grooves in the faces. These grooves pump gas into the gap from the high-pressure side to increase pressure.

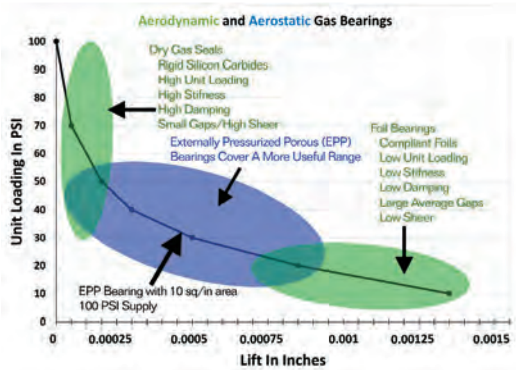
DGS are also balanced. Hydrodynamic pumping grooves in the face of the seal create enough extra pressure in the gap to keep faces from touching. DGS have virtually replaced all oil seals in new compressor builds.

Shear losses in fluid film lubrication are a cubed function of the gap. Very small gaps can generate a lot of shear heat, even in gases. Therefore, DGS seal faces are often made from rigid and thermally stable silicon carbide to keep them flat. If the gas gap is only a few microns, the relative flatness needs to remain less than the gas gap. This is higher unit loading than can be achieved with hydrodynamic oil bearings.

Foil bearings

Foil bearings are another type of gas bearing that employ aerodynamic lubrication. The first production foil gas bearings were developed for the DC-10 in 1969. Today, virtually every medium to large aircraft uses them.

Foil gas bearings have shown long-term reliability. Many have demonstrated operation on other working fluids such as hydrogen, refrigerants, liquid oxygen or supercritical CO_2. The ability to operate at cryogenic or high temperatures is another advantage. Gases also take heat better than oil, and do not change their viscosity much. Foil bearings are commonly used in blowers for water treatment processes, sub megawatt gas turbines and turbo chargers.



Lift vs. load chart for Externally Pressurized Porous (EPP) gas bearings showing the typical operating ranges of dry gas seals and foil bearings. EPP bearings operate with a larger gap than dry gas seals, reducing contact issues yet have good load capacity, stiffness, damping, and speed.

Bump and overleaf are the most common types of foil bearings. The bump foil bearing (BFB) consists of a thin flat piece of spring steel stamped to have bumps. A top foil is inserted into the ID and is supported by the bumps. Instead of a continuous top foil, the overleaf employs separate, stiffer overlapping leaves with longer bending moments for low stiffness over a larger range.

Aerostatic lubrication

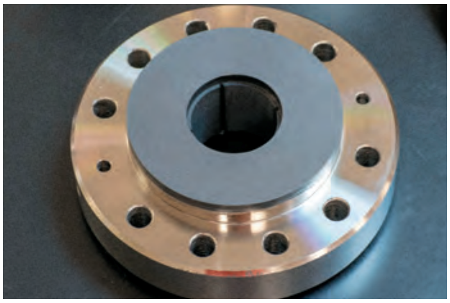
Aerostatic or externally pressurized gas bearings can provide lift even at zero RPM. Although they do not have fine pumping grooves like dynamic bearings, they require some type of restriction for metering the gas into the gap. Air pressure is introduced directly between the bearing surfaces though holes, orifices, grooves, steps or porous compensation techniques.

Compensation enables bearing faces to run close together without touching. The closer they become, the higher the gas pressure repelling the faces. Under a gas bearing, the average pressure in the gap equals the load on the bearing divided by the face area (unit loading). If the source gas pressure is 100 psi, the seal face has 10sq.in. of area and there is 600 lbs. of load, there will be 60 psi in the bearing gap. If the load increases, the gap reduces as there is a restrictor before the gap.

Orifice compensation is the most widely used. Orifices are placed on the bearing face and are often combined with grooves to distribute the pressurized air across the face. If the face becomes scratched, the air that escapes may be more than the orifice can supply, leading to contact or crash. They can also be plagued by contamination.

Porous compensation

The ideal gas bearing design would supply pressure equally across the face of the bearing and automatically restrict and damp the flow of air. This can be achieved by diffusing air through a porous bearing or seal face. Graphite and carbons may be used for this purpose. A damping effect (from passageways the gas flows through) makes it difficult for air volume in the gap to change quickly. This results in a stable gas film that cannot be plugged by particulate. In case of contact, graphite is an excellent plain bearing material.



Externally Pressurized Porous Bearing from New Way Air Bearings

Porous compensation also works well for small gaps and small flows. There is zero lift and zero flow, yet zero load and friction between the faces. The load is taken by the air pressure acting like a hydraulic cylinder. It is not recommended to run a bearing in this mode, but it is another example of why porous compensation has better crash resistance and is more robust then orifice compensation. ■

Drew Devitt is CEO of New Way Air Bearings. For more information, visit newwayairbearings.com

MYTH: THE PARTICULARS ABOUT PARTICULATES ARE IMPORTANT

The automotive industry in Europe, especially in Germany, is in turmoil. Certain European cities are considering a ban on vehicles with diesel engines from downtown areas. The diesel engine, long considered a better alternative to hybrid cars, may have received its death blow. What has happened?

Government regulators, prompted by environmental groups, are alarmed by significant levels of small particles in the air in downtown areas of large European cities (this is also the case in the U.S. and Asia). Small particles sized below 10 microns (PM10) can enter the finest branches of the human lung and are suspected to be the cause of serious ailments. Stuttgart, Germany, home of Porsche and Mercedes, and the former home to one of the authors of this column, is among them.

For turbomachinery engineers the question must be asked: Are gas turbines (GTs) also major emitters of micron level particulate matter? In this context, we primarily focus on industrial GTs that burn gaseous fuels.

Regulators have already created a framework of rules that also apply to GTs. These regulations often limit the annual production of particles below a certain size in tons per year. There are regulations for PM (all particles), PM10 or PM2.5 (particles below 2.5 microns). While in the U.S. the criteria is tons per year, in most other places it is based on particle concentration (mg/Nm^3).

Before we answer the main question, let's consider the technical details. PM10 and PM2.5 emissions from the combustion of gaseous fuels in industrial systems can originate from sources such as: combustion of sulfur and chlorine to acid aerosols and salts; incomplete fuel combustion to form soot or high mole weight organics; vaporization; condensation or transmission of volatile elements in the fuel or combustion air; corrosion or erosion of system elements; entrainment of debris; and particle agglomeration and breakup.

Additionally, post-combustion, emission-control methods, specifically Selective Catalytic Reduction (SCR), while lowering NOx emissions, can also contribute to PM10 and PM2.5 emissions.

For clean natural gas as fuel, and reasonably clean ambient air, the continuous combustion process in a GT produces practically no particulate. The air and exhaust gases in a well-maintained GT never contact lube oil, and the combustion is continuous and well mixed with the air-to-fuel ratio controlled throughout. This further contributes to near PM-free emissions.

In many instances, most particles in the exhaust may have entered the engine with the combustion air. Given the capability of modern GT air filtration systems to remove significant amounts of particles even below 2.5 microns in size, GTs act as an air cleaner in some locations.

"With extremely low PM emissions, GTs should be looked upon as an air filter not a particulate matter emitter."

Particulate matter comes in condensable and filterable (non-condensable) form. Filterable PM is essentially solid. Condensable PM consists of liquid or solid droplets that form in the exhaust gas when it cools down.

If we consider the combustion mechanisms described above, and in the absence of mechanical issues with the GTs while using clean fuel and combustion air, the only particulates that can potentially form are of the condensable variety.

Certainly, fuel-bound sulfur can contribute to particle formation, but the sulfur level in natural gas is usually extremely low. Given the small size of the PM liquid droplets, some may evaporate soon after leaving the gas turbine exhaust.

A key point of contention are the test methods used to detect particulates in the GT exhaust. Some older test methods or methods with short durations lead to unrealistically large or widely varying PM measurement results.

But even carefully and consistently executed tests will have uncertainties that are on the same order of magnitude as the number of particles present in the exhaust stream. Recently analyzed data shows that older tests on the same GT exhibit significantly higher particle levels, and significantly higher variability than newer, more advanced tests. Lastly, some inappropriately applied test methods can generate additional condensable particles in the particle collection system.

It does not really matter whether the PM10 or PM2.5 levels are measured as particles in the gas turbine exhaust. If present, they are usually much smaller than PM2.5. Thus the measured PM, PM10, and PM2.5 values are mostly the same.

This explains part of the measurement problem: very small particles in extremely low concentrations are hard to detect and measure accurately. High measurement uncertainties and wide test variations often result.

Now, let's answer the question at the beginning of the article: Natural gas-fired gas turbines may be more of a solution than a problem where particulates matter. These GTs have extremely low PM emissions. Often, because of their fine inlet filtration and the massive amount of air captured, GTs act as an air filter than a particulate matter emitter.

The authors want to acknowledge the support of Leslie Witherspoon who contributed to this article. ■

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